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Key Enablers of Industrial IoT: Sensing-Part 1

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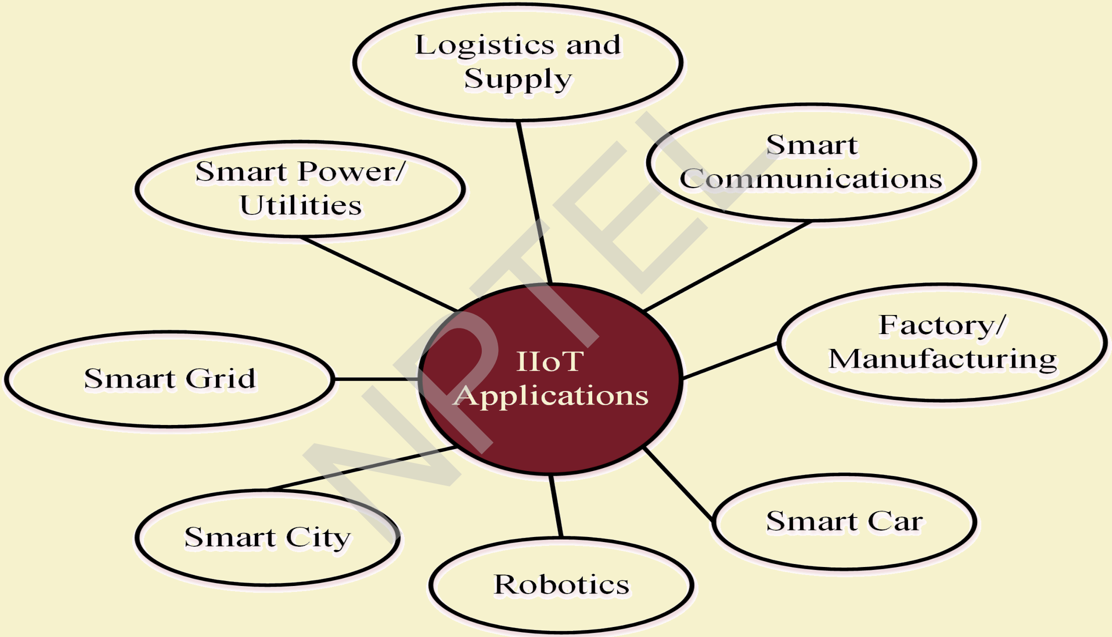
IIoT Features – Recap

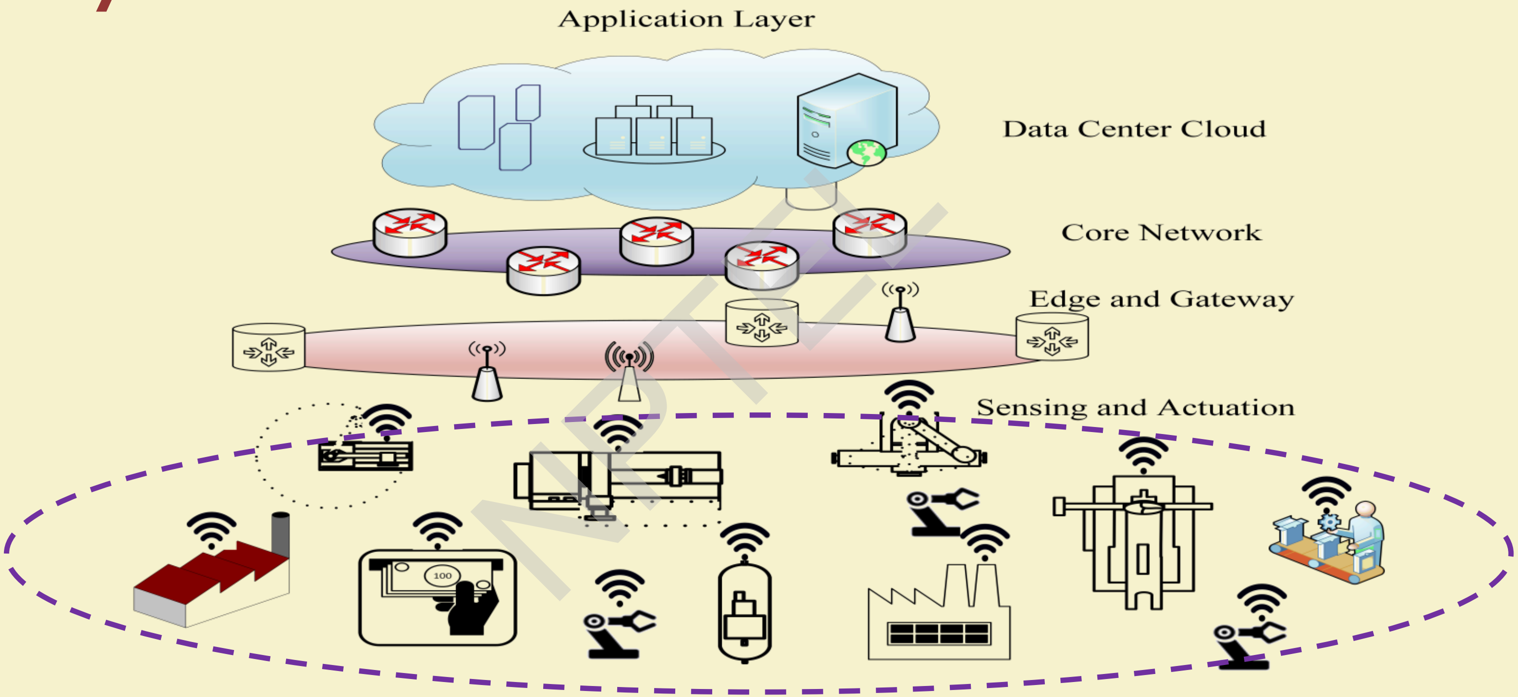
- A network of billions of machines and devices, which are connected by communication technologies
- Smart machines and advanced analytics
- Detection of system/machine/product failure and downtime
- More concern about the improvement of efficiency, productivity, health, and safety of a system

Applications with Smart Sensors



Source: IIoT Application, Online: https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT

IIoT Layer-wise Architecture



Idea Taken from: “Securing the Internet of Things: A Proposed Framework”, Cisco, Online: https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html

Benefits of Sensor Usage in Industry

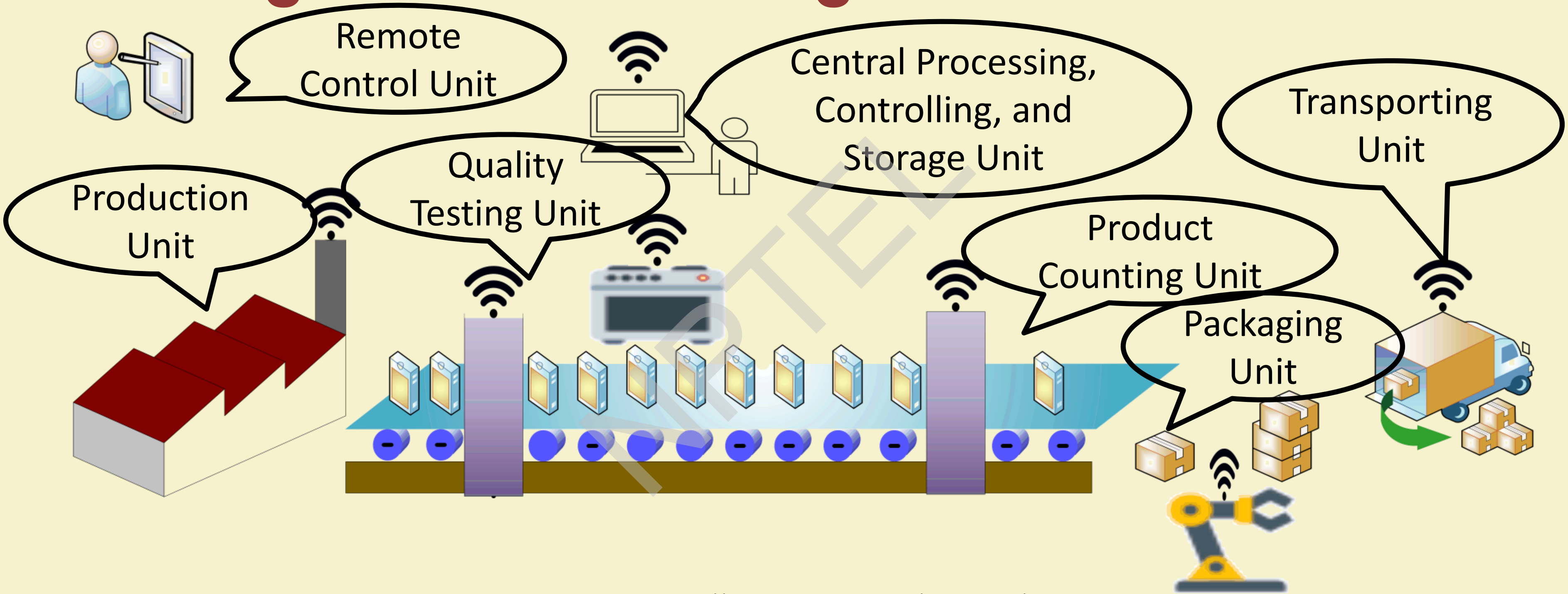
- Real-time monitoring
- Improving visibility
- Operational efficiency
- Increasing productivity
- Efficient quality management

Source: Online: https://www.newgenapps.com/blog/8-uses-applications-and-benefits-of-industrial-iot-in-manufacturing

Benefits of Sensor usage in Industry (Contd.)

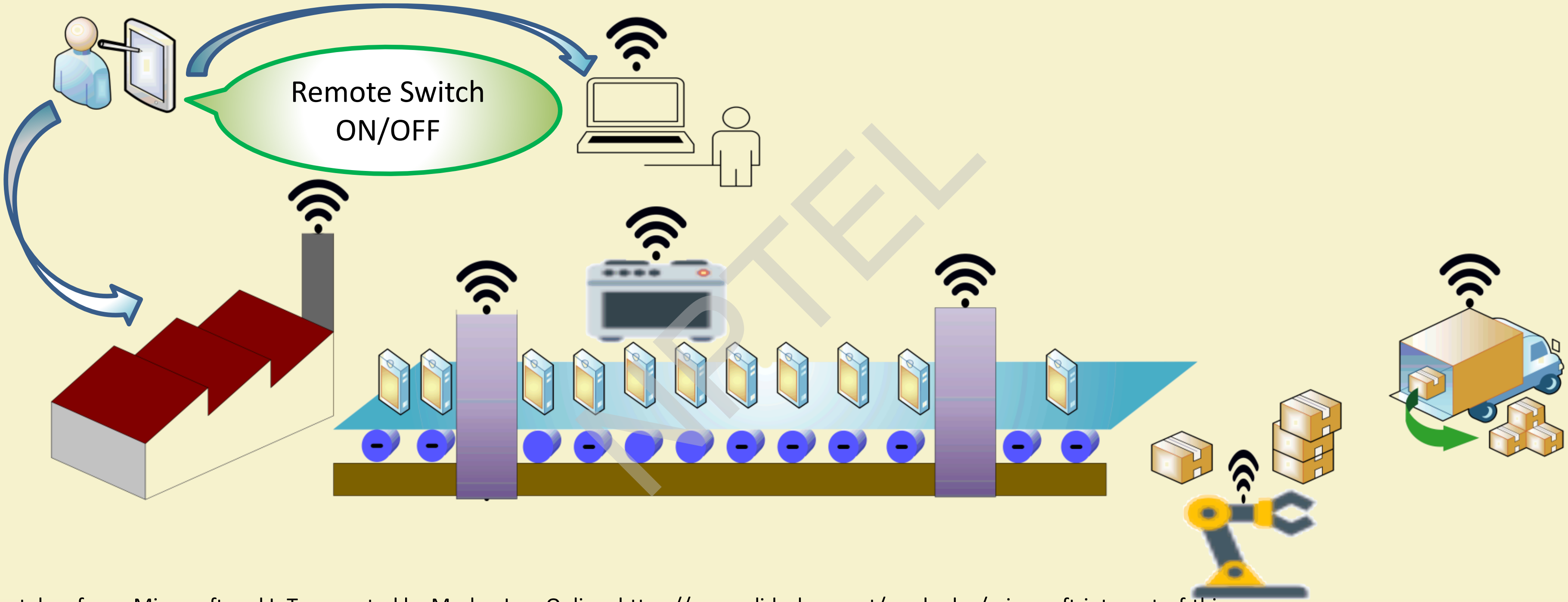
- Improving Safety
- Minimizing downtime
- Improving the prediction and prevention of system failure
- Remote diagnosis

Sensing for Manufacturing Process in IIoT



Idea taken from: Microsoft and IoT presented by Marlon Luz, Online: https://www.slideshare.net/marlonluz/microsoft-internet-of-things

Sensing for Manufacturing Process in IIoT (Contd.)



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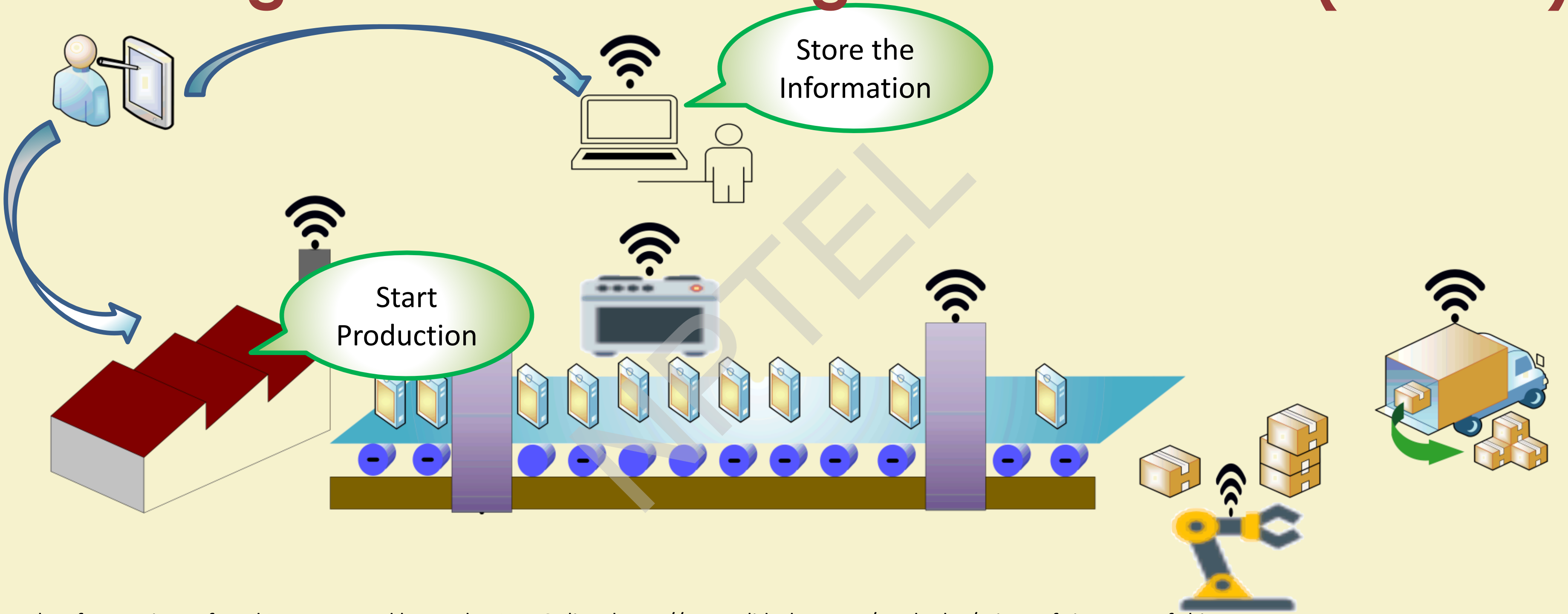

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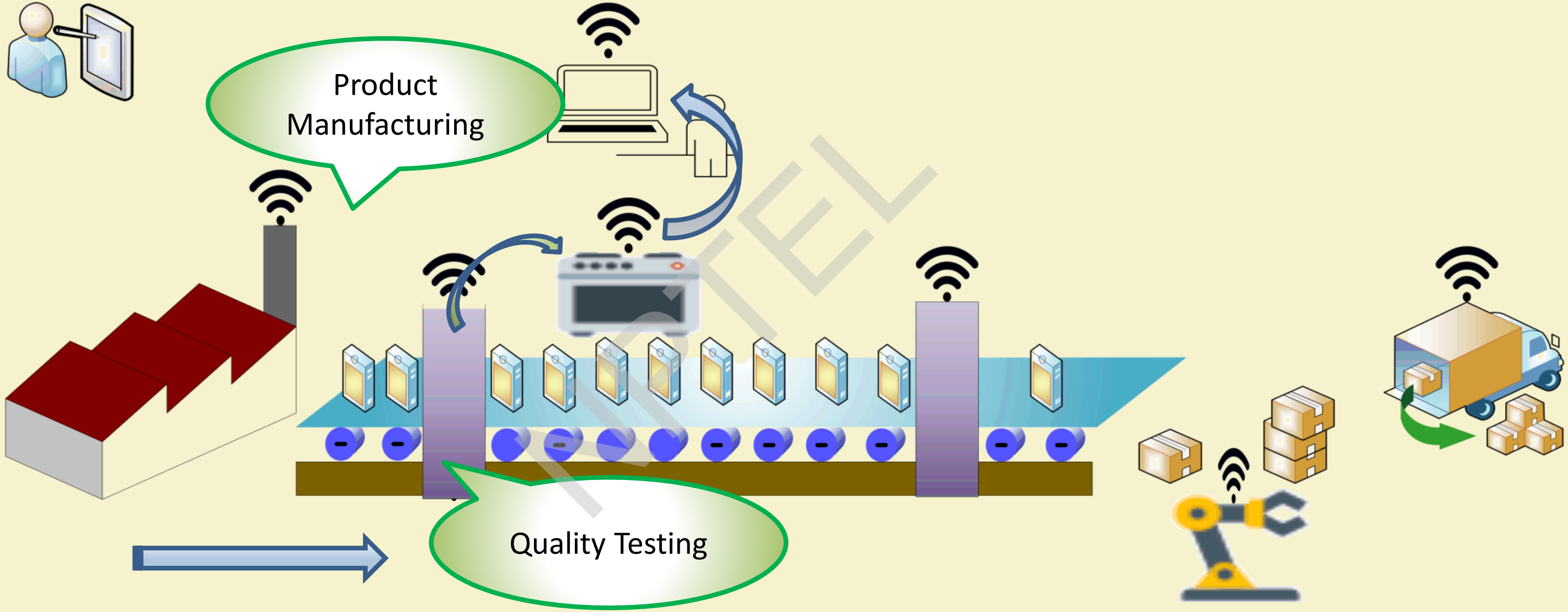

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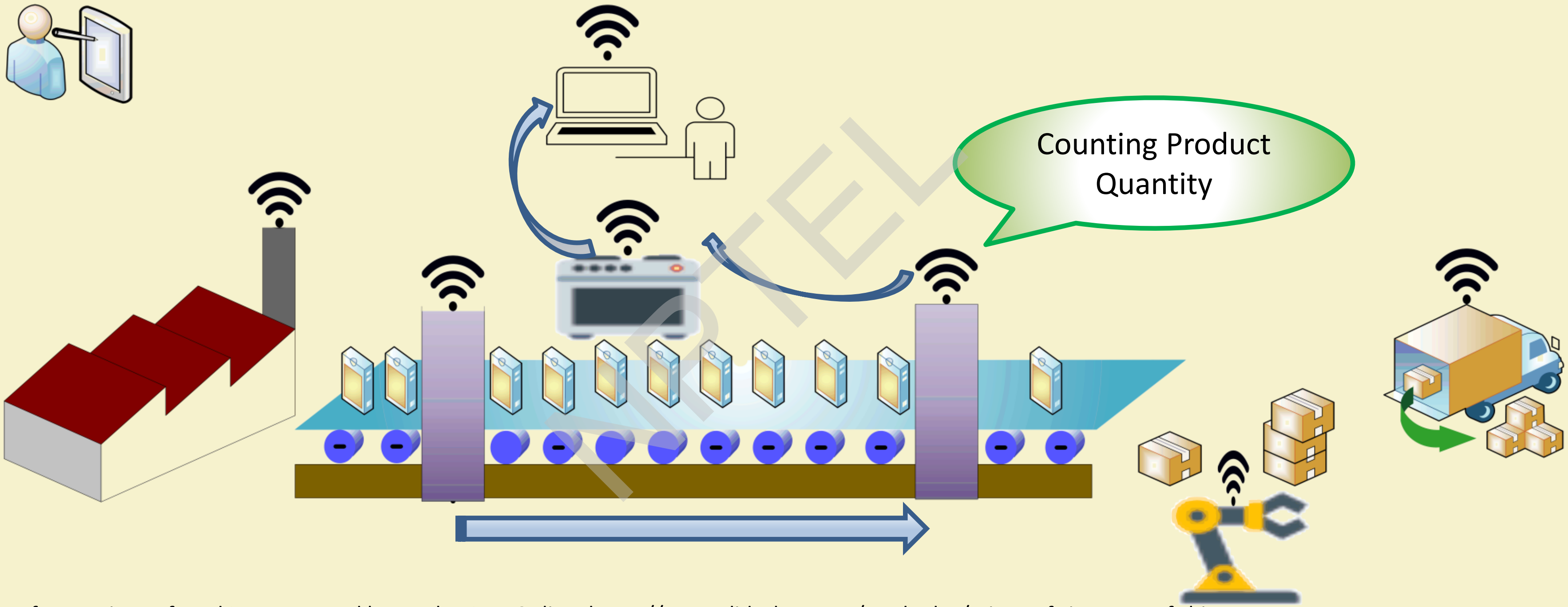

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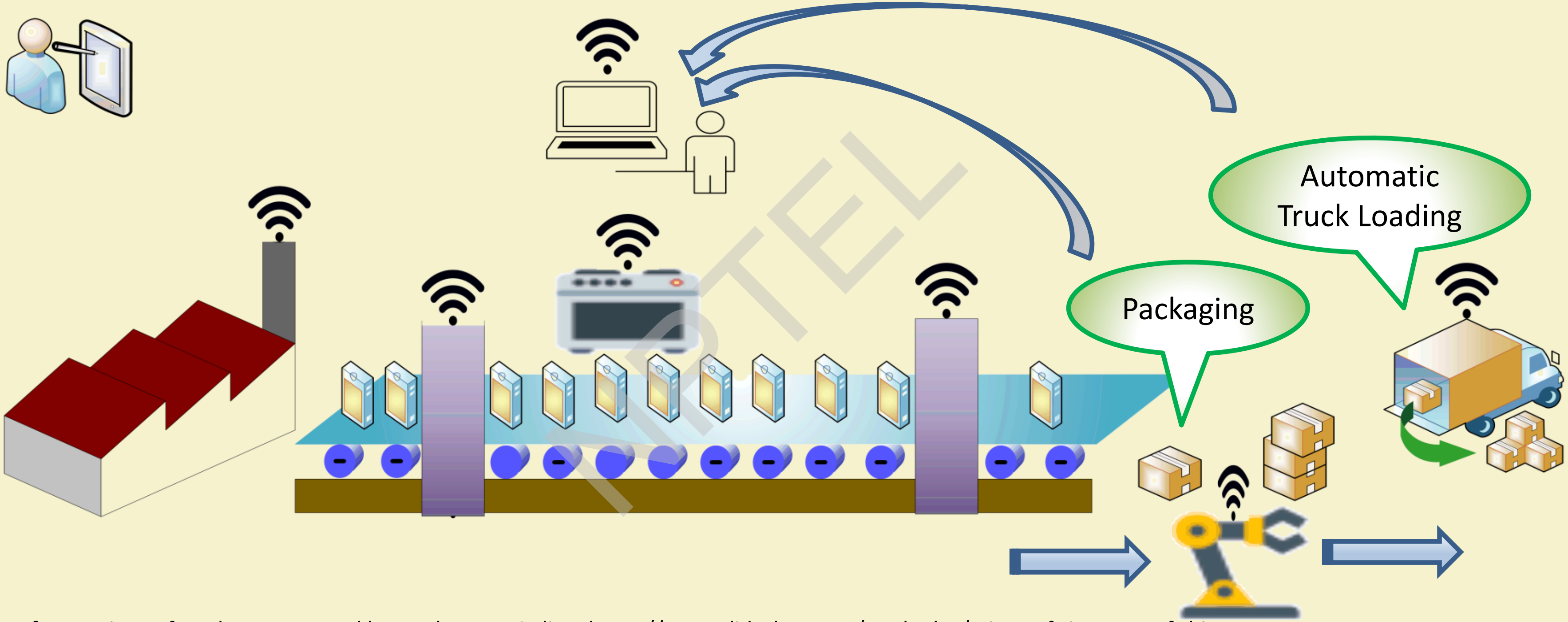

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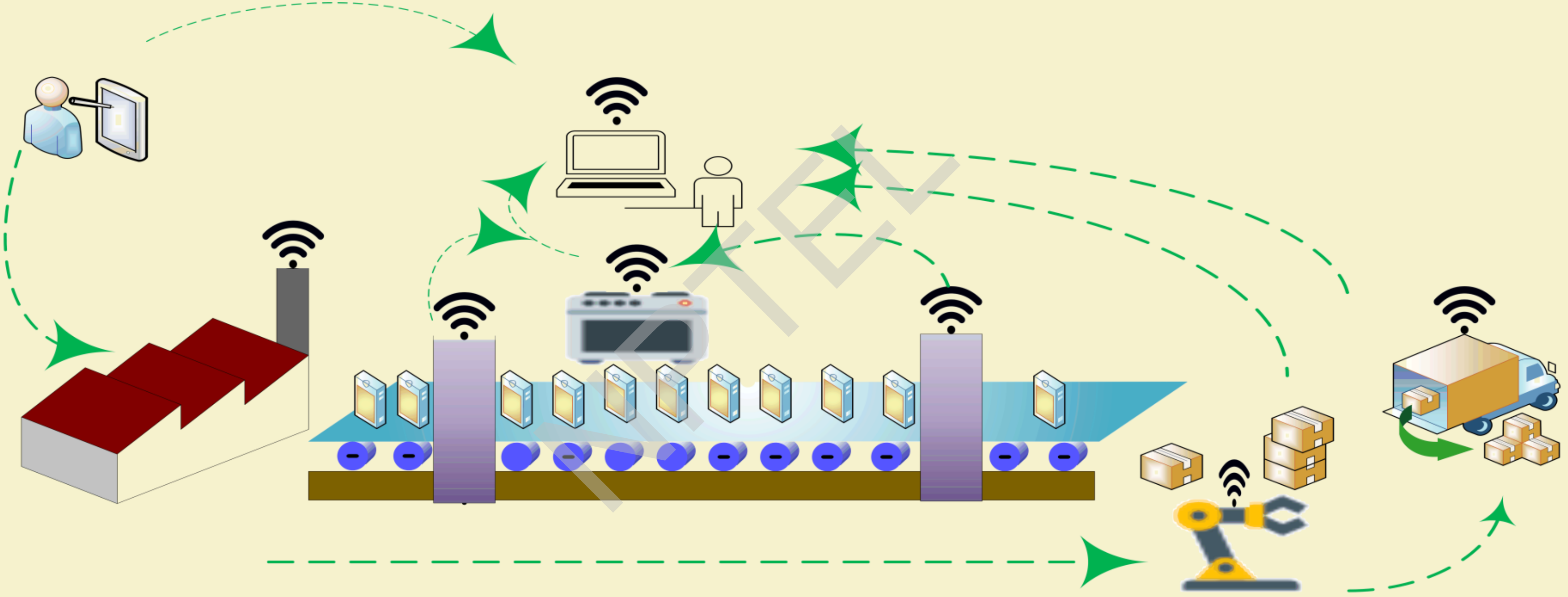

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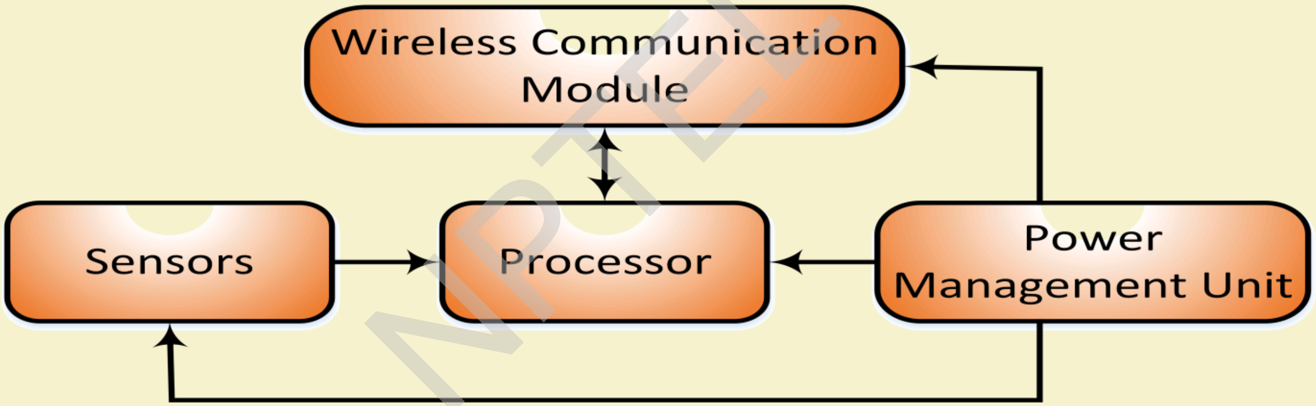
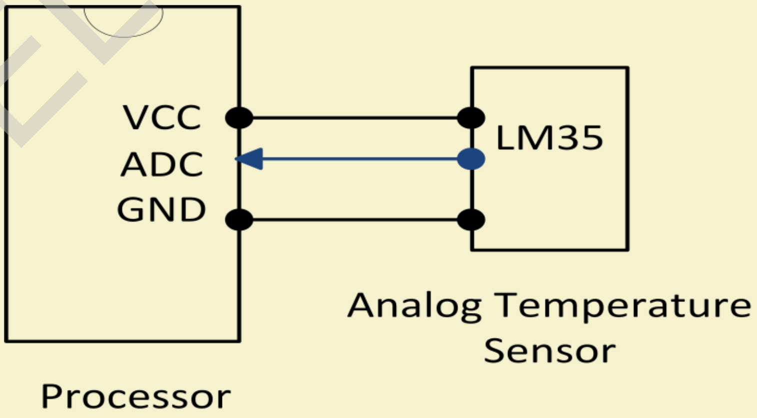
Block Diagram of a IoT Sensing Device



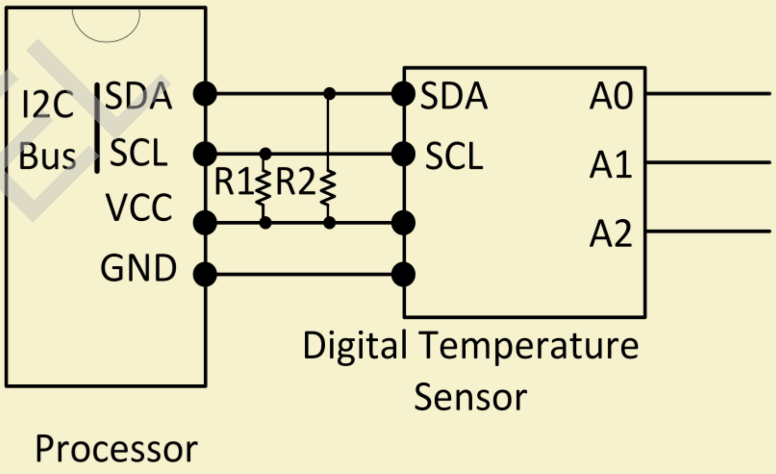
Temperature Sensor Interfacing Circuit

- Monitoring temperature of used devices in industrial applications
- LM 35 temperature sensor generates analog voltage
- The output voltage of LM 35 is linearly proportional to Celsius temperature



Temperature Sensor Interfacing Circuit (Contd.)

- Temperature sensor DS1621 is a digital sensor, which generates 9 bits temperature data.
- Operating voltage from 2.7 to 5.5 Volt
- User can define thermostatic settings
- The value of resistors R1 and R2 is from 4.7 to 10 KOhm



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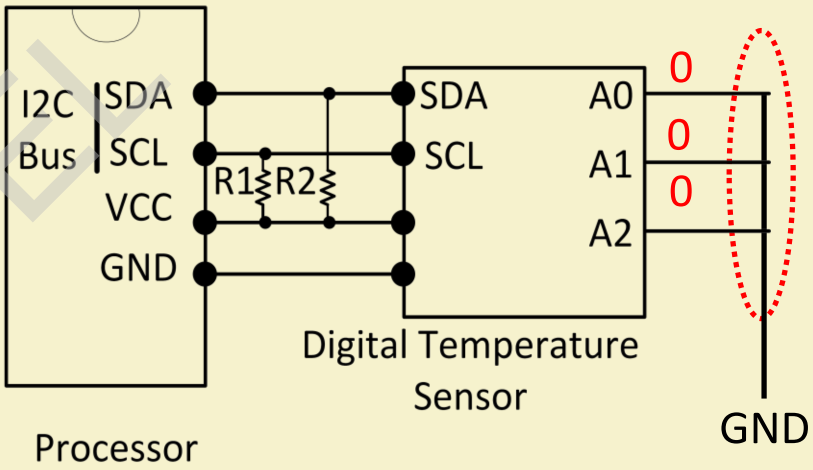

Temperature Sensor Interfacing Circuit (Contd.)

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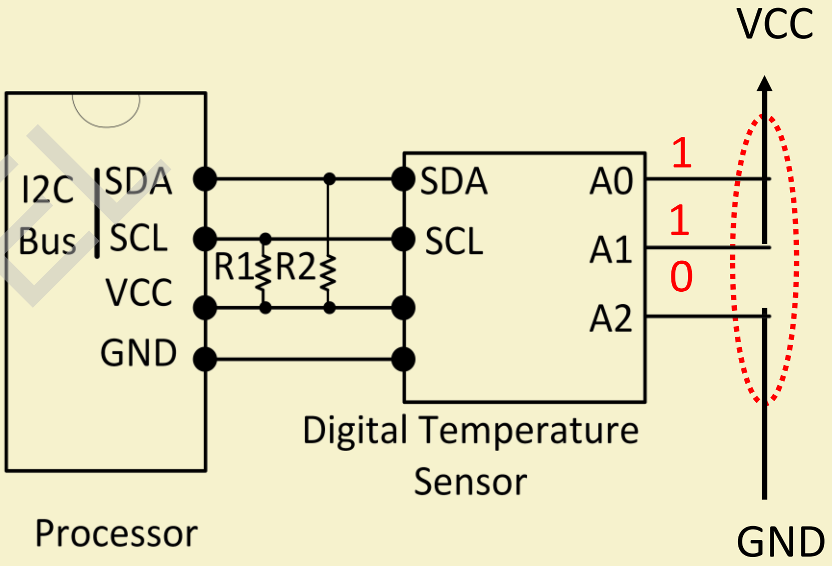
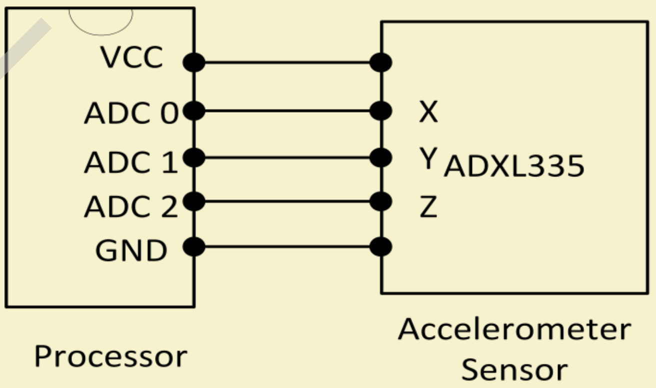


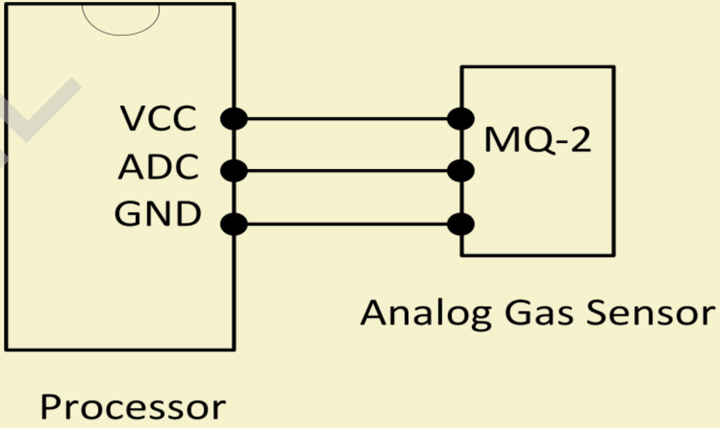
Accelerometer Sensor Interfacing Circuit

- Generates the magnitude and direction of the acceleration
- Accelerometer sensor ADXL335 provides 3 axes (X, Y, and Z) values in analog voltage



Gas Sensor Interfacing Circuit

- Measures and detects concentration of different gases
- Gas sensor MQ-2 provides the concentration of LPG, propane, and hydrogen in analog voltage



Sensors in IIoT Applications

- Temperature sensor
  - Monitoring temperature of used devices in industrial applications such as petrochemical, defense, aerospace, consumer electronics, and automotive
  - Used in some special types of application where a specific temperature is to be maintained, such as fabricate medical drugs and heat liquids.
- Magnetostrictive sensor
  - Measures and detects time-varying stresses or strains in ferromagnetic materials
  - Used for inspection of steel pipes, condition monitoring of machinery, and detection of vehicle safety

Sensors in IIoT Applications (Contd.)

- Torque sensor
  - Measures rotating torque
  - Used to measure the speed of rotation
- Pressure sensor
  - Used to measure pressure in Industrial and hydraulic systems
  - Measures different variables such as speed, water level, and gas/water flow

Sensors in IIoT Applications (Contd.)

- Vacuum sensor
  - Used to measure pressure below than atmospheric pressure
  - Used in different industrial applications such as chemical processing, detection, cathode ray tubes, gas turbine, and helium leak
- Acceleration sensor
  - Measures rate of change of velocity
  - Used to detect the magnitude and direction of the acceleration
  - Used in car electronics, ships, marine, and agricultural machines

Sensors in IIoT Applications (Contd.)

- Speed sensor
  - A measure of how fast
  - Basically measures speed which is determined by the travelling distance in a given time
  - Used in vehicle, diesel engine, engine-powered generator, anti-lock brake, printer, memory, engine-powered compressor
- PIR sensor
  - Detects infrared radiations coming from human body in its surrounding area
  - Used for automatic door open/close, human detection, lift lobby, common staircase, and shopping Mall

Sensors in IIoT Applications (Contd.)

- Image sensor
  - Used for distance measurement, pattern matching, color checking, structured lighting, and motion capture
  - Used in different applications such as 3D imaging, video/broadcast, space, security, automotive, biometrics, medical, and machine vision
- Ultrasonic sensor
  - Mainly uses for object detection, measuring distance, and dynamic body detection
  - Applications: Liquid level monitoring of tank, trash level monitoring, manufacturing process, automobile, and people detection for counting

Source: Camera Sensor's Application, Online: http://www.cmosis.com/technology/applications/

Sensors in IIoT Applications (Contd.)

- Optical sensor
- Radiation sensor
- Level sensor
- Flow sensor
- Touch sensor
- Gas sensor

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Key Enablers of Industrial IoT: Sensing Part-2

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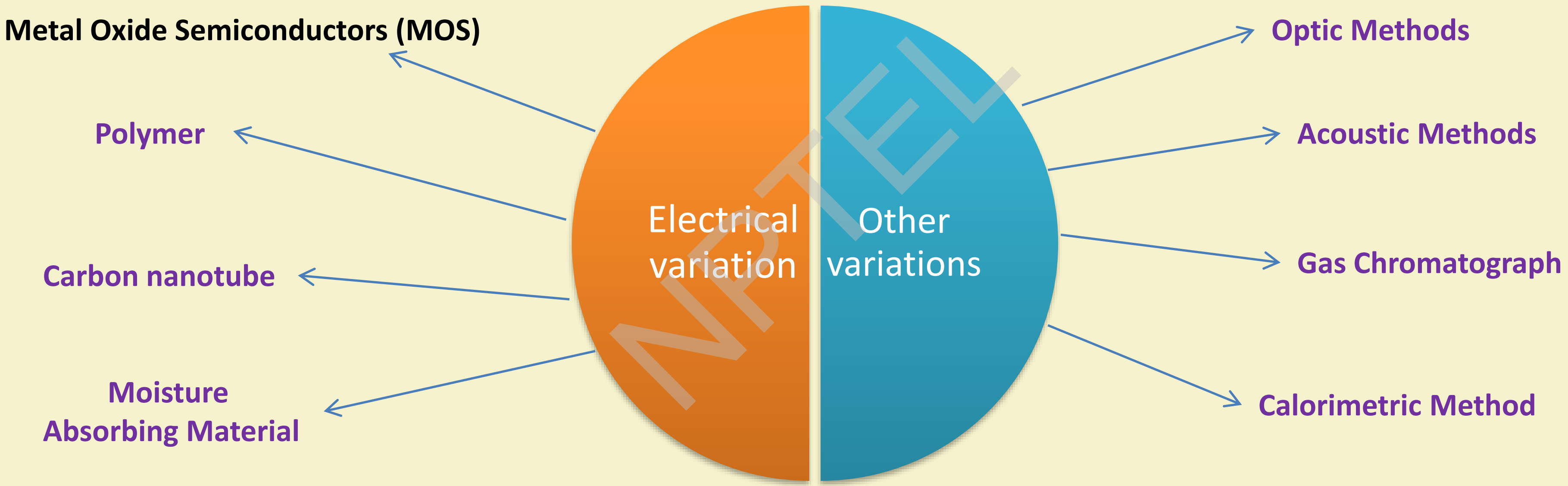
Introduction

- A gas sensing system plays a vital role for monitoring the concentration of flammable, combustible and toxic gases in the environment
- Air quality monitoring and alert systems with gas sensing units may be deployed to avoid risks of harmful exposure of gases in the environment

Gas Sensing Methods



Source: A Survey on Gas Sensing Technology, Sensors 2012

MOS Gas Sensor's Working Principle

- MOS Gas sensors are also called Chemi-Resistive Gas sensors
- Baseline Resistance: Resistance of the sensor material in **air** when not exposed to target gas
- Chemi-resistive gas sensors depend on the thermal energy for its operation which is supplied with an heater
- A particular temperature at which the sensor gives best response is called Optimum Temperature

Source: Electroceramics, Second Edition, A.J.Moulson,J.M.Herbert,Wiley

MOS Gas sensor working Principle(Contd.)

- Resistance changes when exposed to gas depending on the rise or fall in conductivity of the sensor material
- In n-type sensors, resistance decreases, and in p-type sensors, resistance increases with respect to the Baseline resistance when exposed to a reducing gas

Characterisics of Gas Sensor

- **Sensitivity**: It is the change in the output signal with respect to unit change in input (which is the target gas concentration).
- **Selectivity**: Ability to detect a particular gas in a mixture of different gases.
- **Stability**: This parameter determines the robustness in the gas sensing property of a gas sensor in a long time period when exposed to hostile ambience

Characteristics of Gas Sensor (Cond.)

- **Response time:** The time taken by the sensor to stabilize its response while sensing the target gas to reach some percent (80% or 90%) of the final value
- **Reversibility**: Whether the sensor resistance can return back to its base resistance value, if exposure to the target gas is stopped
- **Response Percent:** of a gas sensor is calculated by computing the percentage change in the resistance when exposed to target gas with respect to the resistance when not exposed.

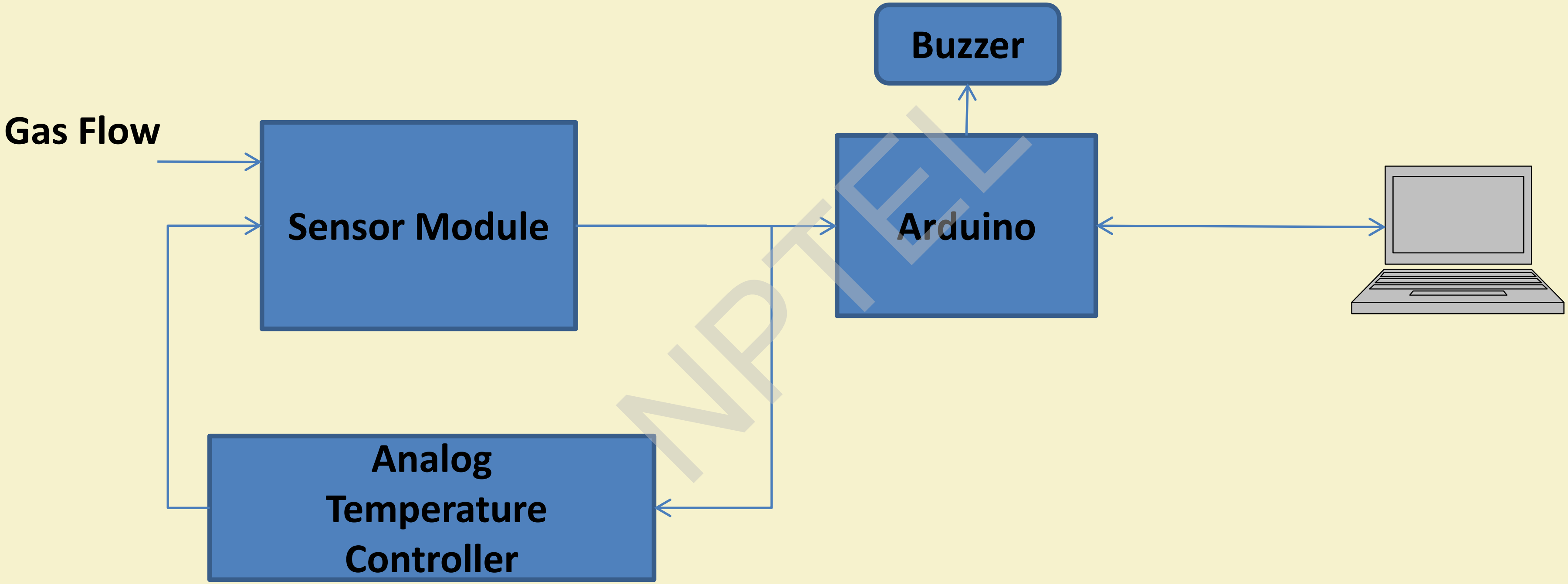
Applications of Gas sensors

- Air quality monitoring
- Leakage Detection of Toxic gases
- Manhole & Sewage Treatment
- Automotive Exhaust
- Alcohol Breath Test

A Demo on VOC Sensing

- **Introduction**
  - This gas sensing system is able to detect the presence of VOCs (Volatile Organic Compounds)
  - As soon as the gas sensors sense these gases, its resistance changes from its baseline resistance.
  - As the resistance changes, an alert is generated

Gas Sensing System



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Key Enablers of Industrial IoT: Connectivity-Part 1

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Industrial Communication

- Typical industrial communication requirements
  - Real-time
  - Very low duty-cycle
  - Very low latency
  - Very low jitter
- Industrial Communication majorly thrives on the following technologies:
  - Industrial Ethernet
    - Industrial Ethernet protocols for real-time control and automation.
    - Used in manufacturing processes dealing with clock synchronization and performance.
  - Fieldbus
    - A communication standard for Local Area Network (LAN) of field devices for industrial automation.
    - Used in manufacturing processes dealing with periodic I/O data transfer.

Industrial Communication (contd.)

- Industrial Ethernet
  - ModBus-TCP
  - EtherCat
  - EtherNet/IP
  - Profinet
  - TSN
- Fieldbus
  - Modbus-RTU
  - Profibus
  - Interbus
  - CC-Link
  - DeviceNet

Reference: Industrial Ethernet & Fieldbus solutions from KUNBUS.

ModBus-TCP

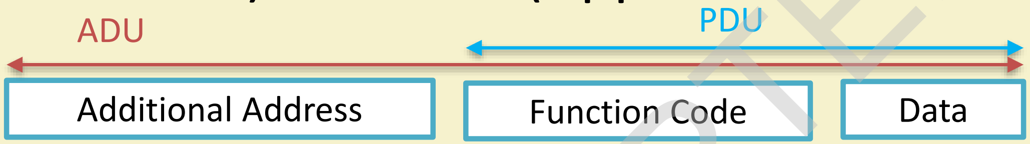
Introduction to ModBus-TCP

- A standard communication protocol used in industry, developed by Modicon Inc (Schneider Electric).
- It uses TCP/IP & Ethernet for data transmission between two compatible devices.
- The communicating system includes several devices:
  - Client-Server devices linked to a TCP/IP network
  - Interlinked devices – bridge or router or gateway
  - Serial line sub-network to grant links between client-server

Source: Modbus messaging on TCP/IP implementation guide.

Features of ModBus-TCP

- A standard date frame is embedded into a TCP frame.
- The protocol defines 2 units in the data frame: PDU (Protocol Data Unit) and ADU (Application Data Unit)



- ADU is identified by a header called MBAP.

Transaction Identifier (2 bytes)	Protocol Identifier (2 bytes)	Length (2 bytes)	Unit Identifier (1 byte)

(MODBUS Application Protocol header – 7 bytes)

Source: Swales, A. Open ModBus/TCP specification.

Features of ModBus-TCP (contd.)

- It is a connection-oriented protocol following the Client-Server architecture.
- Masters are the clients, whereas slaves are denoted as servers.
- The protocol supports up to 10 active connections/sockets at one time.

Source: Introduction to MODBUS TCP/IP.

EtherCat

Introduction to EtherCat

- EthernetCAT (Control Automation Technology) was developed by the ETG (EtherCAT Technology Group).
- It is based on IEC 61158 & IEC 61784 (international standards).
- It follows a master-slave architecture utilizing the standard IEEE 802.3.
- Application areas: time-sensitive scenario (due to high-speed of the system)

Source: Communication solutions for EtherCAT networks from KUNBUS.

Features of EtherCat

- Master and slave exchange data as PDO (process data objects)/telegram.
- Slaves follow multicast or broadcast communication initiated by the master.
- Every PDO contains a distinct address denoting several slaves.
- EtherCAT telegram = Process data + Header.
- Processing incurs a few nanoseconds delay for the telegrams.
- Each telegram utilizes memory up to 4 GB in size.

Source: Communication solutions for EtherCAT networks from KUNBUS.

Features of EtherCat (contd.)

- Data exchange provide low duty cycle time of <~100 µs and low jitter for better synchronization.
- Range of data transmission rate is ~200 Mbps
- Allow transmission range up to 100 m between the individual participants. (Using optical waveguides: up to 20 km).
- Utilizes CRC checksum for fault recognition (bit errors).
- Network topology – tree, star, line, ring, or hybrid.

Source: Communication solutions for EtherCAT networks from KUNBUS.

EtherNet/IP

Introduction to EtherNet/IP

- It is based on the standard Internet Protocol suite and IEEE 802.3.
- EtherNet/IP: CIP (Common Industrial Protocol) Over Ethernet.
- CIP: Unified communication architecture for industrial applications.
  - CIP is a media independent, connection-based, object oriented procedure intended for automation applications.
- It is constructed from layers used in DeviceNet and ControlNet.
- IIoT requires improved throughput and extensive approachability via CIP, which is offered by Ethernet.

Source: EtherNet/IP Quick Start for Vendors Handbook.

Communication Type

- EtherNet/IP defines two primary types of communications:
  - Explicit
    - Provide generic, multi-purpose transmission path between devices.
    - Message transfer is asynchronous.
    - Handles non time-critical information.
  - Implicit
    - Provide distinct and special-purpose transmission paths between a master and several clients.
    - Message transfer is continuous.
    - Handles real-time I/O data.

Source: Brooks, P. EtherNet/IP: Industrial Protocol White Paper.

Features of EtherNet/IP

- Based on active star topology.
- Easy set-up, operation, maintenance, and expansion.
- Handles large amount of information at speed of 10/100 Mbps.
- Maximum data rate up to 1500 bytes per packet.
- Mainly used with PCs, robots, I/O devices, and PLCs (Programmable Logic Controllers).

Source: EtherNet/IP Quick Start for Vendors Handbook.

Profinet

Introduction to Profinet

- Profinet (PROcess FIeld NETwork) is the standard for industrial Ethernet developed by Profibus & Profinet Int.
- The technology is based upon Ethernet/IP.
- Defines the communication channel between controller and distributed devices in the field.
- Basically used for process control and process measurement.

Source: PROFINET Unplugged – An introduction to PROFINET IO.

Communication Channel

- Uses three different communication channels:
  - Non-Real Time (NRT) – Used for non time-critical processes (acyclic read/write operations). Uses standard TCP/IP and UDP/IP to transmit data packets.
  - Real Time (RT) – Used for time-sensitive processes (cyclic data transfer and event-driven procedures). Utilized for optimized and <u>high speed data exchange</u>.
  - Isochronous Real Time (IRT) - Used for clock-synchronized communication. Suitable for <u>motion control applications</u>. Allows short cycle time (~250 µs).

Source: PROFINET. Siemens.

Time-Sensitive Networking (TSN)

Introduction to TSN

- It is an extension of Ethernet based on set of IEEE 802.1Q (virtual LAN) and 802.3 technology.
- It was developed to enable deterministic communication (predictive) for industries on standard Ethernet.
- This protocol is time-aware and distributes data over the bandwidth according to a schedule.
- It is centralized and minimizes jitter using time scheduling for real-time applications.

Source: Time-Sensitive Networking: A Technical Introduction. Cisco Public.

Features of TSN

- It supports cyclic data transfer.
- Provides pre-emption for packets with high priority.
- Network topologies: ring, chain, star, and hybrid topologies.
- Data rate is 100Mbit and 1Gbit for industrial applications.
- TSN offers IT/OT network convergence.
- The network and operation cost is minimized due to the convergence.

Source: TSN: Converging Networks for a Better Industrial IoT.

Modbus-RTU (Remote Terminal Unit)

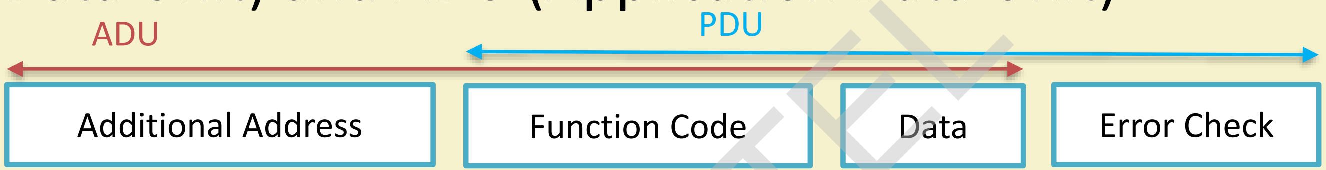
Introduction to Modbus-RTU

- It is a serial protocol (RS-232/485) that follows the Master and Slave architecture.
- It follows a request/response model.
- It is used for transmission of data signal from control/ instrumentation devices to the control unit.
- It is a messaging protocol intended for application layer.

Source: Modbus RTU Unplugged – An introduction to Modbus RTU Addressing, Function Codes and Modbus RTU Networking.

Features of Modbus-RTU

- The protocol defines 2 units in the data frame - PDU (Protocol Data Unit) and ADU (Application Data Unit)



- The client initiates the MODBUS transaction with a request.
- The format of a message request contains the address of the slave, the command (read/write register), the data, and error check.

Source: Modbus RTU Unplugged – An introduction to Modbus RTU Addressing, Function Codes and Modbus RTU Networking.

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Profibus (Process field bus)

Introduction to Profibus

- It is based on the standard IEC 61158.
- It was first started in Germany in late 1980s and then used by Siemens.
- It is a field-bus technology that supports several protocols.
- It supports cyclic as well as acyclic data transmission, isochronous messaging, and alarm-handling.

Source: PROFIBUS Protocol. Smar.

Variants of Profibus

- There are 3 variants:
  - Profibus FMS (Fieldbus Message Specification)
    - Handles communication between PCs and Programmable Logic Controllers.
  - Profibus DP (Decentralized Peripherals)
    - The speed varies from 9.6Kbps to 12Mbps.
    - It uses RS485 balanced transmission.
    - It supports 32 devices at a time (up to 1900 m, up to 10 Km with 4 repeaters).
  - Profibus PA (Process Automation)
    - The speed is fixed at 31.2Kbps.
    - Uses Manchester Bus Power (MBP) for transmission (suits hazardous environment).

Source: PROFIBUS Protocol. Smar.

Features of Profibus

- It defines 2 layers:
  - Data link - accomplished over a FDL (Field bus Data Link).
  - Physical
- It uses bus topology where, the bus or central line is underwired all through the system.
- Buses using MBP supports transmission range up to 1900 meters and can support branches.
- MBP supports data as well as power transmission.

Source: PROFIBUS, PLC Manual; PROFIBUS Protocol. Smar.

Interbus

Introduction to Interbus

- It was developed by Phoenix Contact in 1987.
- It is based upon European Standard, EN 50254 as well as IEC 61158.
- It supports serial communication among control systems (PCs, PLCs) and spatially arranged I/O modules which connects to several sensors & actuators.
- Application areas: sensing-actuating application, machine & system production, and process engineering.

Source: Interbus Basics.

Features of Interbus

- Network topology: Active ring (Supports maximum 512 subscribers, and the last subscriber closes the ring.)
- Total bus length is 13 km. Length between two remote bus devices is 400m.
- Supports master/slave architecture, fixed telegram length, deterministic communication.
- Master & Slave forms a large and distributed shift register ring with master the starting-ending point, while slave as a part of it.
- Transmission rate: 500 kbps

Source: Interbus Basics

CC-Link (Control and Communication)

Introduction to CC-Link

- It is an open industrial network established by Mitsubishi Electric Corporation in 1997.
- It is based upon the standards EN 954 as well as IEC 61508 in the safety area (compatible to ISO 15693 & 14443).
- It enables devices from several manufacturers to communicate.
- Application areas: facilities management, manufacturing & production industries, process control & automation.

Source: CC-Link Protocol. Kunbus.

Variants of CC-Link

Standard CC-Link	CC-Link/LT	CC-Link Safety	CC-Link IE (Industrial Ethernet)
Facilitates transmission of information & control data.	Convenient for implementing sensors and actuators.	Based on CC-Link.	Enables operation, device monitoring & data transmission.
Transmission rate: 10 Mbps	Transmission rate: 2.5 Mbps	Transmission rate: 10 Mbps	Transmission rate: 1 Gbps
Transmission range: up to 1.2 km (RS485), expansible to 13.2 km using repeaters.	Transmission range: up to 500m	-	-
64 stations for every network.	64 stations for every network.	-	Available as fieldbus (254 stations per network) as well as a control network (120 stations per network)

Source: CC-Link Industrial Networks, Wikipedia

Features of CC-Link

- Allows variable communication speed of 2.5Mbps - 1Gbps.
- Maximum transmission distance up to 100 meters (Fieldbus) while 550 meters (Control).
- Operating frequency: 13.56 MHz (licenses global usage).
- Data transmission utilizes both duplex & single lines.
- Facilitates a deterministic communication.

Source: CC-Link Industrial Networks, Wikipedia

DeviceNet

Introduction to DeviceNet

- It is based up on the standard CAN (Controller Area Network) protocol.
- CAN standard is a serial protocol defining the communication of data link layer.
- It links industrial sensors & actuators with high-end devices (Programmable Logic Controllers).
- Application areas: safety devices, data exchange, and large I/O networks.

Source: DeviceNet Communication Manual.

Features of DeviceNet

- Data in CAN is conveyed via data frame: Identifier field (11 bit) and Data field (8 data bytes).
- Also has a remote frame (RTR) that only contains the identifier.
- CAN uses the CSMA/NBA channel access scheme (physical layer).
- It defines different sorts of telegrams (frames), error detecting scheme, and data validation.
- It uses linear network topology that permits the signal (shielded cable) and the power wiring (twisted-pair) in the same cable.

Source: DeviceNet Communication Manual.

Communication Infrastructure

- In IIoT and Industry 4.0 IoT deployments, the connectivity infrastructure can be classified as follows:
  - Wired Connectivity
    - DSL
    - Modem
    - PSTN
  - Wireless Connectivity
    - IEC-PAS 62601/WIA-PA
    - Satellite Connectivity
    - ISA 100
    - LPWAN

Note: ISA 100 is discussed in IoT Communication-Part II of this course.

DSL

Introduction to DSL

- DSL stands for “Digital Subscriber Line”.
- Aims at bringing high data rate to households and industries using the common telecommunication line.
- A DSL line can carry both data and voice signals.
- DSL may be categorized as Asymmetric DSL(ADSL) and Symmetric DSL(SDSL).
- ADSL supports a higher download speed compared to the upload speed.
- SDSL supports equal speed for both upload and download.

Features of DSL

- Supports simultaneous connection for voice and data communication.
- Basic DSL supports data rate between 1.544 Mbps and 8.448 Mbps for download service.
- Data is transmitted in its digital format, without any conversion to analog format.
- This digital transmission allows wide range of bandwidth for communication.
- The speed of the service decreases with the increasing distance of the user from the central office of the service provider.

MODEM

Introduction to MODEM

- MODEM is a short form of Modulator-Demodulator.
- A network hardware device to perform the modulation and demodulation of carrier signals with encoded data.
- Data is modulated into analog form at the transmitting side MODEM.
- The received analog data by the MODEM is transformed into digital form, called demodulation.

Types of MODEM

- On the basis of directional capacity:
  - Simplex: It offers data transmission in only one direction, from digital device to network or vice-versa.
  - Half duplex: It offers bi-directional data transmission but one at a time.
  - Duplex: Data transmission can take place in both directions, simultaneously
- On the basis of transmission mode:
  - Synchronous Mode: In this mode a continuous stream of bits of data can be handled but requires an external clock pulse.
  - Asynchronous Mode: In this mode data bytes with start and stop bits can be handled without any external clock signal.

PSTN

Introduction to PSTN

- PSTN stands for "Public Switched Telephone Network".
- It is considered as an aggregation of all the circuit switched networks across the world, used for public telecommunication.
- PSTN networks are also called POTS, Plain Old Telephone Systems.
- These network run on a regional, local, national and international scale using fiber optic cables, telephone connection lines, cellular communications or microwave transmission links.

Source: TSSN - Telephone Networks, Tutorialspoint.

IEC/PAS 62601: WIA-PA

Introduction to IEC/PAS 62601: WIA-PA

- WIA-PA stands for "Wireless Networks for Industrial Automation-Process Automation", is a wireless communication technology, primarily focused on Industrial IoT.
- It is a variation of IEEE 802.15 and IEC.
- Advantages:
  - It supports Adaptive Frequency Hopping (AFH).
  - Aggregation of data packets is done.
  - Variable routing methodologies and modes of application are available.

Source: Yu Chen. IEC 62601: Wireless Networks for Industrial Automation- Process Automation(WIA-PA).

Satellite Communication Technology

Introduction to Satellite Communication

- Satellite communication handles large number of devices providing long range data transmission with global coverage.
- Advantages:
  - Long range communication with global coverage.
  - Cost of transmission is independent of the geographical coverage region.
- Limitations:
  - Launching of satellite in space comes at a higher cost.
  - Propagation delay is more compared to other terrestrial methods.
  - Difficulty in repairs in case of any damage.

Source: Satellite Communication – Introduction, Tutorialspoint

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Thank You!!

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Key Enablers of Industrial IoT: Connectivity-Part 3

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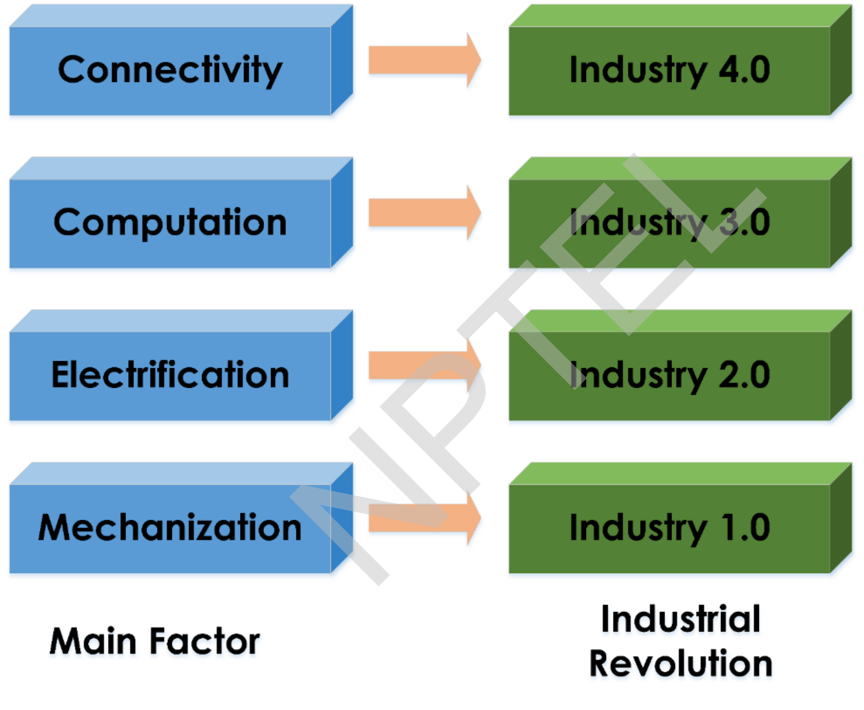

Key Requirements

- Supports heterogeneity
  - Devices: Industrial robots, machineries, security cameras
  - Device-specific QoS parameters: delay, availability, reliability, throughput
- Unified connectivity
- Optimized service
- Dedicated network
- Low-latency communication
- Ultra-reliable communication

Source: G. Brown and M. Yavuz, "What Does 5G NR Bring to the Industrial IoT & the Factory of the Future? " Qualcomm (Producer), June 2018

Community Initiatives

- 3GPP
  - Study communication requirements specific to industries (Release 15)
  - "*Factories of the Future*" 5G usecase in (Release 16)
- 5G-ACIA
  - Unite OT industries, ICT industries and academia for enabling 5G for industries
- IEEE
  - Enabling Ethernet for Time Sensitive Network (TSN) - 802.1Q Ethernet

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3GPP Release16 Usecases

- Rail-bound mass transit
- Building automation
- Smart Health Care
- Smart city
- Factories of the Future
- Smart farming
- Centralized Power generation
- Electric-power distribution
- Programme Making & Special Events

Source: 3GPP Technical Report 22.804, "Study on Communication for Automation in Vertical domains", 2018

Factories of the future

- Realization of heavy industries
  - Oil refineries
  - Mining
  - Manufacturing
  - Warehouses
- Systems in Interest
  - Motion Control
  - Robotics
  - Massive wireless sensor networks

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5G support for Private Network

- 5G new radio (NR)
  - Low band (<1 GHz)
  - Middle band (1-6 GHz)
  - High band (>24 GHz) millimeter wave
- Smallcell deployments
  - Femtocell
  - Picocell
  - Integrated WiFi
- Device-to-Device communication

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5G -NR

5G-NR

- New air-interface proposed by 3GPP
- Aligned with ITU service categories
  - Enhanced mobile broadband (eMBB)
  - Massive machine-type communication (mMTC)
  - Ultra reliable low latency communication (uRLLC)
- Design objectives
  - Backward compatibility
  - Enabling versatile connections

Source: H. Ji et al., "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects," IEEE Wireless Communications, vol. 25, no. 3, pp. 124-130, JUNE 2018.

Smallcell Deployment

Smallcell Deployment

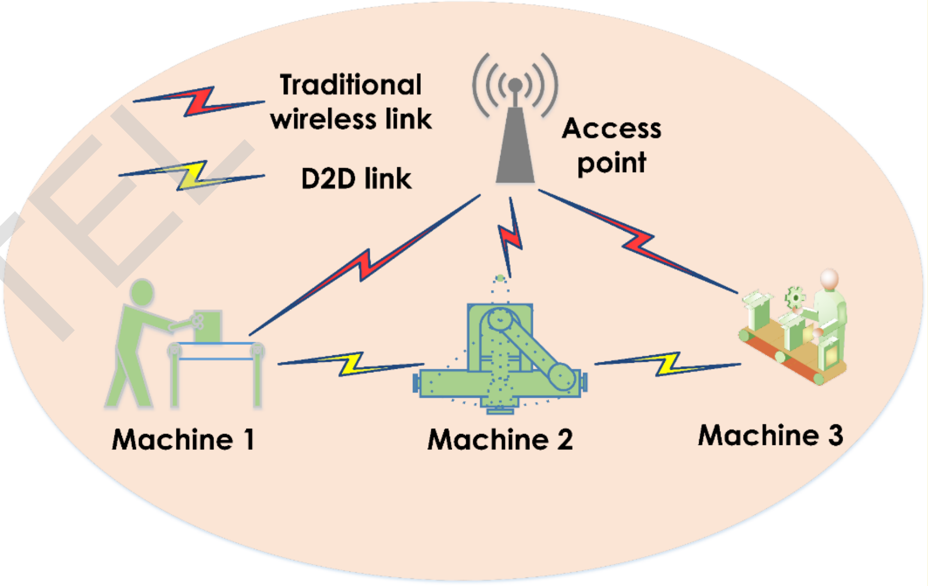
- Objectives
  - Alleviating burden on backhaul
  - Improving energy efficiency
  - Decreasing dead zones
- Operating frequency
  - Licensed spectrum
  - License-exempted spectrum

Source: A. Damnjanovic et al., "A survey on 3GPP heterogeneous networks," IEEE Wireless Communications, vol. 18, no. 3, pp. 10-21, 2011

Device-to-Device Communication

Device-to-Device Communication

- Objectives
  - Achieving low latency
  - Increasing throughput
  - Eliminating load core network
- Operating frequency
  - Inband deployment
    - Overlay, Underlay
  - Outband deployment
    - Controlled, Autonomous



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Tactile Internet

Introduction

- Real-time transmission of touch/sense and actuation
- Provides new facet to human-machine interaction
- Enables haptic communication
- Supports low end-to-end latency
  - < 1 ms round trip latency

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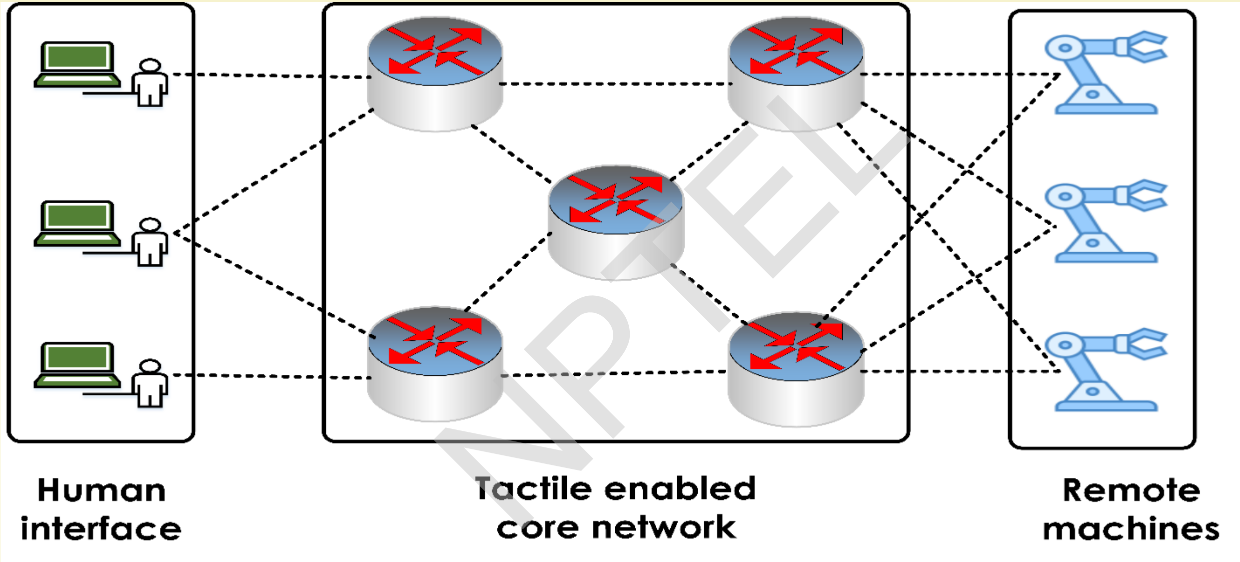
Haptic communication architecture



Source: K. Antonakoglou, et al., "Towards Haptic Communications over the 5G Tactile Internet," in IEEE Communications Surveys & Tutorials. doi: 10.1109/COMST.2018.2851452

Requirements

- Ultra-responsive connectivity
  - Latency in the order of 1 ms
- Ultra-reliable connectivity
  - Ubiquitous connectivity and wide range coverage
- Security and privacy
- Tactile data
- Edge intelligence

Source: M. Simsek, et. al., "5G-Enabled Tactile Internet," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 3, pp. 460-473, 2016.

Way to realizing tactile internet

- Software Defined Networking (SDN)
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- Dual connectivity
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Applications

- Industry automation
- Autonomous driving
- Robotics
- Healthcare
- Virtual and augmented reality
- Gaming
- Unmanned autonomous system

Source: M. Simsek, et. al., "5G-Enabled Tactile Internet," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 3, pp. 460-473, 2016.

URLLC

Introduction

- Ultra-reliable Low Latency Communication
- Requirements:
  - Availability: 6-Nines (99.9999%)
  - End-to-End Latency : 1ms
  - Reliability: < 10^{-5} outage probability
  - Packet size: 32-200 B
  - Smaller transmission duration

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Design Challenges

- Lacuna in traditional communication systems:
  - Primary objective: High throughput
  - Large latency (10 – 100 ms)
  - Large transmission time interval (TTI)
  - Large processing delay
  - Aggressive retransmission scheme
- Shorter TTI
  - Larger signal overhead
- Error prone channel
  - Decreases reliablity

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Shorter TTLs
  - Smaller slot length (micro scale)
  - Flexible transmission frame structure
  - Reducing Orthogonal Frequency Division Multiplexing **symbols** in TTL
  - Reducing symbol duration
  - Application: Mission-critical services

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods (Contd..)

- Fast HARQ Retransmission scheme
  - Procedure: Predicting correctness of received symbol before decoding
  - Advantage: Reduces processing time
  - Disadvantage: False positive error
- Control channel enhancement methods:
  - CQI based Link adaptation
  - Compact downlink control information (DCI)

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

mmWave Communication

Introduction

- Frequency Spectrum : 30 – 300 GHz
  - mmWave for cellular communication: 30 – 100 GHz
  - Indoor communication : 57 – 64 GHz (Unlicensed band)
- Wave length : 1 - 10 mm
- Reduced element size
- MIMO based narrow beam formation

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Heterogeneous structure
  - Single macrocell with multiple smallcell
- Separate control and data channel
  - Control channel : microwave frequency (3G, 4G)
  - Data channel : mmWave frequency
- Dual mode smallcell

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Disadvantages

- Need high-gain and high-directional antennas
- Signal blocking
- Suffer high penetration loss and shadowing
- Focused beam has very less chance to avoid blocking
- Low transmitting power due to maintain power amplifier efficiency

Source: J. G. Andrews, et. al. , "Modeling and Analyzing Millimeter Wave Cellular Systems," in IEEE Transactions on Communications, vol. 65, no. 1, pp. 403-430, 2017.

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Thank You!!

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Key Enablers of Industrial IoT: Connectivity-Part 3

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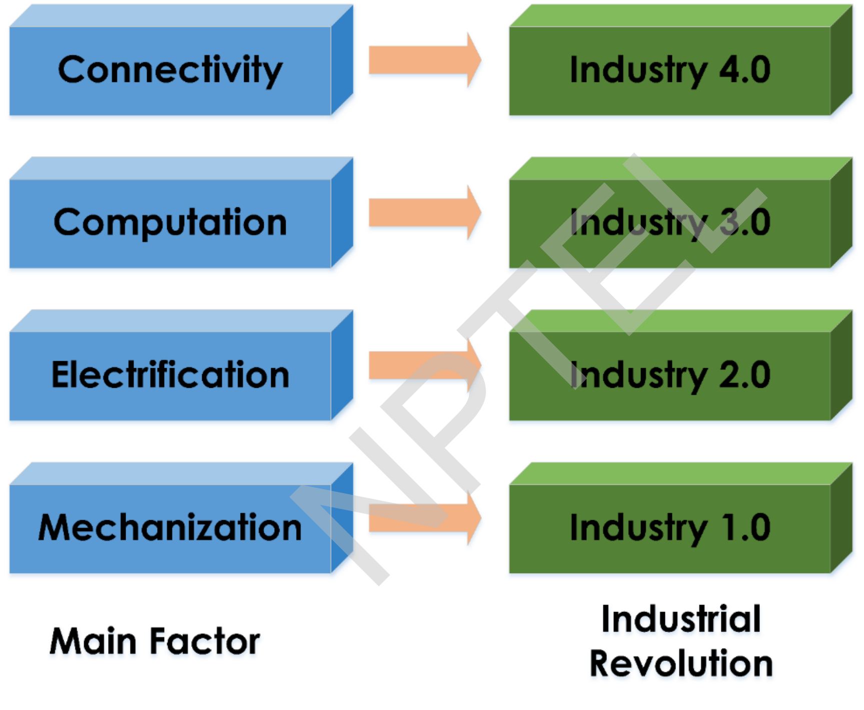

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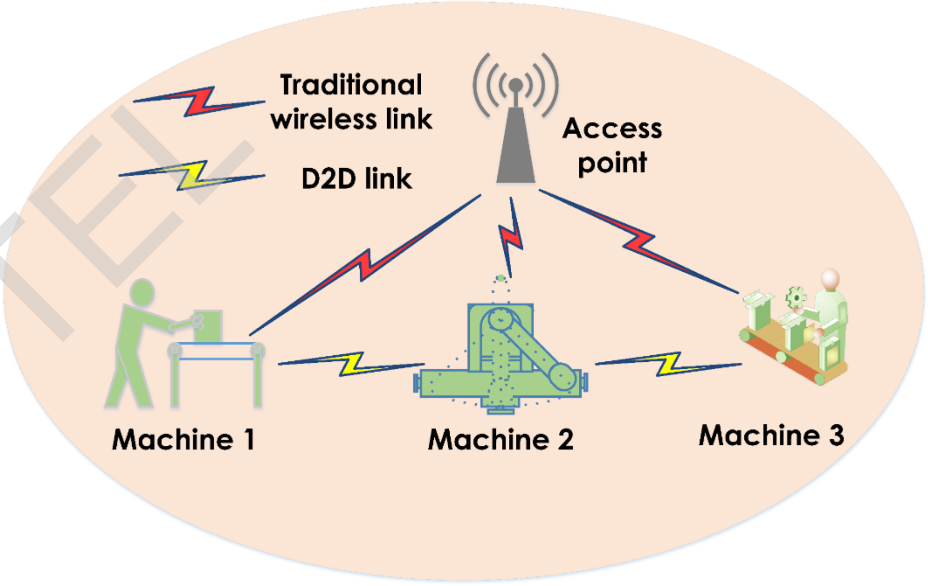

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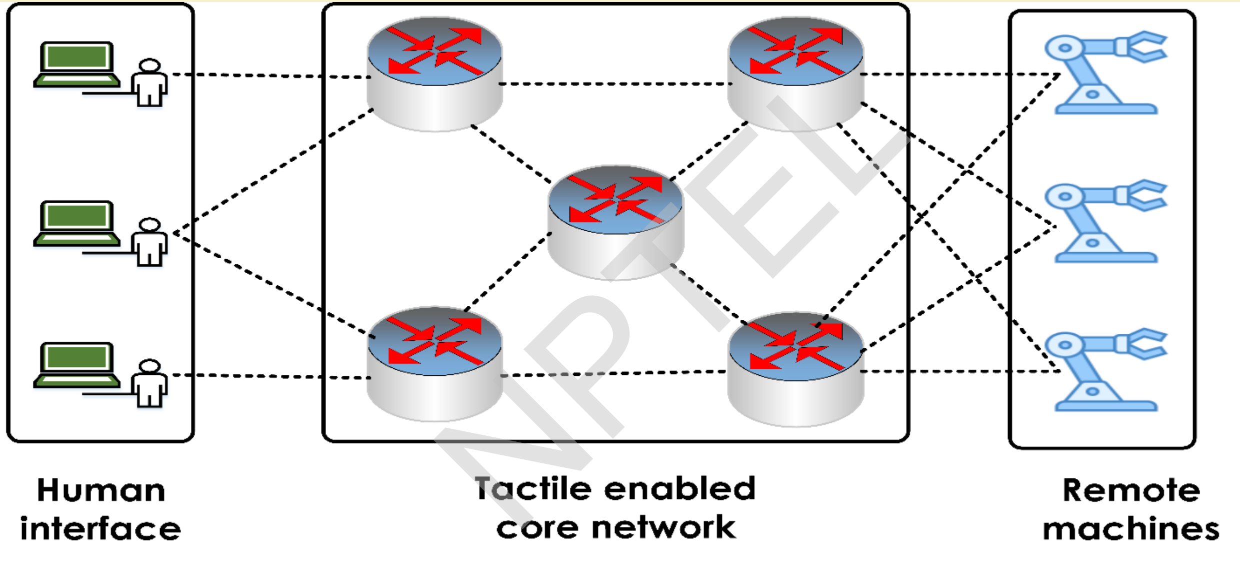

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  - End-to-End Latency : 1ms
  - Reliability: < 10^{-5} outage probability
  - Packet size: 32-200 B
  - Smaller transmission duration

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Design Challenges

- Lacuna in traditional communication systems:
  - Primary objective: High throughput
  - Large latency (10 – 100 ms)
  - Large transmission time interval (TTI)
  - Large processing delay
  - Aggressive retransmission scheme
- Shorter TTI
  - Larger signal overhead
- Error prone channel
  - Decreases reliablity

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Shorter TTLs
  - Smaller slot length (micro scale)
  - Flexible transmission frame structure
  - Reducing Orthogonal Frequency Division Multiplexing **symbols** in TTL
  - Reducing symbol duration
  - Application: Mission-critical services

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods (Contd..)

- Fast HARQ Retransmission scheme
  - Procedure: Predicting correctness of received symbol before decoding
  - Advantage: Reduces processing time
  - Disadvantage: False positive error
- Control channel enhancement methods:
  - CQI based Link adaptation
  - Compact downlink control information (DCI)

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

mmWave Communication

Introduction

- Frequency Spectrum : 30 – 300 GHz
  - mmWave for cellular communication: 30 – 100 GHz
  - Indoor communication : 57 – 64 GHz (Unlicensed band)
- Wave length : 1 - 10 mm
- Reduced element size
- MIMO based narrow beam formation

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Heterogeneous structure
  - Single macrocell with multiple smallcell
- Separate control and data channel
  - Control channel : microwave frequency (3G, 4G)
  - Data channel : mmWave frequency
- Dual mode smallcell

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Disadvantages

- Need high-gain and high-directional antennas
- Signal blocking
- Suffer high penetration loss and shadowing
- Focused beam has very less chance to avoid blocking
- Low transmitting power due to maintain power amplifier efficiency

Source: J. G. Andrews, et. al. , "Modeling and Analyzing Millimeter Wave Cellular Systems," in IEEE Transactions on Communications, vol. 65, no. 1, pp. 403-430, 2017.

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Thank You!!