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IN PURSUIT OF PERFECTION

Introduction to Internet of Things (AIDS/AIML309)

By: Dr. Divya Agarwal

Course Overview:

- This course is foundation course around the Internet of Things (IoT). It overviews about the technology used to build these kinds of devices, how they communicate, how they store data, and the kinds of distributed systems needed to support them. Divided into four modules, the first unit explores about theoretical concepts of IoT while second unit is completely programming based to explore IoT sensors and actuators with Arduino. The rest of the syllabus is application oriented based on learning. In general, through this course students will be explored to the interconnection and integration of the physical world and the cyber space. They will be able to design and develop IOT Devices

Course Objective:

- To learn fundamentals of IoT and how to build IoT based systems
- To emphasize on development of Industrial IoT applications
- To recognize the factors that contributed to the emergence of IoT
- To utilize and implement solid theoretical foundation of the IoT Platform and System Design.

Course Outcomes (CO):

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- CO1: Ability to understand design flow of IoT based systems
- CO2: Analyse and understand different communication protocols for connecting IoT nodes to server
- CO3: Apply coding concepts to design real-time IoT solutions
- CO4: Develop the state-of-the-art IoT based systems, suitable for real life and Industry applications

Syllabus Contents

- **UNIT- I**

❑ **The Internet of Things:** An Overview of what is IoT? Why IoT? Explain the definition and usage of the term "Internet of Things (IOT)" in different contexts. Design Principles for Connected Devices, internet principles: internet communications-An overview, Physical Design of IoT, Logical Design of IoT, IoT standards, IoT generic architecture and IoT protocols. IoT future trends, Understand IoT Applications and Examples. Understand various IoT architectures based on applications. Understand different classes of sensors and actuators. Sensors: sensor terminology, sensor dynamics and specifications. Understand the basics of hardware design needed to build useful circuits using basic sensors and actuators

Syllabus Contents

- **UNIT- II**

❑ **Communication protocols and Arduino Programming:** Understand various network protocols used in IoT, Understand various communication protocols (SPI, I2C, UART). Design and develop Arduino code needed to communicate the microcontroller with sensors and actuators, build circuits using IoT supported Hardware platforms such as Arduino, ESP8266 etc., Use of software libraries with an Arduino sketch that allows a programmer to use complicated hardware without dealing with complexity, Learning IoT application programming and build solutions for real life problems and test them in Arduino and Node MCU environments. Understand various wireless Technologies for IoT and its range, frequency and applications.

Syllabus Contents

- **UNIT- III**

❑**Fundamentals of IEEE 802.15.4, Zigbee and 6LOWPAN:** Importance of IEEE 802.15.4 MAC and IEEE 802.15.4 PHY layer in constrained networks and their header format, Importance of Zigbee technology and its applications, use of IPv6 in IoT Environments, Understanding importance of IPv6 and how constrained nodes deal with bigger headers (IPv6). Understand IPv6 over LowPower WPAN (6LoWPAN) and role of 6LoWPAN in wireless sensor network. Various routing techniques in constrained network. Understanding IoT Application Layer Protocols: HTTP, CoAP Message Queuing Telemetry Transport (MeTT).

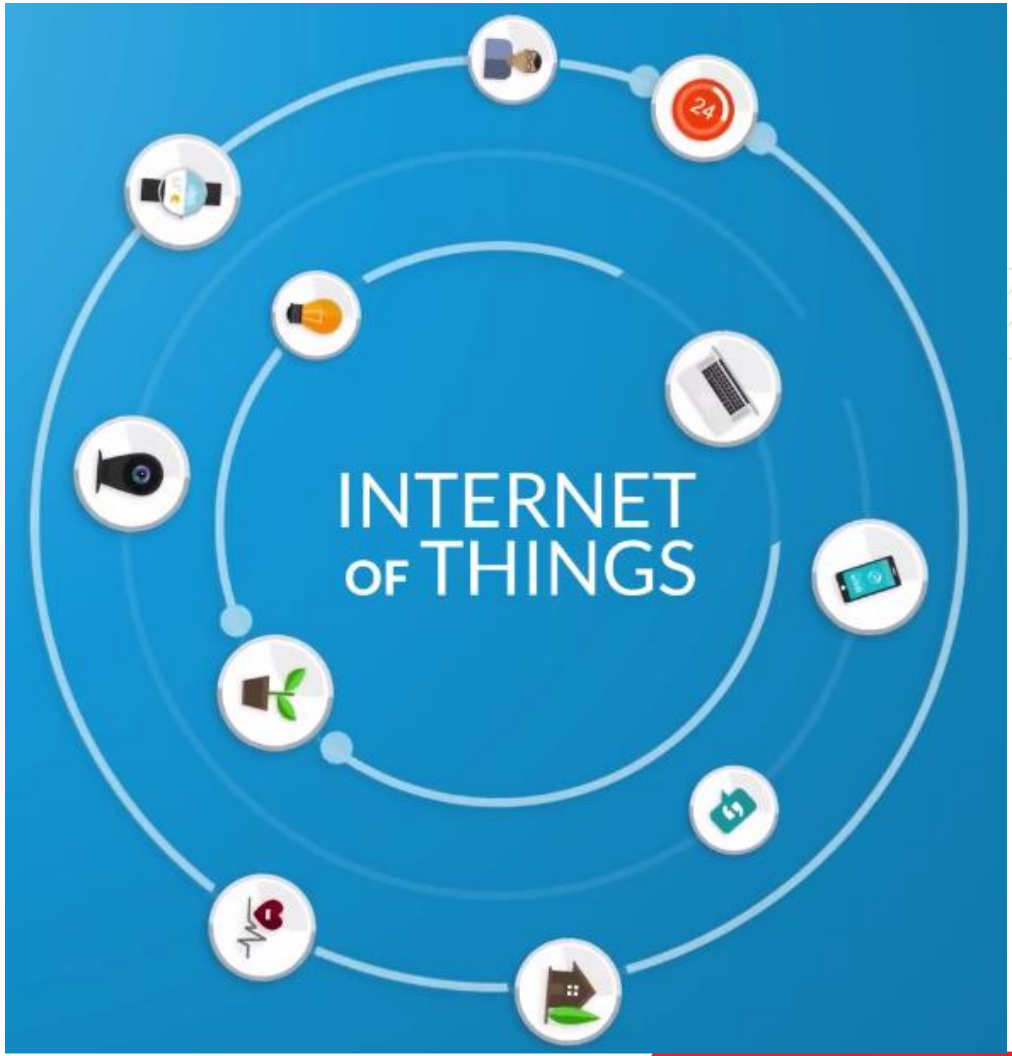
Syllabus Contents

- **UNIT- IV**

❑ **Application areas and Real-time Case Studies:** Role of big data, cloud computing and data analytics in a typical IoT system. Analyze various case studies implementing IoT in real world environment and find out the solutions of various deployment issues. Smart parking system, Smart irrigation system-block diagram, sensors, modules on Arduino and Node MCU

What is Internet of Things?

- **IOT is a giant network of connected devices.**
- **These devices gather and share data about how they're used and the environment in which they're operated.**




AC controller
23°


edureka!
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Let us look closely at our mobile phones

Mobile Gyroscope

GPS Tracking

Adaptive Brightness

Voice Detection

Face Detection

What is Internet of Things?

IoT is connecting everyday things embedded with electronics, software and sensors to the internet enabling them to collect and exchange data

How its done?

Dr. Divya Agarwal

How its done?

It's all done using **sensors**, sensors are **embedded** in every physical device.

Sensors and physical devices

- Physical devices can be mobile phone, electrical appliances, vehicles, barcode sensors, traffic lights and almost everything that we come across in day to day life.
- Sensors continuously emit data about working state of the devices.

How this data is shared to benefit

How this data is shared to benefit

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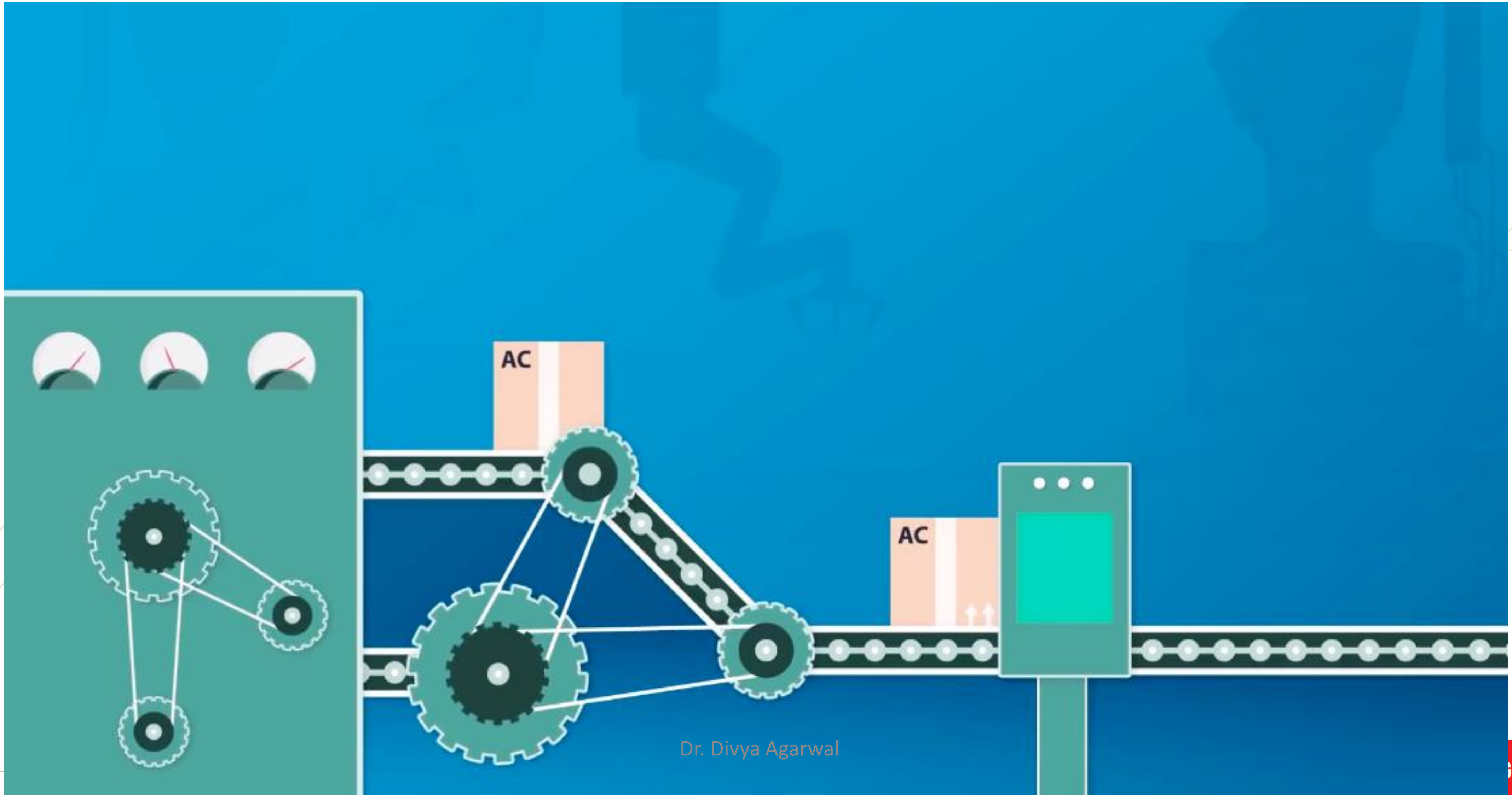
- IOT provides a common platform for all these devices to dump their data and a common language for all devices to communicate with each other.
- Data is emitted from various sensors and sent to IOT platforms.
- Securely IOT platform integrates collected data from various sources.
- Further analytics is performed on data and valuable information is extracted as per requirement.
- Finally, result is shared with other devices for better user experience, automation and improving efficiencies.

IoT in AC manufacturing industry



IoT example in AC manufacturing industry

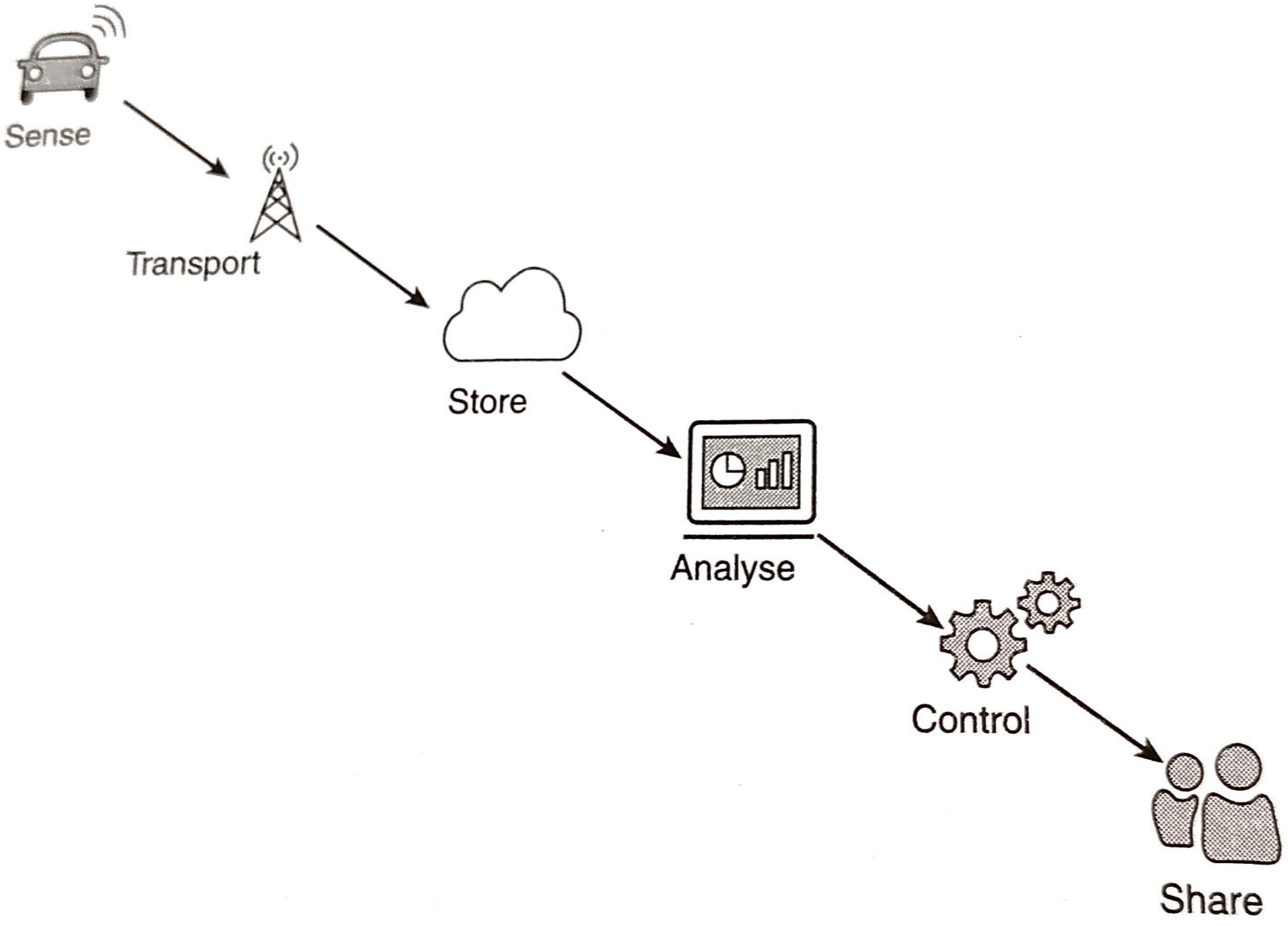
- Both manufacturing machine and belt have sensors attached.
- Both send data regarding machine health and production specifications to manufacturer to identify issues beforehand.
- Barcode is attached to each product before leaving belt containing product code manufacturer details etc.
- Manufacturer uses this data to identify why product was distributed and track retailers in venturing.
- Hence manufacturer can make product running out of stock available Next
- These products are packed and parcel to different retailers.
- Each retailer has a barcode reader to track products coming from.
- Different manufacturers, manage inventory, check special instructions and many more.
- Compressor of AC has an embedded sensor that emits data regarding its health and temperature.
- This data is analyzed continuously allowing customer care to contact you for repair work in time.

IoT Definitions

- **IoT -** An interaction between the physical and digital worlds. The digital world interacts with the physical world using a plethora of sensors and actuators.
- **IoT -** defined as a paradigm in which computing and networking capabilities are embedded in any kind of conceivable object.
- **IoT -** refers to a new kind of world where almost all the devices and appliances that we use are connected to a network, to be used collaboratively to achieve complex tasks that require a high degree of intelligence. For this intelligence and interconnection, IoT devices are equipped with embedded sensors, actuators, processors, and transceivers.
- **IoT -** Not a single technology; rather it is an agglomeration/amalgamation of various technologies that work together in tandem.

IoT Definitions

A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols, where physical and virtual things have identities, physical attributes, and virtual personalities, utilizing intelligent interfaces which are seamlessly integrated into the information network to often communicate data associated with users and their environments.



Benefits of iot

- **Efficient Resource Utilization**
- **Minimizing Human Effort**
- **Saves Time**
- **Development of AI through IoT**
- **Improved Security**

Features of IoT

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- **CONNECT – Connect various things to IoT Platform**
- **ANALYZE – Analyze the data collected and use it to build Business Intelligence**
- **INTEGRATE – Integrate various models to improve user experience**

IoT Characteristics

- **Dynamic and Self-Adapting –** IoT devices and systems have capabilities to dynamically adapt with changing contexts and take actions based on their operating conditions, user's context or sensed environment. For example – **Surveillance Camera**
- **Self- Configuring –** It allows a large number of devices to work together to provide certain functionality such as **weather monitoring.** These devices have ability to configure themselves as per IoT infrastructure, setup the networking and fetch latest softwares upgrades with minimal human intervention.
- **Interoperable Communication Protocols –** Required to communicate with other devices and also with infrastructure.

IoT Characteristics

- **Unique Identity –** Each IoT device has a unique identity and a unique identifier such as an IP address. They have intelligent interfaces which adapt based on context and allow communicating with users and environments. IoT devices interfaces allow users to query the devices, monitor their status and control them remotely, in association with control, configuration and arrangement infrastructure.
- **Integrated into Information Network–** It allows them communicate and exchange data with other devices and systems. IoT devices can be dynamically discovered in network or other networks. For example- **weather monitoring**
- **Interconnectivity-** With regard to the IoT, anything can be interconnected with the global information and communication infrastructure

Physical design of an IoT

- "Things" in IoT usually refers to IoT devices which have unique identities and can perform remote sensing and actuating and have monitoring capabilities.
- IoT devices can:
  - ❑Exchange data with other connected devices and applications (directly or indirectly), or
  - ❑Collect data from other devices and process the data locally, or
  - ❑Send the data to centralized servers or cloud-based application back-ends for processing the data, or
  - ❑Perform some tasks locally and other tasks within the IoT infrastructure, based on temporal and space constraints

Generic Block Diagram of an IoT Device (Architecture)

- **IoT** device consists of several interfaces for connections together devices, both wired and wireless. These include
  1. I/O interfaces for sensors
  2. Interfaces for internet connectivity
  3. Memory and storage interfaces and
  4. Audio / video interfaces.

Generic Block Diagram of an IoT Device (Architecture)

Connectivity
- User Host
- Ethernet

Processor
- CPU

Audio/ Video Interfaces
- HDMI
- 3.5mm audio
- RCA video

I/O Interfaces (for sensors, actuators, etc.)
- UART
- SPI
- I2C
- CAN

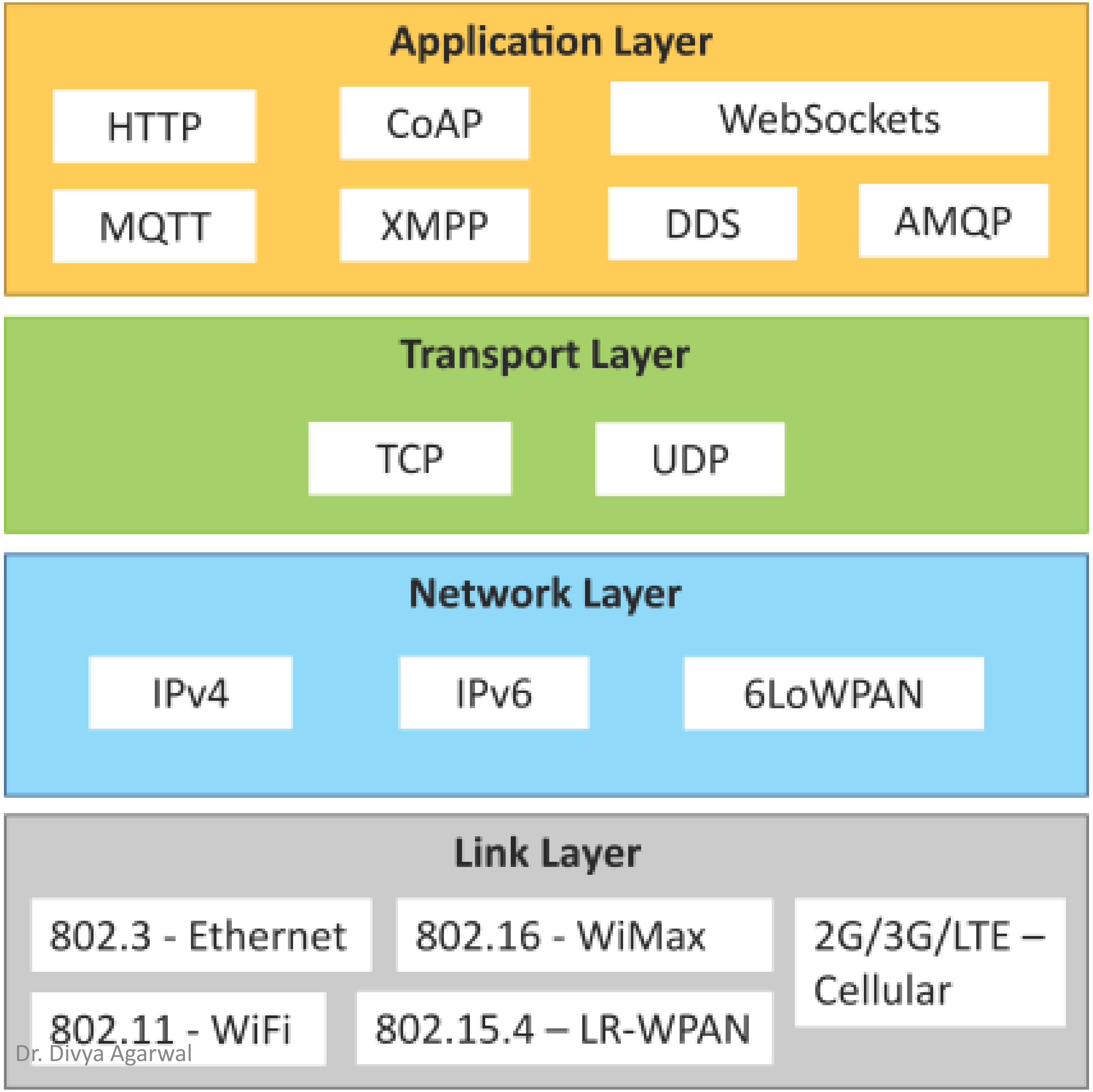
Memory Interfaces
- NAND/NOR
- DDR1/DDR2/DDR3

Graphics
- GPU

Storage Interfaces
- SD
- MMC
- SDIO

IoT Architecture

- **Link Layer**
- **Network/Internet Layer**
- **Transport Layer**
- **Application Layer**



What are protocols

- In a network, communication occurs between entities in different systems which is capable of sending or receiving information.
- However, two entities cannot simply send bit streams to each other and expect to be understood.
- For communication to occur, entities must agree on a protocol.
- **A protocol is a set of rules that govern data communications.**
- Protocol defines **what** is communicated, **how** it is communicated, and **when** it is communicated.

What are protocols

- Key elements of a protocol are **syntax, semantics, and timing**.
  - **Syntax-** Syntax refers to the correct structure and format of the code.
    For example, int ledPin = 13;
  - **Semantics-** Semantics refers to the meaning of the code and semantic errors are related to whether the code behaves as intended and whether it correctly represents the desired logic and hardware configuration.

  For example, A common semantic error in Arduino programming is using the wrong pin number or incorrect logic in your code.

  - **Timing-** Refers to two characteristics: when data should be sent and how fast they can be sent. For example, if a sender produces data at 100 Mbps but receiver process data at only 1 Mbps, transmission will overload receiver and some data will be lost.

IoT Architecture and Protocols

- **Link Layer** Determines how data is physically sent over network layer (e.g. copper wire, coaxial cable or a radio wave).
- Determines how packet are coded and signaled by hardware device over medium to which host is attached.
- Link Layer Protocols:-
  1. IEEE 802.3 - Ethernet (wired connection)
  2. 802.11 –Wi-Fi
  3. 802.16—WiMax
  4. 802.15.4 – LR-WPAN
  5. 2G/3G/4G—Mobile communication

1. **Link Layer**.
   - Its scope is local network connection to which host is attached.
   - Hosts on same link exchange data packets over link layer using link layer protocols.

1. **IEEE 802.3 - Ethernet :** IEEE 802.3 is a collection of wired Ethernet standards for link layer.

✓ For example 802.3 is standard for 10BASE5 Ethernet that uses co-axial cable as a shared medium,

✓ 802.3.i is standard for 10BASE-T Ethernet over copper twisted pair connections,

✓ 802.3.j is standard for 10BASE-F Ethernet over fibre optic connections,

✓ 802.3ae is standard for 10Gbit/s Ethernet over fiber, etc.

Standards provide data rates from 10 Mb/s to 40 Gb/s and higher. Shared medium in Ethernet can be a coaxial cable, twisted pair wire or an optical fiber which carries communication for all devices on Internet, thus data sent by one device can be received by all devices subject to propagation conditions and transceiver capabilities.

Link Layer

2. **IEEE 802.11 –Wi-Fi :** IEEE 802.11 is a collection of wireless LAN (WLAN) communication standards including extensive description of link layer. For example 802.11a operates in 5Ghz band, 802.11b and 802.11g operate in 2.4 GHz band, 802.11n operates in 2.4/5 GHz bands, 802.11 ac operates in 5GHz band and 802.11ad operates in 60 GHz band. Standards provide data rates from 1 Mb/s to 6.75 Gb/s.
3. **IEEE 802.16—WiMax :** IEEE 802.16 is a collection of wireless broadband standards including extensive descriptions for link layer also called WiMax. WiMax standards provide data rates from 1.5 Mb/s to 1 Gb/s. Recent update provides data rates of 100 Mbit/s for mobile stations and 1Gbit/s for fixed stations.

Link Layer

4. **802.15.4 – LR-WPAN:** IEEE 802.15.4 is collection of standards for Low Rate Wireless PAN (LR-WPAN). Standards form basis of specifications for high level communication protocols such as ZigBee. LR-WPAN standards provide data rates from 40 Kb/s to 250 Kb/s. Standards provide low cost and low speed communication for power constraint devices.
5. **2G/3G/4G—Mobile communication:** There are different generations of mobile communication standards including 2G (GSM and CDMA), 3G (UMTS and CDMA 2000) and 4G (LTE), IoT devices based on these standards can communicate over cellular networks, Data rates range from 9.6 Kb/s (for 2G) to 100 Mb/s (for 4G).

IoT Protocols

2. **Network/Internet Layer** -This layer performs host addressing and packet routing. Datagram contain source and destination addresses which are used to route them from source to destination across multiple networks.
   - **IPv4:** Internet protocol version 4 is most deployed internet protocol, used to identify devices on network using hierarchical addressing scheme. It uses 32 bit address scheme that allows 2^{32} addresses. It is succeeded by IPv6. IP protocols establish connections on packet networks, but do not guarantee delivery of packets. Guaranteed delivery and Data integrity are handled by upper layer protocols such as TCP.
   - **IPV6:-** New version of internet protocol which uses 128-bits address that allows 2^{128} or 3.4×10^{38} address.
   - **6LoWPAN:- IPv6 over Low-Power Wireless Personal Area Networks (*6LoWPAN*)** brings IP protocol to low power devices which have limited processing capabilities. Operates in 2.4 GHz frequency range and provides data transfer rates of 250 Kb/s. 6LoWPAN works with 802.15.4 link layer protocol and defines compression mechanisms for IPv6 datagrams over IEEE 802.15.4-based networks.

Transport Layer

Provide end to end message transfer capability independent of underlying network.

- Message transfer capability can be set up on connections using handshakes (as in TCP) for without using handshakes (as in UDP) . Provides functions such as error control segmentation, flow control and congestion control.

1. **Transmission Control Protocol (TCP): -** Widely used for data transmission in communication network such as internet. It is a **connection oriented** and stateful protocol. While IP protocols deals with sending packets, TCP ensures reliable transmission of packets in order. It provides error detection capability so that duplicate packets can be discarded and lost packets are retransmitted. Flow control capability ensures that rate at which sender sends data is not too high for receiver to process. Congestion control capability helps in avoiding network congestion and congestion collapse which can lead to degradation of network performance.

2. **User Datagram Protocol (UDP): -** Transaction oriented, stateless and **connectionless protocol**. Useful for time-sensitive applications that have very small data units to exchange and do not want connection setup-overhead. Does not provide guaranteed delivery, ordering of message and duplicate elimination.

IoT Protocols

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4. **Application Layer** Defines how application processes (clients and servers), running on different end systems, pass messages to each other. It defines:

- Types of messages, e.g., request messages and response messages.
- Syntax of various message types, i.e., fields in message and how fields are delineated.
- Meaning of information that field is supposed to contain.
- Rules for determining when and how a process sends messages and responds to messages

Application Type	Application-Layer Protocol
Electronic Mail	**Send:** Simple Mail Transfer Protocol (SMTP) **Receive:** Post Office Protocol v3 (POP3)
M2M	CoAP
World Wide Web (WWW)	Hyper Text Transfer Protocol 1.1 (HTTP 1.1)
File Transfer	File Transfer Protocol (FTP) Trivial File Transfer Protocol (TFTP)
Internet Telephony	Proprietary (e.g. Vocaltec)

Application Layer

4. **Application Layer** Defines how application interface with the lower layer protocols to send data over network. It enables process-to-process connections using ports.

- **HTTP:** Hypertext Transfer Protocol (HTTP) forms foundation of WWW.
  - Includes commands such as GET, PUT, POST, DELETE, HEAD, TRACE, OPTIONS, etc.
  - Follows **request response model** where client sends requests to server using HTTP commands.
  - Stateless protocol where each HTTP request is independent of other requests.
  - HTTP client can be a browser or an application running on client (e.g., an application running on an IoT device, a mobile application or other software.)
  - Uses Universal Resources Identities (URIs) to identify HTTP resources.

Application Layer

- **Constrained Application Protocol (CoAP):** used for machine-to-machine applications.
  - Meant for constrained environments with constrained devices and networks. Like, HTTP, CoAP is a web transfer protocol and uses a request-response model, however it runs on top of UDP instead of TCP.
  - Uses a client-server architecture where clients communicate with servers using connectionless datagrams.
  - Designed to easily interface with HTTP.
  - Supports methods such a GET, POST, PUT, and DELETE.

Application Layer

- **WebSocket:** allows full-duplex communications over a single socket connection for sending messages between client and server.
  - Based on TCP and allows streams of messages to be sent back and forth between client and server while keeping TCP connection open.
  - Client can be browser, mobile application or an IoT device
- **Message Queue Telemetry Transport (MQTT):** light weight messaging protocol based on publish-subscribe model.
  - Uses a client-server architecture where clients connects to server and publishes messages to topics on server.
  - Broker forwards the messages to clients subscribed to topics
  - Well suited for constrained environments where devices have limited processing and memory resources and network bandwidth is low.

Application Layer

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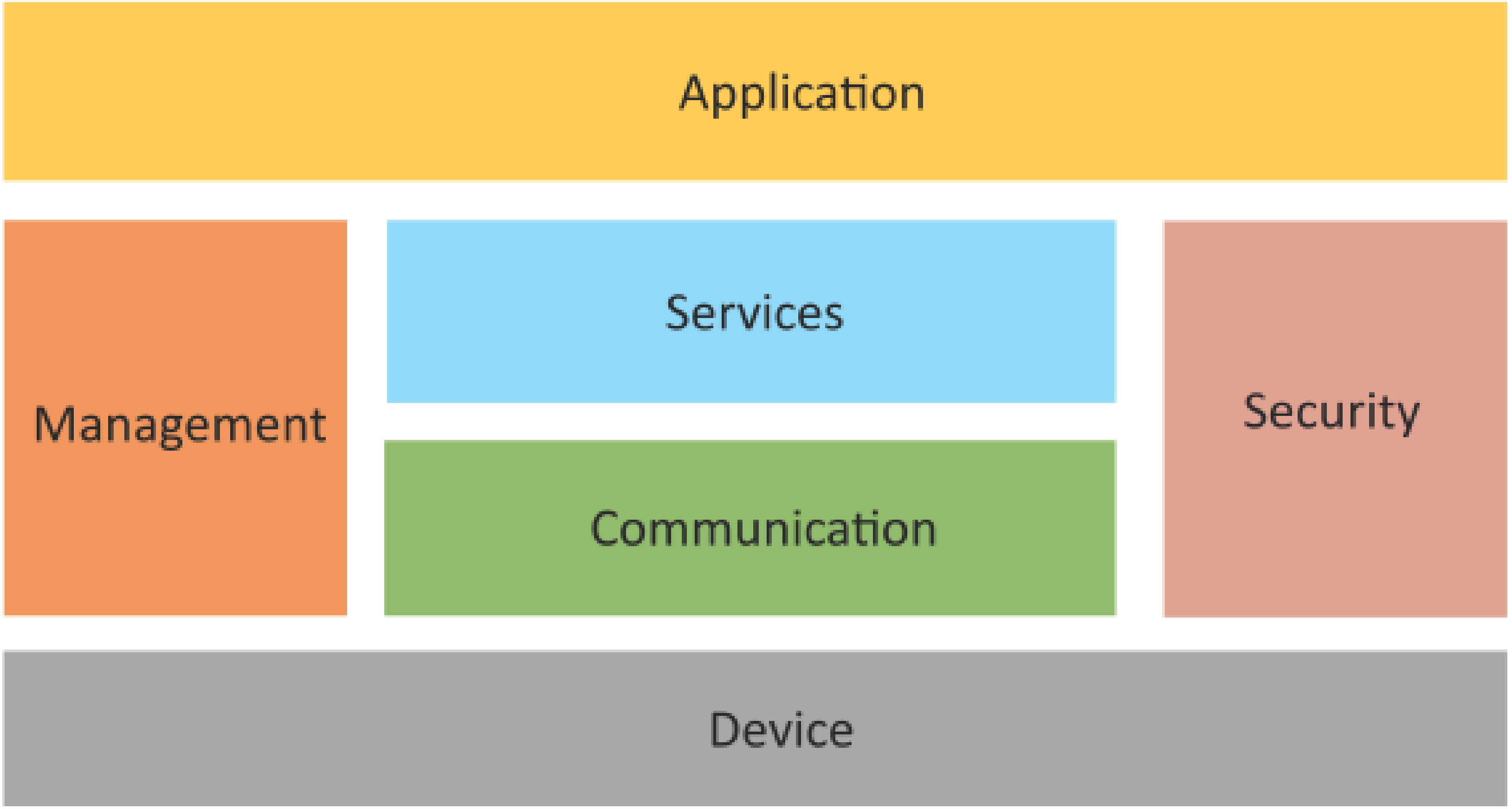
- **Extensible Messaging and Presence Protocol (XMPP):** Protocol for real-time communication and streaming XML data between network entities.
  - Powers wide range applications including messaging, presence, data syndication, gaming, multi-party chat and voice/video calls.
  - Allows sending small chunks of XML data from one network entity to another in near real-time.
  - Decentralized protocol and uses a client-server architecture.
  - Supports both client-to-server and server-to-server communication paths.
  - Allows real-time communication between IoT devices.

Application Layer

- **Data –Distribution Service (DDS):** Data-centric middleware standard for device-todevice or machine-to-machine communication.
  - Uses publish-subscribe model where publishers create topics which subscribers subscribe.
  - Publisher- responsible for data distribution; subscriber- responsible for receiving published data.
  - Provides quality-of-service (QoS) control and configurable reliability.
- **Advanced Message Queuing Protocol (AMQP):** Protocol for business messaging.
  - Supports both point-to-point and publisher-subscriber model, routing and queuing
  - AMQP brokers receives messages from publishers and route them to consumers.
  - Publishers publish messages to exchange which then distributes message copies to queues.
  - Messages are either delivered by broker to consumer which have subscribed to queues or consumers can pull messages from queues.

Logical design of an IoT

- It refers to an abstract representation of entities and processes without going into low-level specifics of implementation.
- IoT system comprises a number of functional blocks that provide system the capabilities for identification, sensing, actuation, communication and management.



IoT system functional blocks

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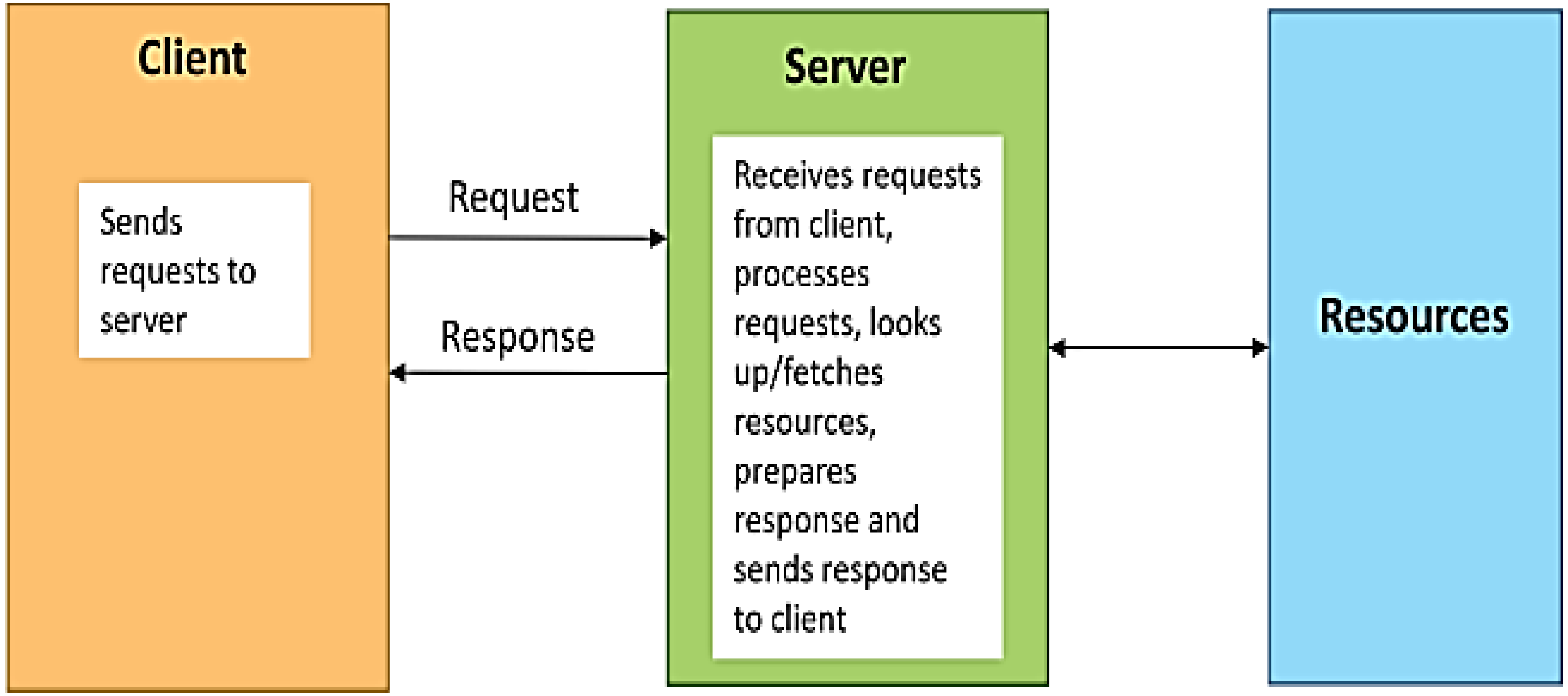
- **Device:** Comprises of devices that provide sensing, actuation, monitoring and control functions
- **Communication**: Handles communication for IoTsystem.
- **Services:** Types of IoT services include services for device monitoring, device control services, data publishing services and services for device discovery.
- **Management**: Provides various functions to govern IoT system
- **Security**: Secures IoT system and by providing functions such as authentications, authorization, message and content integrity, and data security
- **Application**: IoT applications provide an interface that users can use to control and monitor various aspects of IoT system. Allow users to view system status and view or analyse processed data.

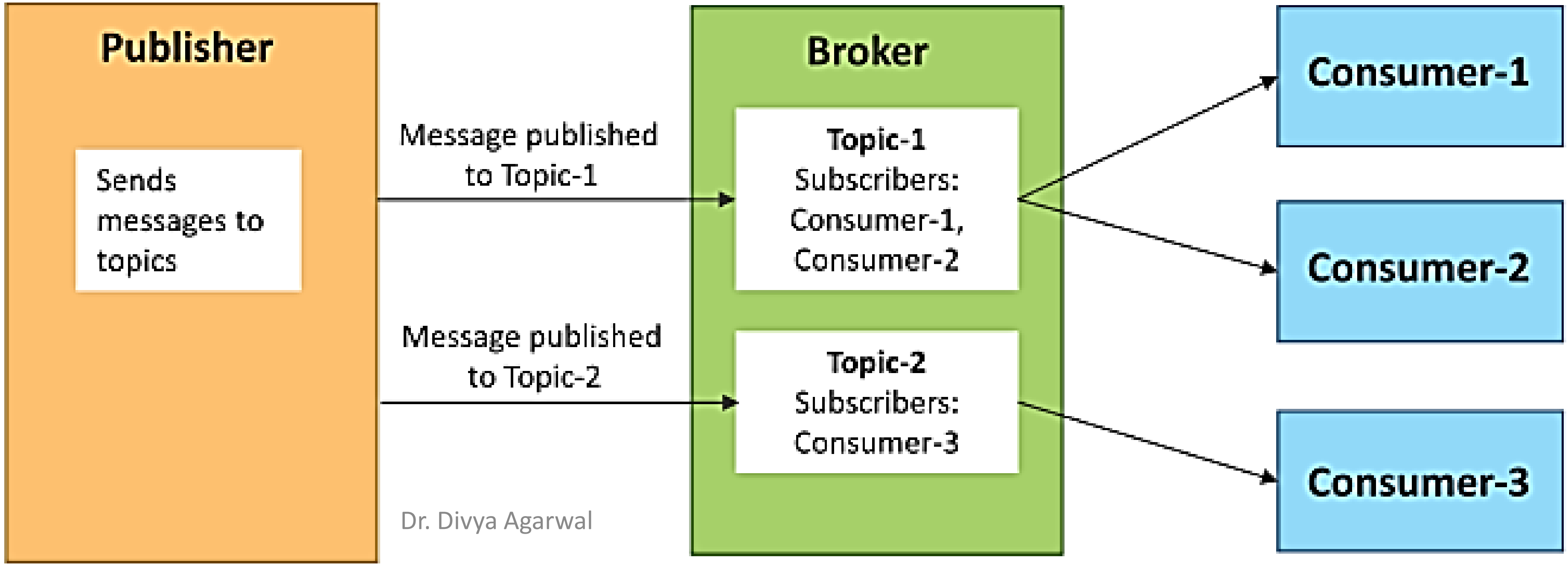
IoT Communication models

- **Request-Response Model:** Here, client sends requests to server and server responds to requests.
- When server receives a request, it decides how to respond, fetch data, retrieve resource representations, prepare response, and then sends response to client.
- Stateless communication model and each request-response pair is independent of others.



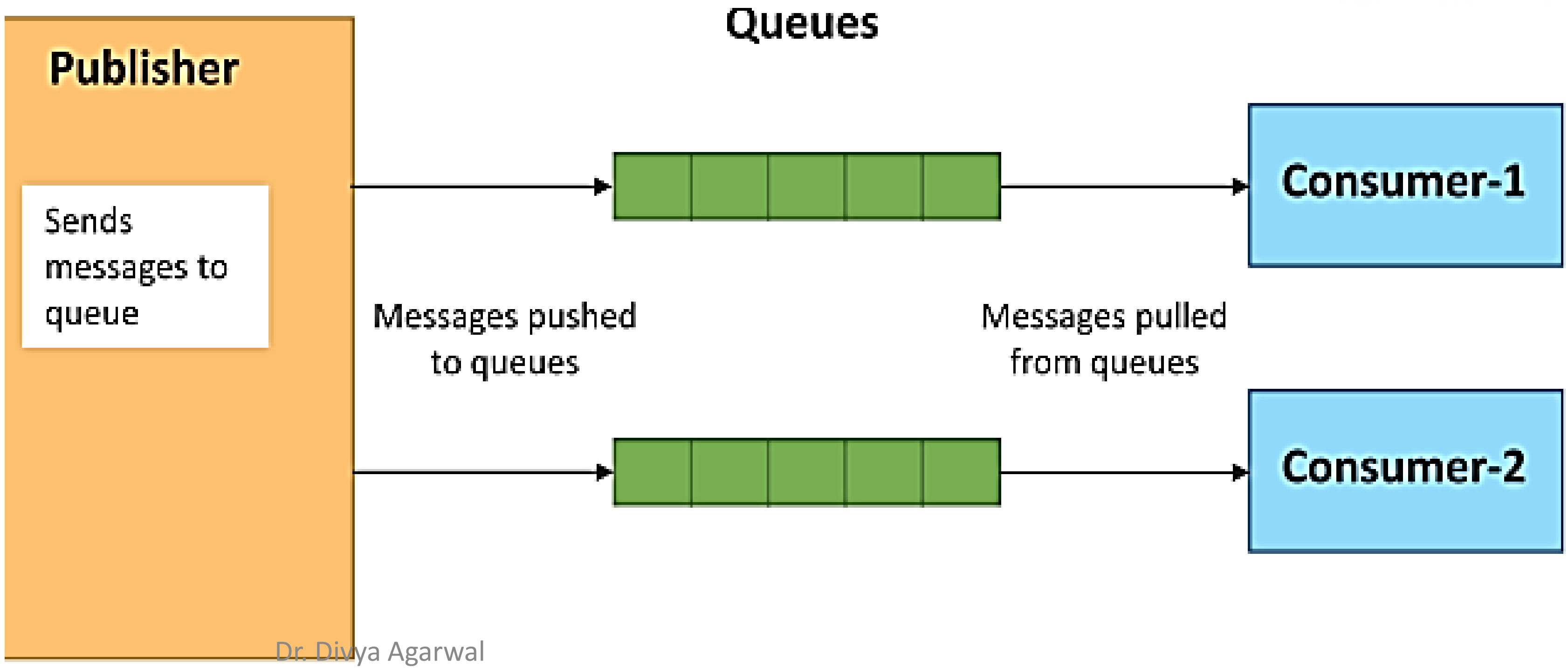
IoT Communication models

- **Publish–Subscribe Model:** Communication model that involves publishers, brokers and consumers.
- Publishers are source of data, which send data to topics, managed by broker.
- Publishers are not aware of consumers.
- Consumers subscribe managed by
- When broker receives data for a topic from data to all subscribed



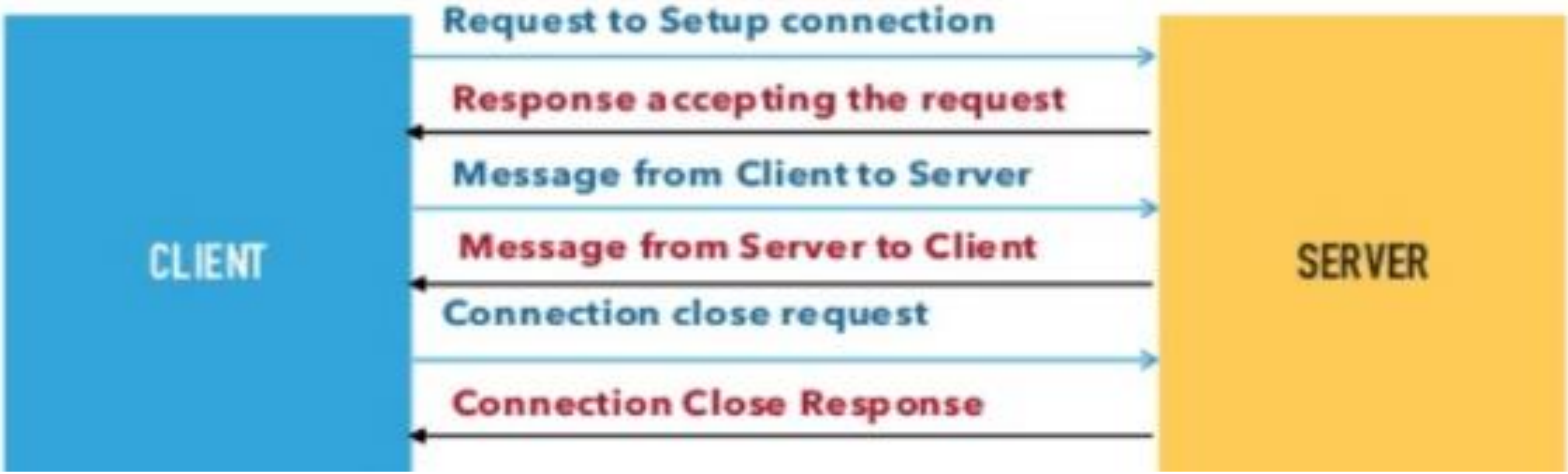
IoT Communication models

- **Push–Pull Communication Model:** Communication model in which data producers push data to queues and consumers pull data from queues.
- Producers do not need to be aware of consumers.
- Queues help in decoupling messaging between producers consumers.
- Queues act as buffer which situations when there mismatch between rate at producers push data which consumers

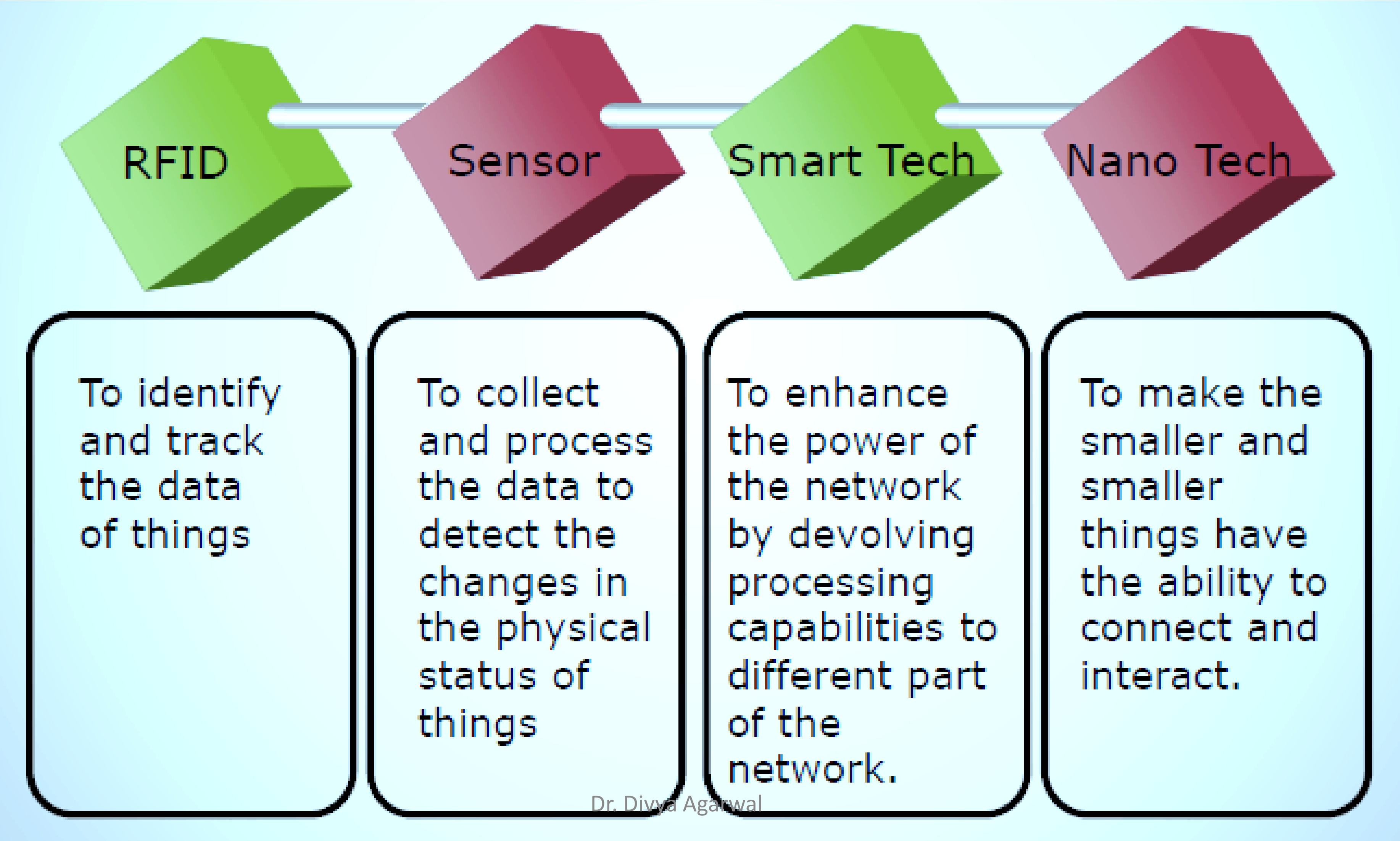


IoT Communication models

- **Exclusive Pair**: Bi-directional, fully duplex communication model that uses persistent connection between client and server, once connection is established it remains open until client sends a request to close connection.
- Client and server can send message to each other after connection setup.
- Stateful communication model, Here, server is aware of all open connections



How IoT works



IoT as a Network of Networks:

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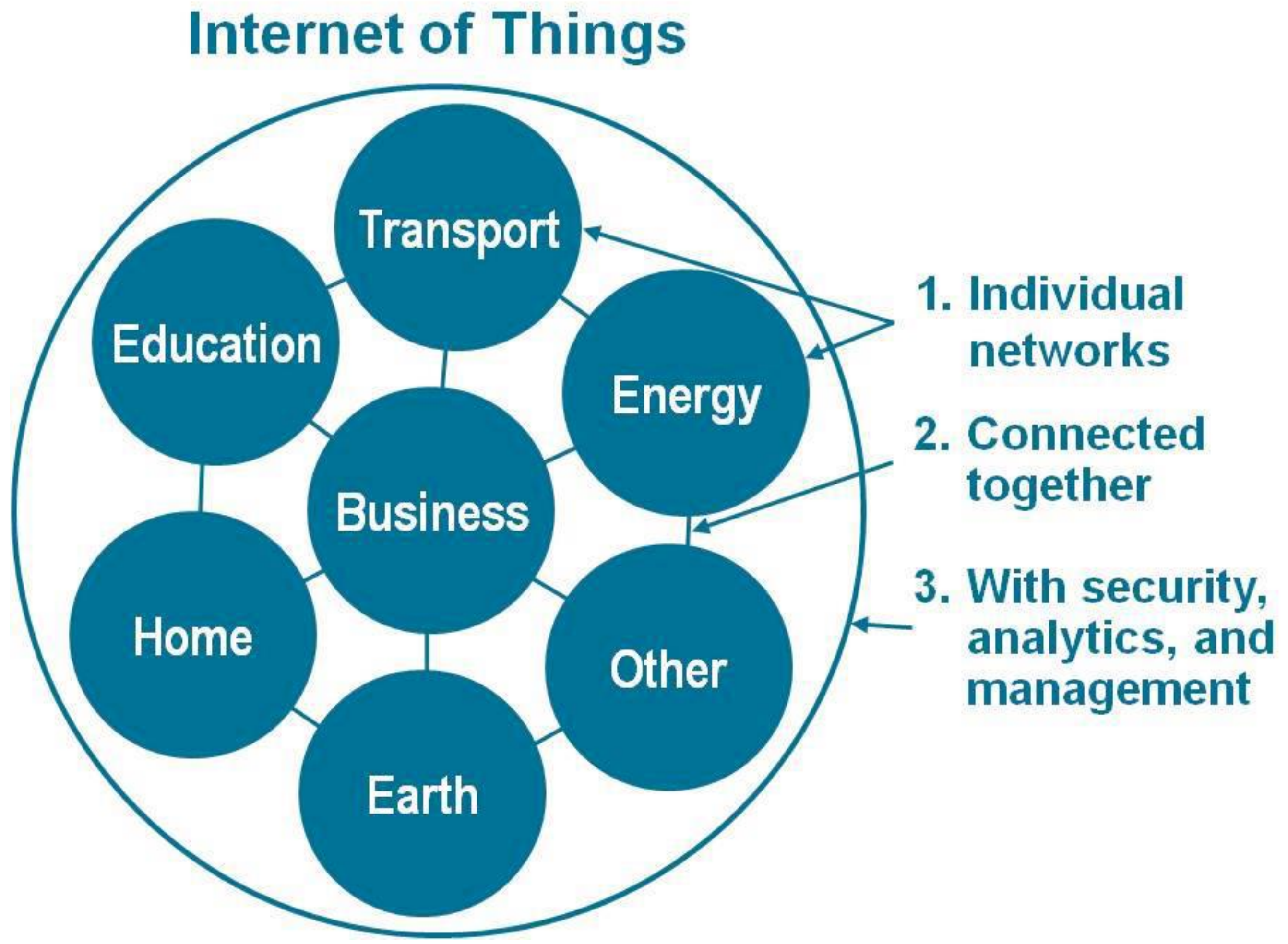
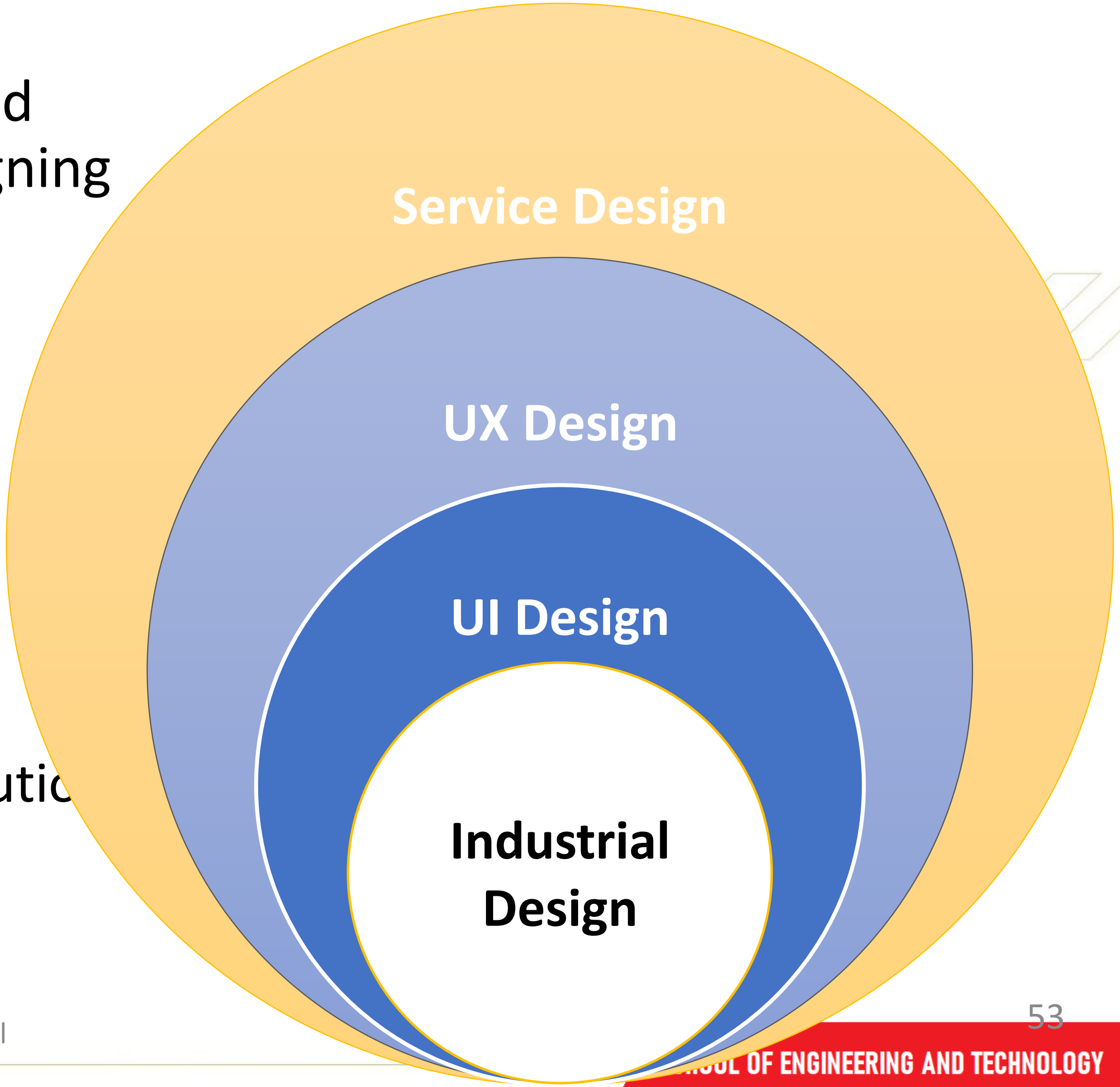
- These networks connected with added security, analytics, and management capabilities.
- This will allow IoT to become even more powerful in what it can help people achieve.



Design Principles for Connected Devices

- For designers focused on designing SW services and screen based interfaces or physical products, designing IoT solutions imposes design challenges.
- IoT solutions consist of multiple elements:
  - **physical devices** like sensors, actuators and
  - **interactive devices,**
  - **network connecting these devices**,
  - **data gathered** from these devices and
  - **analyzed** to create a meaningful experience and
  - **physical context** in which user interacts with solutic



Design Principles for Connected Devices

1. Focus on value

- User research and service design are more crucial than ever.
- For your IoT solution to become widely adopted, you need to dig deep into users' needs in order to find out where lies a problem truly worth solving and what is the real end user value of the solution.
- Understand barriers of adopting new technology and your solution specifically.
- Need to plan carefully what features to include and in which order.

2. Take a holistic view

- IoT solutions consist of multiple devices with different capabilities and both physical and digital touchpoints.
- Solution to be provided in co-operation with multiple different service providers.
- Conceptualize model of how user understands and perceives system.
- Whole system needs to work seamlessly together in order to create a meaningful experience.

Design Principles for Connected Devices

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3. **Put safety first**
   - Consequences can be serious, when something goes wrong.
   - Building trust should be one of your main design drivers which is built slowly and lost easily,
   - Understand possible error situations related to context of use, HW, SW and network as well as to user interactions and trying to prevent them
   - If the error situations still occur, it means appropriately informing user about them and helping them to recover.
   - Consider data security & privacy as key elements of your design
   - Quality assurance is critical and it should not only focus on testing the SW, but on testing end to end system, in a real-world context.

Design Principles for Connected Devices

4. **Consider the context**
    - IoT solutions exist at crossroads of physical and digital worlds. Commands given through digital interfaces may produce real world effects, but unlike digital commands, actions happening in the real-world cannot necessarily be undone.
    - Make dynamic platform. For ex. Design devices that hold up against changing weather conditions.
5. **Build a strong brand**
    - Aim to build trust, something unexpected will happen at some point and your solution is somehow going to fail so build a strong brand that truly resonates with end users.
    - Trust should be a key element of brand which should also be reflected in rest of brand elements, like choice of color, tone of voice, imagery etc.

Design Principles for Connected Devices

6. Prototype early and often

- HW and SW have quite different lifespans, but as successful IoT solution needs both HW and SW elements, lifespans should be aligned.
- IoT solutions are hard to upgrade, because once connected object is placed somewhere, it is not so easy to replace it with a newer version and even software may be hard to update due to security and privacy reasons. Due to these factors and to avoid costly hardware iterations, it's crucial to get solution right, from beginning of implementation.

7. Use data responsibly

- IoT solutions generate tons of data.
- Identify data points that are needed to make solution functional and useful.
- Learn to understand data science and analyse that data to extract meaningful results.
- Data science provides a lot of opportunities to reduce user friction, i.e. reducing use of time, energy and attention or diminishing stress.

Internet Principles

1. **IoT Principle 1** – Be passionately obsessive about your customer experiences.

   Connected devices and sensors are a vehicle to improve customer experience. Sometimes you must put profit on back burner to enhance experience with technology.

2. **IoT Principle 2** – Create a seamless experience across all platforms and channels.

   Mastering information continuity is key to great omnichannel experiences. As an example, if a customer has a faulty connected vacuum cleaner and calls one of your customer-service agents, that agent should already be able to see where vacuum cleaner is and what's wrong with it — better yet, that agent could contact customer proactively with a solution.

3. **IoT Principle 3** – Always look for ways to improve.

   Provide tools to drive change and improvement on a continuing basis with much better data and analytics. It creates high visibility and process improvement within an organization. IoT can give you real-time insight into flow, status, and state of key items in your process.

Internet Principles

4. **IoT Principle 4** – Just having data isn't enough.

   Collect data at an alarming rate, however data isn't enough. That data needs to be leveraged with models, analytics, and algorithms to extract insight from it. This will help you dig deep into your processes and consistently be improving them.

5. **IoT Principle 5** – Think Big, take small bites.

   Bite sized, discreet projects together bring most big visions. These allow you fail and iterate experience gained IoT is a journey and you should have an idea of just how long it is going to be. To be successful you need to move forward in small steps, learning from mistakes.

6. **IoT Principle 6** – Become a Platform company with IoT.

   By creating a platform business model, you allow other businesses to leverage your capabilities to grow their own businesses and thus creates a long, sustainable competitive advantage for your business. Think of ways to allow other businesses to leverage your connected devices.

Internet Principles

7. **IoT Principle 7** – Outcome based business models are where it's at.

   IOT connected devices allow to sell outcomes. In this model, customer pays for results that a product or service provides rather than for product or service itself. This is not a fit for every business, however, if implemented, they can they can increase your profits, improve your relationships with customers and increase customer loyalty.

8. **IoT principle 8** – Next generation is finding a way between monetizing your data and protecting privacy.

   Some companies are monetizing data they collect from sensors. Financial trading companies are buying cargo ship transit and port arrival information. Utility companies are buying building and appliance energy-consumption data. Smart home companies are selling data to advertisers and insurance companies.

Internet Principles

9. **IoT Principle 9** – Disrupt the value chain by exploring HOT products and services.

   Innovation is key. It creates opportunities for growth up and down value-chain. Learn industry and look for areas in which there are customer issues or stranded excess margin. Look for strategy that will disrupt industry value-chain. A value chain is end-to-end set of processes and activities for an industry.

10. **IoT Principle 10** – Create a Flywheel for your IoT Strategy.

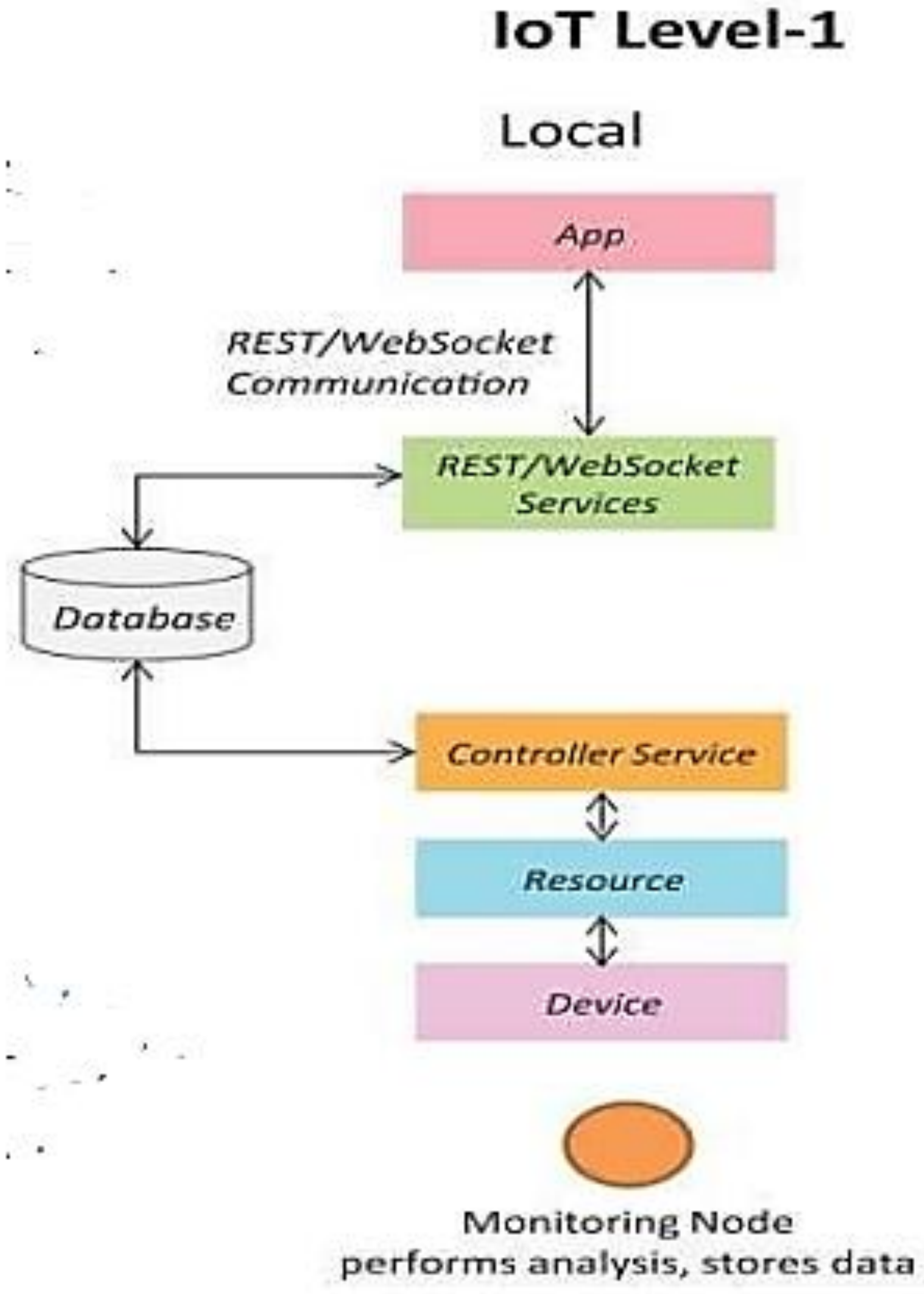
    A lot of effort should be put into identifying factors that will generate and keep the most momentum in creating upward growth patterns. If you have a good handle on systems dynamics, you can then use IoT to identify and execute on opportunities and risks in your business. Understanding the moving pieces will give a company greater momentum to carry a company to improved things.

IoT standards

1. **IPv6 over Low-Power Wireless Personal Area Networks (*6LoWPAN)*** is an open standard defined by the Internet Engineering Task Force (IETF). 6LoWPAN standard enables any low-power radio to communicate to the internet, including 804.15.4, Bluetooth Low Energy (BLE) and Z-Wave (for home automation).
2. **ZigBee** is a low-power, low-data rate wireless network used mainly in industrial settings. ZigBee is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard. The ZigBee Alliance created Dotdot, the universal language for IoT that enables smart objects to work securely on any network and understand each other.
3. **LiteOS** is a Unix-like operating system (OS) for wireless sensor networks. LiteOS supports smartphones, wearables, intelligent manufacturing applications, smart homes and the internet of vehicles (IoV). The OS also serves as a smart device development platform.
4. **Constrained Application Protocol (CoAP)** is a protocol designed by the IETF that specifies how low-power, compute-constrained devices can operate in the internet of things.

IoT standards

4. **OneM2M** is a machine-to-machine service layer that can be embedded in software and hardware to connect devices. Global standardization body, OneM2M, was created to develop reusable standards to enable IoT applications across different verticals to communicate.
5. **Data Distribution Service (DDS)** was developed by Object Management Group (OMG) and is an IoT standard for real-time, scalable and high-performance M2M communication.
6. **Advanced Message Queuing Protocol (AMQP)** is an open source published standard for asynchronous messaging by wire. AMQP enables encrypted and interoperable messaging between organizations and applications. The protocol is used in client-server messaging and in IoT device management.
7. **Long Range Wide Area Network (LoRaWAN)** is a protocol for WANs designed to support huge networks, such as smart cities, with millions of low-power devices.



IoT Architectures

IoT Level 1

- Single node/device, performs sensing and/or actuation, stores data, performs analysis, and hosts application.
- Appropriate for modeling low-cost and low-complexity approaches where data involved is minimal and analysis criteria are not computationally intensive.
- Data sensing and processing is performed locally.
- Monitoring and control are performed using a mobile app or a web app.

IoT Level-1 Example

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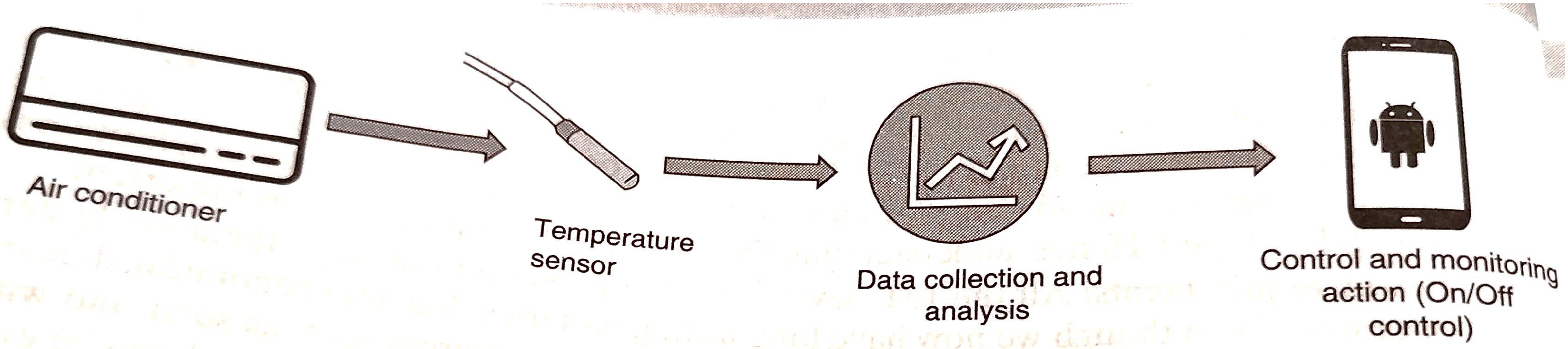
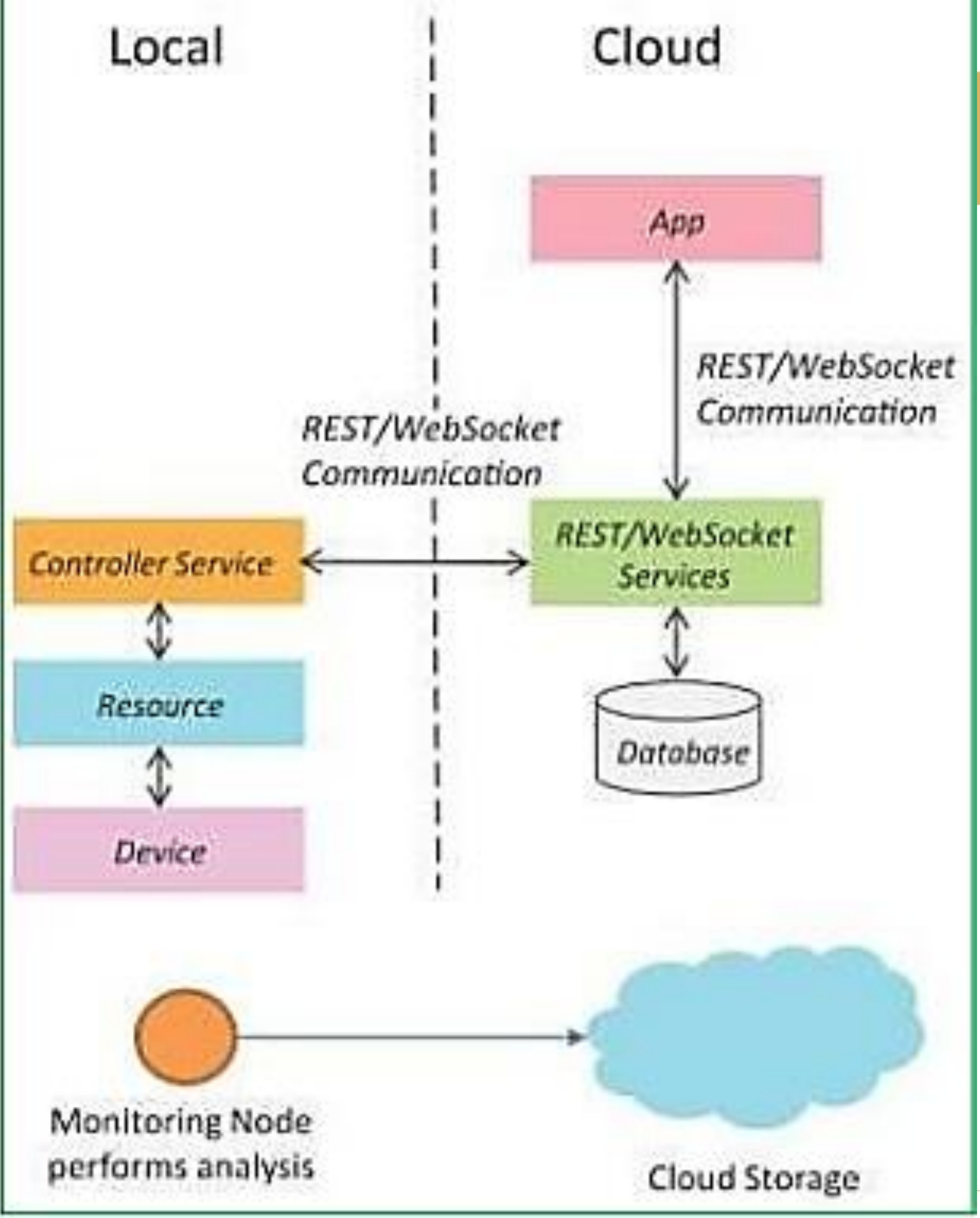
IoT for Home Automation

- Temperature sensor senses room temperature and data is stored and analysed locally.
- Based on analysis, control action is triggered through mobile app
- Mobile app helps in monitoring status





IoT Architectures

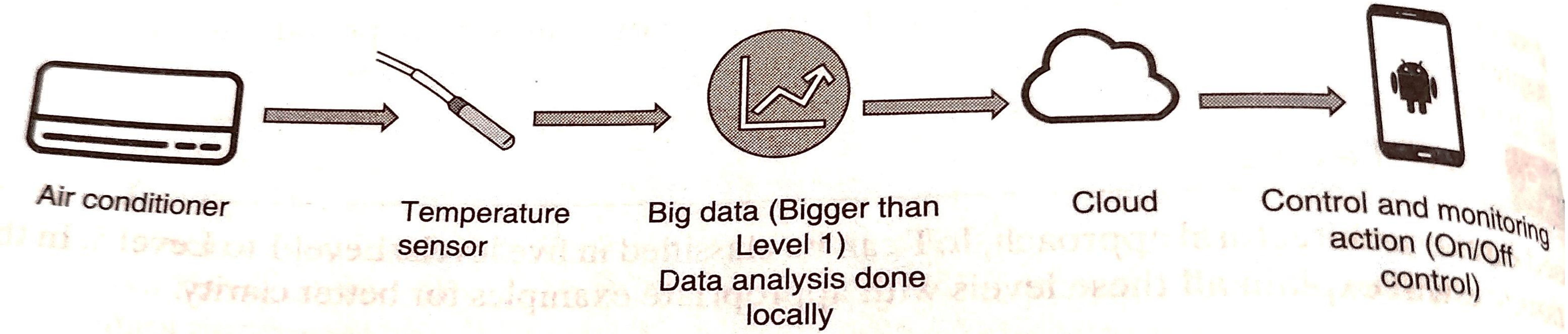
IoT Level 2

- Consists of a single node that performs sensing, actuation, and local analysis (IoT Device and collected data).
- Data is stored in cloud and application is usually cloud-based.
- Suitable for solutions where data is large, but primary analysis criterion is not computationally intensive and can be performed locally.

IoT Level-2 Example

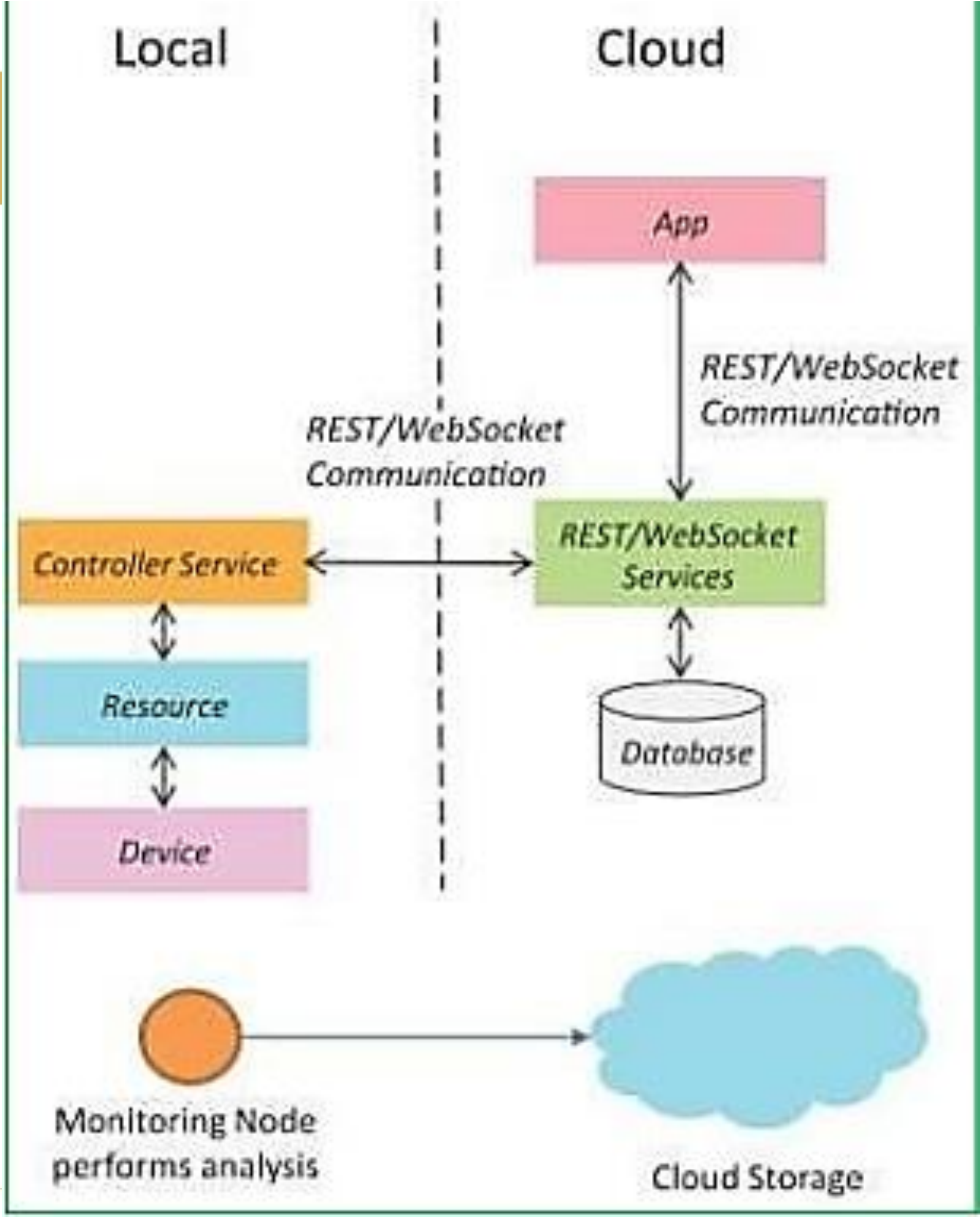
IoT for Home Automation

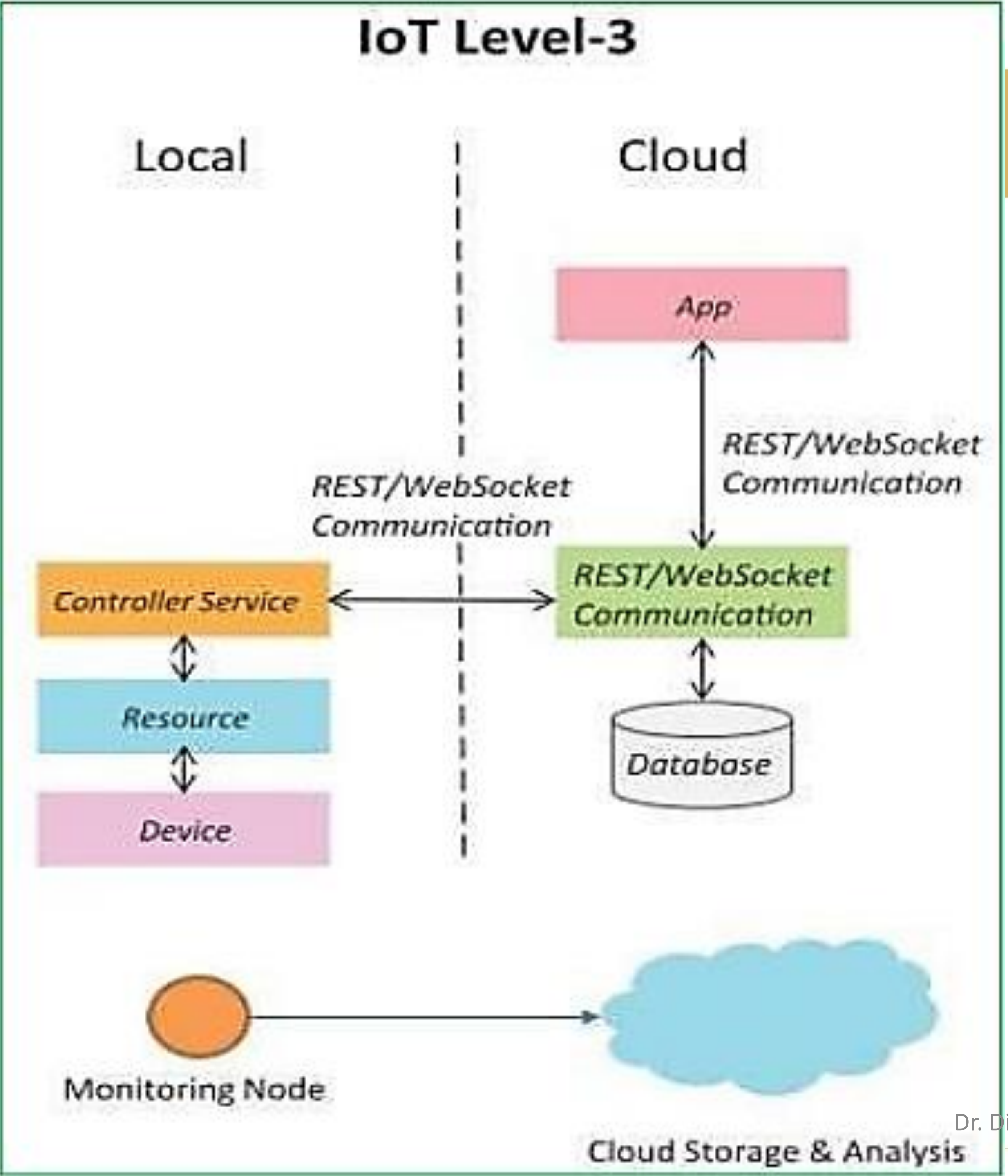
- Temperature sensor senses room temperature at a better pace and rate then level 1
- Data is stored in a cloud storage and analysed locally.
- Based on analysis, control action is triggered through mobile app
- Mobile app helps in monitoring status



IoT Level-2 Example
IoT for smart irrigation

- Single node monitors soil moisture and controls irrigation system.
- If moisture level falls below prescribed threshold, irrigation system is enabled.
- IoT device detects soil moisture using sensors, and controller tracks it and sends data to cloud.
- Moisture levels are shown to users in an application, which can be used to create an irrigation schedule.
- This level has a voluminous size of data, hence cloud storage is used.
- Data analysis is carried out locally.
- Cloud is used for only storage purposes.





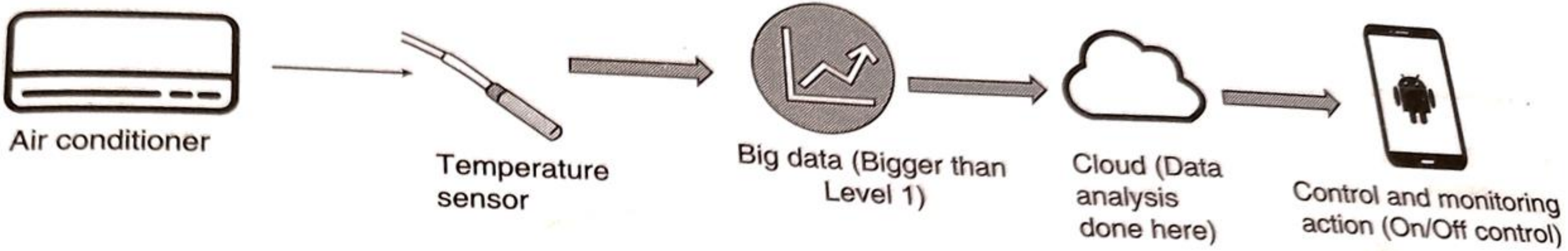
IoT Level 3

- Has one node.
- In cloud, a database and an application are created.
- Appropriate for solutions involving large amounts of data and computationally intensive research criteria.

IoT Level-3 Example

IoT for Home Automation

- Temperature sensor senses room temperature at a better pace and rate then level 1
- Data is stored in a cloud storage and analysed on cloud.
- Based on analysis, control action is triggered through mobile app
- Mobile app helps in monitoring status



IoT Level-3 Example

IoT system for tracking package handling

- System consists of a single node that monitors vibration levels for a package being shipped.
- Device in this system uses accelerometers and gyroscope sensors for monitoring vibration levels.
- Controller service uses WebSocket API to send real-time data to the cloud, which is useful in real-time applications due to its low overhead.
- Analysis components in cloud can trigger alerts if vibration levels become greater than a threshold.
- Cloud-based WebSocket service retrieves real-time data from IoT devices and stores in database.
- Data is voluminous, i.e. large data, in this case.
- Data sensing frequency is high, and collected sensed data is stored on cloud because it is large.
- Data is analyzed in cloud, and control actions are activated using a mobile app or a web app based on results of analysis.

IoT architectures - IoT Level 4

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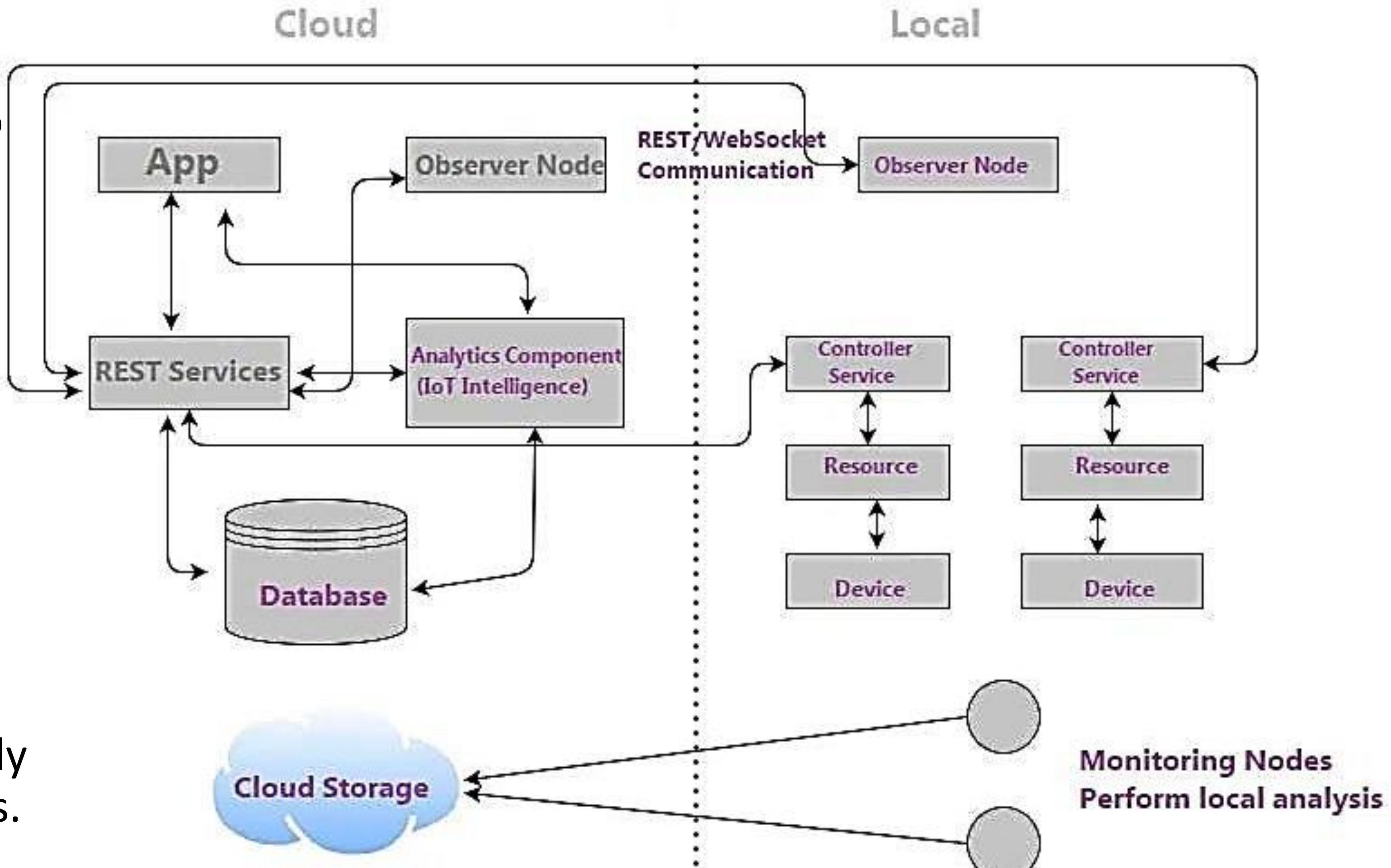
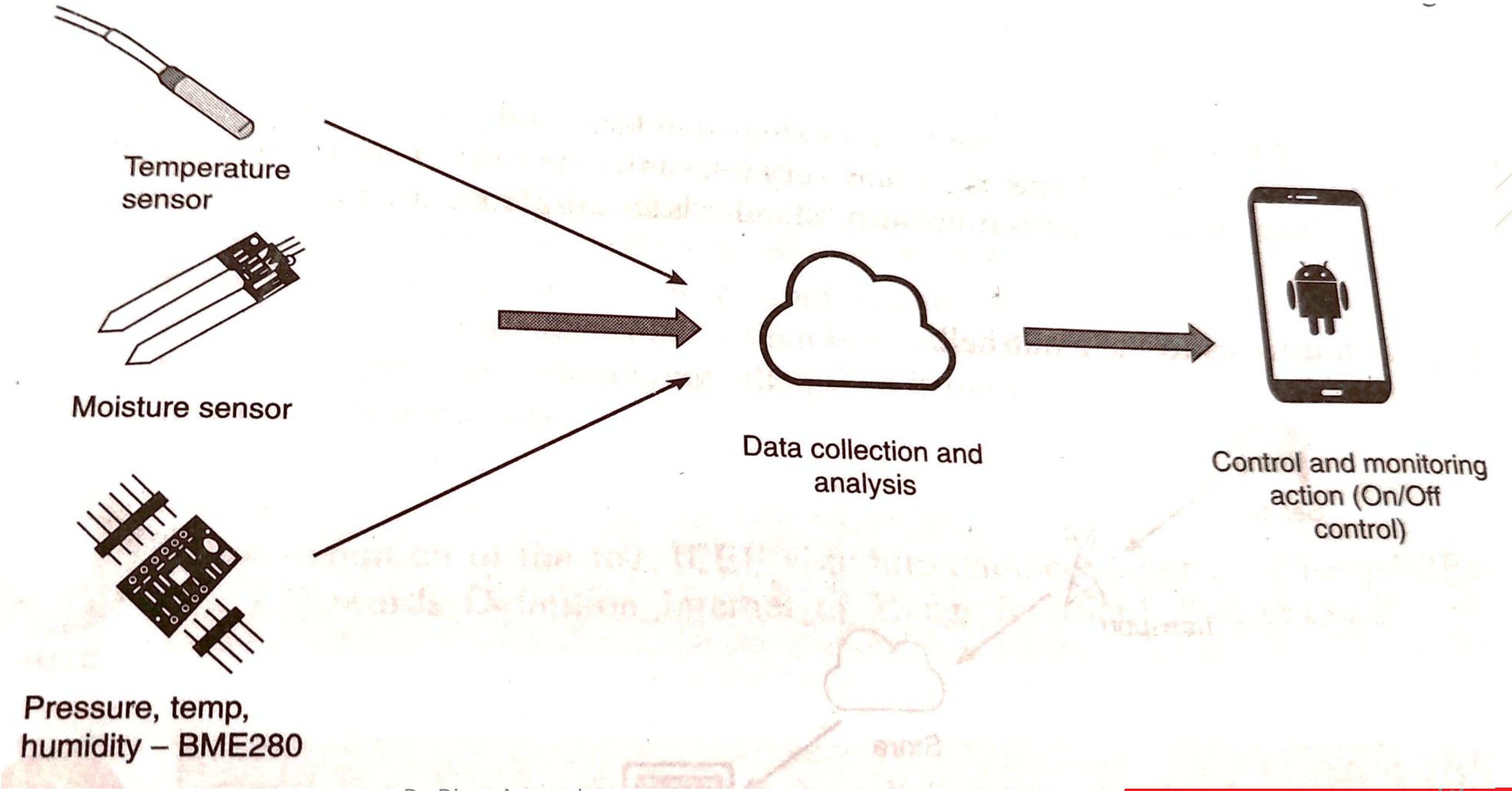
- Multiple independent nodes to conduct local analysis.
- Has database and application that are hosted in cloud.
- Provide both local and cloud-based observer nodes that can subscribe to and receive collected data in cloud via IoT node devices.
- Appropriate for solutions involving, voluminous data, multiple nodes, computationally intensive analysis requirements.



IoT Level-4 Example

IoT for Home Automation

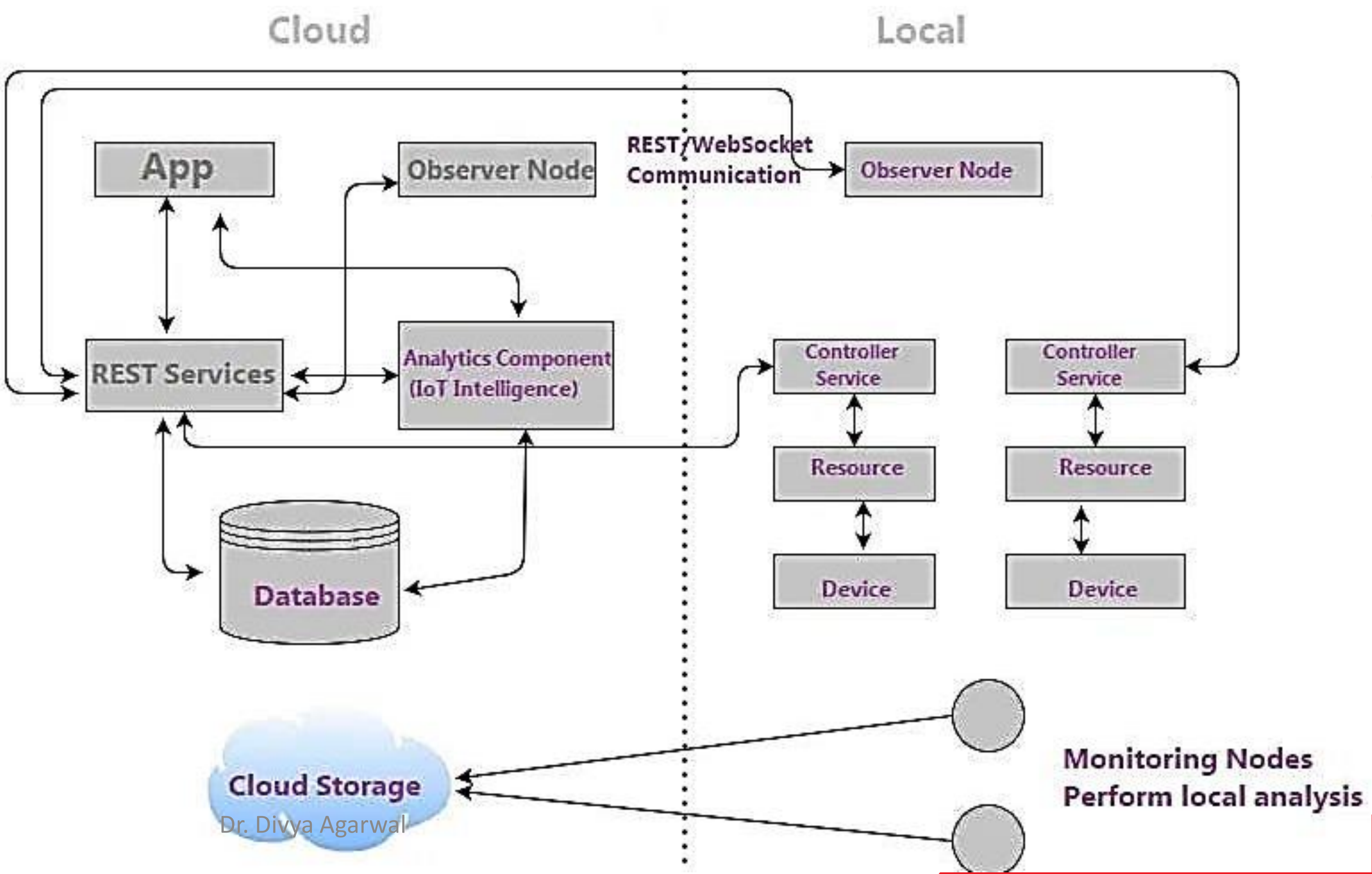
- All sensors upload, sensed and read sensory inputs
- Cloud storage is preferred due to voluminous data
- Analysis is also carried out on cloud
- Control action is triggered based on analysis through a mobile application or web application



IoT Level-4 Example

IoT-based noise monitoring device

- Here, nodes are dispatched in various locations to detect noise in a specific region.
- Sound sensors are examples of Nodes/Devices in this context.
- Each Node/Device is self-contained, with its own controller service to deliver data to cloud for storage and processing.
- Includes numerous sensors, data collection, and analysis, as well as a control and monitoring app.



IoT architectures - IoT Level 5

- Several end nodes and a supervisor node.
- For sensing and/or actuation, end nodes are used.
- Coordinator Node model gathers data and transfers it to cloud from end nodes.
- Ideal for solutions focused on wireless networks with large data and computer-intensive analysis requirements.

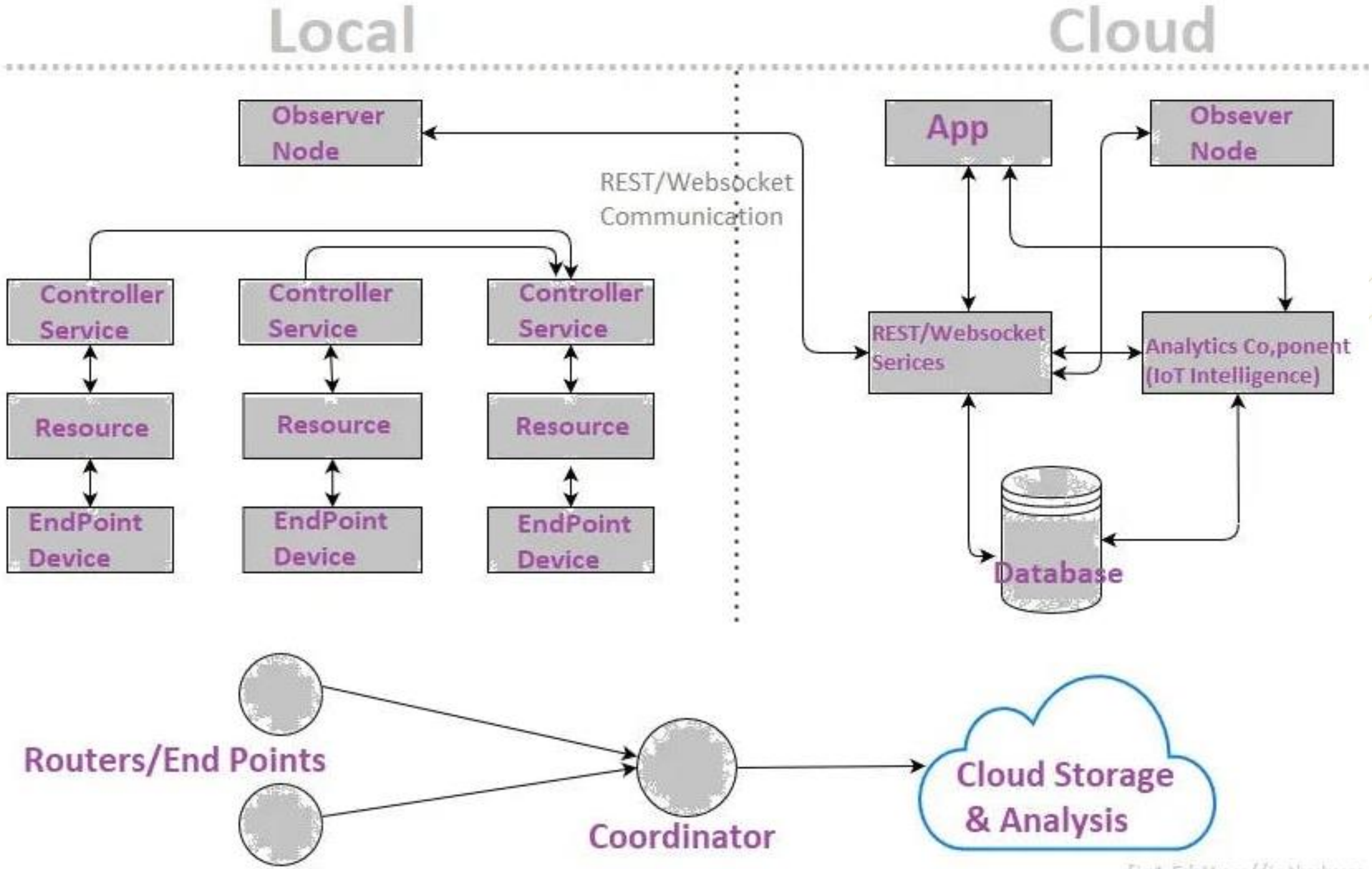
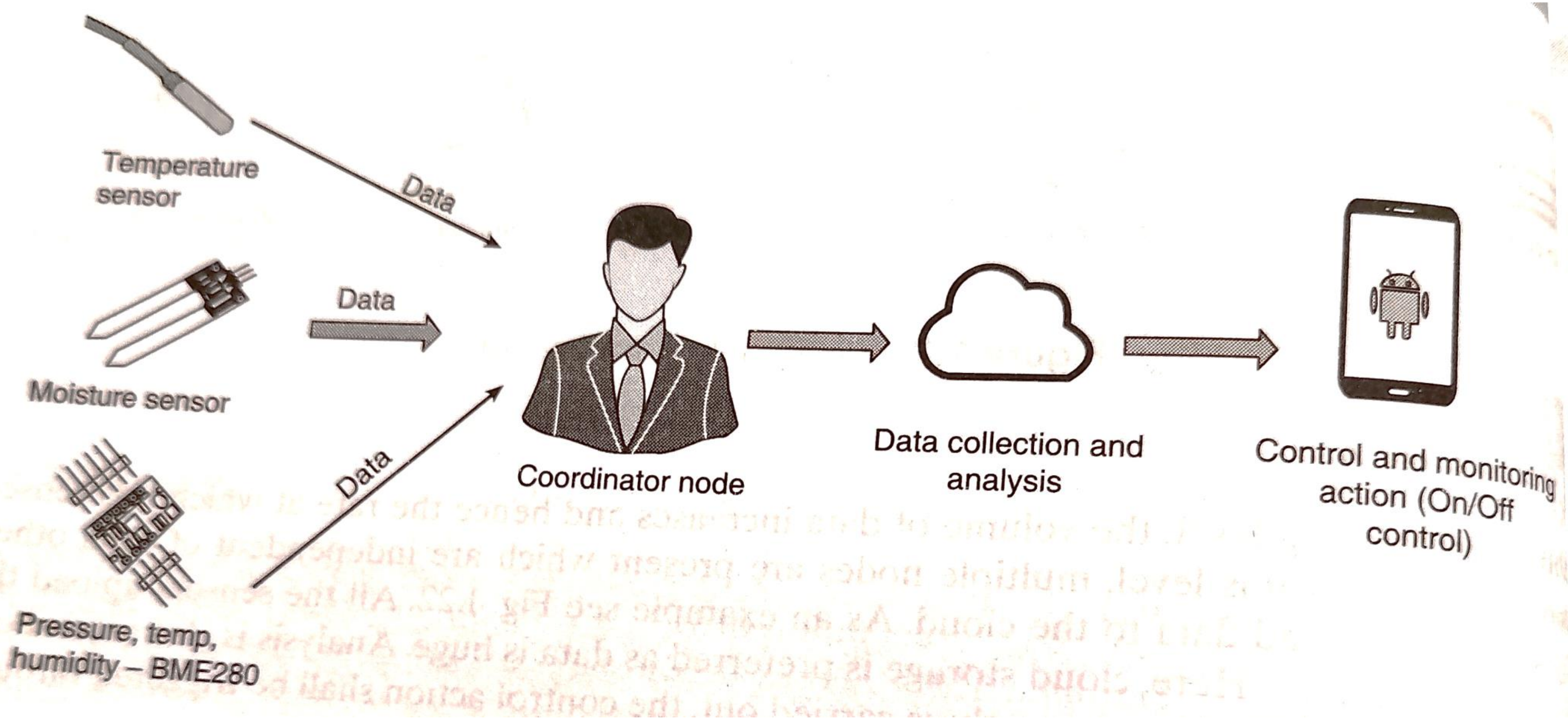


fig1.5 https://iotbyhvm.

IoT Level-5 Example

IoT for Home Automation

- All sensors upload, sensed and read sensory inputs
- Coordinator Node model gathers data and transfers it to cloud from end nodes.
- Cloud storage is preferred due to voluminous data
- Analysis is also carried out on cloud
- Control action is triggered based on analysis through a mobile application or web application



IoT Level-5 Example

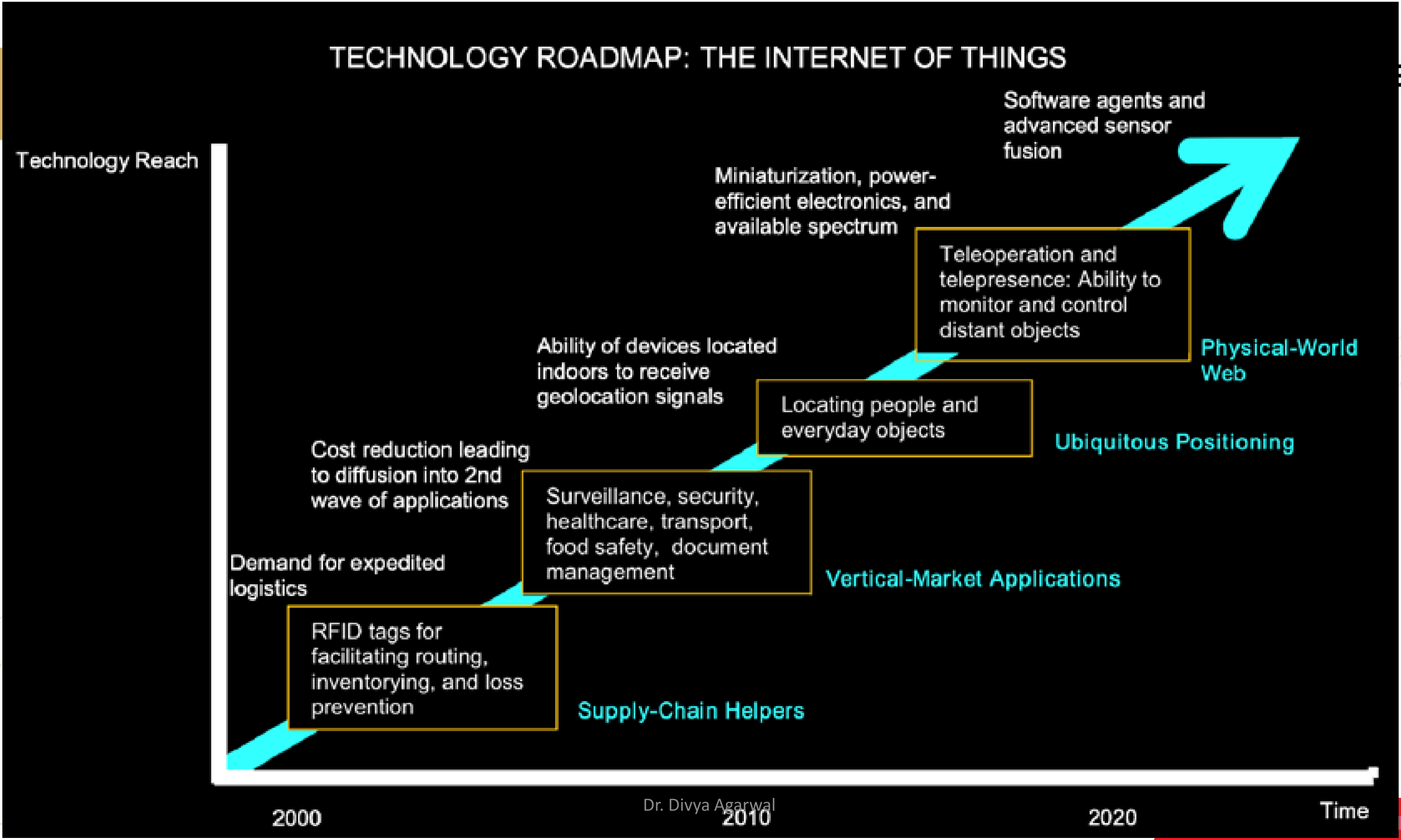
IoT-based Forest Fire Detection System

- Nodes/devices are mainly used to detect temperature, moisture, and CO_2 levels in this kind of system.
- Sensors are used for temperature, humidity, and CO_2.
- Nodes detect data, coordinator node collects data and controller service on coordinator is migrated into cloud.
- Node Coordinator serves as a portal to IoT-based system and provides Internet access.
- Analytics module can be used to predict/generate results to data stored in cloud.
- Data collection and data analysis are performed at cloud level.

IoT Level-5 Example

IoT-based system of weather surveillance

- Numerous temperature, humidity, stress, etc. sensors are contained in this system.
- Nodes are installed in various locations and are sent via WebSocket-based API to cloud-based storage in real-time.
- Any node update or changes are performed via centralized controller.
- Analytics module is used to forecast/generate reports to data stored on cloud.


TECHNOLOGY ROADMAP: THE INTERNET OF THINGS
Technology Reach
Software agents and advanced sensor fusion
Miniaturization, power-efficient electronics, and available spectrum
Teleoperation and telepresence: Ability to monitor and control distant objects
Physical-World Web
Ability of devices located indoors to receive geolocation signals
Locating people and everyday objects
Ubiquitous Positioning
Cost reduction leading to diffusion into 2nd wave of applications
Surveillance, security, healthcare, transport, food safety, document management
Vertical-Market Applications
Demand for expedited logistics
RFID tags for facilitating routing, inventorying, and loss prevention
Supply-Chain Helpers
2000
2010
2020
Time

Domain Specific IoTs Applications for

- Home
- Cities
- Environment
- Energy Systems
- Retail
- Logistics
- Industry
- Agriculture
- Health & Lifestyle

INTERNET OF THINGS APPLICATIONS

- **IoT applications for smart homes:**
  - ❑Smart Lighting
  - ❑Smart Appliances
  - ❑Intrusion Detection
  - ❑Smoke / Gas Detectors
- **IoT applications for smart environments:**
  - ❑Weather Monitoring
  - ❑Air Pollution Monitoring
  - ❑Noise Pollution Monitoring
  - ❑Forest Fire Detection
  - ❑River Flood Detection
- **IoT applications for smart energy systems:**
  - ❑Smart Grid
  - ❑Renewable Energy Systems
  - ❑Prognostics
- **IoT applications for smart cities:**
  - ❑Smart Parking
  - ❑Smart Lighting for Road
  - ❑Smart Road
  - ❑Structural Health Monitoring
  - ❑Surveillance
  - ❑Emergency Response

INTERNET OF THINGS APPLICATIONS

- **IoT applications in smart retail systems:**
  - ❑Inventory Management
  - ❑Smart Payments
  - ❑Smart Vending Machines
- **IoT applications for smart logistic systems:**
  - ❑Fleet Tracking
  - ❑Route Generation and Scheduling
  - ❑Shipment Monitoring
  - ❑Remote Vehicle Diagnostics
- **IoT applications for smart logistic systems:**
  - ❑Machine Diagnosis and Prognosis
  - ❑Indoor Air Quality Monitoring
- **IoT applications for health and Lifestyle:**
  - ❑Health and Fitness Monitoring
  - ❑Wearable Electronics
- **IoT applications for smart agriculture:**
  - ❑Smart Irrigation
  - ❑Green House Control

Sensors

- **Sensors and actuators** are two critical components of every closed loop control system. Such a system is also called a ***mechatronics system***.
- **Mechatronics system** consists of a sensing unit, a controller, and an actuating unit.
- **Sensing unit** consist of additional components such as filters, amplifiers, modulators, and other signal conditioners.
- **Controller** accepts information from sensing unit, makes decisions based on control algorithm, and outputs commands to actuating unit.
- **Actuating unit** consists of an actuator and optionally a power supply and a coupling mechanism.

Sensors

- Device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).
- Transducer synonymous with sensors.
- **Sensor** is a device that responds to a change in physical phenomenon while **transducer** is a device that converts one form of energy into another form of energy.
- **Sensors** are transducers when they sense one form of energy input and output in a different form of energy. For example, a thermocouple responds to a temperature change (thermal energy) and outputs a proportional change in electromotive force (electrical energy). Therefore, a thermocouple can be called a sensor or transducer.

Different Types of Sensors

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1. Temperature Sensor
2. Proximity Sensor
3. Accelerometer
4. IR Sensor (Infrared Sensor)
5. Pressure Sensor
6. Light Sensor
7. Ultrasonic Sensor
8. Smoke, Gas and Alcohol Sensor
9. Touch Sensor
10. Color Sensor
11. Humidity Sensor
12. Position Sensor
13. Magnetic Sensor (Hall Effect Sensor)
14. Microphone (Sound Sensor)
15. Tilt Sensor
16. Flow and Level Sensor
17. PIR Sensor
18. Touch Sensor
19. Strain and Weight Sensor

Different Types of Sensors

Selection Criteria

Multiple static and dynamic factors are considered in selecting a suitable sensor to measure desired physical parameter. Following is a list of typical factors:

- **Range—**Difference between the maximum and minimum value of the sensed parameter
- **Resolution—**The smallest change the sensor can differentiate
- **Accuracy—**Difference between the measured value and the true value
- **Precision—**Ability to reproduce repeatedly with a given accuracy
- **Sensitivity—**Ratio of change in output to a unit change of the input
- **Zero offset—**A nonzero value output for no input
- **Linearity—**Percentage of deviation from the best-fit linear calibration curve
- **Zero Drift—**The departure of output from zero value over a period of time for no input
- **Response time—**The time lag between the input and output
- **Bandwidth—**Frequency at which the output magnitude drops by 3 dB
- **Resonance—**The frequency at which the output magnitude peak occurs

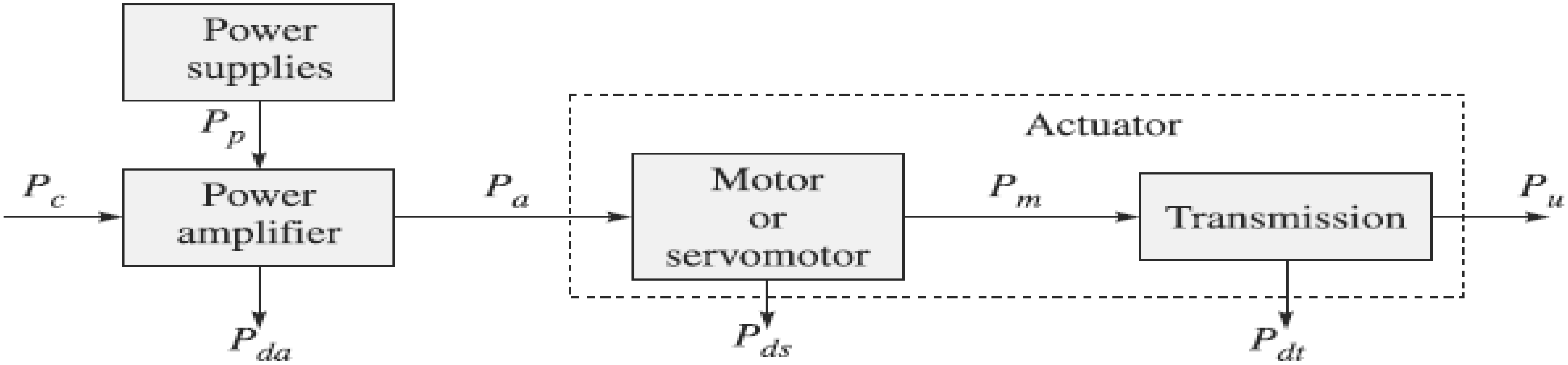
Actuators

- Actuators are devices which drive a machine (robot) including its grippers.
- Muscles of a human arm and hand.
- While human arm provides motion, hand is used for object manipulation.
- So, actuators in robots (machine) provides motion while grippers manipulates objects.
- An actuator system comprises of several subsystems, namely,

  (i) Power supply; (ii) Power amplifier;

  (iii) Servomotor; (iv) Transmission system.

Connections Between All Actuator Components



P_p: Primary source of power (electricity or pressurized fluid or compressed air);
P_c: Input control power (usually electric);
P_a: Input power to motor (electric or hydraulic or pneumatic type);
P_m: Power output from motor;
P_u: Mechanical power required;
P_{da}, P_{ds}, and P_{dt}: Powers lost in dissipation for conversions performed by amplifier, motor, and transmission

Characteristics Of Actuator

- Low inertia
- High power-to-weight ratio
- Possibility of overload and delivery of impulse torques
- Capacity to develop high accelerations
- Wide velocity ranges
- High positioning accuracy
- Good trajectory tracking and positioning accuracy

Choice of Actuator

- Choice of actuator depends on mechanical power required P_u and velocity that describe joint motion.
- Based on source of input power P_a, the actuators can be classified into three groups:

1. **Electric Actuators:** Primary input power supply is electric energy from electric distribution system.
2. **Hydraulic Actuators:** Transform hydraulic energy stored in a reservoir into mechanical energy by means of suitable pumps.
3. **Pneumatic Actuators:** Utilize pneumatic energy, i.e., compressed air, provided by a compressor and transform it into mechanical energy by means of pistons or turbines.

Choice of Actuator

- Electric actuators in industrial robots have wide availability due to their easy availability followed by hydraulic and pneumatic actuators.
- Hydraulic actuators are suitable for applications where the requirement is high power-to-weight ratio
- Pneumatic actuators are often used by electrically actuated robots for their grippers requiring only on-off motions of the jaws.
- Use of a pneumatic gripper makes the robot system a little lighter and cost effective.

ELECTRIC ACTUATORS

- Electric actuators are generally those where an electric motor drives robot links through some mechanical transmission, e.g., gears, etc.
- The first commercial electrically driven industrial robot was introduced in 1974 by ABB.
- Different types of electric motors are stepper motors, and the dc and ac motors.

Advantages of Electric Actuators

- Widespread availability of power supply.
- Basic drive element in an electric motor is usually lighter than that for fluid power, i.e., pressurized fluid or compressed air.
- High power-conversion efficiency.
- No pollution of working environment.
- Accuracy and repeatability of electric drive robots are normally better than fluid power robots in relation to cost.
- Being relatively quiet and clean - acceptable environmentally.
- Easy maintenance and repair.
- Structural components can be lightweight.
- Drive system is well suited to electronic control.

Disadvantages of Electric Actuators

- Electrically driven robots often require incorporation of some sort of mechanical transmission system.
- Additional power is required to move the additional masses of the transmission system.
- Unwanted movements due to backlash in transmission elements.
- Due to increased complexity in transmission system, there is need of complex control and thus, additional cost for their procurement and maintenance.
- Electric motors are not intrinsically safe, mainly, in explosive environments.

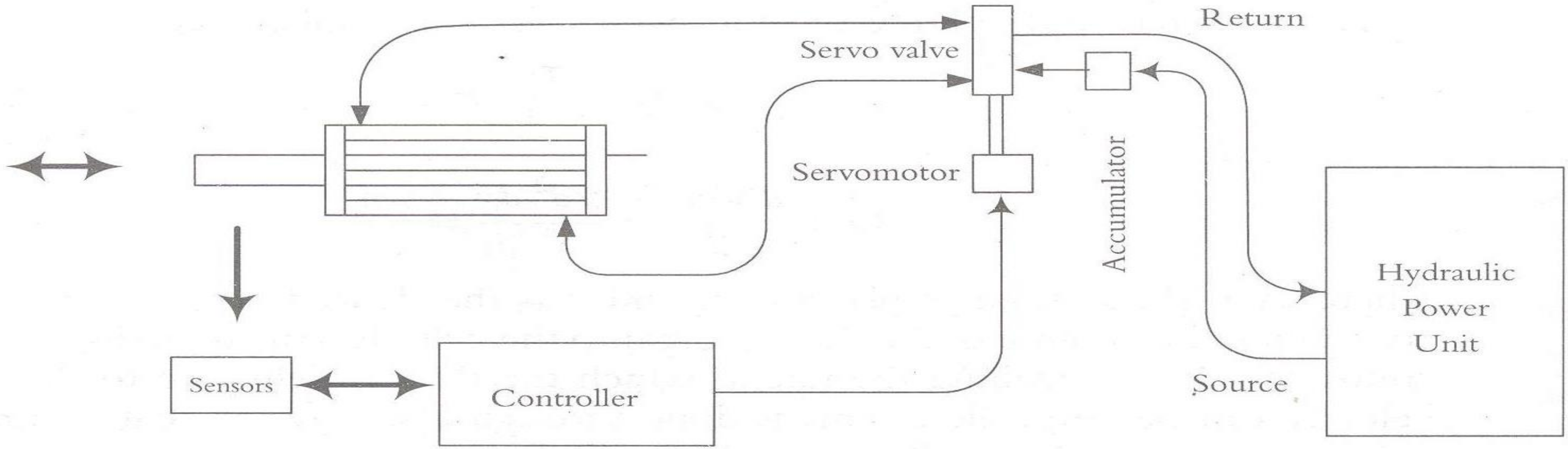
Overcoming Gaps of Electric Actuators

- Introduction of direct-drive motor system, in which electric motor is a part of relevant robot arm joint, eliminates need of transmission elements.
- Furthermore, introduction of newer brushless motors allow electric robots to be used in some fire-risk applications such as spray painting, as the possibility of sparking at the motor brushes is eliminated.

Hydraulic Actuators

- HAs Offer high power to weight ratio, large forces at low speeds, both linear and rotary motion, compatibility with microprocessor and electronic controllers and tolerance of extremely hazardous environment.
- Can hold load without break, generate less heat at actuator and apply torque without gearing.
- Hydraulic pumps may be designed for average load whereas electric motors are designed for maximum load. Accumulator stores energy and supplies when required.
- EAs are located at or near joint, adding to mass and inertia of robot.
- In HAs only actuator, control valves and accumulators are near the joints.
- Linear cylinder and rotary vane cylinder.

Hydraulic System



Hydraulic Actuators

- **Linear of rotary actuator-** to provide force or torque
- **Hydraulic pump** – provide high fluid pressure to the system
- **Electric motor** – to operate hydraulic pump
- **Cooling system** – to remove generated heat
- **Reservoir** – to maintain fluid supply
- **Accumulator** – to store energy

- **Servo valve** – driven by hydraulic servomotor, controls the amount and rate of fluid
- **Check valve** – safety valve
- **Holding valve** – acts as brake
- **Connecting hoses**
- **Filtering system**
- **Sensors**

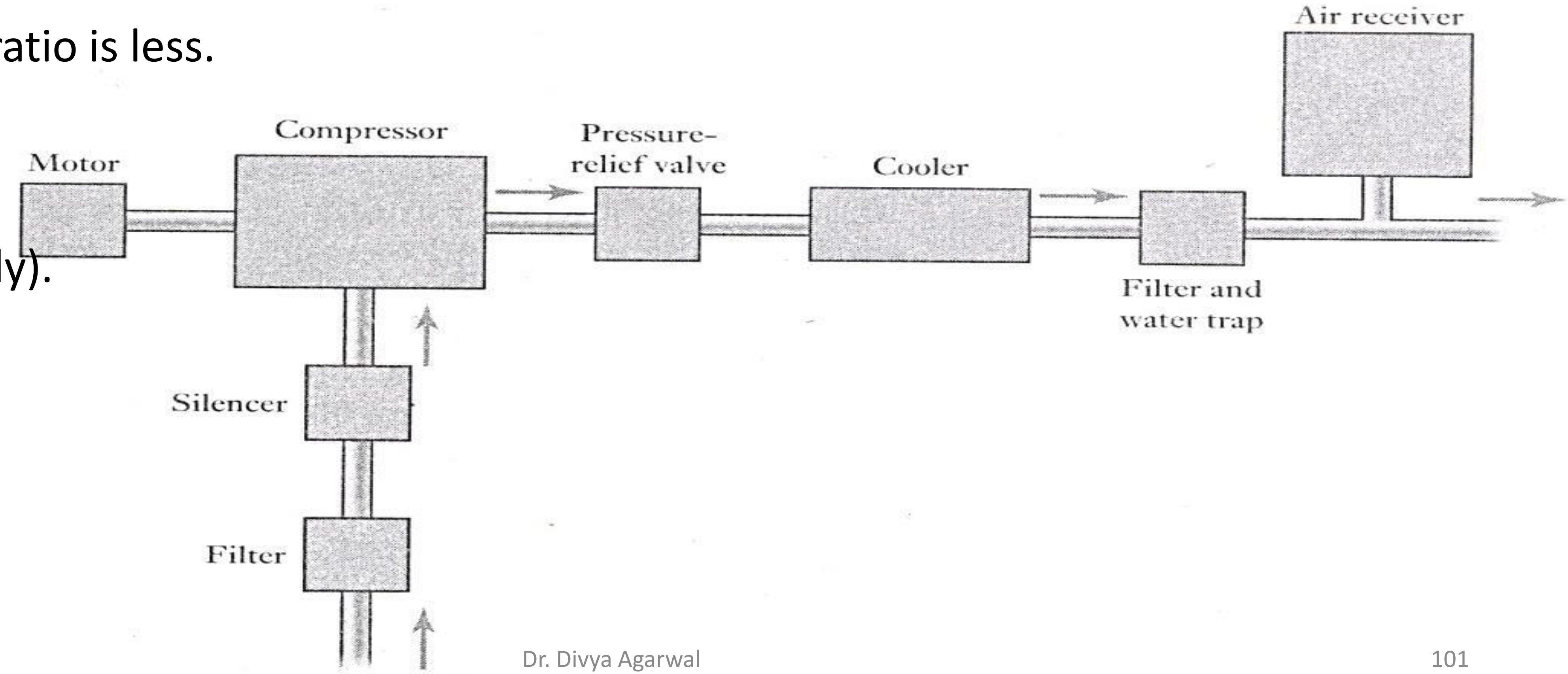
Hydraulic Actuators

Disadvantages:

- May leak, not fit for clean room application
- Requires pump, reservoir etc.
- Expensive and noisy, requires maintenance
- Viscosity of oil changes with temperature
- High torque, high pressure
- Susceptible to dirt and other foreign material in oil

Pneumatic Actuators

- Principally very similar to hydraulic system.
- Pressurised air is used to power and drive linear and rotary cylinders.
- Power to weight ratio is less.
- Simple and safe.
- Have half degree of freedom(mostly).



Unit 1 – Completed

THANKS

By: Dr. Divya Agarwal