UNIT III : IoT Design Methodology

Notes Written By: Prof.P.R.Patil

2-1 Introduction to IOT Design Methodology

- Design methodology for IOT system design which is independent of specific product service or programming language.

Purpose & Requirements.
Define purpose & Requirements of IoT System

Process model Specification
Define the use cases

Domain model Specification
Define virtual entities, physical entities, Devices, Resources & services in IOT platform.

Information Model Specification
Define structure. (e.g. relations, attributes of all information in IoT system)

Service Specifications
Map process and information model to services & define service specification.

IOT Level Specification
Define IOT level for the system

Functional Level (view) specification
Map IOT Level to functional groups

Operational view Specifications.
Define commn option, service hosting options, storage & device

Application Development

Fig: Steps involved in IOT system Design Methodology

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- The complexcity & application domains of IOT devices range from simple self monitoring devices in vending machine to complex interactive devices with artifical intelligence in smart vechicles & drones.

- An IOT platform facilitates comm^{n}, data flow, device management & the function-ality of applications.

- The goal is to build IOT appl^{n} with an IOT platform, framework.

- IOT platform allows applications to connect machines, devices, applications and people to data & control centers.

- Home automation can be described as introduction of technology within the home envo. to provide convenience, security & energy efficiency to its occupants.

- Home automation system can involve switching off electrical appliances like air conditioning, referigerators when desired temp has been reached then switching on when desired temp has crossed certain value.

Sensors :- Sensors are the eyes of home automation system. They see the environment & convert when they find electrical quantity that can be measured by a microcontroller or system processor.

Remote Connectivity :- Depending on need & various design considerations, users need to be able to control the system & appliances.

2.2. Purpose & Requirement specification

- The first step in IOT design methodology

- In this step the system purpose, behavior and requirements (such as data colln requirements, data analysis requirements, system management requirements, data privacy and security requirements, user interface requirements) are captured.

- Applying this to our example of a smart home automation system, the purpose & requirement for the system may be described as follows :-

(i) Purpose :- Using web application, user can remotely control the home electronic devices (light & air conditioner)

(ii) Behavior :- Home automation system will works in two modes : manual & automatic mode, In manual mode, web system provides options of manually & remotely switching ON/OFF the light. In automatic mode sensor is provided in the room. System measures the darkness of the room & light is on when darkness increases. Room temp. is measured by another sensor, air conditioner is ON when room temp is increases.

(iii) System Management Requirement :- Remote monitoring and control function is provided by system.

(iv) Data analysis Requirement :- Data analysis is based on local data.

(v) Application Deployment Requirement :- Application is installed on local device but it support remote operation.

(vi) Security Requirement :- Basic authentication mechanism must be provided.

2.3 Process Specification :-

- In this step the use cases of the IoT system are formally described based on and derived from the purpose & requirement specification.

- Process specification is defined after requirement step. Draw the use case based upon the first stage.

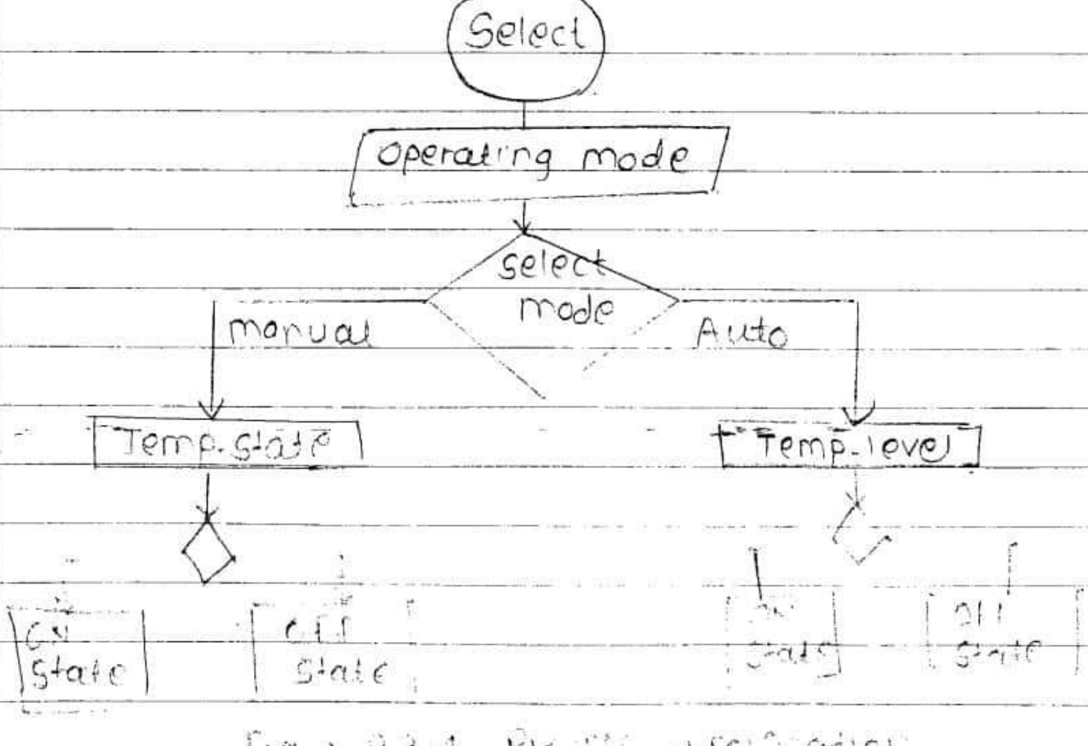

Fig: 2.3.1 Process specification

Purpose & Requirement Specifications :-

- Fig. shows the process diagram for the home automation system.
- The process diagram shows the two modes of the system auto & manual.
- In a process diagram the circle denotes start of process, diamond denotes decision box & rectange denotes a state or attribute.
- When auto mode choosen the system monitors light level. When the light level is low system changes state of the light is on. & if high system changes state off.

2.4 Domain Model Specification

- The domain model describes main concepts, entities & objects in the domain IOT system to be designed.
- Domain model defines attibutes of objects & relationships betn objects.
- Domain model provides an abstract represent ation of concepts, objects & entities in IOT domain.
- Domain model defines main concept of a specific area of intrest.
- The IOT is a support infrastructure for enabling objects & places in the physical world to have corresponding representation in digital world.
- Fig. Shows mapping concept of physical world to virtual world.

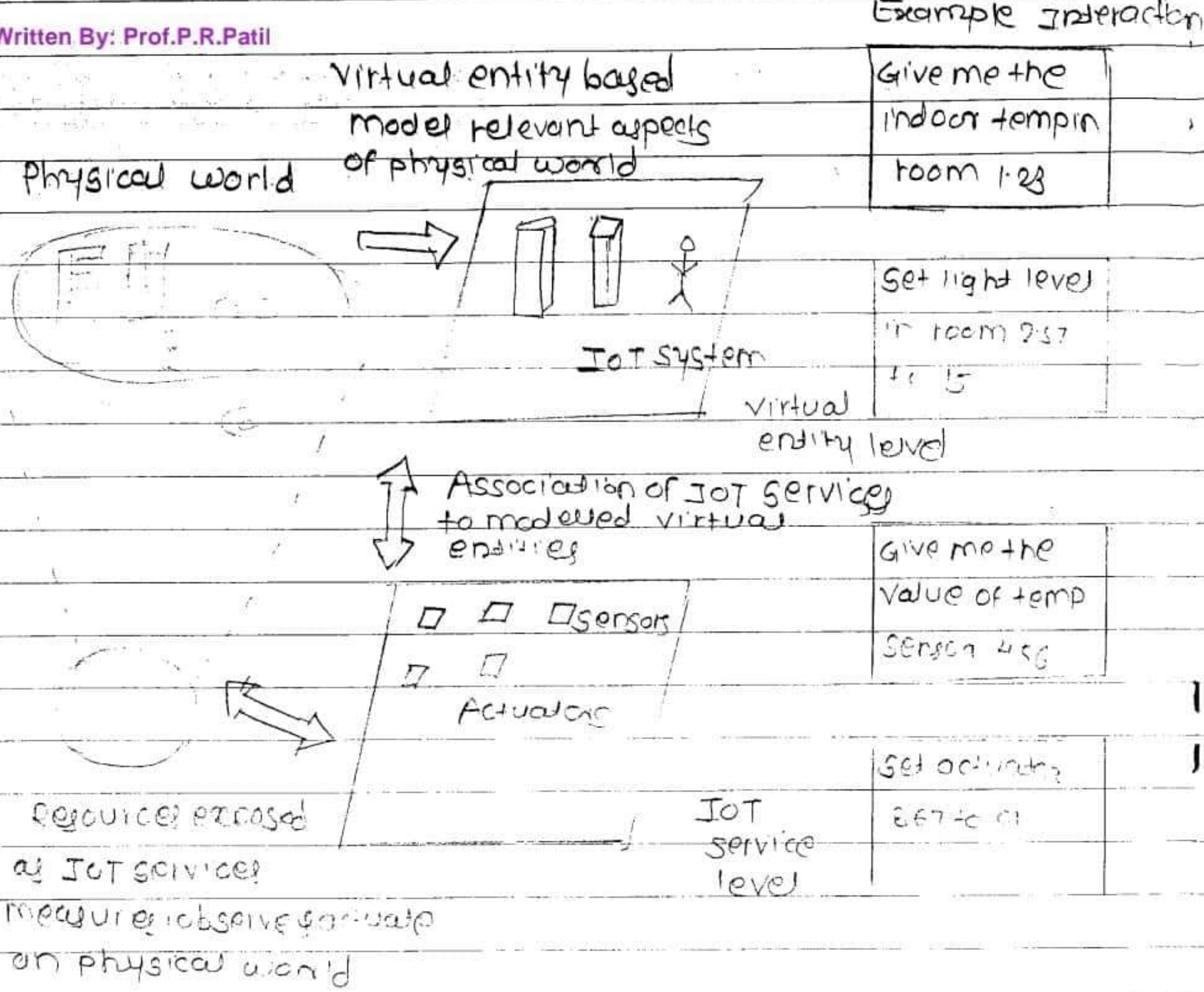

fig: 24.1 Mapping concept of physical world to Virtual

An interaction with the physical world is key for IOT, it needs to be captured in domain model.

- DM defines main concepts of the IOT & reln between these concepts.

- User & physical entity are two concept that belong to a domain model. A user can be a human & interaction can be physical.

- The physical interaction is the result of of the intention of the human to achieve certain goal.

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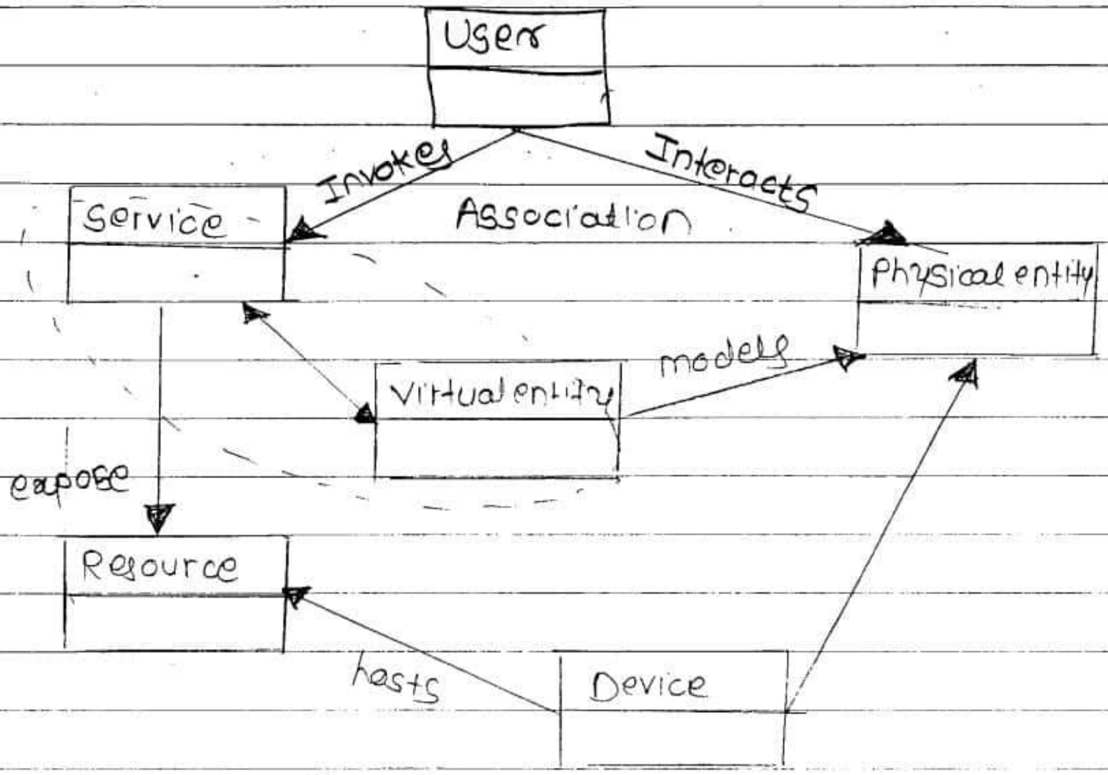

Fig: 2.4.2 IOT Domain Model

(i) Physical entity :-

- physical entity is a discrete & identifible entity in the physical enviroment
e.g. building is made up of several floors & each floor has several rooms. Or
Home - physical entity rooms & light appliance

(ii) Virtual entity :-

- A physical entity is represented in the digital world as a virtual entity.
- A virtual entity can be a database entry, a geographical model, an image or avatar or any other digital Artifact.
- Rel'n betn services & entities are modeled as associations. These association can be static.
e.g. in case the device is embedded into entity & could also the dynamic.

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(v) Service :- service provide an interface for interfacing with the physical entity.
Services access the resources hosted on the device to obtain infoⁿ about physical entity.
eg. Mode selection, controller device which runs services on the device, retrive the room temp.

2.5 Information Model Specification

- Information model defines the structure of all the information in the IOT system.
e.g. attributes of virtual entities, relations etc.
- Information model does not describes the specifics of how the information is represented or stored.
- To define the information model we first list the virtual entities defined in domain model.

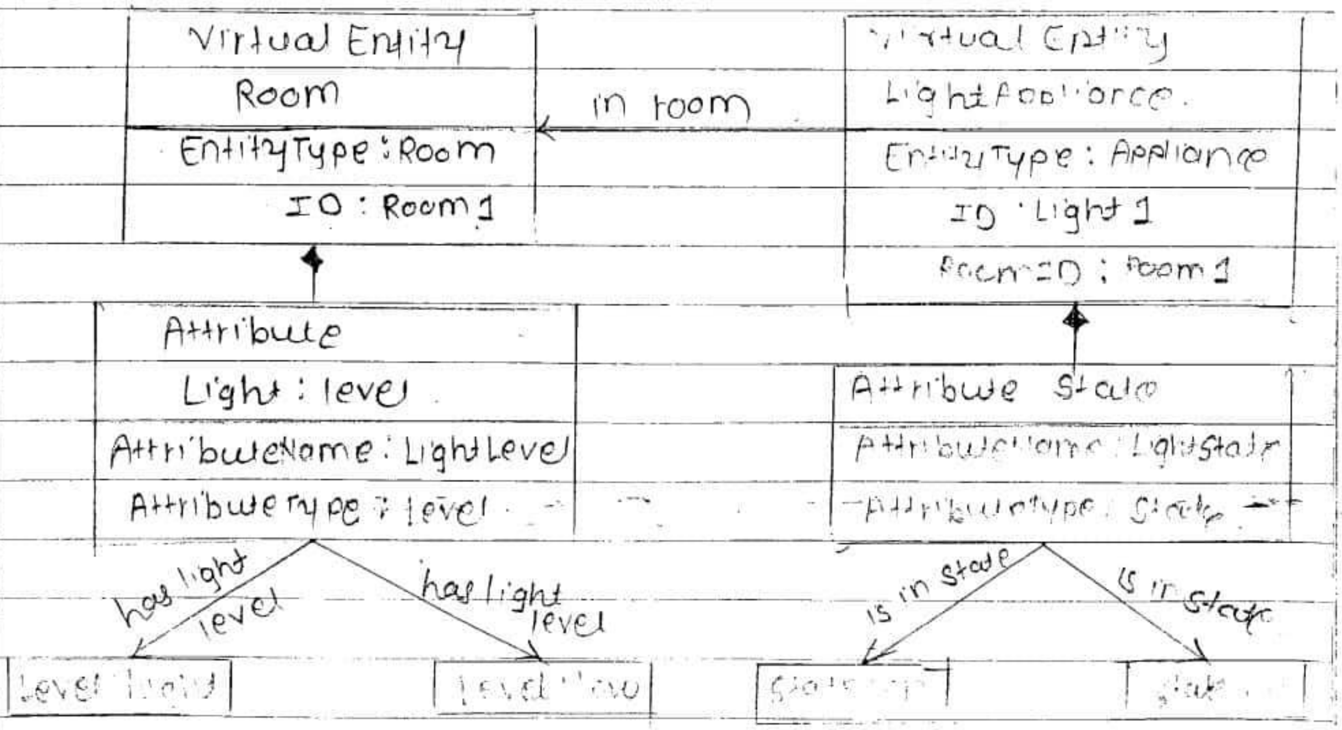


fig : Information model of the home automation IOT system

Example - Home Automation there are two virtual entities - virtual entity for light appliance of room.

- Information model is a meta model that provides a structure for the information.
- IOT information model is represented using Unified Modeling Language (UML) diagram
- The information model for an object can contain information about objects structure & resource types.
- Additional metadata can indicate context such as geographical location & bindings such as message protocols & event handlers & access control information.

2.6 Service Specifications :-

- The fifth step in IOT design methodology is to define the service specifications.
- Service specifications define services in the IOT system, service types, service input/output, service endpoints, service schedules, service preconditions & service efforts.
- State & attributes are defined in process specification & information model.
- For example - in home automation system mode setting is an example of mode service. User can set the auto or manual mode.
- Mode services sets mode to auto or manual or retrives the current mode.
- In manual mode, the controller service, retrives the current state from database & switches air conditioner ON/OFF.

- The state service sets the light appliance state to on/off or retrives the current light state.
- Controller service monitors the light level in auto mode & switches the light on/off & update status in database.

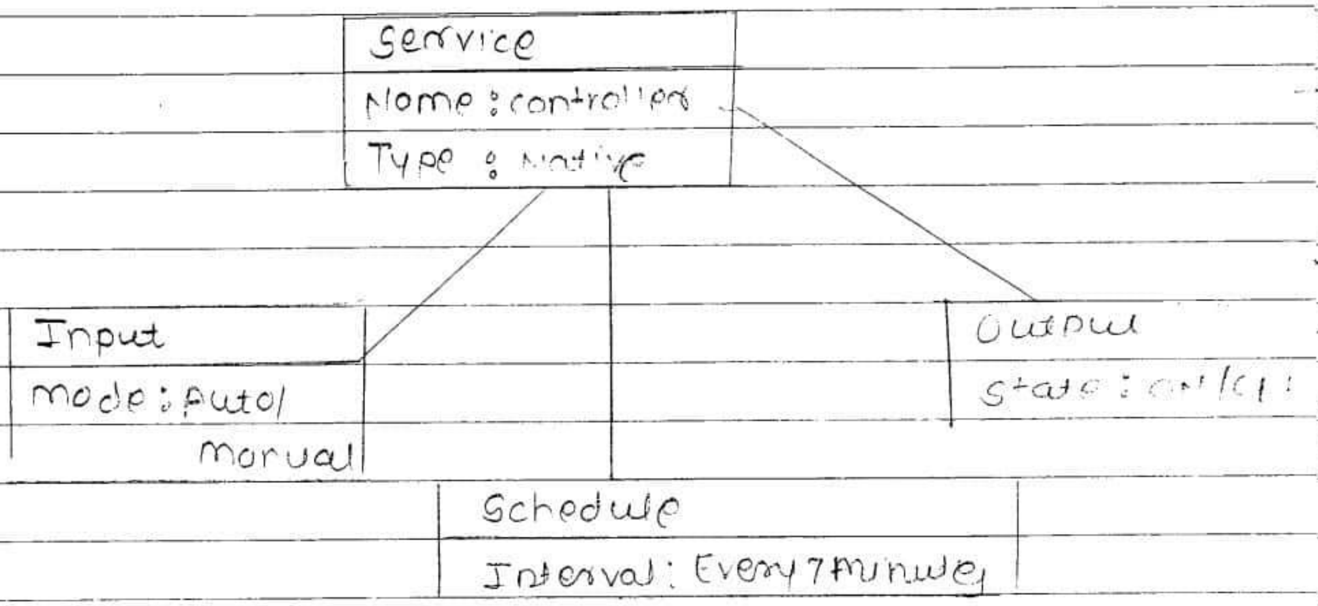


fig. Home Automation controller service

2.7 IOT Level Specification:-

- The sixth step in the IOT design methodology is to define IOT level for the system.
- IOT development level are six types.

IOT Level 1 :- Single node, perform sensing, local analysis & hosts the appln

IOT Level 2 :- Single node, perform sensing, perform local analysis.

IOT Level 3 :- Single node, data is analyzed in cloud & appln is cloud based.

IOT Level 4 :- Multiple node, perform local analysis, appln is cloud based.

IOT Level 5 :- Multiple end node & Coordinator node

IOT Level 6 :- Multiple independent node, perform sensing, send data to cloud.

2.8 functional View Specification :-

- The seventh step in the IOT design methodology is to define functional view.
- The functional view defines functions of the IOT systems grouped into various functional group
- Functional view describes the system's runtime functional components, their responsibilities default functions, interfaces & primary interactions,
- The functional view derives from functional model & reflects the developer's perspectives on the system.
- It will need to be extended with all identified (& recommended) new profile specific functional components including their interfaces & list of sequence charts illustrating recommended usage of these components.

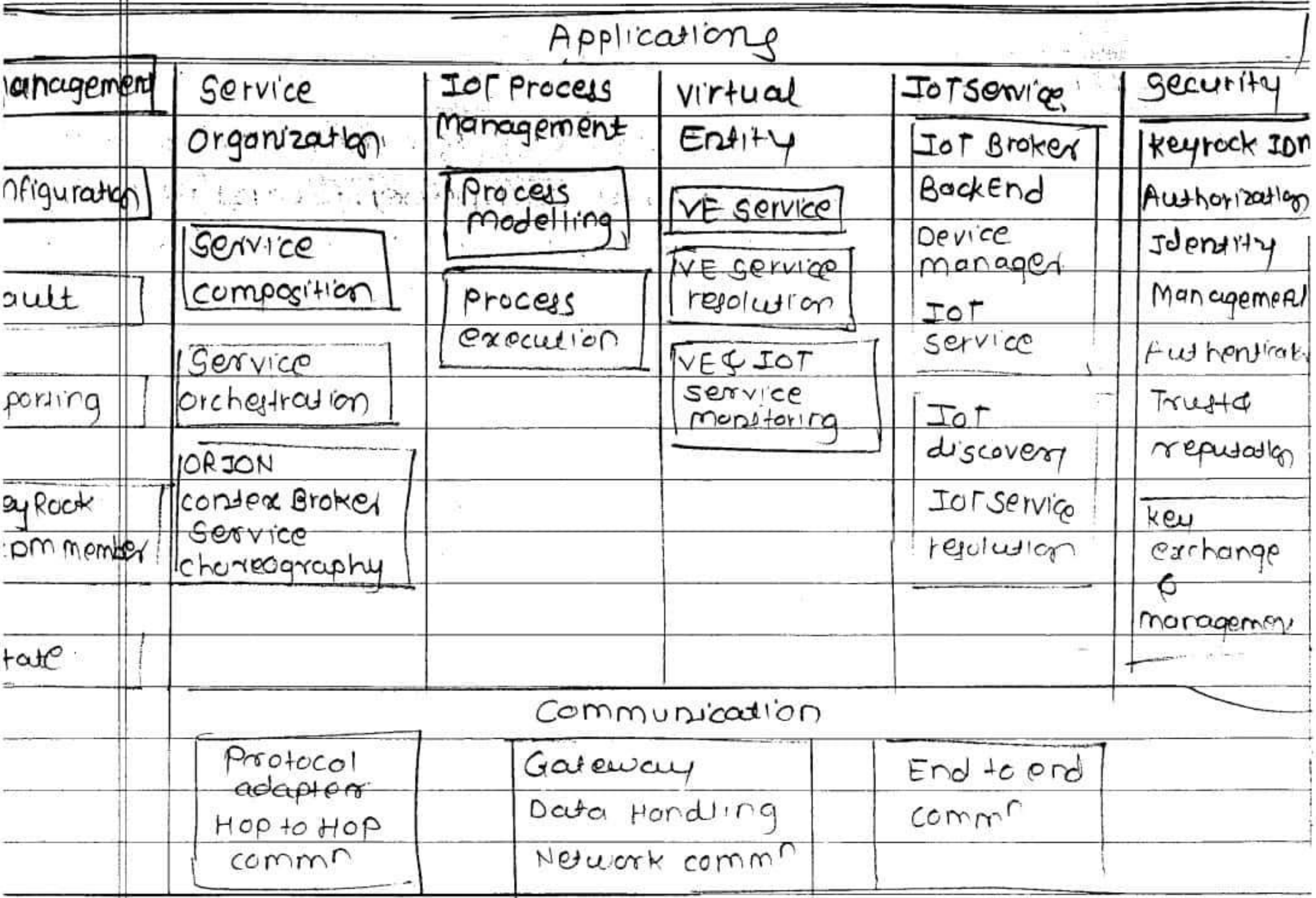


fig 2.8 Functional view

The viewpoints used for constructing the IOT functional view are.

① The Unified Requirements
② The IOT functional Model

- once all functional components are defined the default function set, system use cases, sequence charts & interface definitions are made.

The functional group (FG) included in a functional view include :-

• Device FG :-

- It contains devices for monitoring & control.

- Devices functional component contains the sensing, actuation tag, processing & storage components. e.g. Home automation - Device FG include mini comp, light sensor, relay switch (actuator)

• Application FG :-

- Application FG contains standalone appl^n

- It includes appl^n that provides interface to users to control & monitor various aspects of IOT system.

- It allows to view system status & processed data.

• Communication FG :-

- It contains the components for end-to-end comm^n, network comm^n & Hop-by-Hop commn.

Communication type	Description
End-to-end comm^n FC	- Responsible for end-to-end trasport of appl^n layer messages through diverse network & MAC/physical layer
Hop-by-hop FC	- Responsible for transmission & reception of physical & MAC layer frames to from/ other devices,
Network FC	- Responsible for message routing & forwarding & necessary translation of various identifiers & addresses.

- IOT Service FG :-
  - It consist of IOT service FC & IOT service Resolution FC.
  - It consist services for device monitoring, device control services, data publishing services & services for device discovery.

  e.g. Home Automation - Two services - REST service (mode & state service) & native service (controller)

- Virtual Entity FG :-
  - It contains functions that support the interactions between user & physical things through virtual entity services.

- Process Management FG :-
  - provides functional concepts necessary to conceptually integrate the IOT world into traditional (business) processes
  - Process modeling FC which provides the tools required for modeling IOT-aware business processes that will be serialized & executed in process services with extended functionality by composing IOT services with other services.

- Virtual Entity FG :-
  - VE Resolution FC provides discovery services for associations betn VEs & IOT.
  - VE Service & IOT monitoring responsible for automatically finding new associations based on betn VEs & IOT.

- Security FG :-

  - It is responsible for security & privacy matters in IOT-A-Compliant IOT systems. It include IOT authentication, authorization, data security mechanisms.

  - Authorization FC is used to apply access control & access policy management while ~~auth~~ authentication FC is used for user & service authentication.

  - Key exchange & management (KEM) FC enables secure commn ensuring integrity & confidentiality by distributing keys upon request in secure way.

- Management FG :-

  - It includes all functionalities that are needed to configure & manage the IOT system.

  - It is responsible for composition & tracking of actions that involve othe FGs

    (i) configuration FC is responsible for initializing the system's configuration.

    (ii) The fault FC is used to identity, isolate correct & log faults that occure in IOT system.

    (iii) The member FC is responsible for management of membership of any relevant entity.

  - reporting FC generates reports about system & finally state FC can exchange a particular state.

2.9 Operational View Specification :-

- The eight step in the IOT design is to define operational view specifications.

- In this step various options pertaining to the IOT system deployment & operations are defined such as service hosting options, storage options, device options, appln hosting options, etc.

- Deployment & operational view depends on the specific actual use case & requirements. Smart object in the IOT uses different methods for commn using diffn methodology.

- It provides an IOT Reference Mode with a set of guidelines to appln layer users.

- The viewpoints used in the Deployment & operation view are following

① IOT domain model diagram is used as guideline to describe specific appln domain

② Functional Model is used as a reference to system definition.

③ Network connectivity diagrams can be used to plan connectivity topology to enable desired networking capability of the target appln.

④ Device descriptions can be used to map actual hardware on the device & resource requirements of the target system.

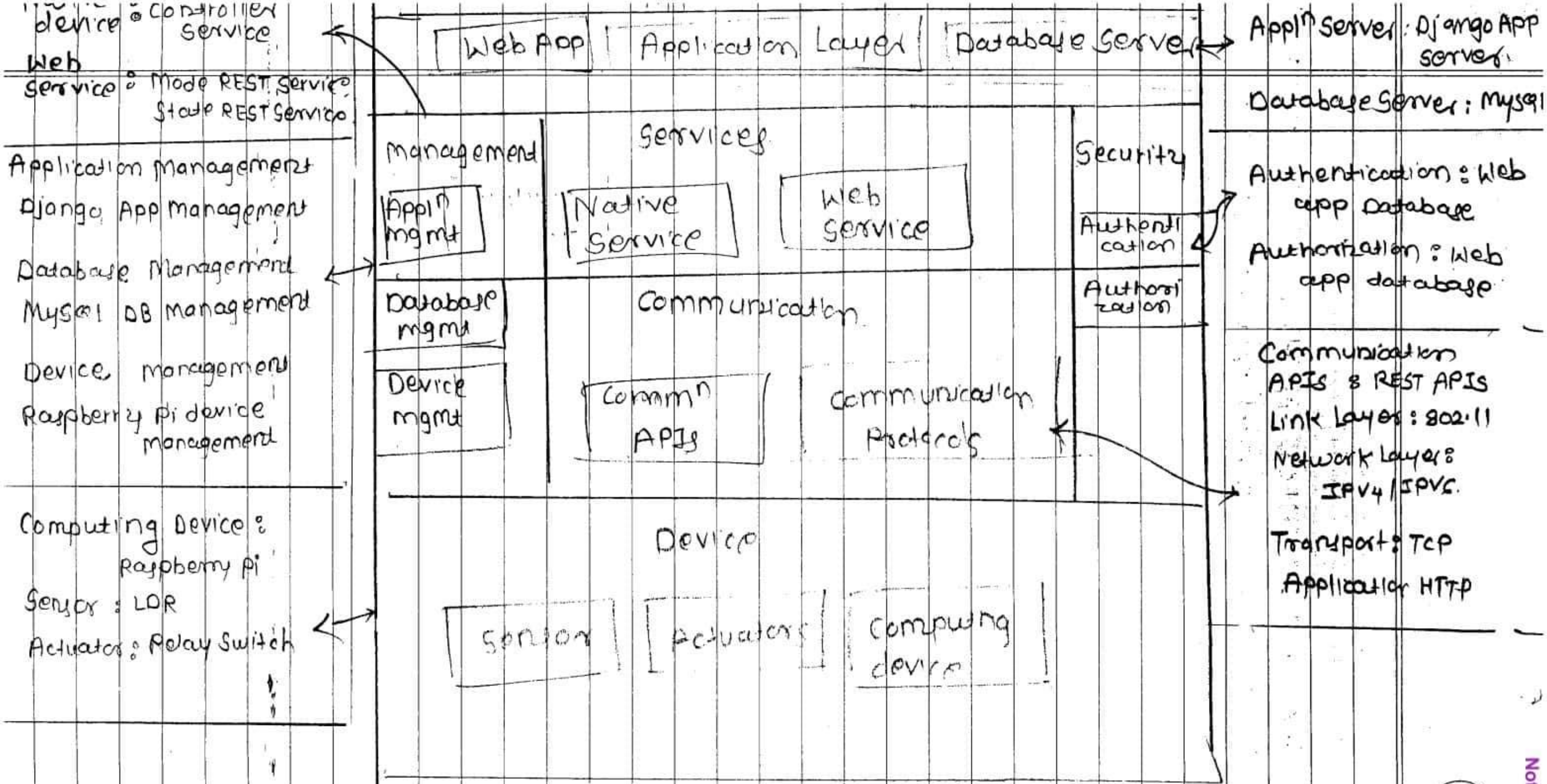


Fig: Mapping functional groups to operational view for Home Automation IoT System

Device & Component Integration

- The ninth step in the IOT design methodology is the integration of the ~~segs~~ devices & components.
- The devices & components used in home automation eg are rasberry pi, sensor, laser pointer, light dependent resistor (LDR) sensor & relay.
- Rasberry pi used in IOT project developement.
- From controlling the room lights with your smartphone to scheduling events to occur automatically, home automation has taken convenience to a whole new level.

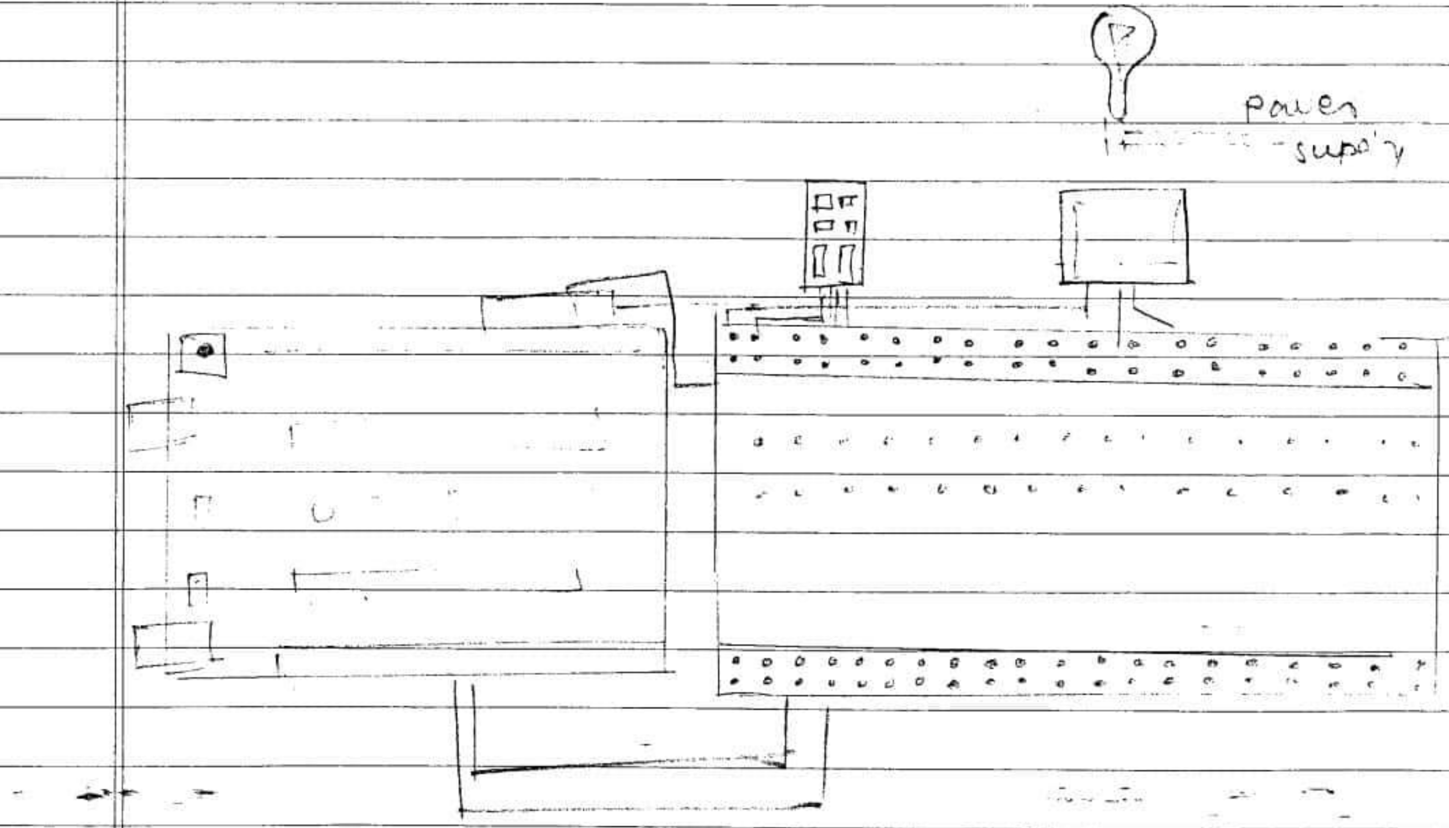
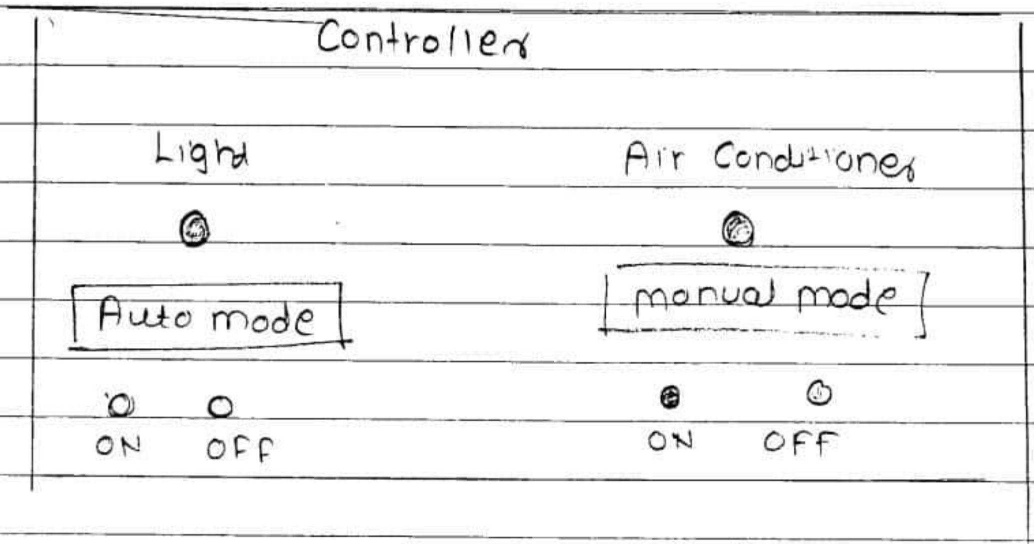


Fig. 2.10 Schematic diagram for Home Automation

2.11 Application Development :-

→ Appln development is final stage in developing IoT appln.

– In web application, it display mode control Auto & Manual.



– Two modes are provided - auto mode & manual mode.

– If auto mode is enabled the light control in the web application is disabled & it reflects the current state of light.

– If auto mode disabled the light control is enabled & it is used for manually controlling light & air conditioner.

* Basics of IOT Networking :-

- An IOT network refers to a collection of interconnected device that communicate with other devices without the need for human involvement such as autonomous cars, smart appliances & wearable technology.

- The network infrastures most associated with IOT networks are 4G LTE & 5G which are built to support the resource demands of the IOT.

* IOT Networks - 5G Networks.

① 5G standards have set expectations for the network to handle tens of billions of IOT network connections, IOT devices need a reliable connection with low latency.

② 4G LTE networks have long supported IOT devices with technology like Cat-M1 chipset

③ Wifi facility.

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* Networking components

① Sensors / Devices

- Sensors / Devices help in collecting very minute data from surrounding environment.
- A device can have multiple sensors that can bundle together to do more than just sensing that things.

example - our phone is device that has multiple sensors such as GPS, camera, accelerometer.

② Connectivity

- collected data is sent to a cloud infrastructure but it needs a medium for transport. like cellular n/w, satellite n/w, Wifi, Bluetooth, WAN, etc.

③ Data processing

- once the data is collected and it gets to the cloud, the software perform processing on the acquired data.

④ User Interface

Information made available to the end user in some way. This can achieve by triggering alarms on their phones or notifying through texts or emails.

* Internet structure.

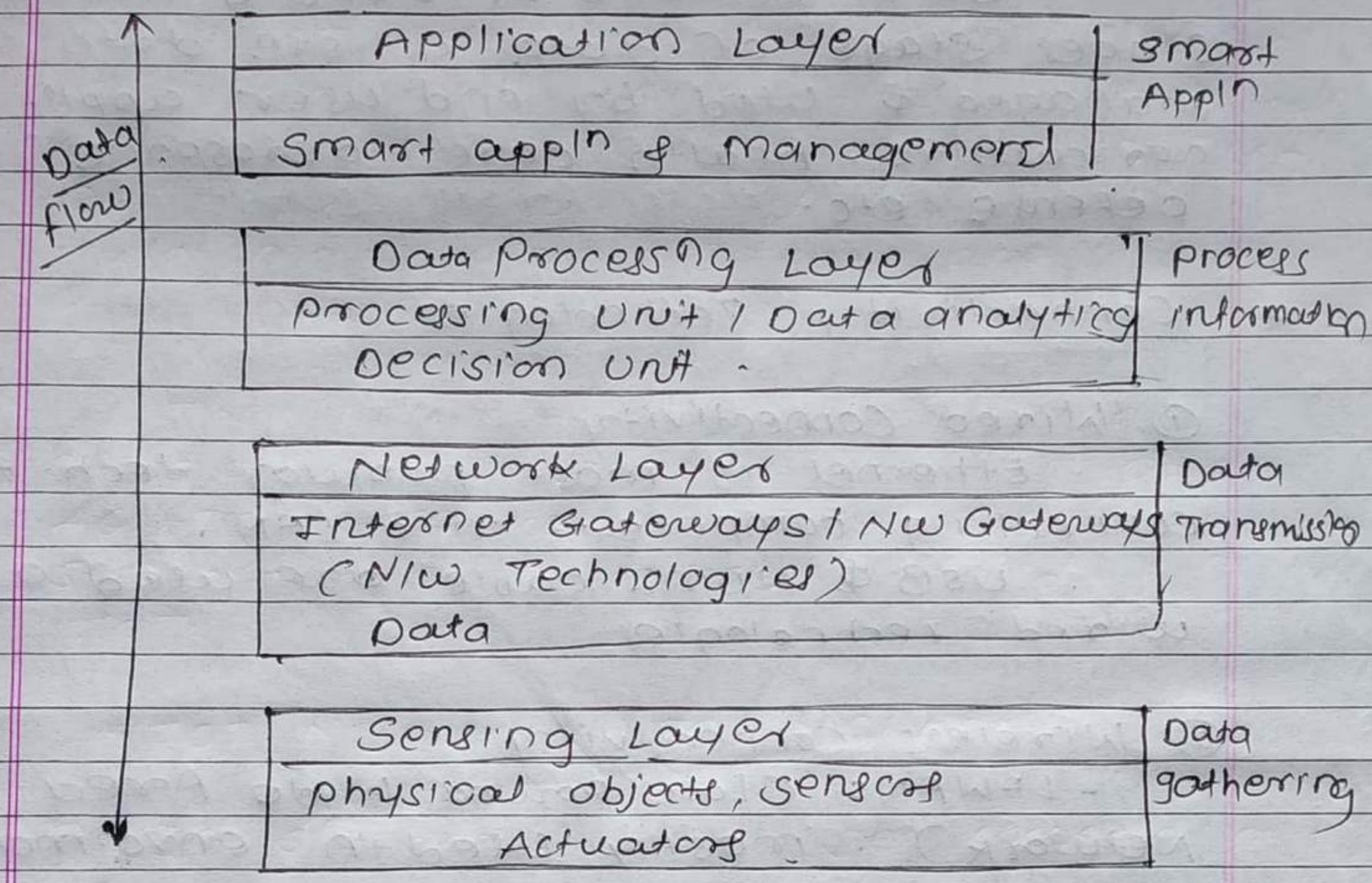

Fig. Internet structure

① Sensing Layer.
- Sensors, Actuators, devices are present in this layer. These sensors or Actuators accepts data, process data & emits data over network

② Network Layer
- Internet / Network gateways, Data Acquisition system (DAS) are present in this layer.
- sensor network & Internet also perform many basic gateway functionalities like malware protection & filtering of data, also decision making based input data, data management services

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④ Application Layer
- Data centeres or cloud is management stages stage of data where data is managed & used by end user appln like agriculture, health care, aeraspace, defense etc.

* Connectivity Technologies -

① Wired Connectivity
- Ethernet is most popular tech. for connecting computers in a LAN.
- USB & HDMI cable are used as wired technologies.

② Wireless Connectivity
- LPWANS (Low power Wide Area Network). mostly used in envo. monitoring

- Zigbee. is a short range, low power wireless standard (IEEE 802.15.4) (<100m)

- Bluetooth is a short range commn technology.

- WIFI - high throughput data transfer

- RFID (Radio Frequency Identification) uses radio waves to transmit small amount of data from an RFID tag reader within a very short distance

④ Security :-

- Security manages authorization, authentication, integrity & data security in an IOT system.

⑤ Application :-

- An IOT system manages various "things" and notifies user about any conditions or generate results based on sensed data. Applications are needed to represent such data relevant to the user.

- Application are also used to control & monitor such IOT systems. This is front end part of an IoT application which is accessible to the user.

>> IOT communication Models (T.B 1, Page No 32)

Communication Models
- ①. Request - Response
- ② Publish - Subscribe
- ③ Push - Pull
- ④ Exclusive Pair

① Request-Response model

- In this client sent request & server responds to the request.

- Request-Response is independent of other request & responses. This make it a stateless model of communication.

- Server fetches data from the storage (local or remote) & prepares a responses with the fetched data. Server sends this to client as a final completing one request-response cycle.

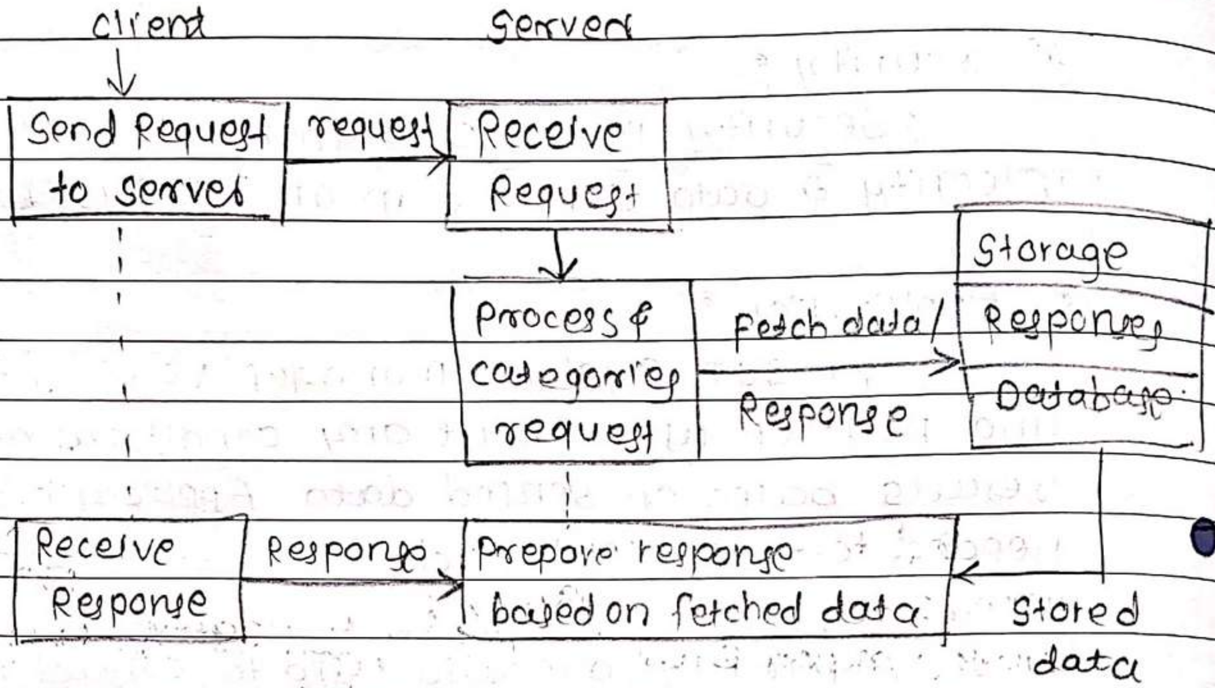


Fig: Request - Response Model

② Publish - Subscribe Model

- It has three key elements publishers, brokers & consumers.
- Publishers are source of data & in comm? Brokers are intermediate entity that manage publisher send data.
- consumers read messages from topics maintaine by brokers. publisher not aware of consumers.

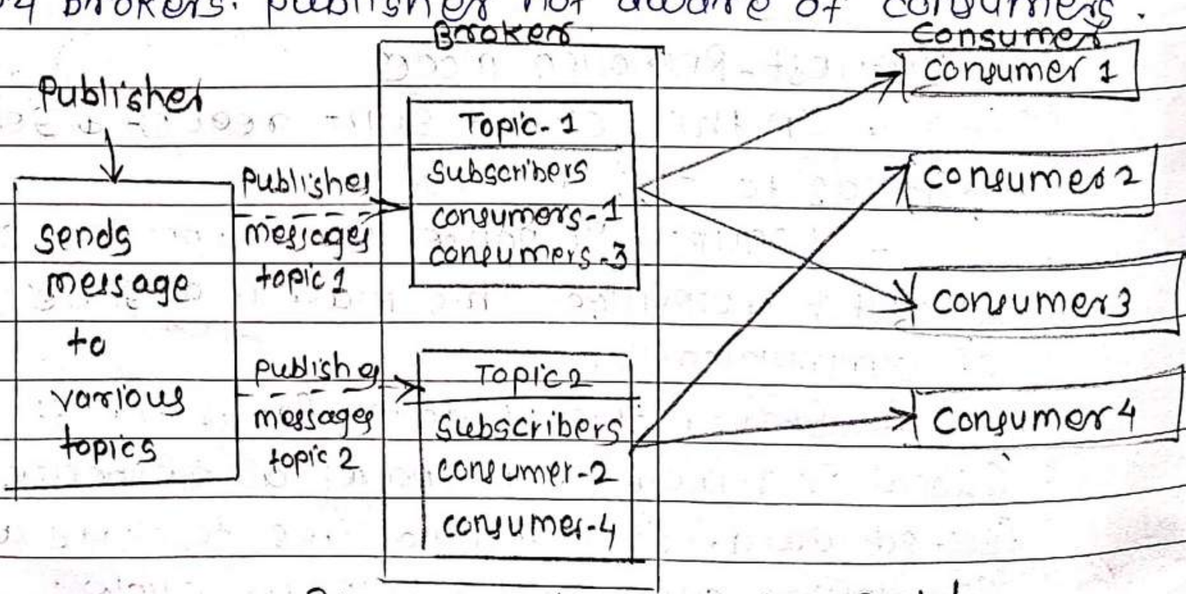


Fig: Publish - Subscribe Model

③ Push-Pull Model

- In push-pull commⁿ Model data producers push the data to queues, & consumers pulls data from queues as per needs.

- Queues are used to separate out single producer consumer commⁿ.

- Queues works as buffer mechanism & flow control mechanism.

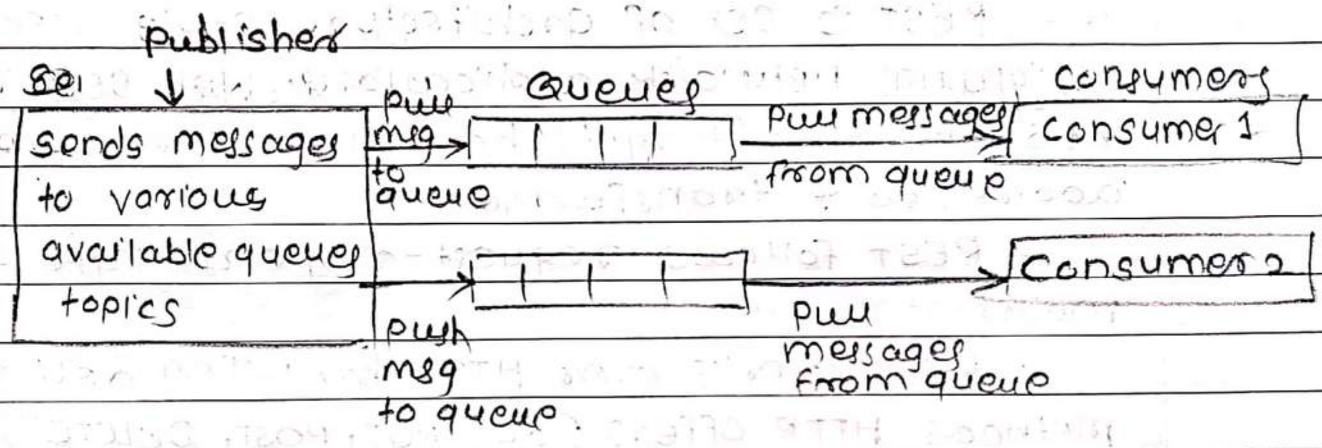


Fig :- Push-Pull Model

④ Exclusive Pair Model

- In exclusive pair commⁿ model a dedicated commⁿ link is set between the client & server.

- This provides full duplex & bidirectional commⁿ betⁿ client & server.

- once connection is established it remains open until client send request to close it.

- It is stateful type of communication & server is aware of all open connections.

» IOT Communication APIs

- There are two commⁿ APIs that most frequently used in IOT based applications.
  (i) REST (Representational State Transfer)
  (ii) WebSocket.

(I) REST

- REST is set of architecture style used for designing network applications, Web services or web API that targets how server resources are addressed & transferred.
- REST follows request-response type of commⁿ model.
- REST works over HTTP by using delivery methods HTTP offers (GET, PUT, POST, DELETE).

Characteristics :-

1. Stateless
2. client-server
3. Cacheable
4. Layered system
5. Uniform Interface
6. Code on Demand

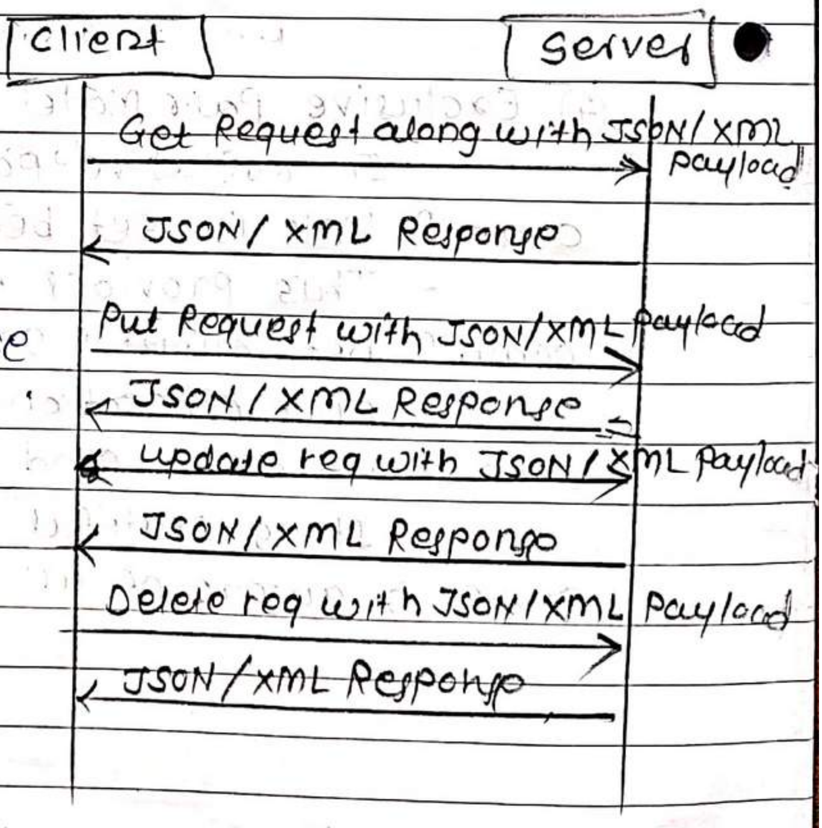


Fig: client server communication using REST

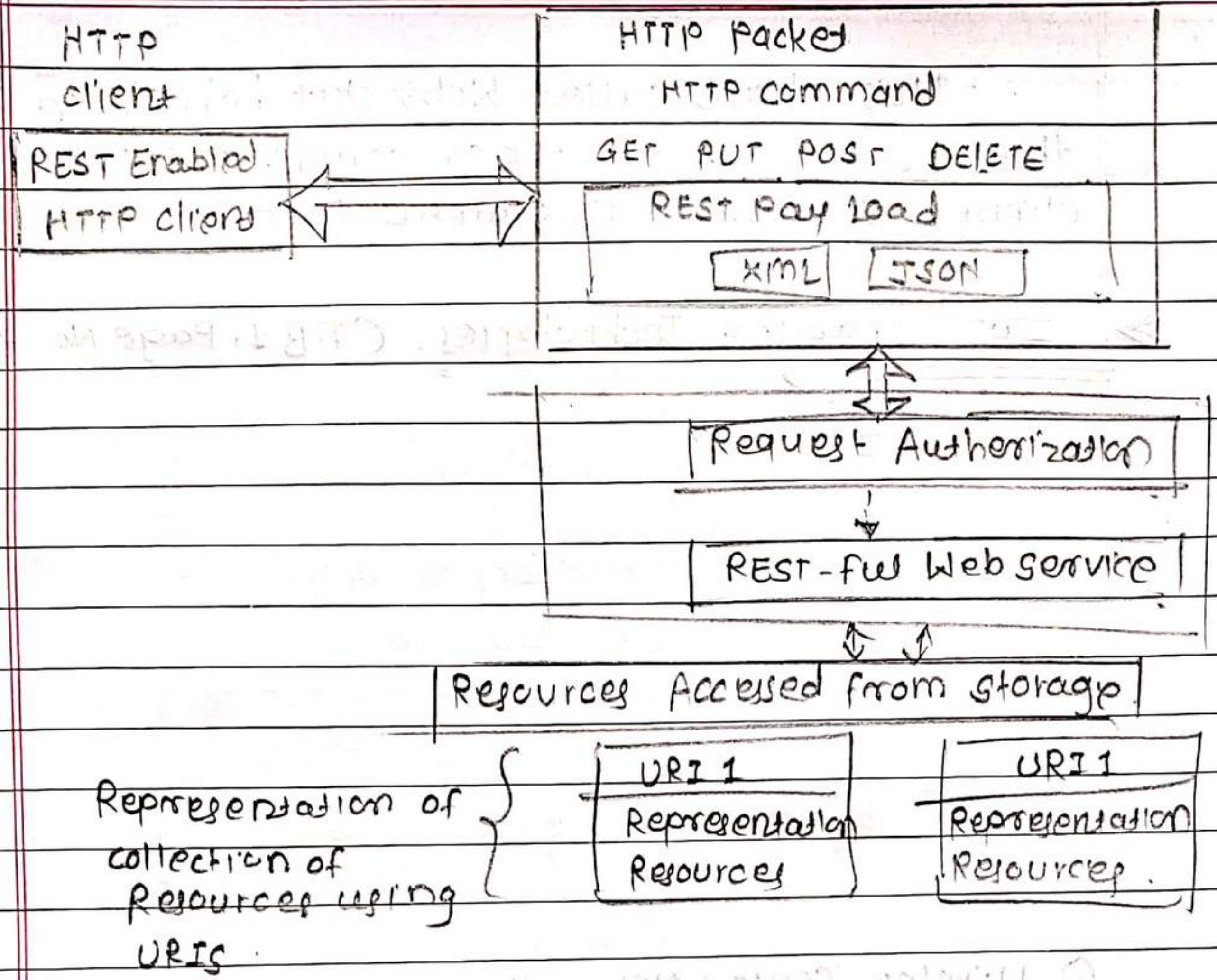
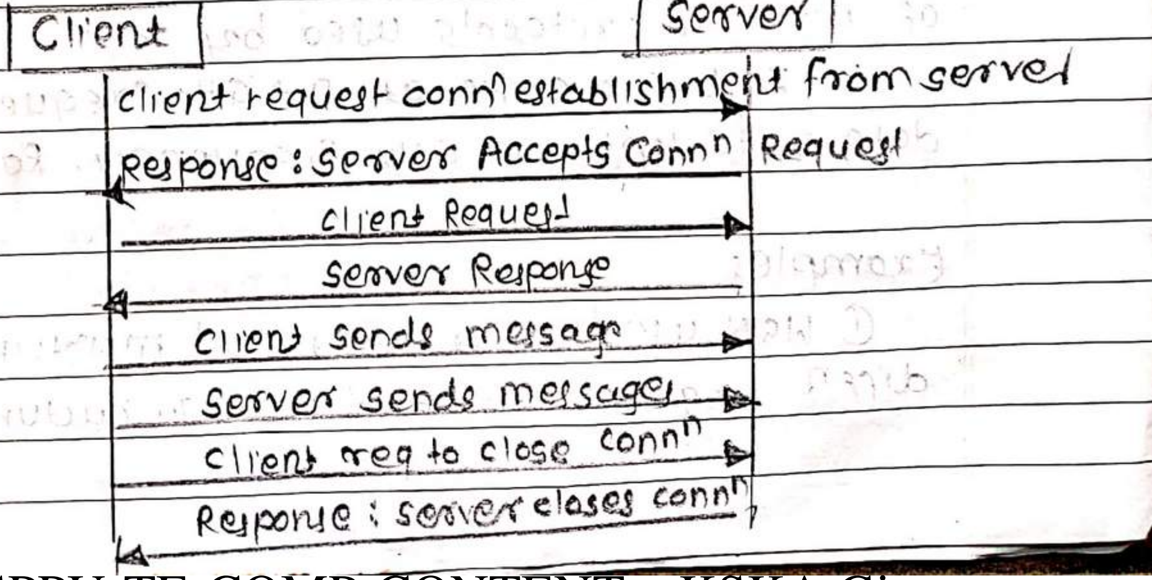


Fig: REST communication flow

(2) WebSocket :-

- It is full duplex, bidirectional commⁿ in client & server.
- Web Sockets follow exclusive pair type of commⁿ model.



* Sensor Network

- Sensor N/w is a group of sensors where each sensor monitors data in a diffn location & sends that data to a central location for storage, viewing & analysis.

- sensor n/w have emerged as a promising tool for monitoring physical world that can sense, process & communicate.

- A sensor n/w is network of many tiny disposable low power devices called node.

- Wireless sensor node consist of sensing, computing, commn, actuation & power components.

- Current WSN used in different application -

  - precision agriculture
  - Health care
  - smart cities.

- WSN n/w provides self organizing & self configurable n/w.

- WSN has coordinators & routers.

>> Four Pillars of IOT (T.B2, Page No 64.)

- IOT based appln connect together smart devices and processes the data in background. IOT appln are implemented in such way that architecture & working are unknown to user. IOT resets four pillars used to connect devices using common infrastructure for commn, policies for gathering data & how it should processed.

Four pillars used for representation

1. IOT based appln connect together smart devices & processes the data in the background. IOT appln. four pillars are

1. M2M (Machine to machine)
2. RFID (Radio Frequency Identification)
3. WSN (Wireless Sensor Network)
4. SCADA (Supervisory Control and Data Acquisition)

① M2M

- M2M uses smart devices/objects to detect events and transfer it to other devices (usually of higher processing capacity) which translate such sensed data to the meaningful information.

e.g. WAN, GPRS, Cellular & fixed Networks

② RFID

- RFID uses radio frequency to communicate between the tag attached on a device & RFID reader that identifies the unique RFID tag which can be used for identifying and tracking the implented object.

e.g. Radio waves, NFC, IC cards.

(3) WSN

- WSN senses & gathers together data using sensors distributed spatially in the geographical region and collects it to a centralized location with help of wired, wireless or sometimes hybrid network for processing.

e.g. ZigBee, Bluetooth, Wireless Mesh Network.

(4) SCADA

- It focuses upon independent systems that work upon closed loop control systems that connect monitor & control equipment using a short range network inside a building or an industrial plant.

e.g. BacNet, CanBus, Wired Field Buses.

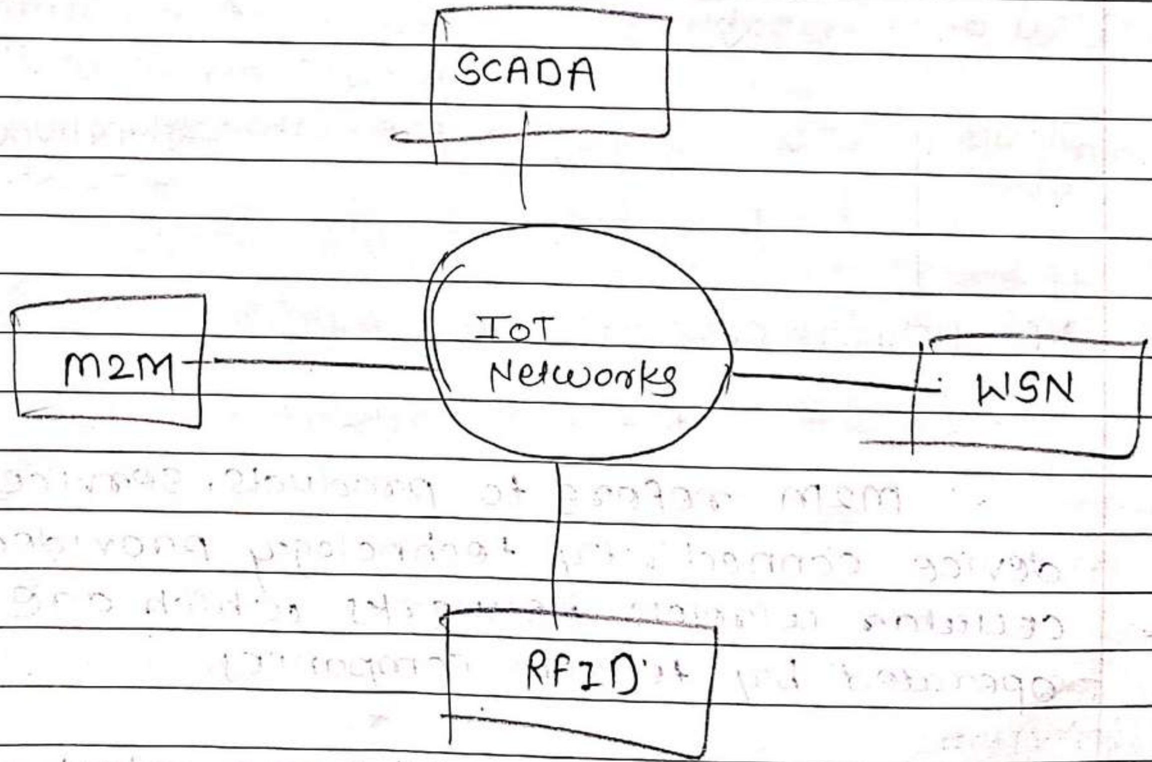


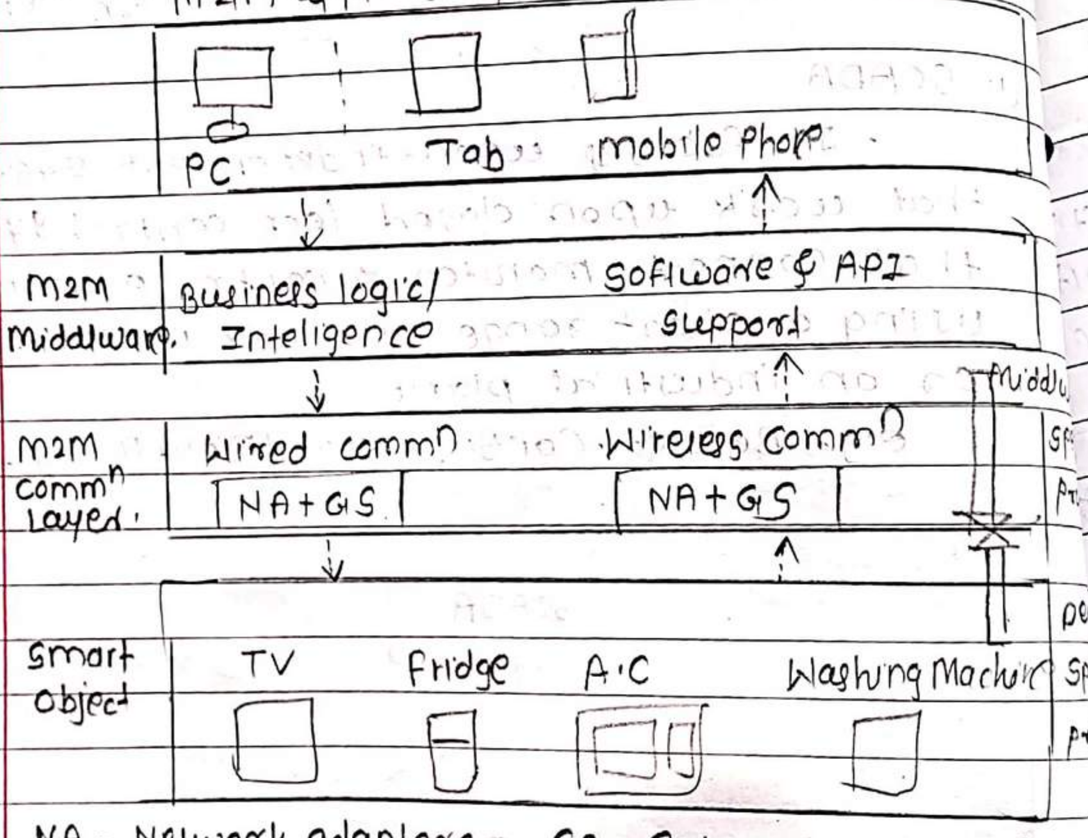
fig- Four pillars of IoT

» M2M : The Internet of Devices

(T.B 2, Page No 65)

- M2M connectivity considers cellular Network for its commn. GPRS, cellular fixed networks makes M2M functionality.

M2M appln & appln access



NA = Network adapters GS = Gateway Control Software

Fig: M2M Architecture

- M2M refers to products, services and device connectivity technology provided by cellular wireless networks which are operated by telecom companies.

- There are some consumer electronics services in place which follows M2M approach.

- M2M includes telematics (long distance transmission of data and information) and telemetry (reading & transmitting the sensed data from devices).

- As shown in fig. middleware placed on server side is the backbone of M2M archi.

- At bottom smart object electronic devices like AC etc. These objects accessed by using M2M framework.

- Next layer provides commⁿ & network solⁿ for smart devices deployed in below layer. It consists of wired & wireless network adapters which are managed by gateway manager software for accessing smart devices some protocols used.

- Next is middleware brain of M2M. M2M uses specific protocols to collect data from gateway via network & process into useful info using business intelligence.

- Middleware provides platform to the developers.

- Top layer appln layer accessible to user. Provides platforms to users to access smart device.

Examples of M2M appln

1. Medical - wireless medical service can be used for remote patient monitoring.
2. Transport - Traffic control system.
3. Industry - Automation of manufacturing process improve productivity.
4. Automobile - Tracking & antitheft alarm system.

RFID : The Internet of objects
(T.B 2, Page No 73)

- RFID uses radio frequency to commn betn tag attached on device and RFID reader that identifies unique RFID tag can be used for identifying & tracking implemented object that is in use.
- RFID are attached physically to the device which needs unique identification.
- RFID tag stores a serial number that identifies the object and some additional data can also be stored on device along with serial number according to size limitations.
- It has antenna that transmit data from tag to reader.
- RFID provide low cost contactless identification of devices.
- When device come in range of RFID reader equipment, readers read data on tag using radio frequency event without actual contact.

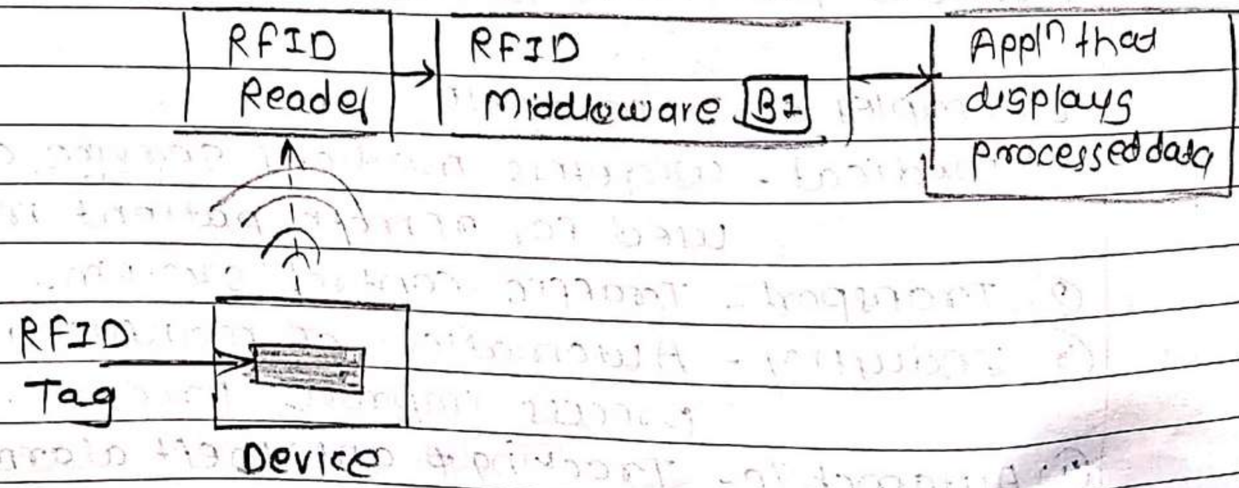


Fig: RFID Tag Commn.

- In fig RFID systems contain device impl^n with RFID tag, RFID reader is middleware which can be used to specify business logic if any to process data. (e.g. payment of vehicle on toll plaza).
- RFID tags are three type active, passive & semipassive depends on battery support.
- RFID technology is frequently used with RFID tags implanted on animals, cloths, cards books etc.
- Before RFID barcodes and plain texts used for object & article identification.
- Universal Product Code (UPC) was used in USA and Canda for object identification & tracking.

RFID used to develop new technologies like

① Auto-ID is a mechanism that uses identification technology like RFID and manages automatic data capturing & storage of this information over the internet.

② Electronic Product Code (EPC) is designed to be stored on RFID tag to provide unique identification for a product.

Examples of RFID applications with standardization.

① A low frequency RFID is used for animal identification & tracking.

② vehicle identification & toll collection systems uses long ranged passive & active RFID reading with working frequency 5.8 GHz & Standardization ISO 18000-5

WSN : The Internet of Transducer
(T.B2, Page No 80)

WSN :-

- Wirless Sensor Network senses and gathers together data using sensors distribute spatically in the geographical region and collects it to a centralized location with help of wired, wireless or sometimes hybrid network for processing.
- WSN is used to detect physical and environmental changes like temp, motion, heat etc.
- WSN focuses on sensing and gathering data and routing it for further processing.
- Motive behind WSN for military and battlefield surveillance.
- WSN has multiple nodes ranging from hundreds to thousands. single node has multiple sensors.
- A node has electronic circuit for sensors inside, a microcontroller, a radio transreceiver with antenna and battery as energy source.
- These node senses data has a routing capability.

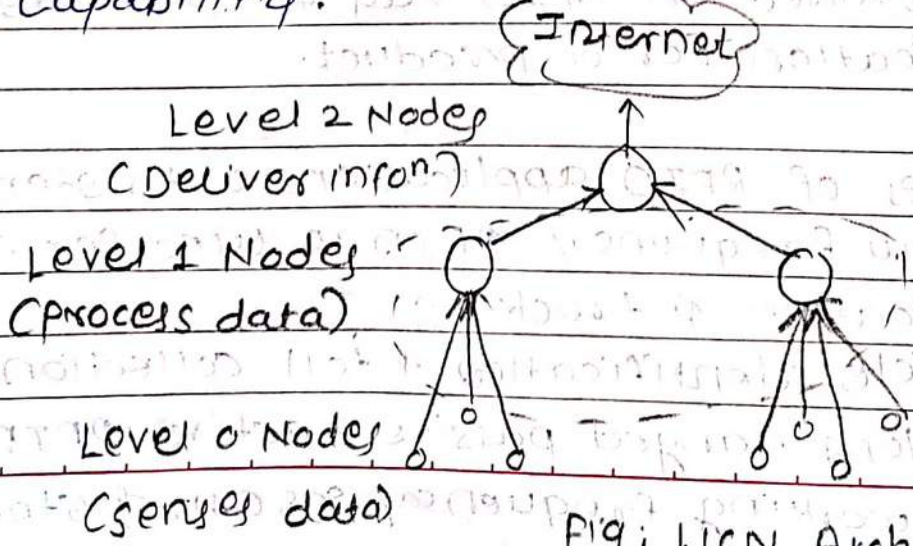


Fig: WSN Architecture

- This data is processed and provided to the end user in upper layers.
- Sensors nodes usually connected to the base station or sink that communicate betn nodes & users.
- Intelligent logic can be provided for processing & computing data gathered by nodes.
- Processed data is converted into user representable info & provided to end user via Internet.
- Routing protocols used in WSN are distributed and reactive.
- Ad hoc ~~for~~ on demand distance vector (AODV) and Dynamic Source Routing (DSR) are used for routing.
- Topology of WSN can be simple star / multiple mesh network.
- Lifespan of a WSN depends upon energy source of nodes are distributed over a large geographical area. So algo & protocols used in WSN must be fault tolerant & robust to increase lifespan of node.
- Mobile Sensor Network (MSN) is a WSN in which nodes are mobile & can change location based upon envo. changes
- Main difference betn WSN & MSN is data routing algorithm.

Examples of WSN

① Forest fire detection
② Weather monitoring systems
③ Military surveillance.

>> SCADA :- The Internet of Controllers (Supervisory Control and Data Acquisition)

(Fig No. 8.8 T.B.2)

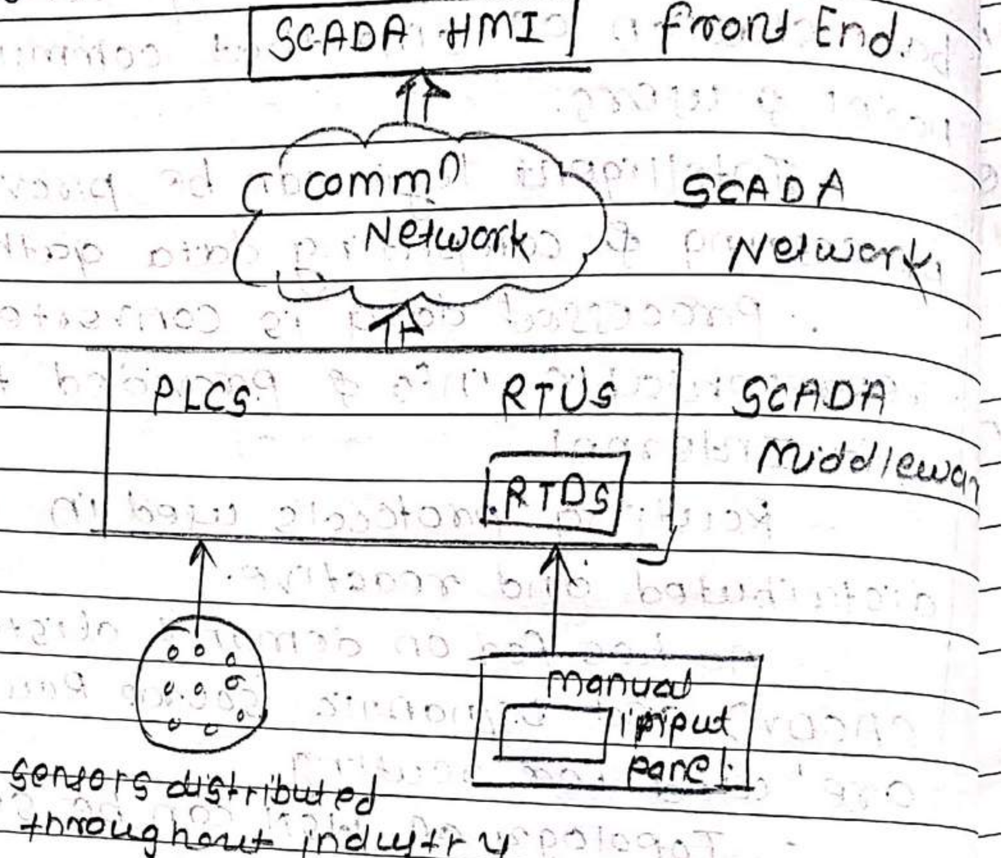


Fig: SCADA Architecture

- SCADA mainly focuses on independent systems that work upon closed loop control systems that connect monitor & control equipment using a short range network inside a building or industrial plant.

- The foundation architecture of SCADA begins from PLCs and RTU. PLC & RTU are micro computing devices which communicate & coordinate with sensors & nodes.

- The SCADA software analyzes, distributes & generates results which are displayed over the HMIs

SCADA Archi containg

>> HMI :- Human machine Interface

- HMI is user interface (UI) of SCADA system.
- All data processed via supervisory system is represented to the user in understandable way with help of results like schematic, logistic information. Human operator use this & control process.

>> RTU :- Remote Terminal Units

- RTU receives signals data from sensors & sensors signals are converted into digital data by RTU.
- Digital data sent to supervisory system for further processing.
- RTU provides interface betn SCADA & physical objects.

>> PLC :- Programmable Logic Controller

- PLCs are used alongside RTU to monitor & control incoming data as they are flexible, configurable & economical compared to RTUs.
- PLCs provide functionalities like motion control, relay control, provide local control.

>> DCS :- Distributed Control Systems

- DCS is a control system in which control elements are distributed throughout plant or industry.
- DCS has multiple local controllers distributes in various sections of the plant connected with high speed network. DCS is suited for large scale industries or manufacturing plants.

- SCADA system is middleware betn h.. level large systems like ERP, warehouse mgt systems (WMS), Enterprise Asset mgmt (EAM) lower layer RTU, PLC, DCS etc.

- SCADA is being implemented as a core mechanism in many geographically separated services.

- SCADA automates complex industrial practices & processes when human control is not feasible.

Examples of SCADA

① manufacturing process in an industry.

② Industrial control systems.

③ Oil & Gas Industry.