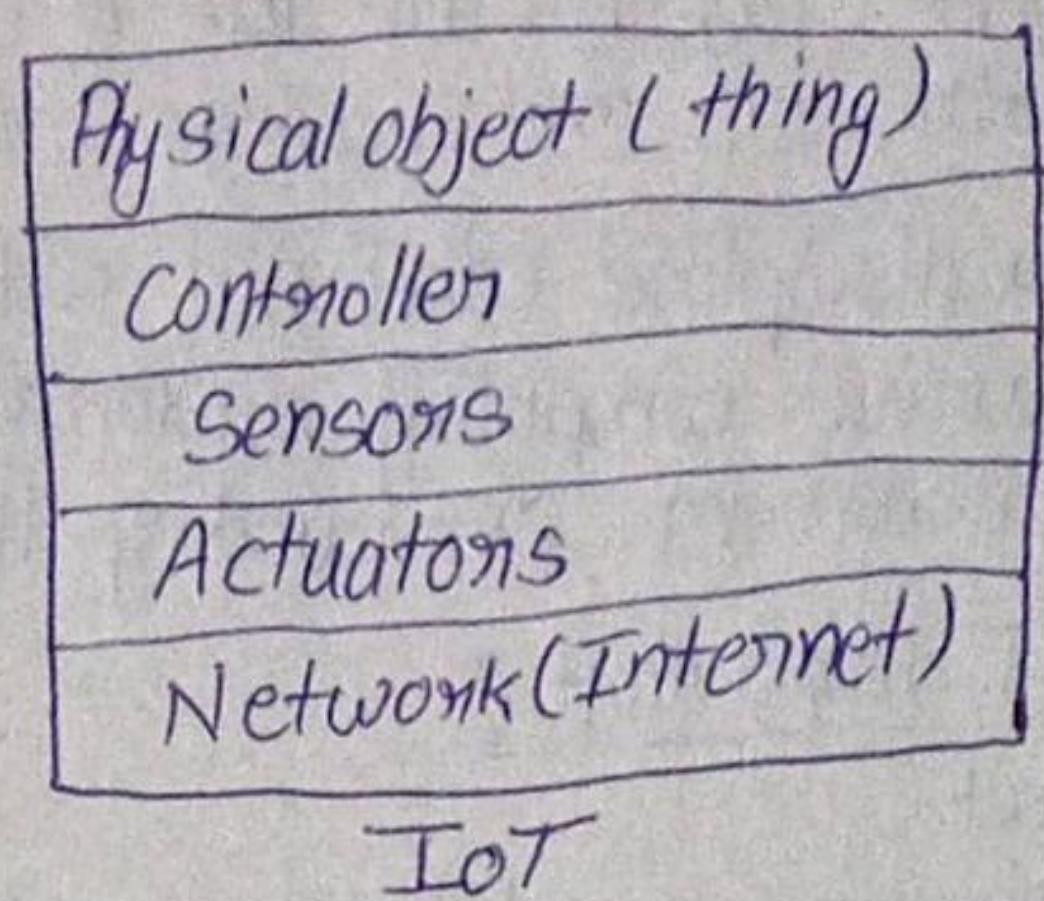


# Internet of Things

IoT is the network of physical devices, vehicles, home appliances and other items with embedded with electronics, software, sensors, actuators and connectivity which enable these things to connect, collect and exchange data.



## Applications

- Smart home
  - wearable
  - smart city
  - smart cars
  - smart creatures etc

## Enablers

- Portability : small size , miniaturization
  - low power low heat
  - connectivity
  - Convergence and divergence
  - Ecosystems

## Issues and challenges

- control
  - privacy
  - disrupt services

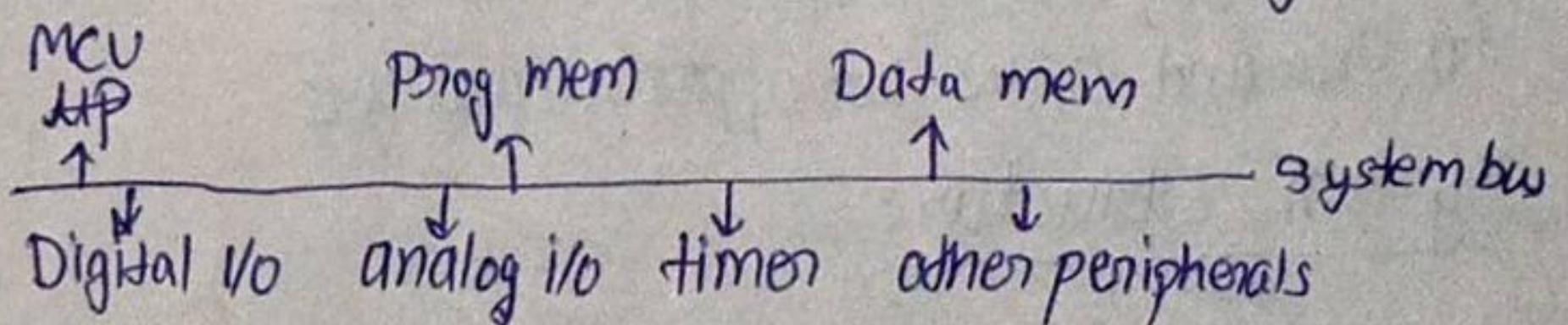
## Embedded System/computer

Special-purpose computer  
Any sort of device which includes a programmable computer but itself is not intended to be a general-purpose computer.

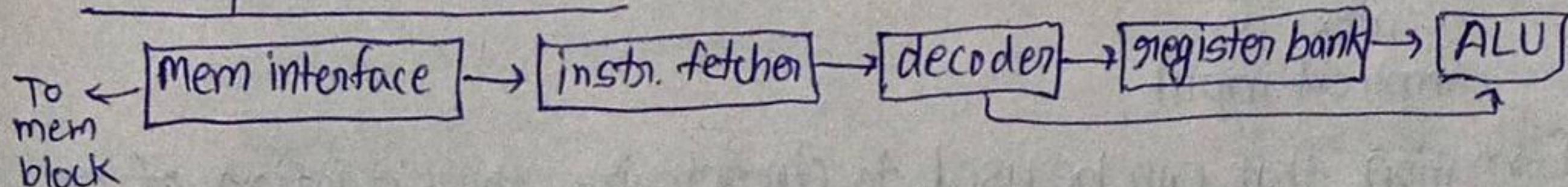
- Application specific computer system, built into larger system
  - often with real-time computing constraints.
  - Better performance, more functions and features, low cost, more dependability.

## Microcontroller Unit (MCU)

- typically single core
  - used for basic control purposes such as embedded applications.



## Microprocessor or CPU



## Embeddes system

- typically implemented using MCUs
  - often integrated into a larger mechanical or electrical system
  - usually real-time constraints

## - Human Computer Interaction (HCI)

Smart Objects: Obj that are able to sense the env, interpret, self-config., interact w/ other obj and exchange info with people

HCI is a discipline concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them.

### Why is HCI important?

it can affect

- effectiveness, productivity, morale, safety

Bad interface

- confusing, cumbersome, time-consuming, uninformative, leads to error.

## Interfaces

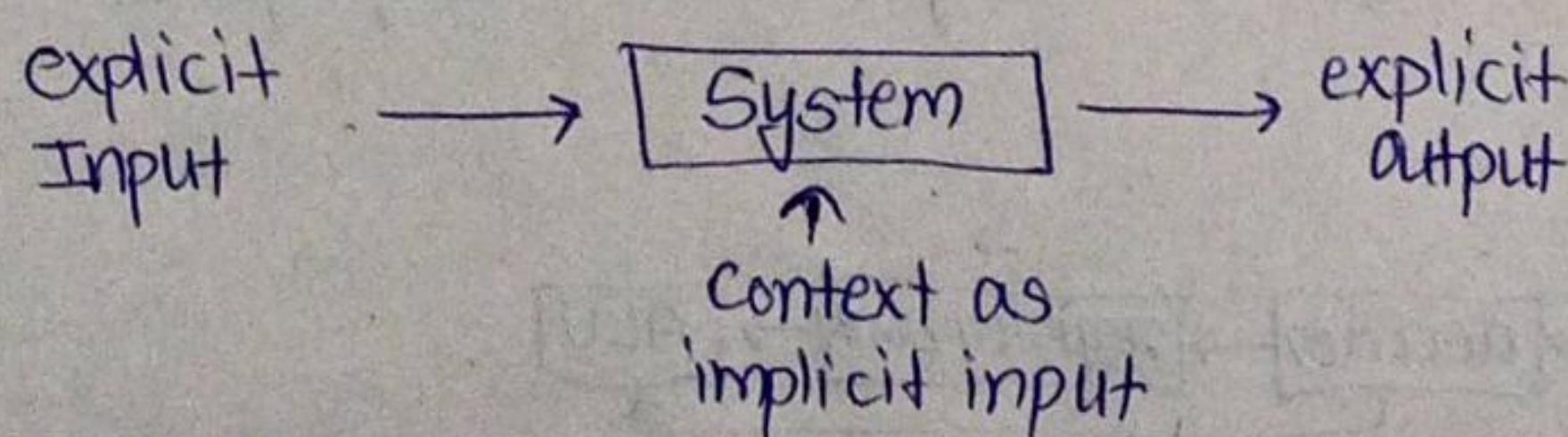
- Keyboard, mouse, screen, speakers, GUI
- Pen input, touch
- Speech, audio sound
- gesture, eye movement
- tangible interface, VR, AR, wearable
- multimodal interactive interface

- Ease of use
- Flexibility
- Accuracy
- Safety
- Privacy

## Seven Design Principle

- 1) Equitable use - same means for all users.
- 2) Flexibility in use
- 3) Simplicity and Intuitiveness of use
- 4) Perceptible info
- 5) Tolerance for error
- 6) Low physical effort
- 7) Size and space for approach and use.

## System Structure



Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction b/w user and application, including the user and app themselves.

- External (physical) - measurable by hardware, ie. temp, light etc.
- Internal (logical) - captured by analysis, ie. emotions, goals etc.

## challenges

- Lack of self-awareness: not knowing when to do or not to do.
- Complexity:
- human in loop vs automation - loss of control vs risk of human error.
- Development - sensing, aggregation etc are complex issues.
- Privacy
- User preferences
- info overload

## Sensors

A sensor is a device that receives a stimulus and responds with an electrical signal.

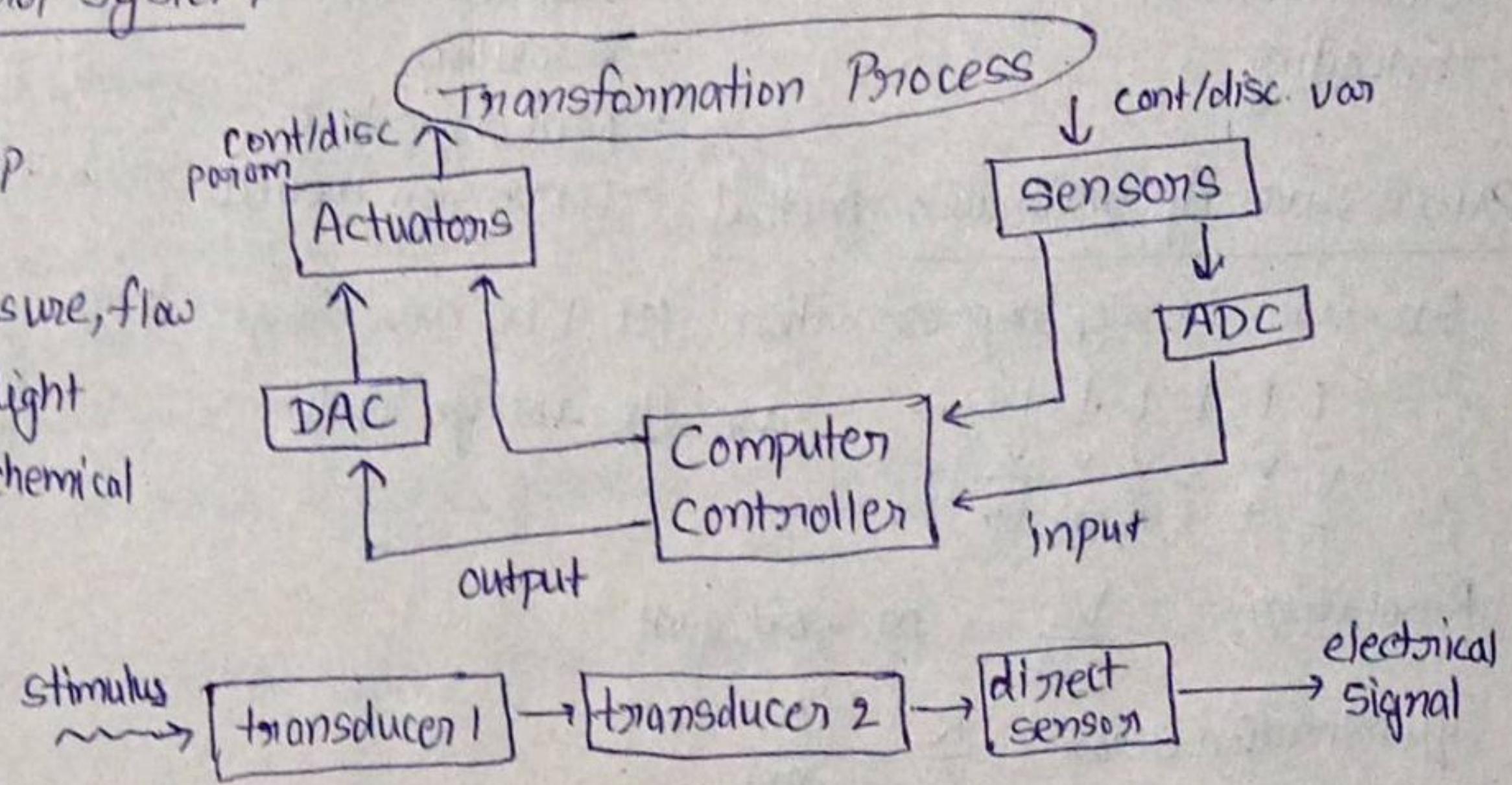
- typically linear mapping of physical properties
- sensitivity is the minimum value (input) that can produce output signal.
- Analog-to-Digital converter are used

## Computer Process Control System

- Stimulus
  - motion, position, disp.
  - vel., acceleration
  - force, strain, pressure, flow
  - sound, moisture, light
  - Radiation, temp, chemical

- Response
  - Voltage
  - Current
  - Charge

- Principles of sensing
  - charges, fields, potentials
  - capacitance
  - magnetism
  - induction, resistance
  - Piezoelectric effect
  - Seebeck and Peltier effects
  - thermal properties of materials
  - heat transfer
  - Light



## Input/Output

- different I/O protocols are available
- Universal Asynchronous Receiver/Transmitter (UART), Rx, Tx
- Serial Peripheral Interface (SPI) data transfer without interruption
- Inter-Integrated Circuit (I<sup>2</sup>C) combines UART and SPI
- General purpose I/O (GPIO) controllable by user at run time.

## GPIO

- Can be set up for different voltage levels.
- Can be configured for interrupts
- Can be grouped into GPIO port
- Pulse width modulation, for linear processes
- Low-current applications only

## PWM

$$\text{Duty cycle} \Rightarrow D = \frac{\text{PW}}{T} \times 100\%$$

$$\text{Freq} \Rightarrow f = \frac{1}{T} \text{ Hz}$$

$$\text{Avg V, } V_{\text{avg}} = \frac{V_{\text{high}} \times D}{100}$$

## Analog-to-Digital Conversion

- Sampling
- Quantization
- Encoding

### features

- Sampling rate
- Quantization
- Resolution
- Conversion time
- Conversion method

## Successive Approximation method

We use binary representation. let  $V$  be max Range. then

$$\begin{array}{cccccc} 1 & 1 & 1 & 1 & 1 & \dots \\ \frac{V}{2} & \frac{V}{4} & \frac{V}{8} & \frac{V}{16} & \frac{V}{32} & \dots \end{array} \text{ are the voltage levels}$$

$$\text{Resolution} = \frac{V}{2^m}; m \rightarrow \text{bit count}$$

$$\text{Quantization error} = \frac{R}{2} = \frac{V}{2^{m+1}}$$

## Types of Sensors

- Hardware-based sensors
- Software-based sensors
- Active sensor: send signal into env. and measure interaction of signal with env  
eg. radar, sonar.
- Passive sensor: record signals already present in env.  
eg. video camera.

## Actuators

Hardware device that convert a controller command signal into a change in a physical parameter

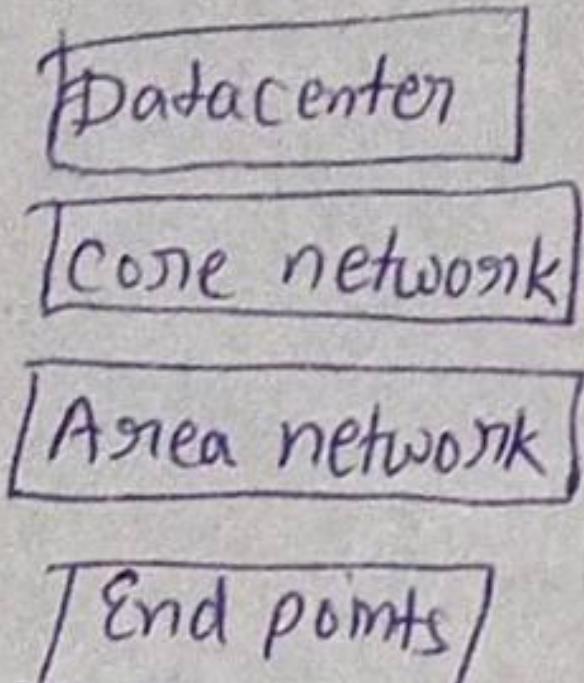
### Electrical actuators

- Motors
- Solenoid

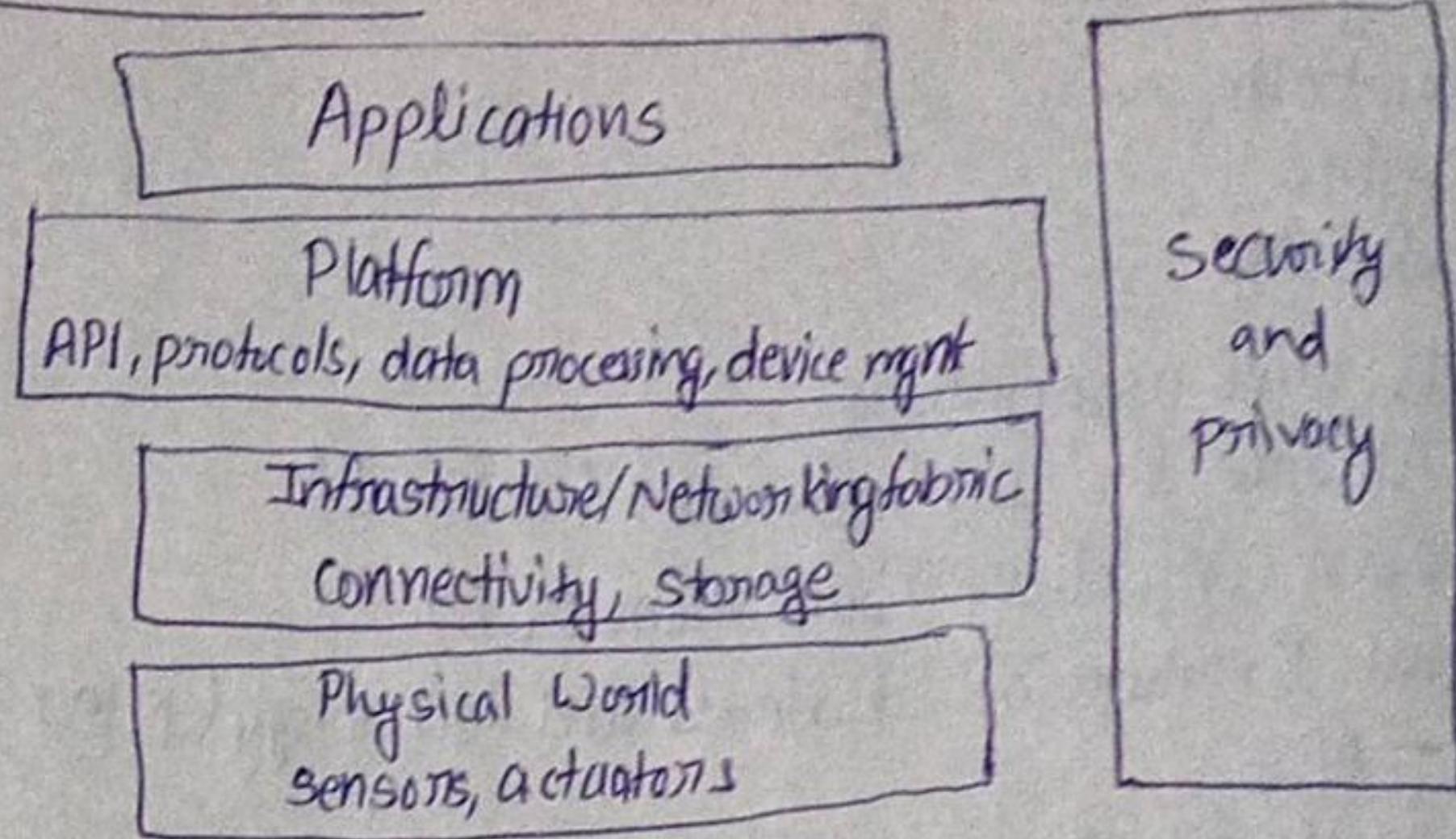
### Hydraulic actuators

- Pneumatic actuators → use compressed air as a driving force.

# IoT System Architecture and Standards



Network centric view



Security and privacy

## - Cloud Computing

All the processing and decision making at cloud servers

Generic architecture

## - Fog Computing

In it some of the processing is pushed towards devices. Here a common point is responsible to make partial processing and decision making.

## - Role of gateways in fog architecture

- data filtering and processing (aggregation, compression, etc)
- protocol translation and interfacing among different connectivity technology.
- data flow multiplexing, packet routing.
- Security (data encryption, firewalls)
- Scalability problem: as devices increase, gateways req. increase

## - Edge Computing

In it computations are pushed to the sensor level to minimize load at gateways and cloud.

## Standards for IoT

Institute of Electrical and Electronics Engineers (IEEE) deals with standards

- primarily dealing with defining protocols for (wireless) access networks
  - 802.15.4 on which ZigBee builds
  - 802.11ah amended 802.11 for wifi

3rd Generation Partnership Project (3GPP)

- focus on cellular network arch. and protocols (GSM, 3G, 4G-LTE etc.)
  - LTE-M
  - NB-IoT - does not require gateways, low capacity, different modulation and coding scheme

Internet Engineering Task Force (IETF)

- focus on internet specific protocols known as Requests for Comments (RFCs)
  - LoWPAN
  - Routing (ROLL)
  - End-to-end (CoAP)
  - DTLS
  - SUE

## Industry alliances

- Bluetooth
- ZigBee
- LoRaWAN
- Collaborative associations
  - Alliance for IoT Innovation (AIOTI)
  - Open Connectivity Foundation (OCF)
- National Institute of Standards and Technology (NIST)
  - AES
- International Organization for Standardization (ISO)
- International Telecommunication Union (ITU)

## Computer Networks

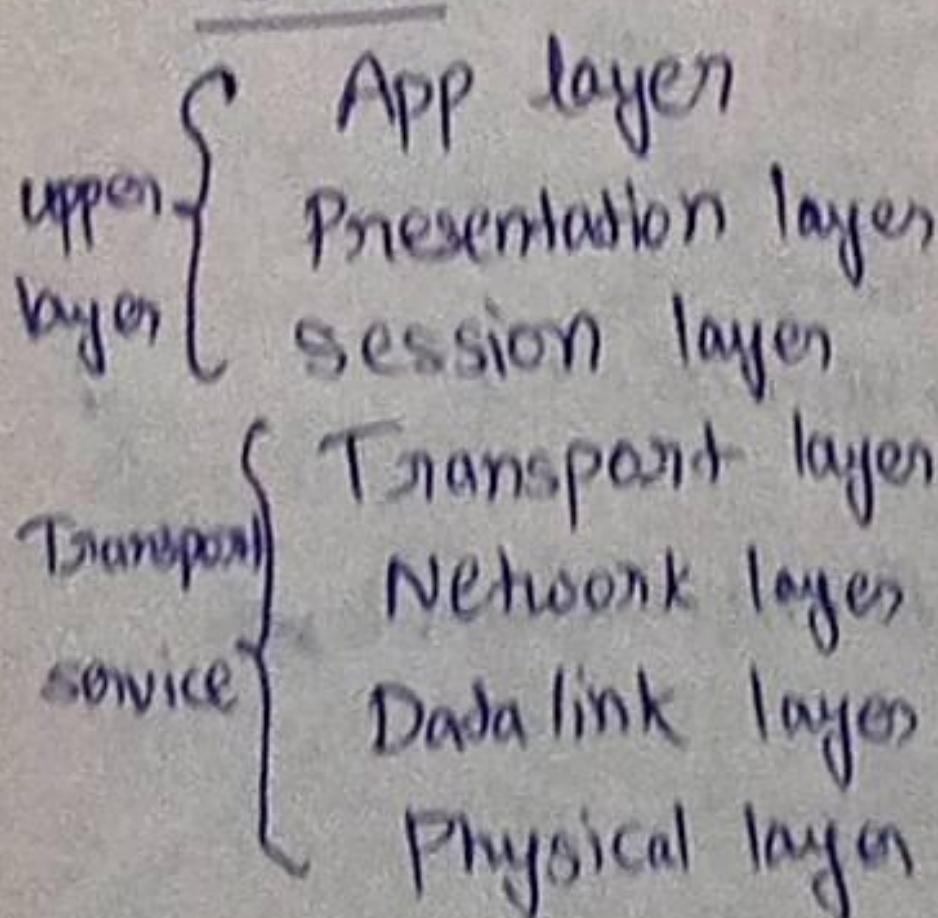
group of computers and associated devices that are connected by communication facilities.

- Wide Area Network (WAN) 802.3 ethernet
- Metropolitan Area Network (MAN) 802.11 WLAN
- Local Area Network (LAN) 802.15 WPAN
  - WLAN (wifi)
  - WPAN (bluetooth)
  - WBAN (wireless body area network)

## Client/Server Mode

- HTTP (Hypertext Transfer Protocol)
- SMTP (Simple Mail Transfer Protocol)
- SSH (Secure Shell)
- DNS (Domain Name System)
- NFS/AFS (Network/Andrew File System)

## OSI



### Low frequencies

- low data rates, long distance, follow surface
- penetrate objects and water

### High frequencies

- high data rates, short distance, straight line
- cannot penetrate objects
- Line of Sight LoS

## User Datagram Protocol (UDP)

- send data, without any reliability
- data may get lost
- out of order arrival
- no flow and congestion control

Integrated application

Information processing

Network Construction

Sensing and identification

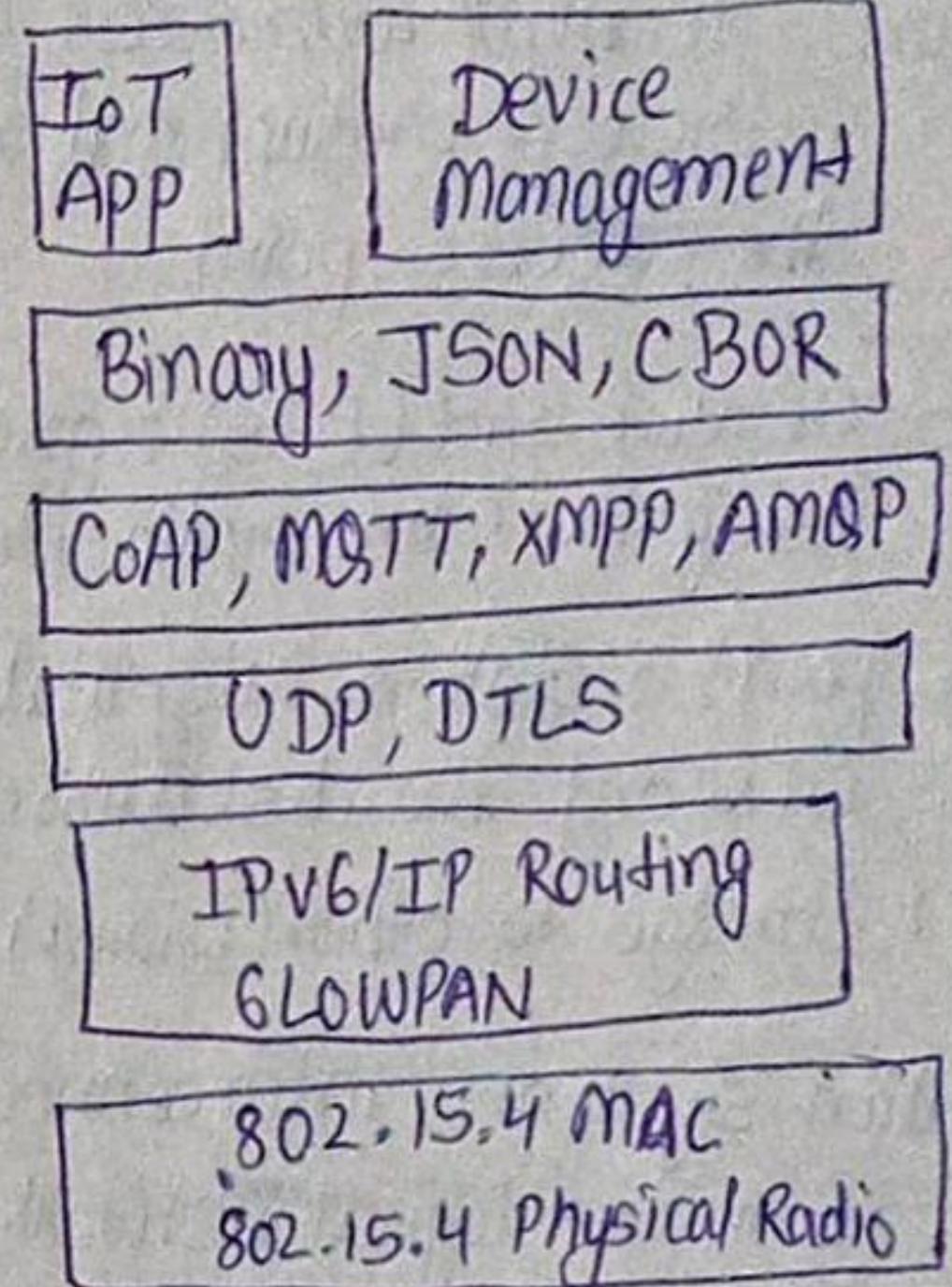
## Transmission Control Protocol

- send data with reliability
- data can not get lost, because of ack system.
- ordering maintained by using sequence number
- flow and congestion control.

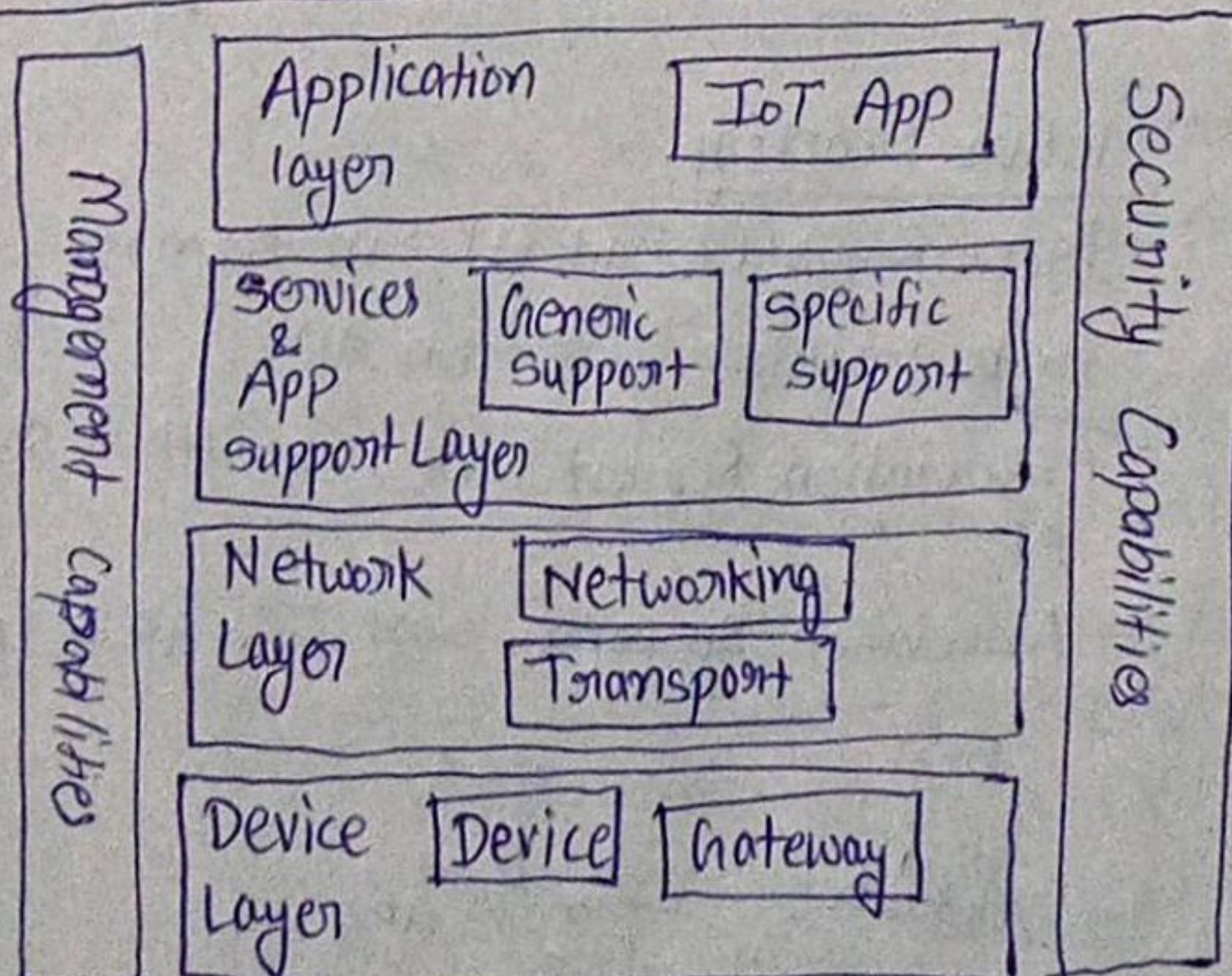
## Reference Model

- 1) physical devices & controllers
- 2) connectivity
- 3) Edge (Fog) Computing
- 4) Data Accumulation
- 5) Data Abstraction
- 6) Application
- 7) Collaboration & Processes

### TCP/IP Model



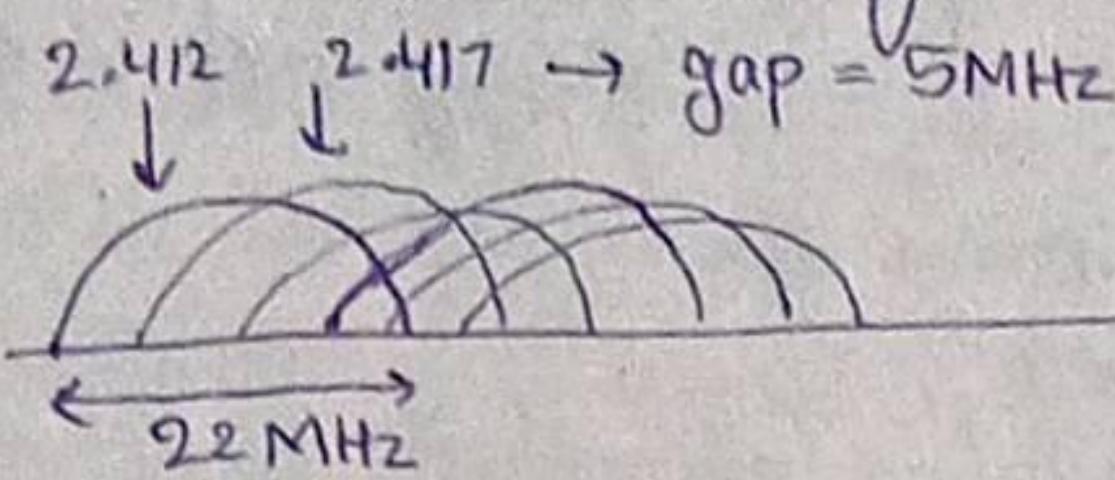
## ITU-T IoT Reference Model



# Mobile Adhoc Networks

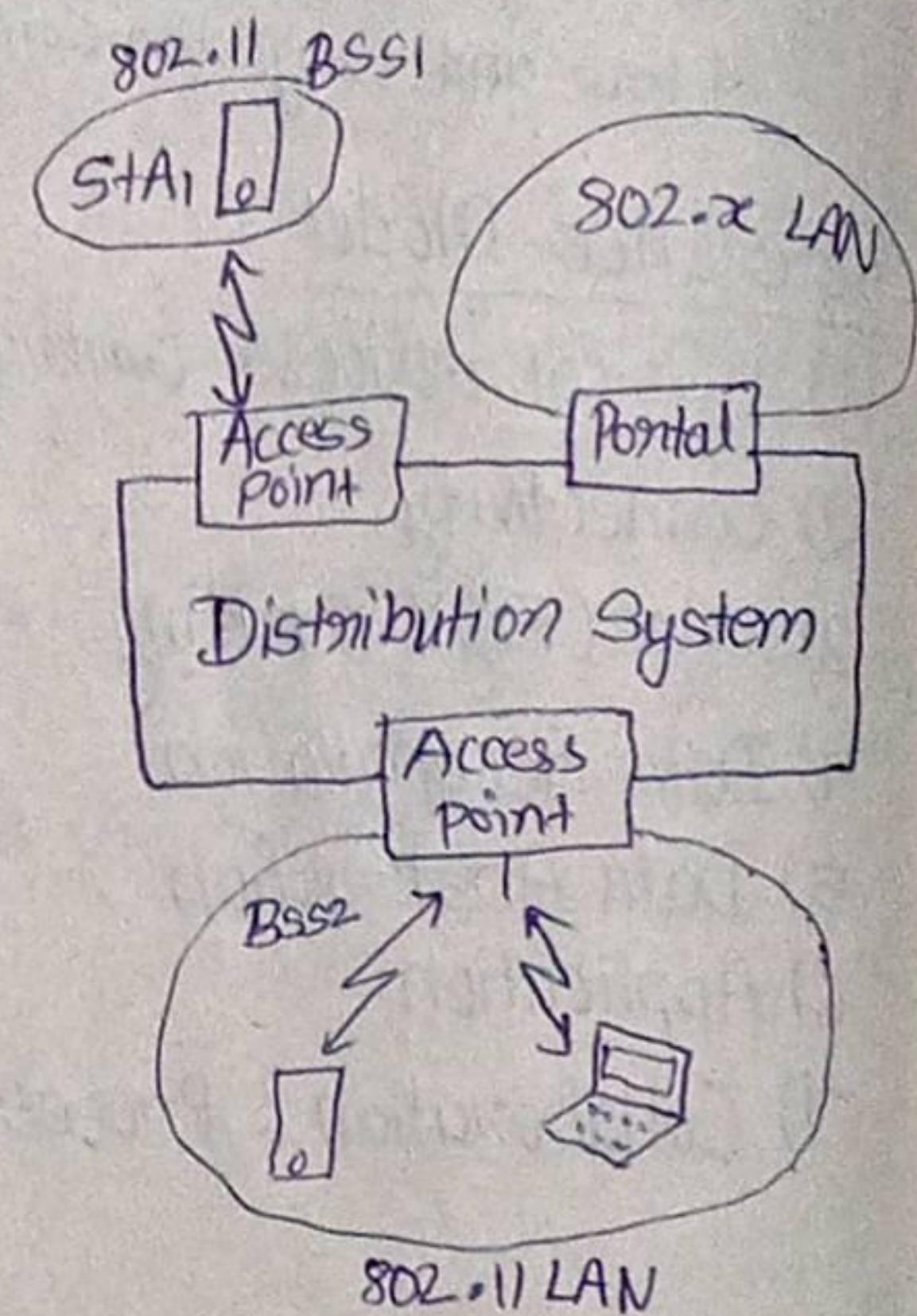
## Wifi/WLAN (wireless local area network)

- 2.4 and 5 GHz bands
- IEEE 802.11 family standards



## Architecture of an infrastructure Network

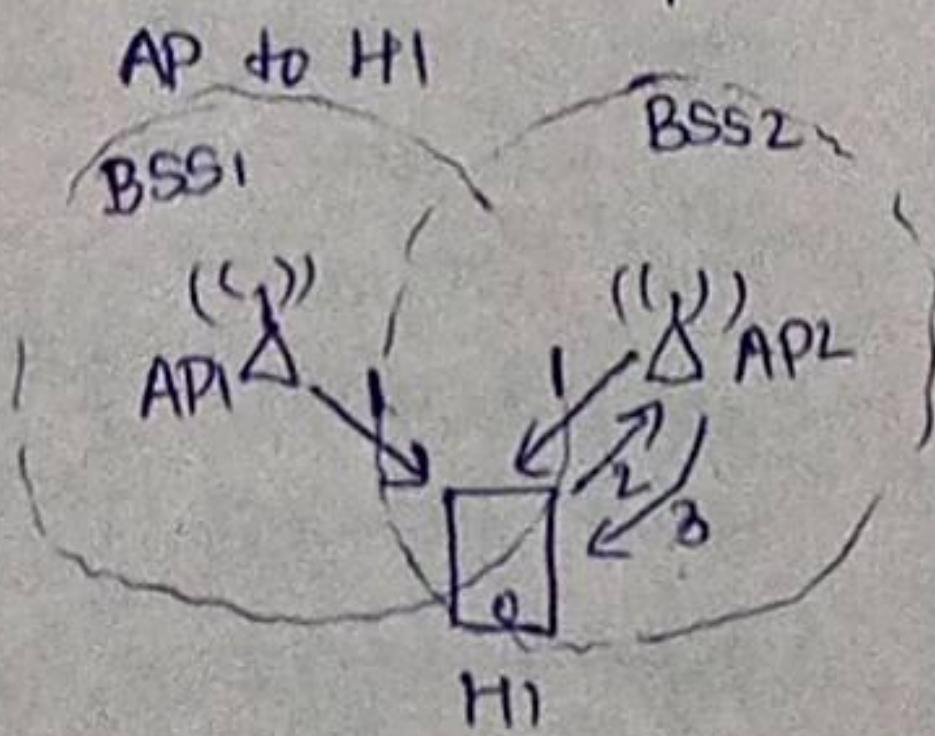
- Station : terminal with access mechanism to the wireless medium and radio contact to the access point
- Basic Service Set (BSS) : group of stations using the same radio frequency
- Access point : station integrated into the wireless LAN and the distribution system
- Portal : bridge to other (wired) networks
- Distribution system : interconnection network to form one logical network (ESS: extended service set) based on several BSS



## Scanning

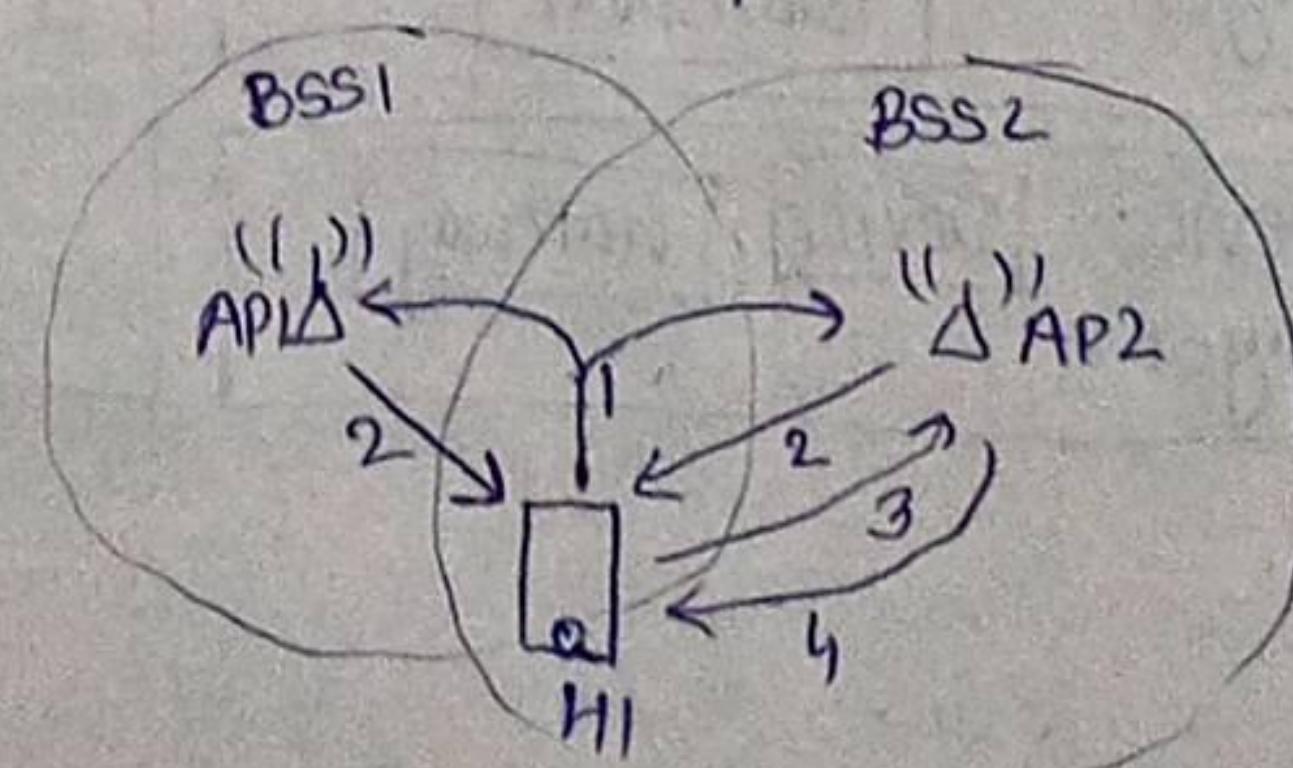
### Passive scanning

- Beacons sent from APs
- Association Request sent from H1 to selected AP
- Association response sent from AP to H1



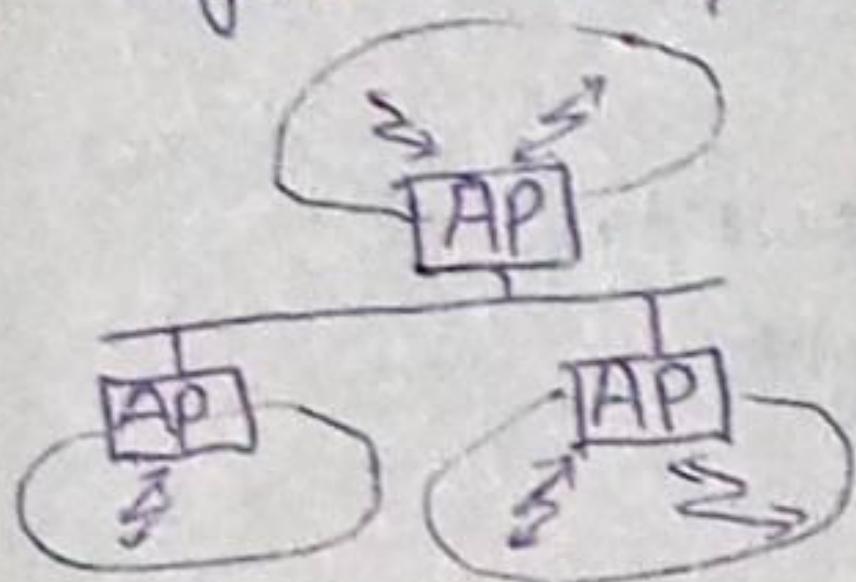
### Active Scanning

- Probe Request (broadcast) sent from H1
- Probe response sent from APs
- Association Request sent from H1 to selected AP
- Association response sent from AP to H1

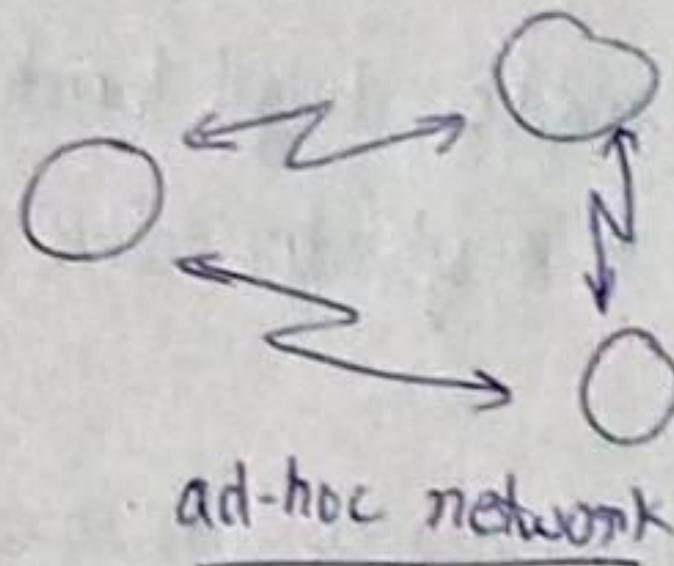


## Wifi Alliance Mission Statement

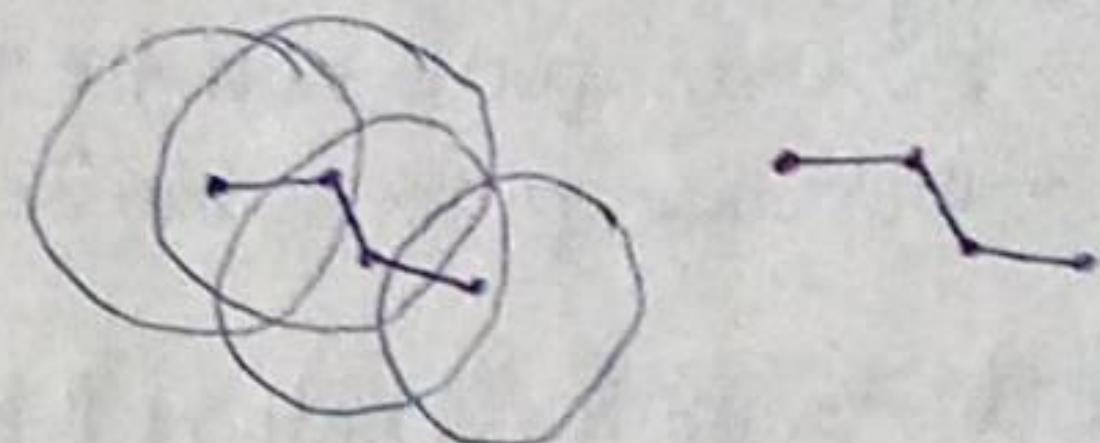
- non-profit organization
- Certify the interoperability of products and services based on IEEE 802.11 tech.
- Grow the global market for wifi certified products and services across all market segments, platforms, and applications
- Rigorous interoperability testing requirements



infrastructure network



ad-hoc network



## Infrastructure-Less (Ad-hoc)

- only for single purpose
- no need of routers, towers etc.
- MANet : Mobile Ad-Hoc Network

### Protocol

#### neighbor discovery

- nodes send periodic announcements as broadcast packets (beacon, alive msg)
- can embed "neighbor table" into such messages ; allows nodes to learn "2-hop neighborhood"

#### Popular types of routing protocols

- Proactive : "Link State" Algorithms.
  - each node stores its link info. so that all nodes can build a map of the full network topology.
  - assumes stable topology for sufficient time.
  - Link info is updated when a link changes state (goes up or down)
- Reactive : DSR (Dynamic Source Routing)
  - search route when needed only
  - Search using Route Req. (RREQ) broadcasts
  - Response using Route Reply (RREP) message.
  - Every message along route contains entire path to help intermediate nodes to decide what to do with message.

- Geographic Routing : nodes use location info to make decisions
- sender must know its destinations and its neighbors location
- location info can be queried or obtained from a location broker
- location info can come from GPS or other tech

- Unicast Location-Based Routing

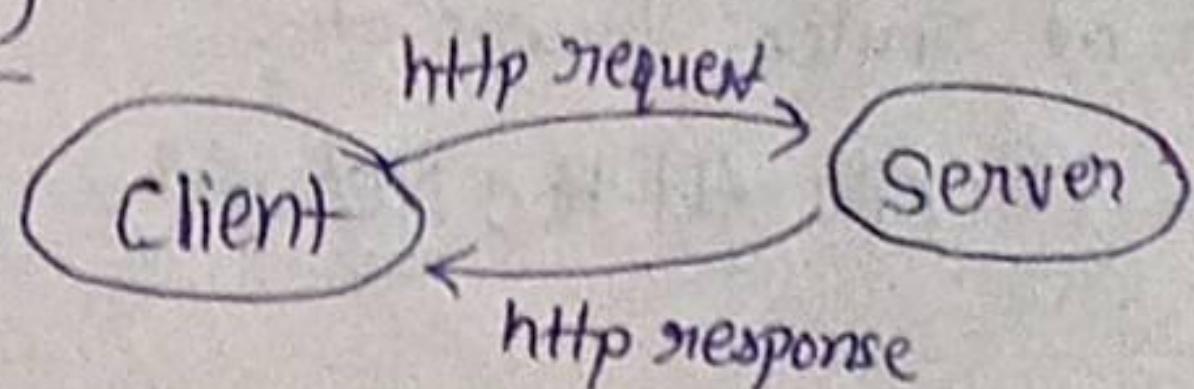
- One single destination
- node send data to neighbour based on target location (greedy forwarding)
- challenge: data may reach a neighbour with no further neighbours

- Geocasting

- packet sent to all or some nodes within specific geographic region
- challenges
  - propagate packet near the target region (unicast)
  - distribute packet within the target region (same as flooding)

## HyperText Transfer Protocol (HTTP)

Response - Sequence of bytes with an associated MIME type  
 (Multipurpose Internet Mail Extension)



- static response: stored files (html file, image, audio).
- Dynamic response: created when requested.

### URL (Universal Resource Locator)

static - `http://domain/index.html`

dynamic - `http://domain/adden?1500&213`

### Request

`<method><uri><version>`

method - GET, POST, DELETE, OPTIONS, HEAD, PUT or TRACE

uri - url

version - HTTP/1.0 or HTTP/1.1

### Response

`<version><status code><status msg>`

↑              ↑              ↑  
 version    numeric code    corresponding msg.

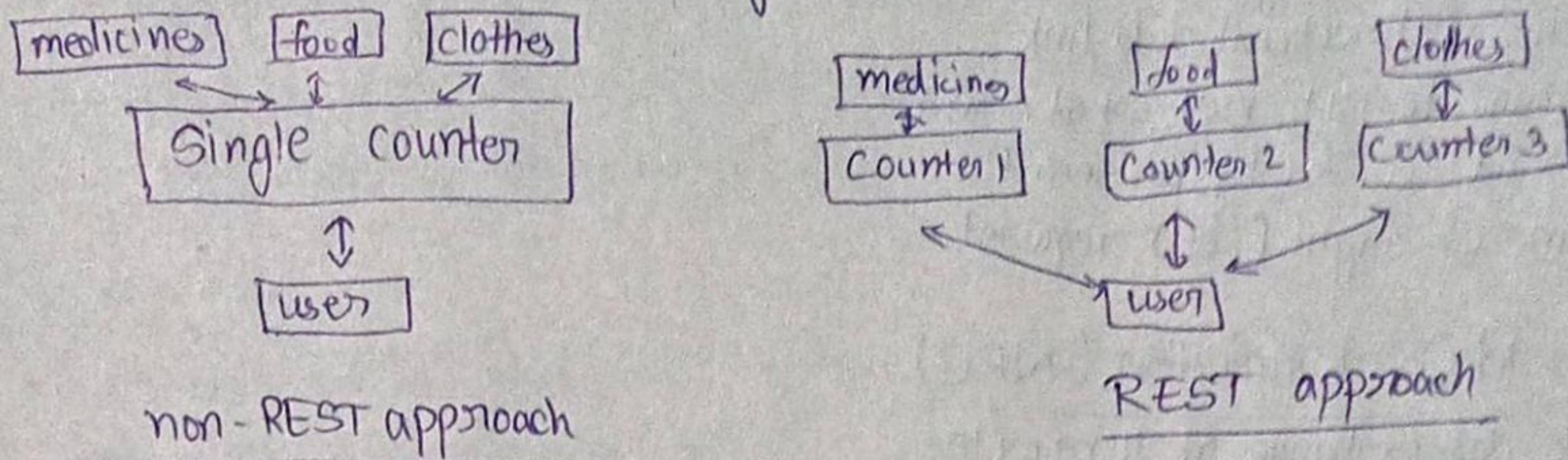
200 OK

403 Forbidden

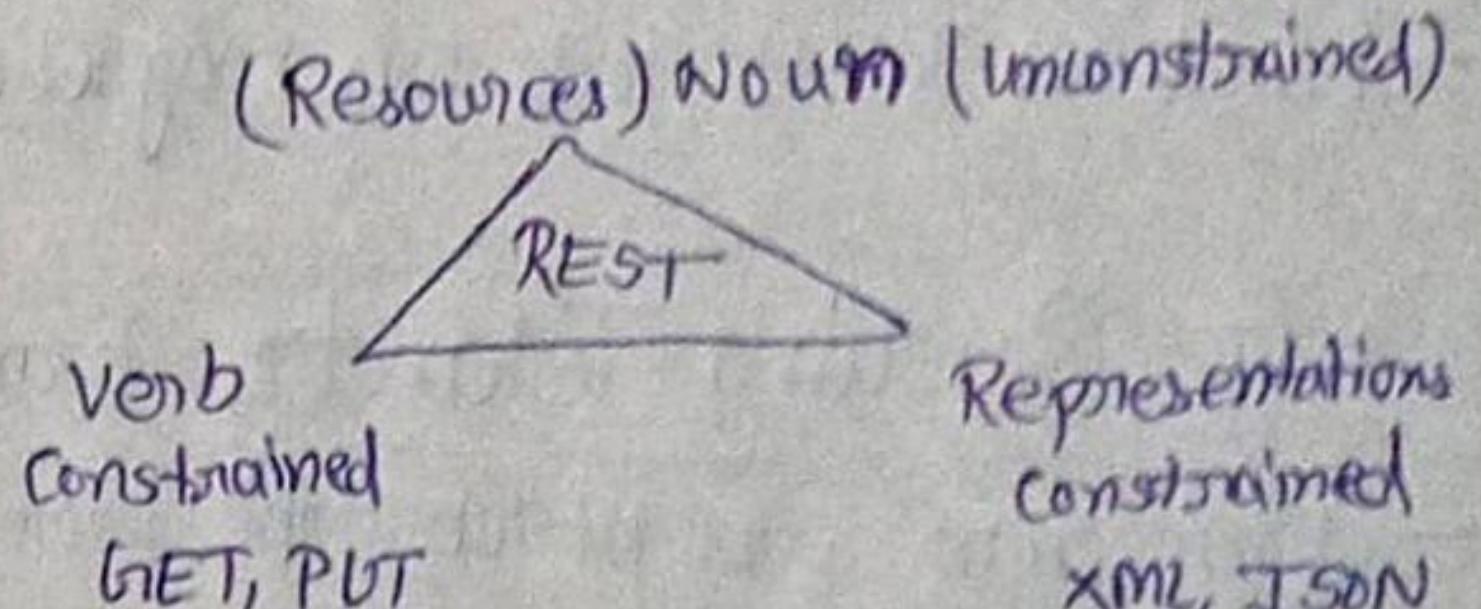
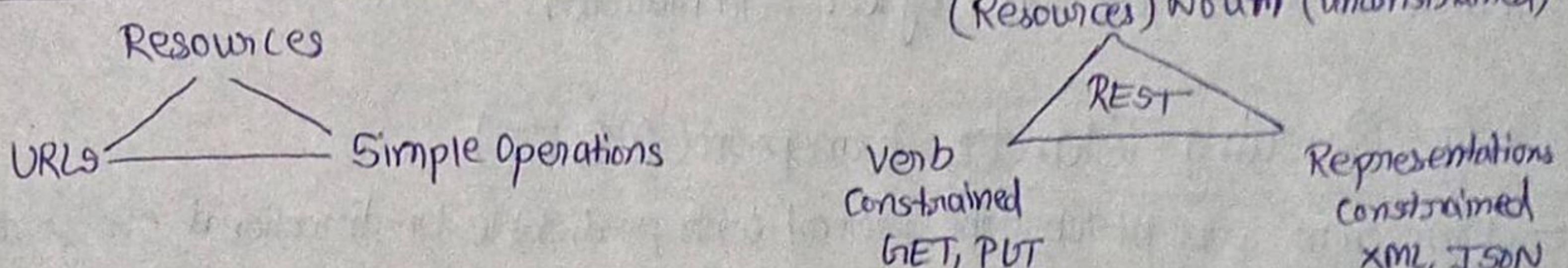
404 Not found

## REST

- Representational State Transfer (REST) is a design pattern
- A style of soft. arch. for distributed hypermedia systems such as www.
- Collection of network arch. principles which outlines how resources are defined and addressed.
- it is certain approach to creating web services



## 3 fundamental aspects of REST design



## Radio Frequency Identification (RFID)

- An automated Data collection (ADC) technology
- uses radio frequency
- fast and contactless
- low cost components

Other ADC tech: Barcode, OCR (optical code reader)

## Tags

- memory (16 bits - 512 KB, Readonly, Read/write, Write once read many (WORM))
- Arbitration( Anti-collision) : read/write one or many tags at a time
- freq (125 kHz - 5.8 GHz)
- Price (\$0.1 to \$250)
- Physical dimension (Thumbnail to bricksize)

## Active tag

- greater range : 20-200m
- self-powered
- high storage, costly

## Passive tag

- shorter range : < 10m
- power from interrogator RF beam
- low storage, cheaper

## RFID Reader

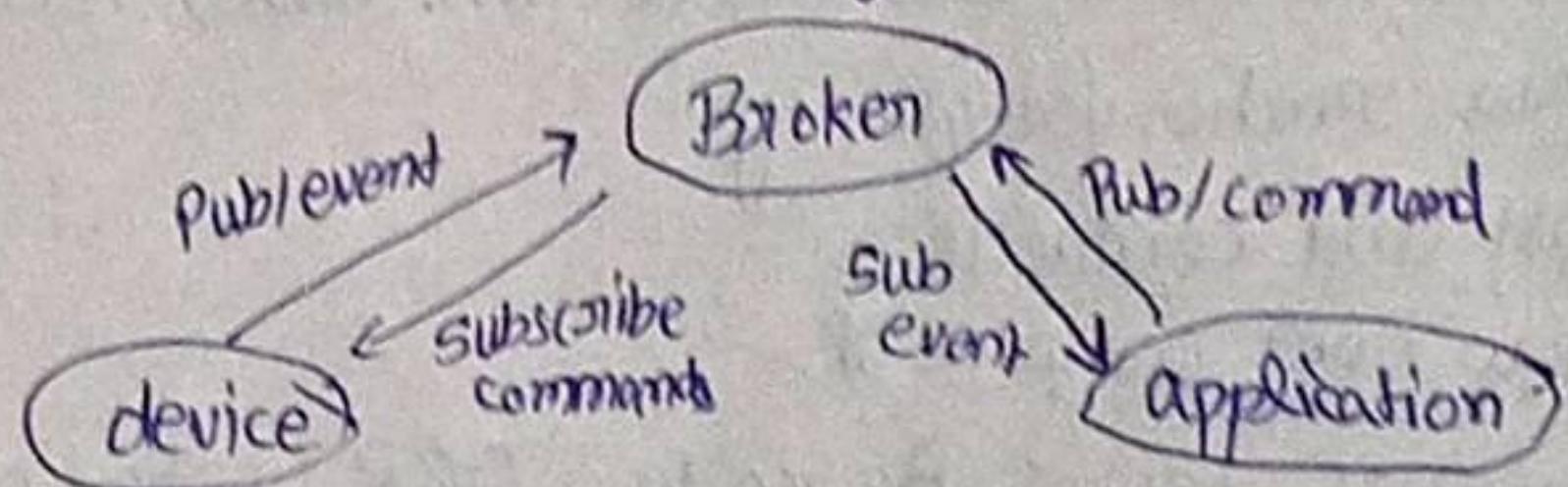
- remotely power tags
- establish bidirectional data link
- communicate with networked servers
- can read 100-300 tags per second
- no line-of-sight (LoS) required.

## Near-Field Communication (NFC)

- enable data exchange at 4cm or less
- operates at 13.56 MHz and rates 106 Kbps to 848 Kbps
- based on RFID tech uses magnetic field induction

## Message Queuing Telemetry Transport (MQTT)

- lightweight publish/subscribe protocol with predictable bi-directional message delivery
- it is M2M/IoT connectivity protocol
- MQTT is an Event based IoT middleware (one to many)
- three parts
  - Brokers
  - Subscribers
  - Publishers
- msg size upto 256 MB
- for unreliable networks



## Topics

- Each published data specifies a topic
- Each subscriber subscribed to that topic will receive it
- Topic format
  - /sub-topic/sub-topic/subtopic
  - /home/grooms/kitchen/temperature

## Subscriptions

- Durable: if subscriber disconnected, msg get buffered and delivered when reconnected. (whatsapp)
- non-durable: Connection lifetime gives subscription lifetime.

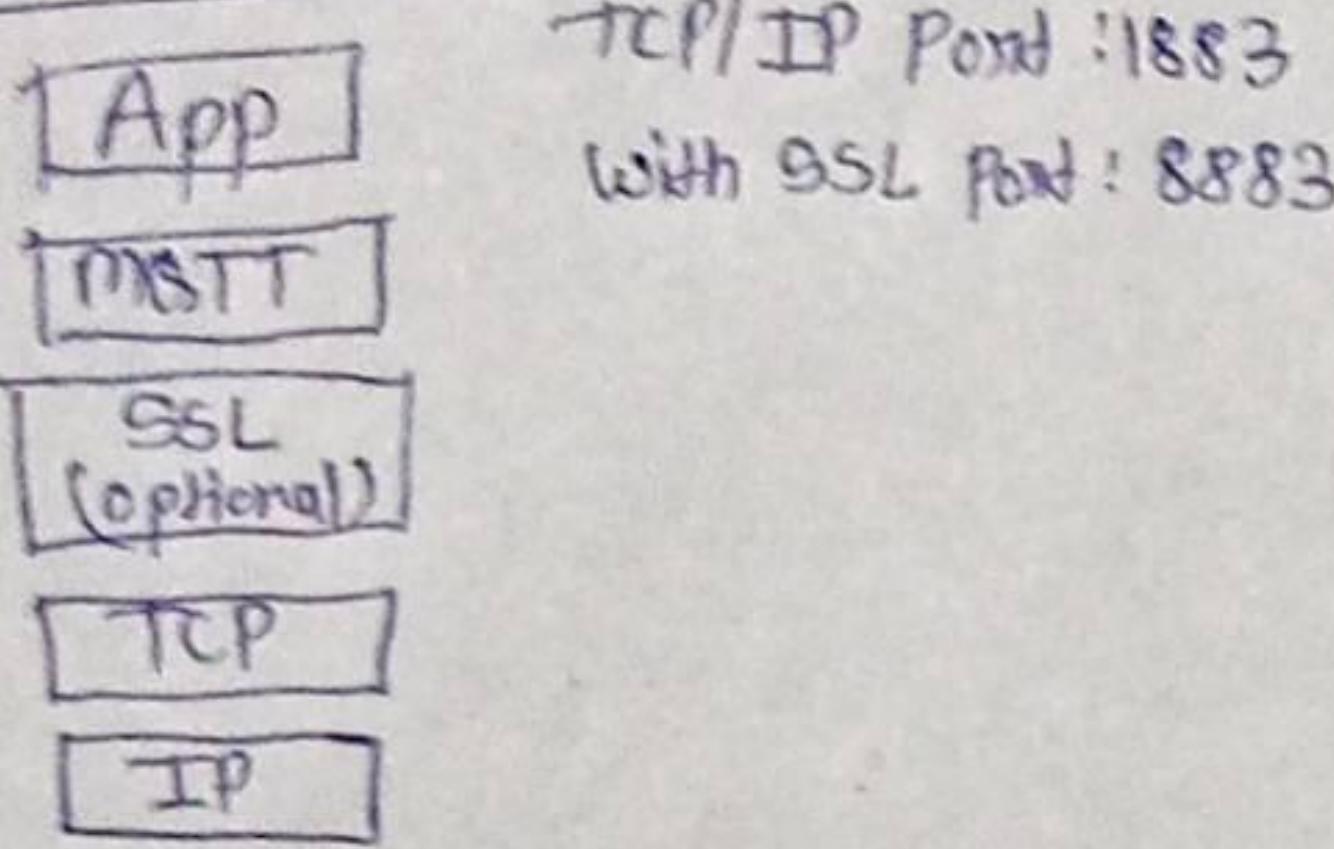
## State Retention

- Retained ("persistent" msg): subscriber gets latest good published msg
- One flag set both in the publish packet to the broker and subscribers, only most recent persistent msg is stored and distributed.

## Session Aware

- Last will and Testament (LWT) — topic published upon disconnecting a connection
- only client can register an LWT
- anybody subscribing to the LWT topic will be notified

## Protocol Stack

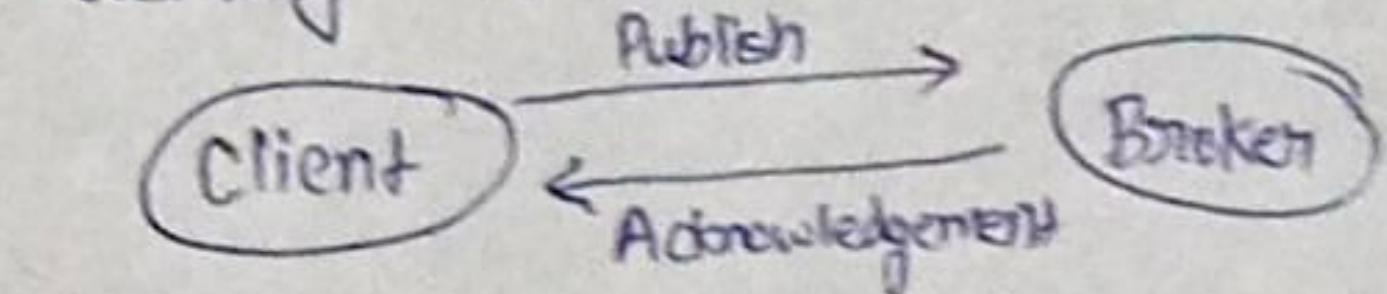


## Msg format

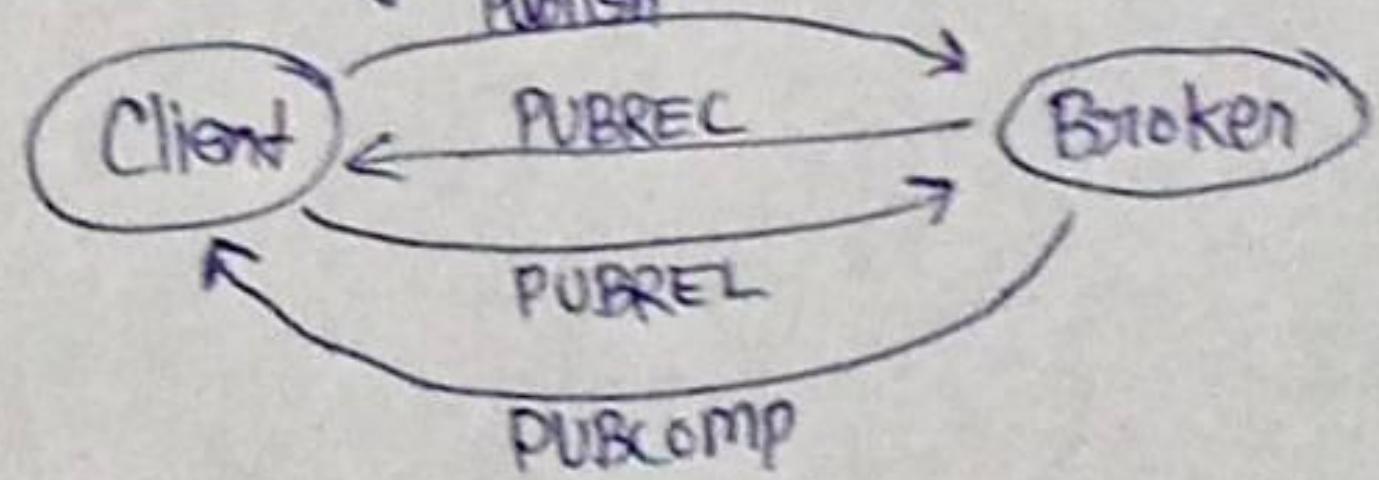
B1	0 1 1 2 1 3	4	5	6	7	} MQTT fixed header	
B2	Msg type			DUP	QoS lvl	Retain	
	Rem. length (1-4 bytes)						
	Optional: var. len header						
	Optional: Var len msg payload						

## Publishing QoS (Reliability)

- 0 - unreliable: publish and forget
- 1 - delivery: "at least once" (2msg)



- 2 - delivery: exactly once. (4msg)



shortest msg = 2 bytes