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Physical Layer

Prof. Ling Li | Dr. Nadith Pathirage | Lecture 02

Semester 1, 2021

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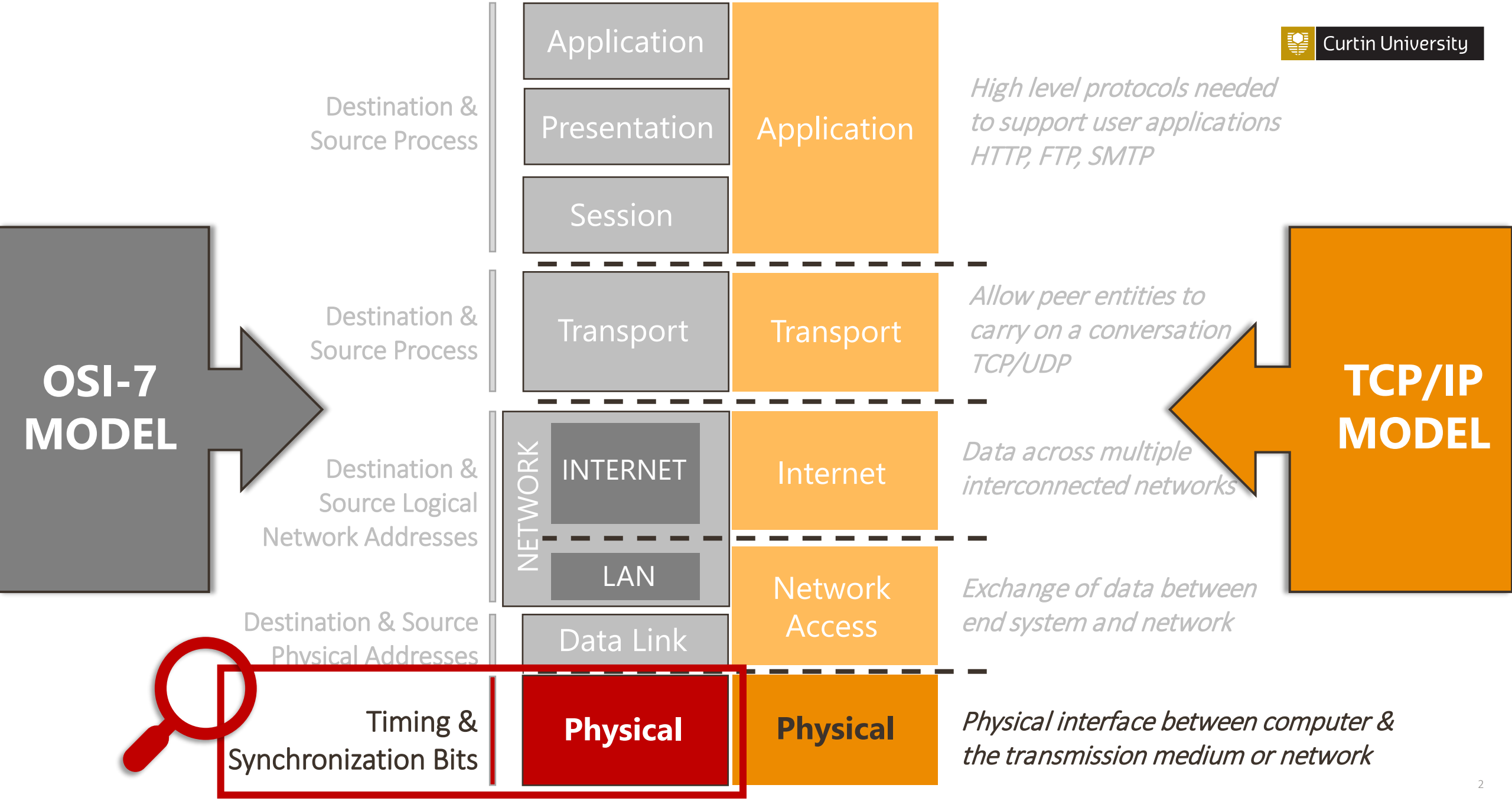

Physical Layer

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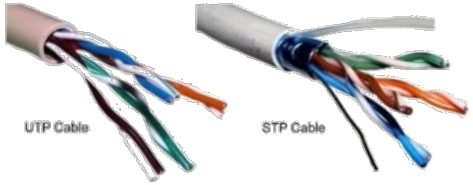
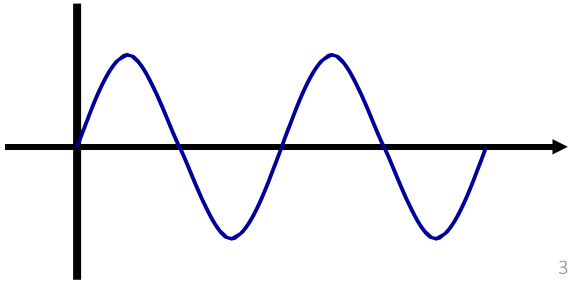


Defines physical characteristics of **interfaces** & **mediums**

Mechanical/electrical specifications

Stream of bits
01000110000

Move **data** as electromagnetic signals



Physical Layer

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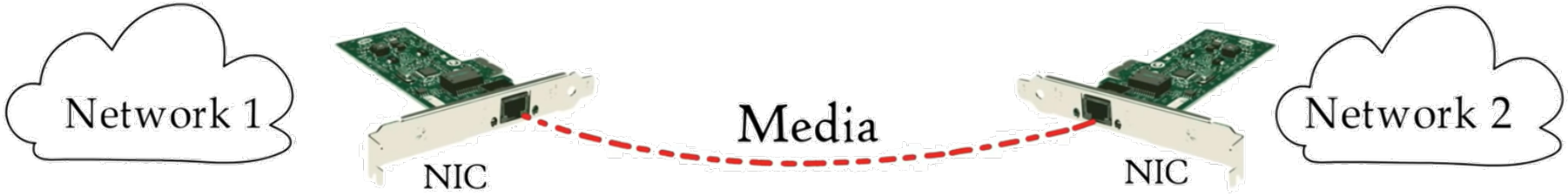

- Primarily consists of hardware (unless virtual)
- Provides the basic communication channel that two network devices (e.g. computers) used to send and receive messages
- Provides transmission & reception hardware

Physical Layer: Services

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- Transmits bits over a physical link between devices
- Encodes/Decodes **bits into/from ⇔ physical signals**
- Most common **Analog signals** *(Electromagnetic waves)*
  - ✓ Electrical pulses over wire
  - ✓ Radio signals through the air
  - ✓ Pulses of light through fiber optic cable

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Signals

- Analog signals
- Digital signals
- Signal attenuation and amplification

Signals

1. **Frequency** Hertz (cycles/sec)
2. **Amplitude**
3. **Phase shift**

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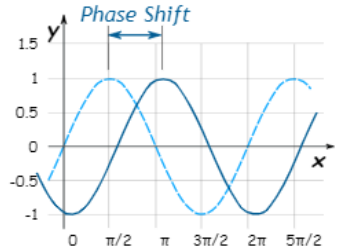
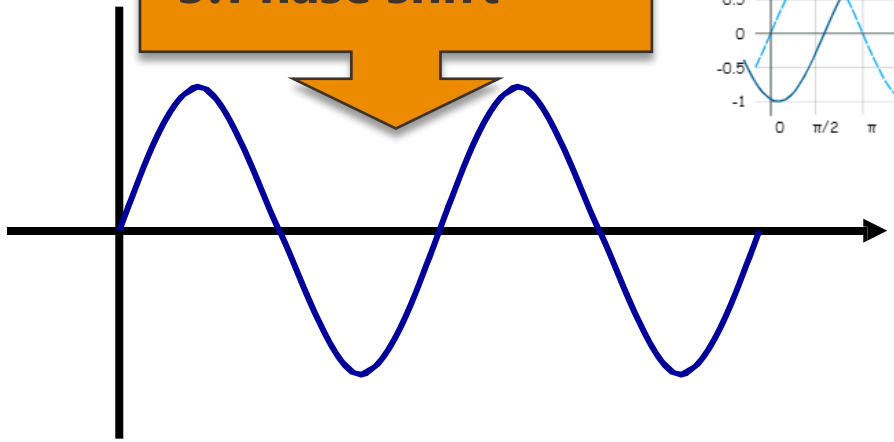
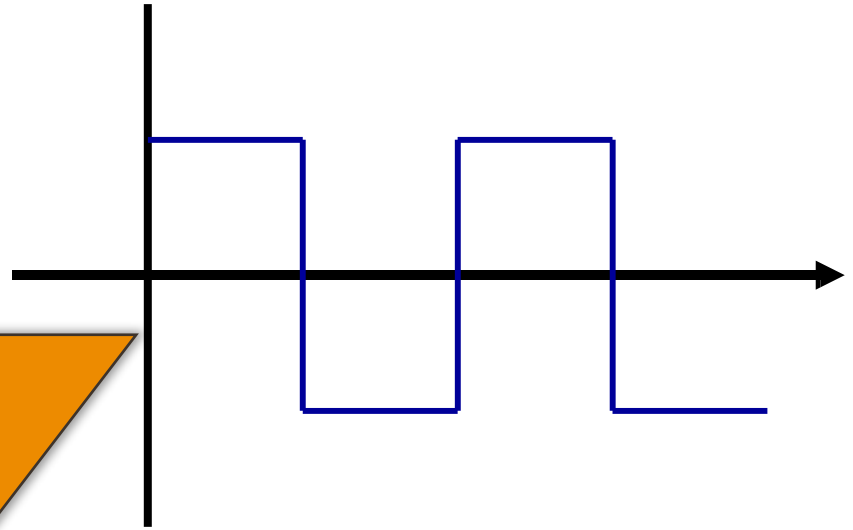


- Analog
  - ✓ **Continuously** varying voltage



- Digital
  - ✓ Sequences of specified **voltage levels** (high, low)



Digital Encoding

Digital ⇄ Analogue

Analog to Digital

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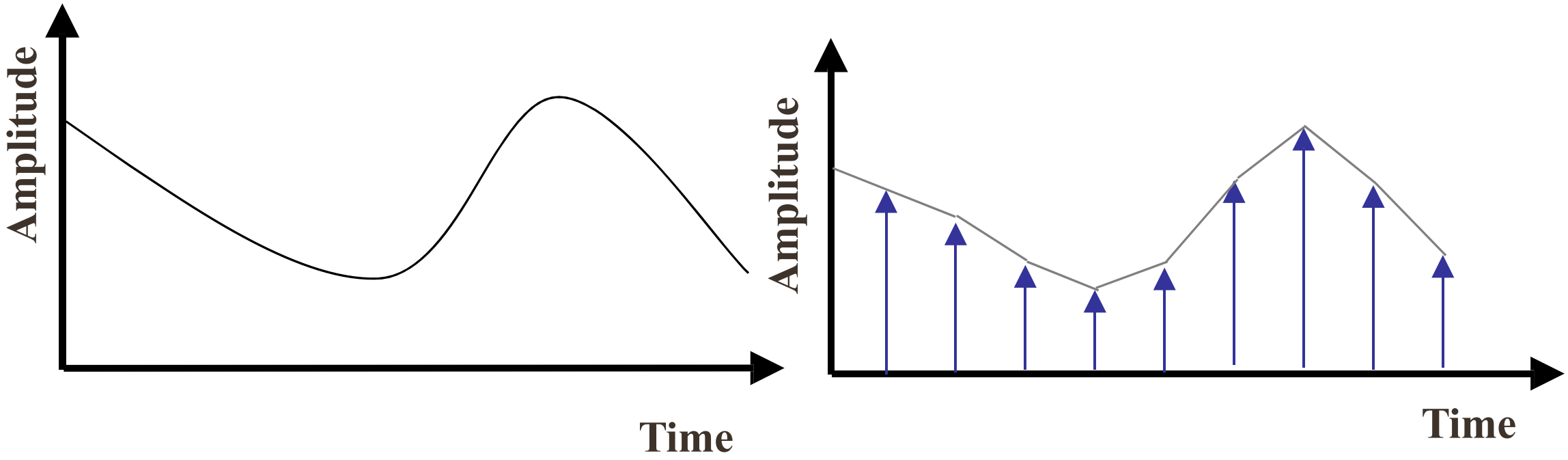
- Sampling



Digital to Analog

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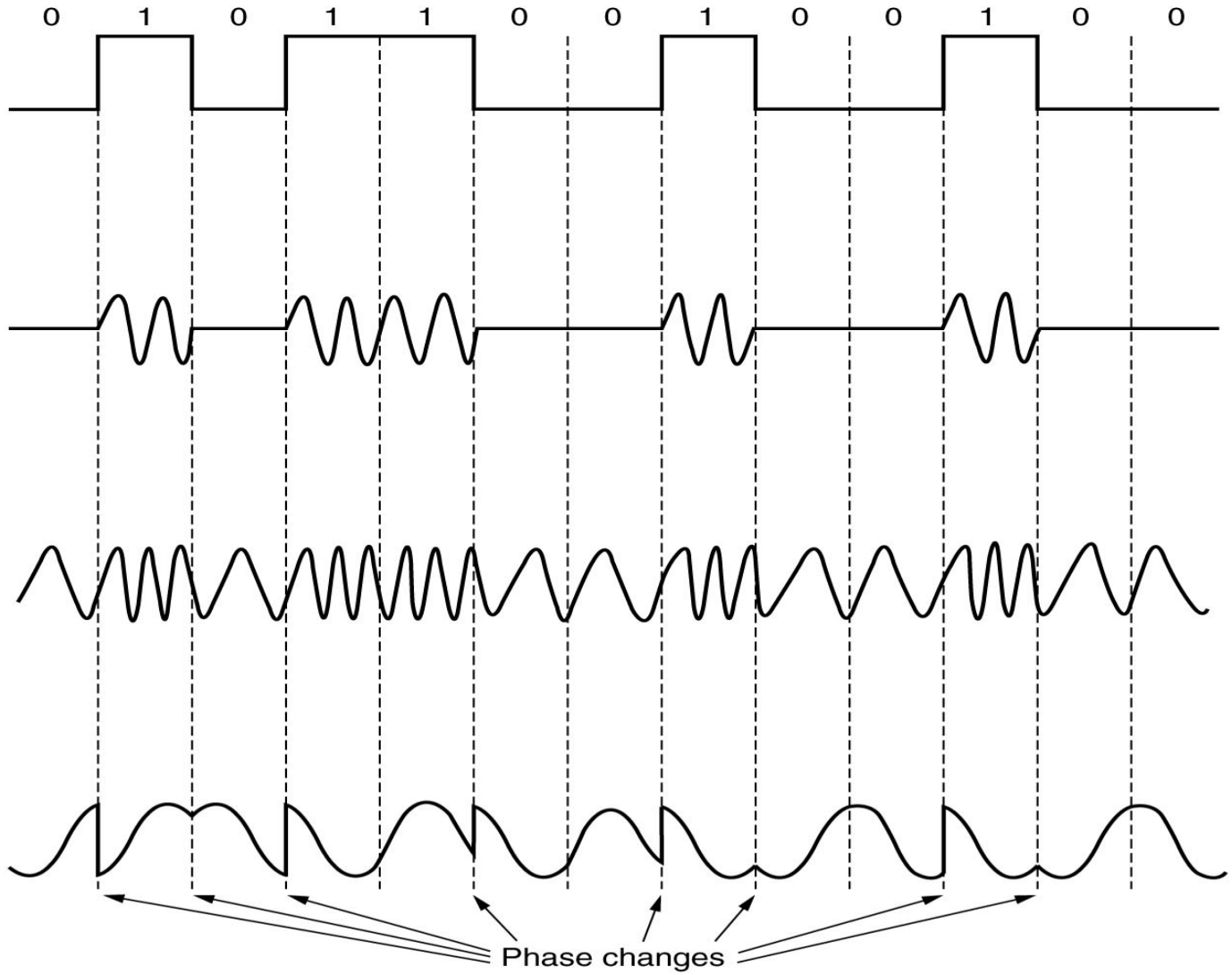
- Amplitude Modulation **(AM)**
- Frequency Modulation **(FM)**
- Phase Modulation **(PM)**

Assign a group of one or more-bit values to a particular analog signal.



Signal Attenuation & Amplification

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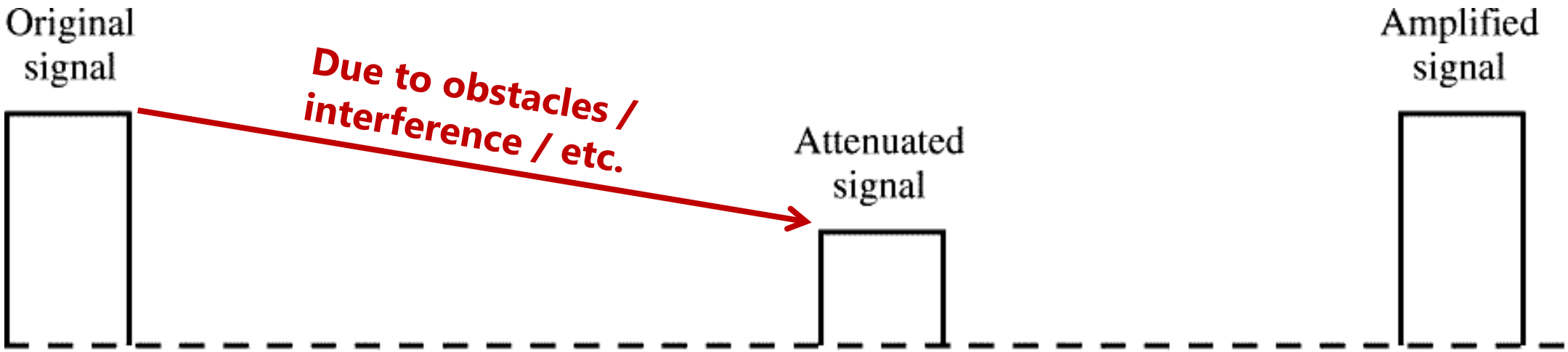

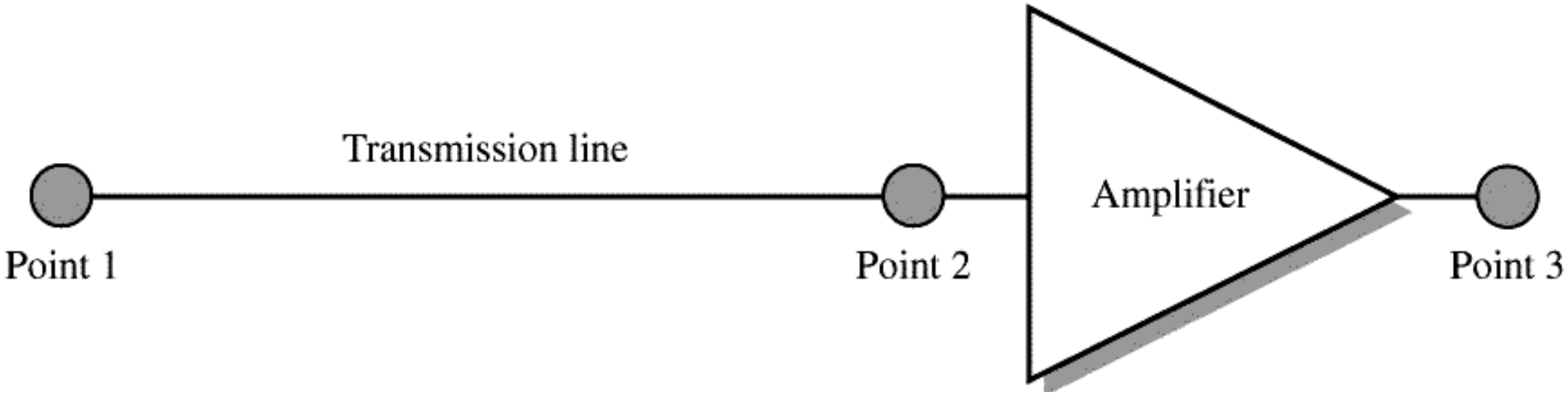

Signal Attenuation & Amplification

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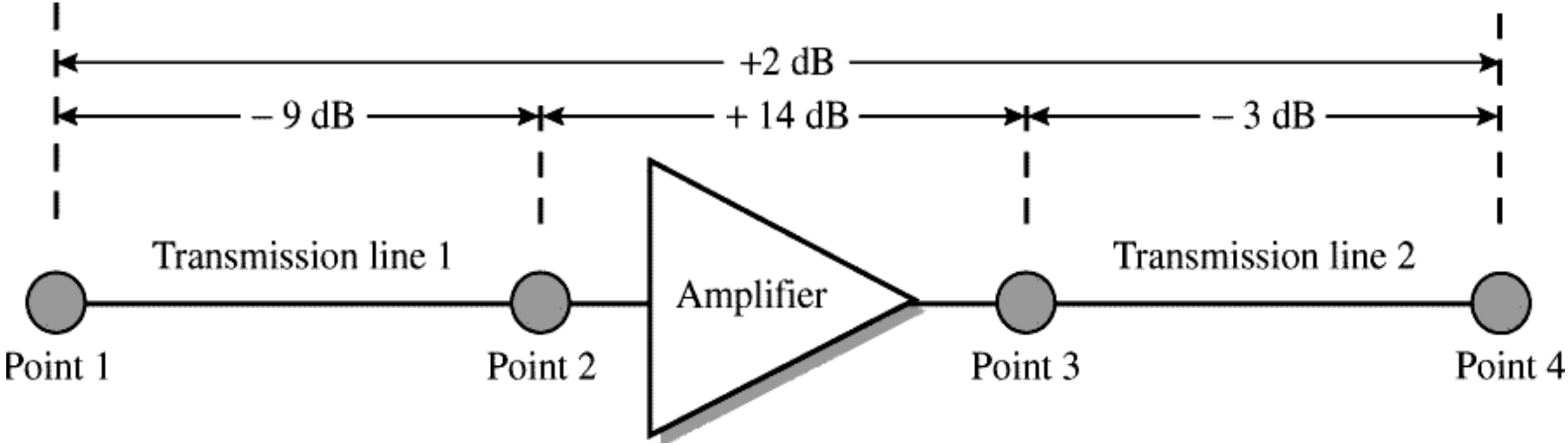

- Positive or negative **dB** represents the **system loss/gain between two points**
- dB level at point 4 => **(-9)+(14)+(-3)=+2dB**

Signal Attenuation & Amplification

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- The decibel (**dB**) is a logarithmic unit used to measure sound level. It is also widely used in electronics, signals and communication.
- The dB is a logarithmic way of describing a **ratio**.
- Suppose we have two signals, the first one with power p_1, and the second with power p_2. Using the decibel unit, the **difference in signal power,** between the two signals is defined to be:

$$power\_ratio\_in\_db = 10 \log {}^{p_2}/_{P_1}$$

e.g., $p_2 = 5\ p_1$, the difference in dB is $10 \log (p_2/p_1) = 10 \log 5 \approx 7$

$p_2 = 0.1\ p_1$, the difference in dB is $10 \log (p_2/p_1) = 10 \log 0.1 = -10$

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Digital Encoding

- Bit Encoding
- Manchester Encoding
- Differential Manchester Encoding
- MLT-3

Digital Encoding

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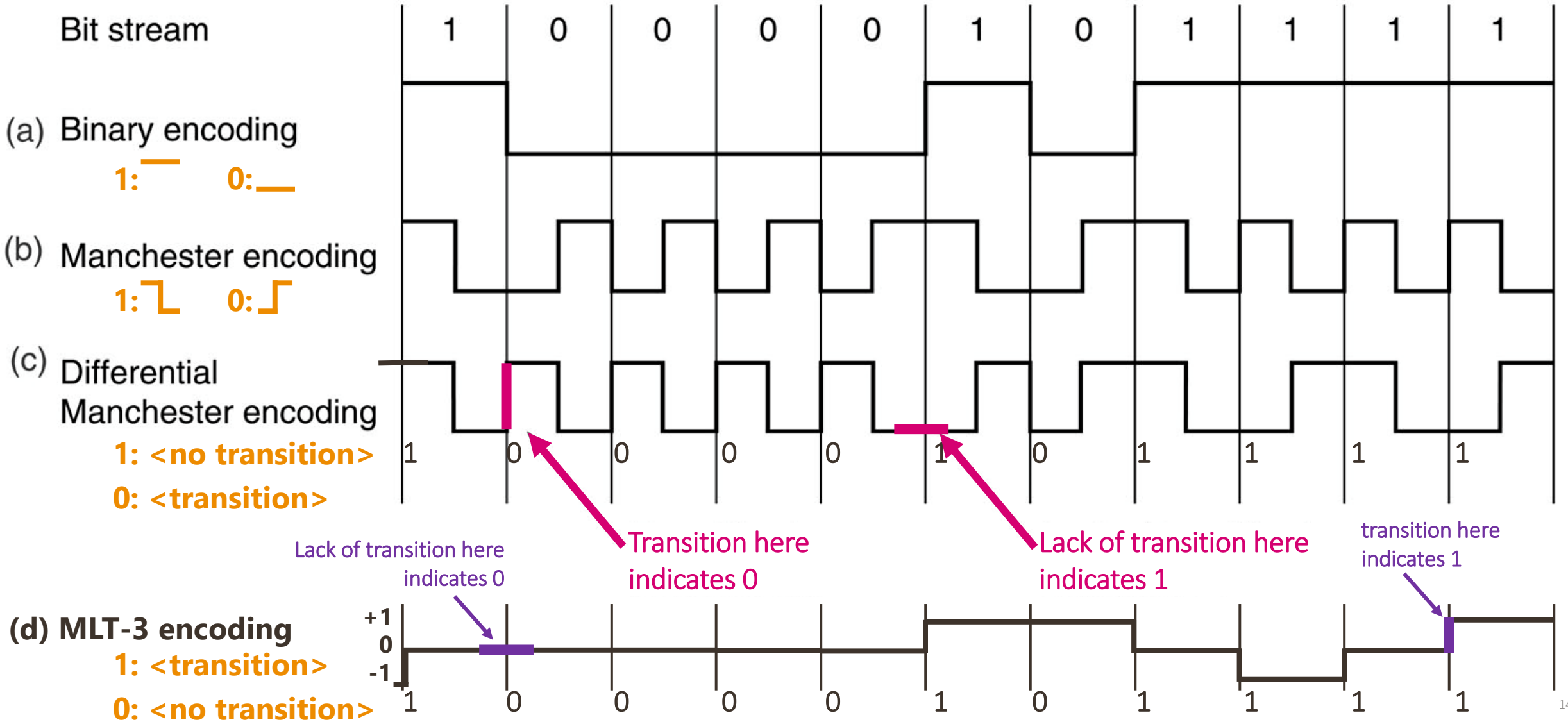

Encoding – cont.

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- **[Differential] Manchester Encoding**
  - ✓ Self-Ticking Signal *(no need to synchronize the sender/receiver clocks)*
  - ✓ Robust to noise

- **MLT-3**
  - ✓ 3 Levels of power (+1, 0, -1)
  - ✓ Emits less electromagnetic interference
  - ✓ Requires less bandwidth than other encoding techniques
  - ✓ Used in **Fast Ethernet**

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Medium Capacity

- Bandwidth, Speed, Lag, Throughput
- Multiplexing: FDM
- Multiplexing: TDM

Medium Capacity

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- Measured in bits per seconds **(bps)**
- Even a perfect channel has a finite transmission capacity
- **Bandwidth:**
  - Maximum amount of data transfer per second **(capacity)**
  - The range of frequencies used to transmit signals without being strongly attenuated **(range)**

Gigabit Ethernet – Bandwidth: 1Gbps

Bandwidth (capacity) for single mode fiber 10Gbps with **a Bandwidth (range)** of 20Ghz

Medium Capacity – cont.

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- No transmission facility can transmit without some **degradation**.

Loss of some frequency components

- Usually, frequencies from 0-f_{max} are transmitted, and **above f_{max} are attenuated**

Analog voice signal: 300-3000Hz

Speed ∝ 1/Distance

- **Wi-Fi 2.4GHz**
  - ✓ long distance
  - ✓ low speed
- **Wi-Fi 5GHz**
  - ✓ shorter distance
  - ✓ high speed

Bandwidth vs Speed

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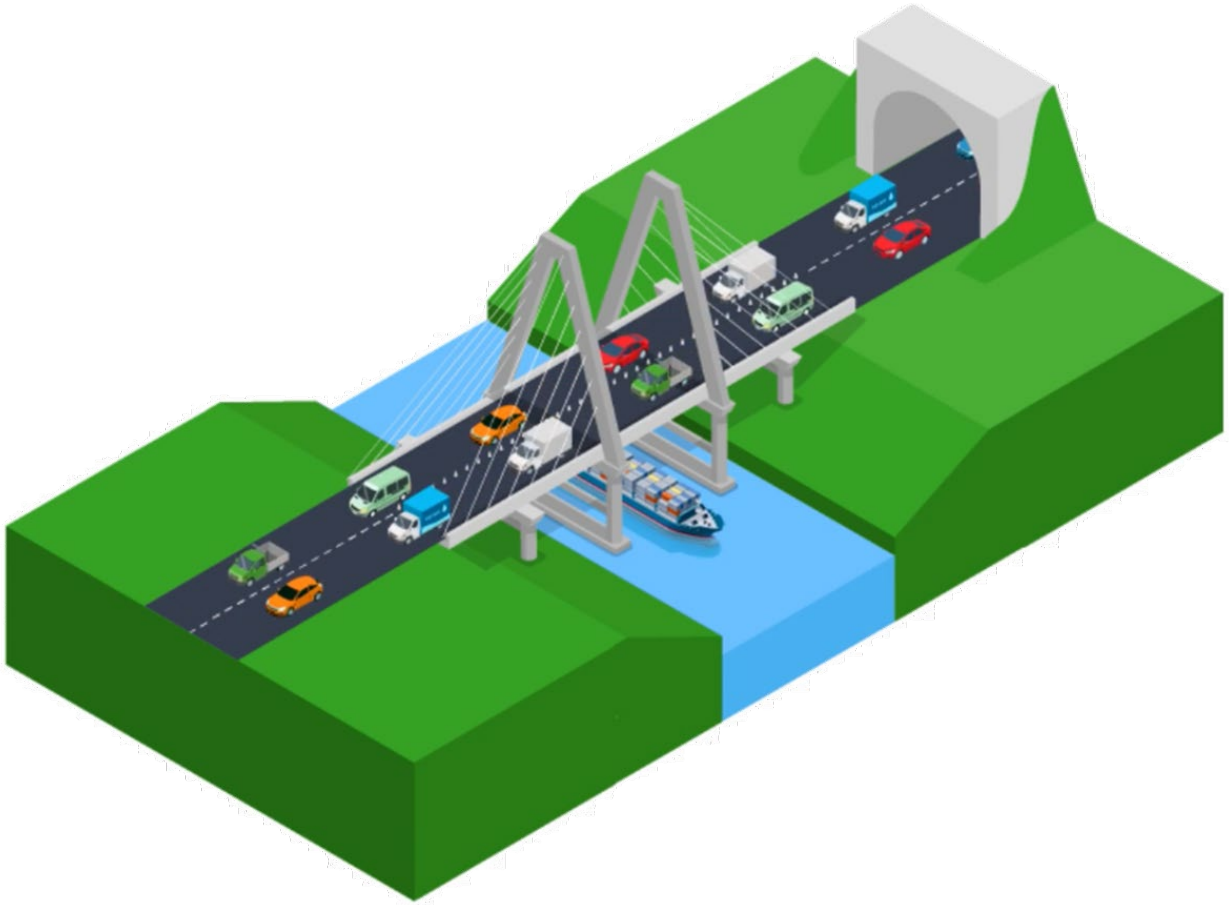
- **Bandwidth:** max amount of vehicles passing bridge/hour



- **Speed:** End-to-end flow

Bandwidth vs Latency

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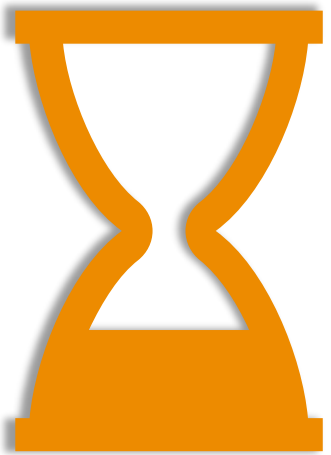
- Latency is sometimes referred to as delay or ping rate.
- It's the **lag** you experience while waiting for something to load.
- If bandwidth is the amount of information sent per second, **latency is the amount of time** it takes that information to get from its source to destination



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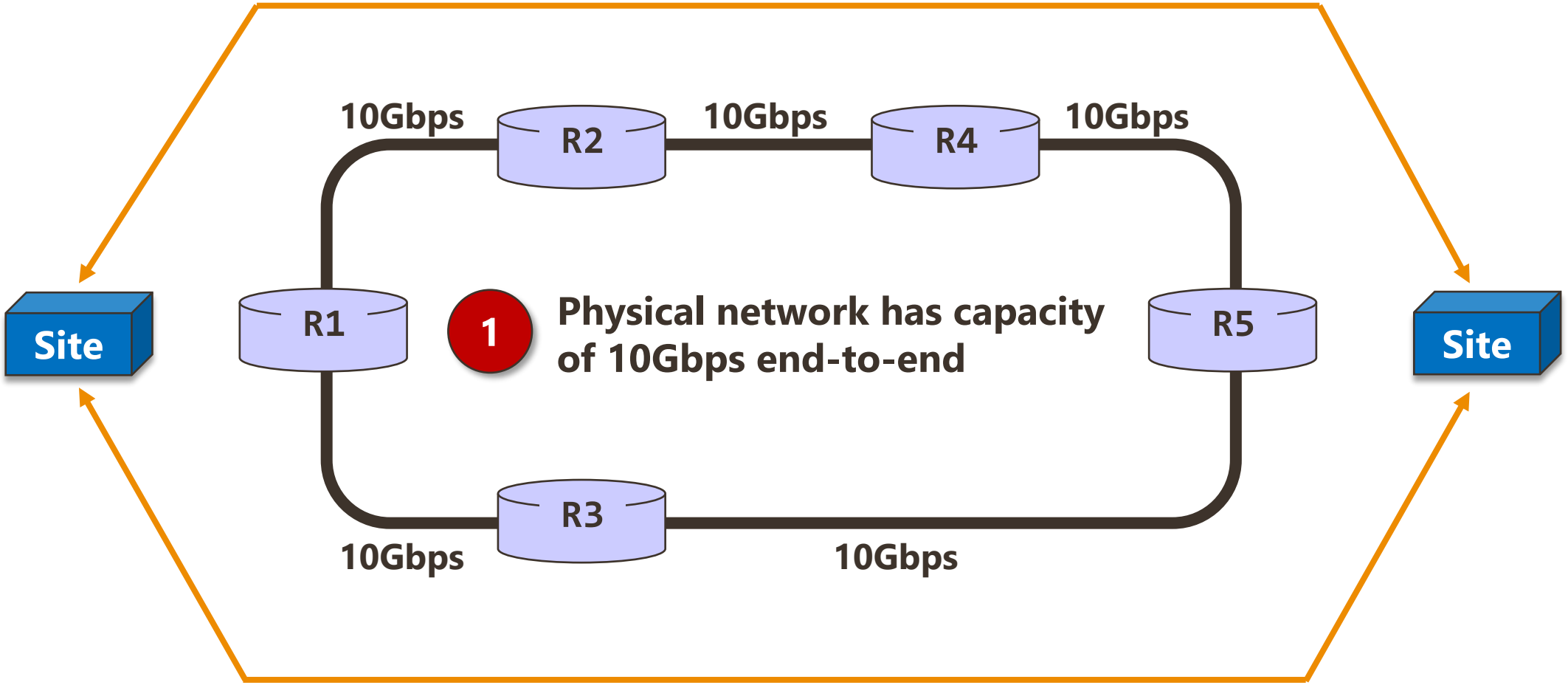
Physical network can have less speed than the total bandwidth/capacity

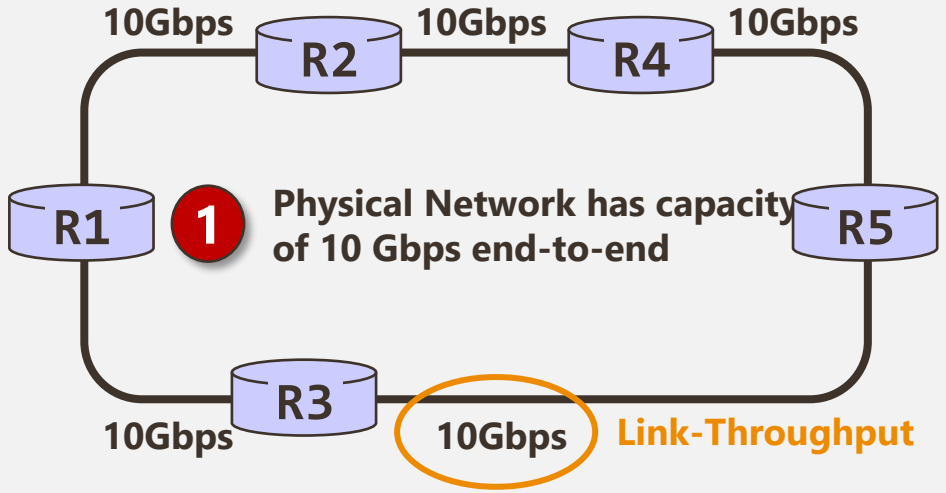


2 End-to-end IP or Ethernet speed is limited to something less, say 100Mbps

Bandwidth vs Throughput

Actual amount of data transfer per second

- ✓ Taking latency, network speed, packet loss and other factors into account



Bandwidth: max amount of vehicles passing bridge/hour

Throughput: Actual number of vehicles passing the bridge/hour

Throughput: Node to Node (link) | Speed: End-To-End

Multiplexing

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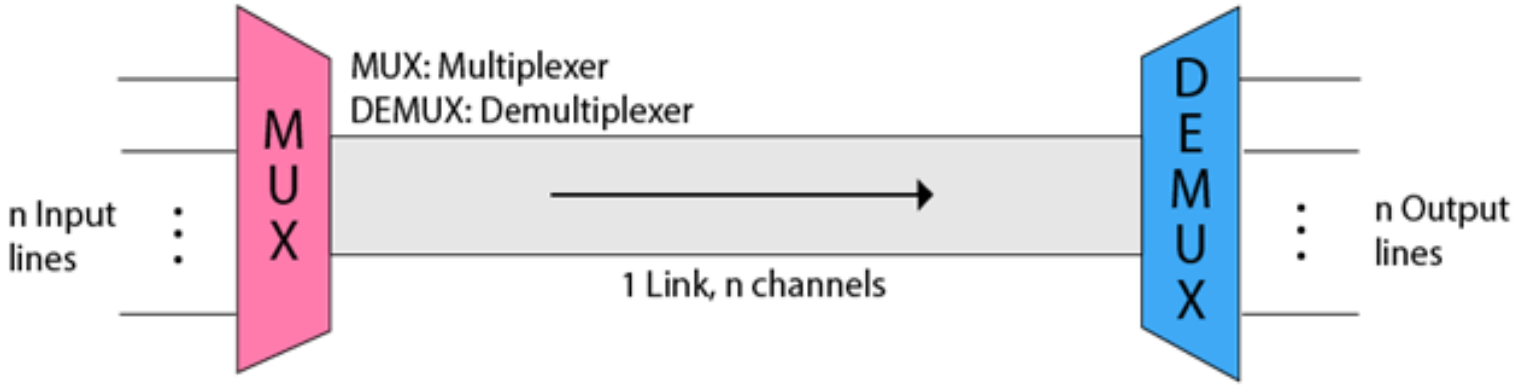
- A technique used to combine and send the multiple data streams over a single medium.
  - The process of combining the data streams is known as multiplexing
  - hardware used for multiplexing is known as a multiplexer.



Frequency Division Multiplexing (FDM)

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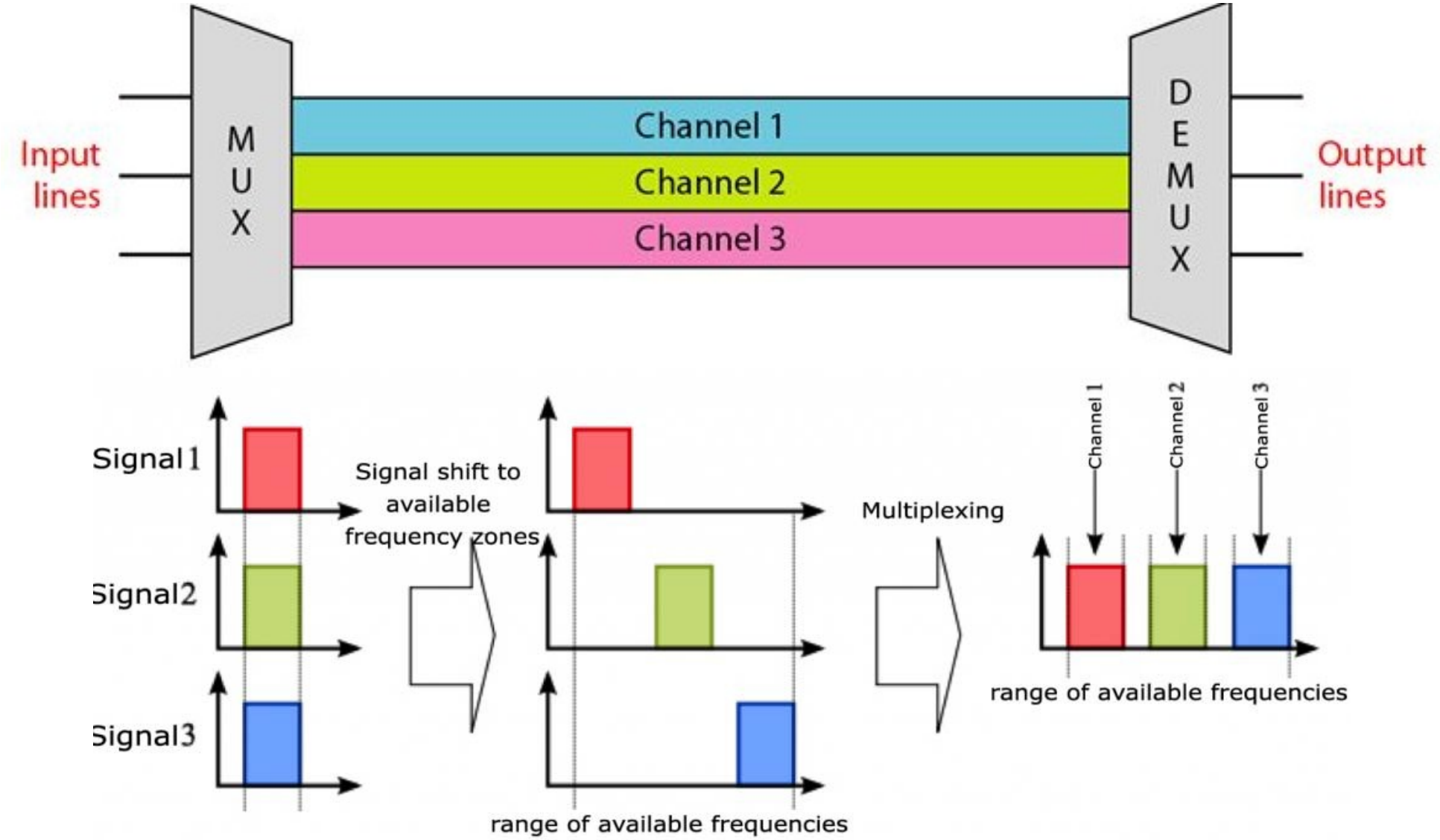

Time Division Multiplexing (TDM)

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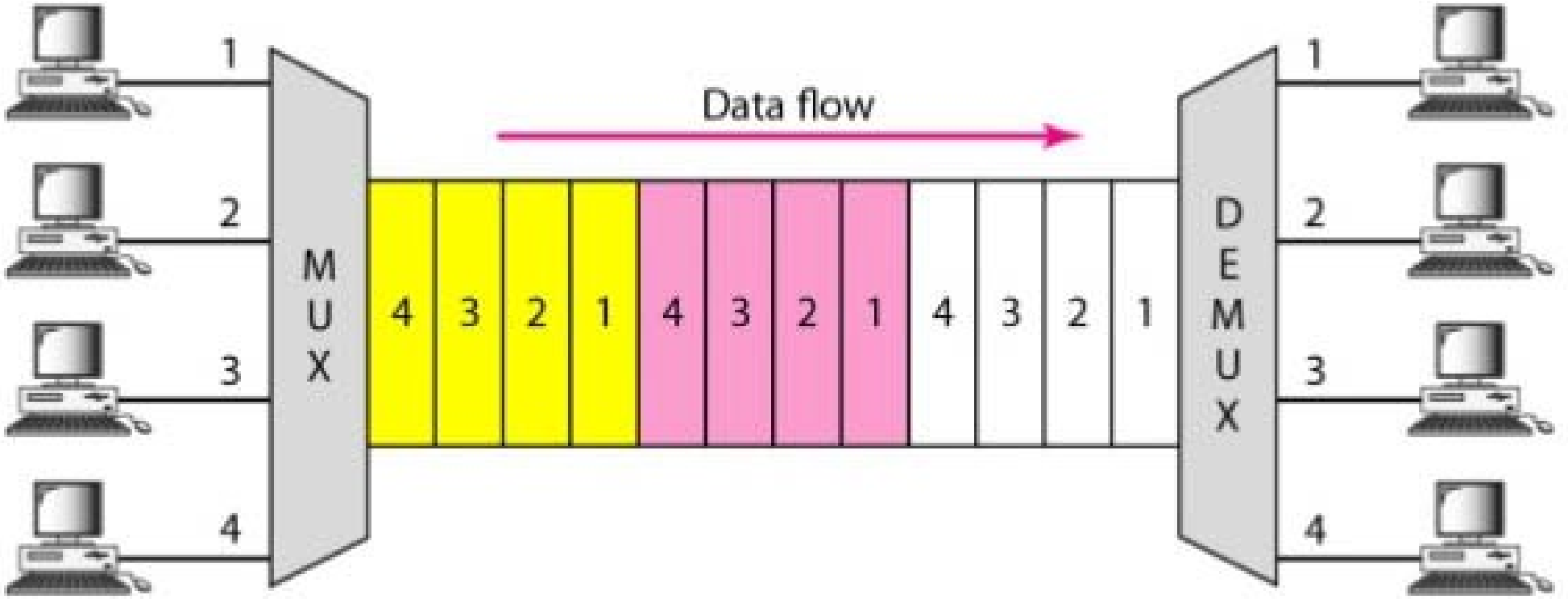

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Network Topologies

- Physical Topology
- Logical Topology
- Hybrid Topology

Network Topology

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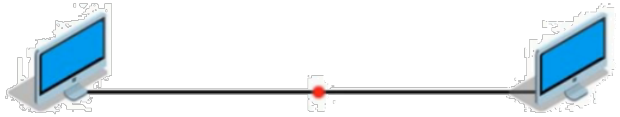
- Refers to **how network devices are connected**
- 3 Aspects
  - **Physical Topology**
    - How network devices are physically connected
    - Layout of the network
  - **Logical Topology**
    - The way signal passes through the network
    - *i.e. In this class there are always students physically sitting in the classroom, but logically they are far far away ☺*
  - **Hybrid Topology**
    - Combination of physical and logical

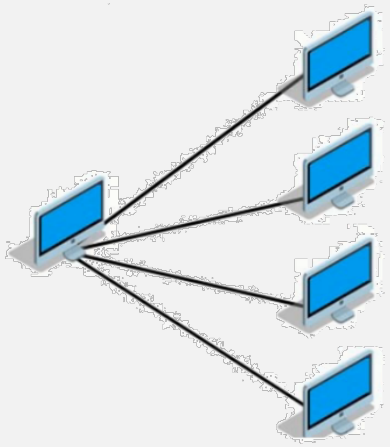


Point-to-Point (PTP, P2P)

- Foundation of all other topologies

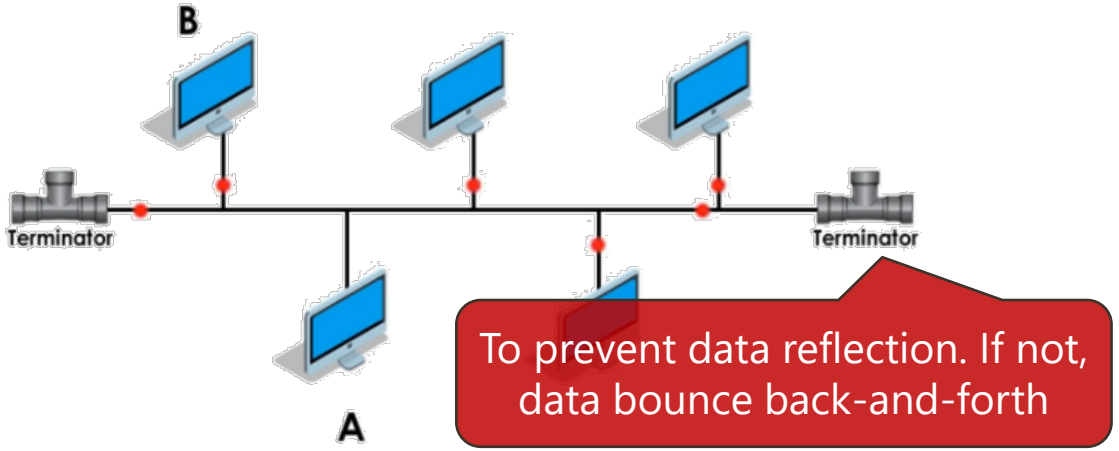
Data from central **base station** is **broadcasted;**

Data from subscribers only received by central **base** station



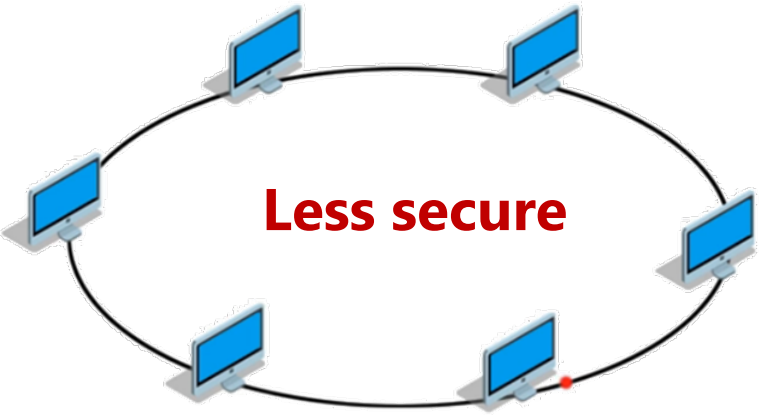
Point-to-Multipoint (PTMP, P2MP)

- Central **base station**, supports subscriber stations
- i.e. *Wireless LAN*



Bus (daisy chain topology)

- No central base station
- Nodes attached to **one shared bus cable**
- One single point failure=whole network failure
- Less secure

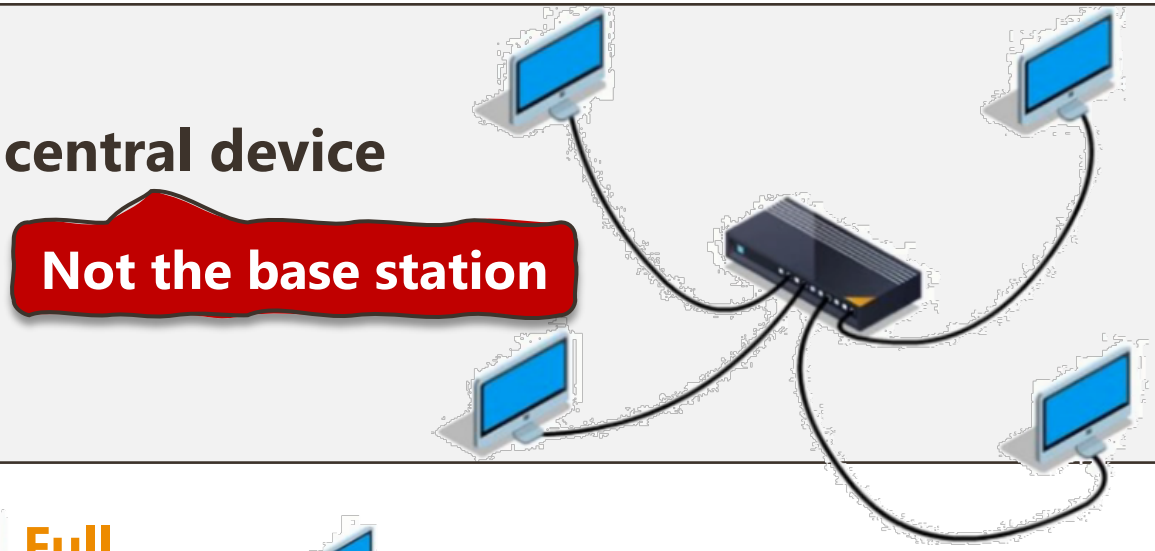


Ring Topology

- Nodes attached to a cable forming a closed loop
- No need for Terminators
- **Data** travels from **one node to another** via a token passing
- One single point failure=whole network failure

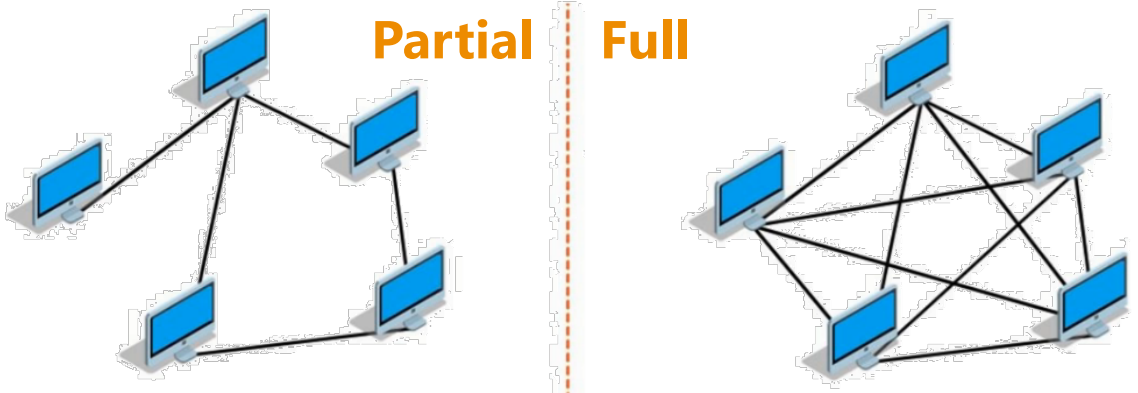
Star Topology

- Nodes communicate with other Nodes via a **central device**
- Fault Tolerant (if one node goes down)
- Scalable, Easy Maintenance
- **-VE: Central Point of Failure**



Mesh Topology

- Partially Meshed
- Fully Meshed



i.e. ad hoc wireless LAN

Hybrid Topology

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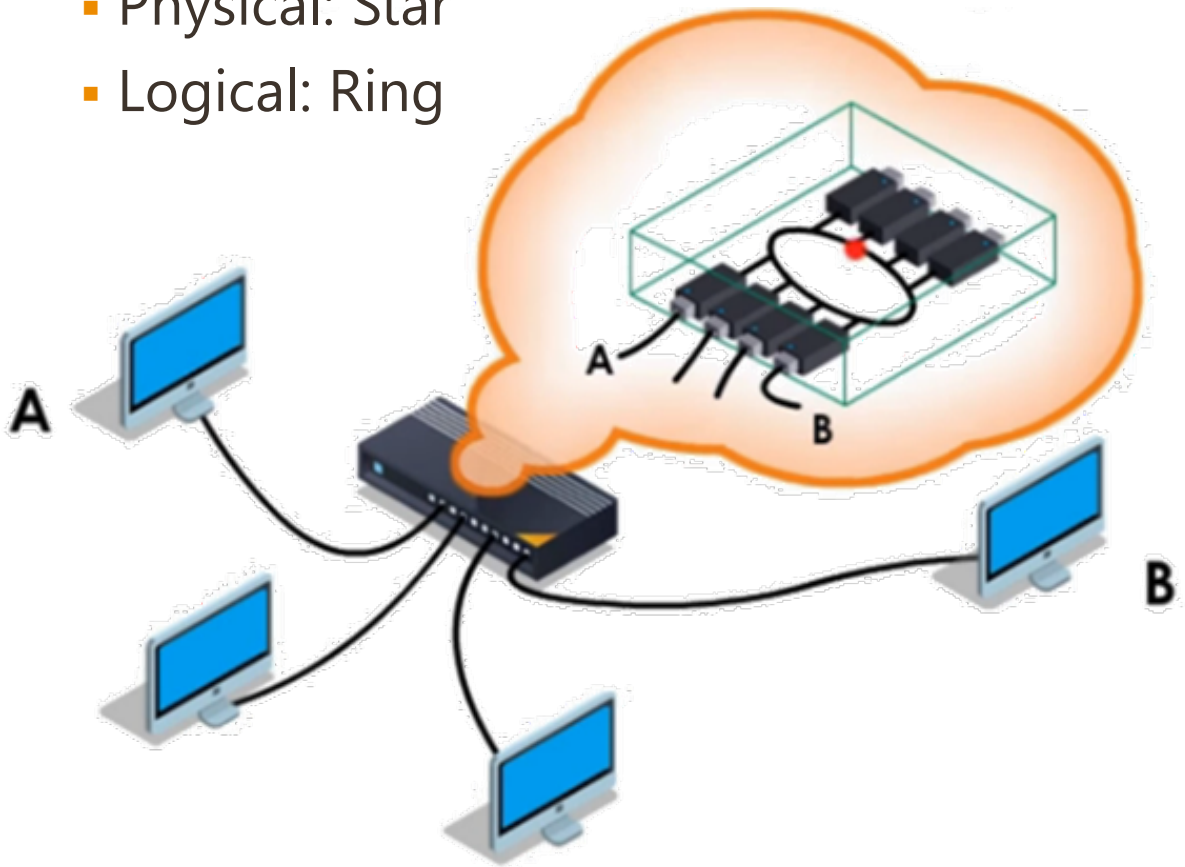
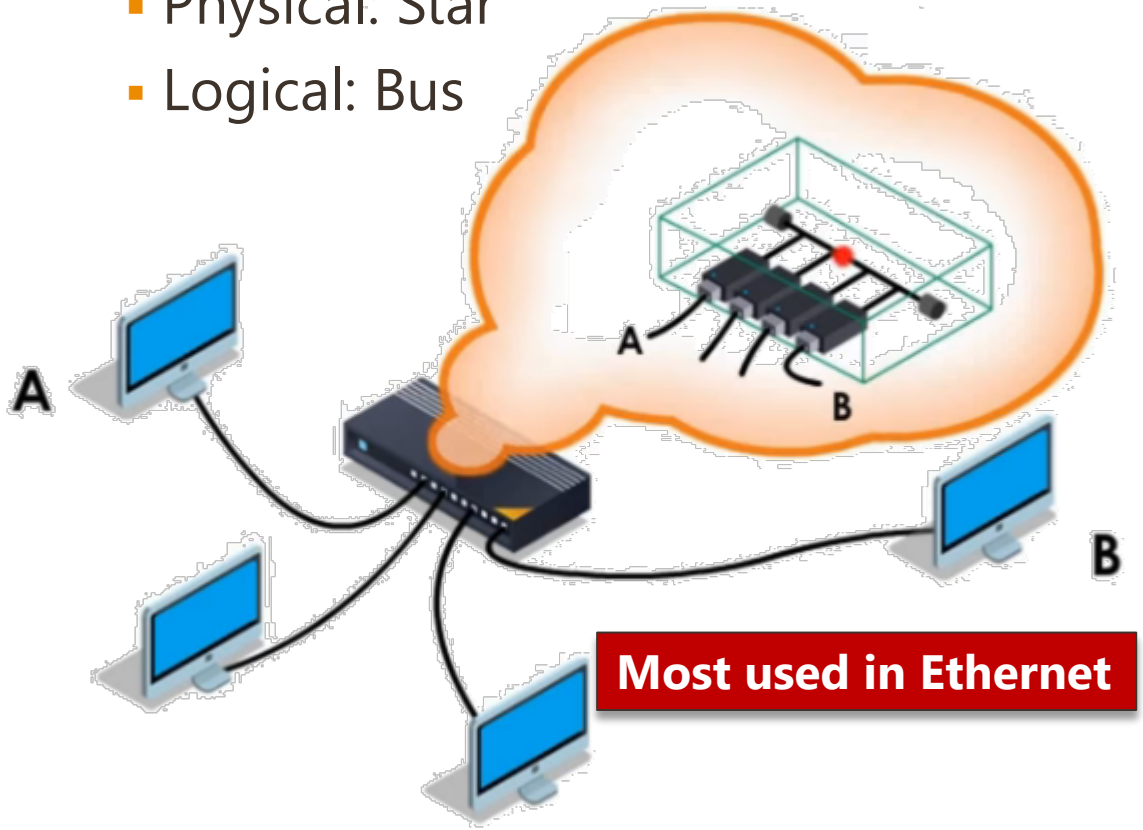
Star-ring Topology

- Physical: Star
- Logical: Ring



Star-bus Topology

- Physical: Star
- Logical: Bus



Most used in Ethernet

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Transmission Media

- Transmission Modes
- Guided Media
- Unguided Media
- Wireless Signals
- Wireless Signal Attenuation

Transmission Modes

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- **Simplex Mode:** communication is unidirectional **Only 1-way**
  - ✓ Sender -> Receiver | **not Receiver -> Sender**
  - ✓ Entire bandwidth can be used
    - E.g. A keyboard -> monitor
    - E.g. Radio station -> audience

- **Half Duplex Mode:** communication is two-directional **1-way at a time**
  - ✓ Sender -> Receiver | Receiver -> Sender (one at a time)

- **Full Duplex Mode:** communication is bi-directional **2-way, same time**
  - ✓ Sender -> Receiver | Receiver -> Sender (at the same time)

Transmission Modes – cont.

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Comparison	Simplex	Half Duplex	Full Duplex
Direction of Communication	Unidirectional One-way	Two-directional, one at a time	Two-directional, simultaneously
Send / Receive	Sender can only send data	Sender can send, receive data, but one a time	Sender can send and receive data simultaneously
Performance	Worst performance	Better than Simplex	Best performing mode of transmission
Example	Keyboard and monitor	Walkie-talkie	Telephone

Transmission Media

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- **Guided:**
  - ✓ Twisted Pair
  - ✓ Coaxial Cable
  - ✓ Fiber Optics
- **Unguided:**
  - ✓ Radio
  - ✓ Microwave
  - ✓ Lightwave
  - ✓ Infra-red

Unshielded Twisted Pairs (UTP)

Shielded Twisted Pairs (STP)

Fiber Optic Cable

Coaxial Cable

Twisted Pair

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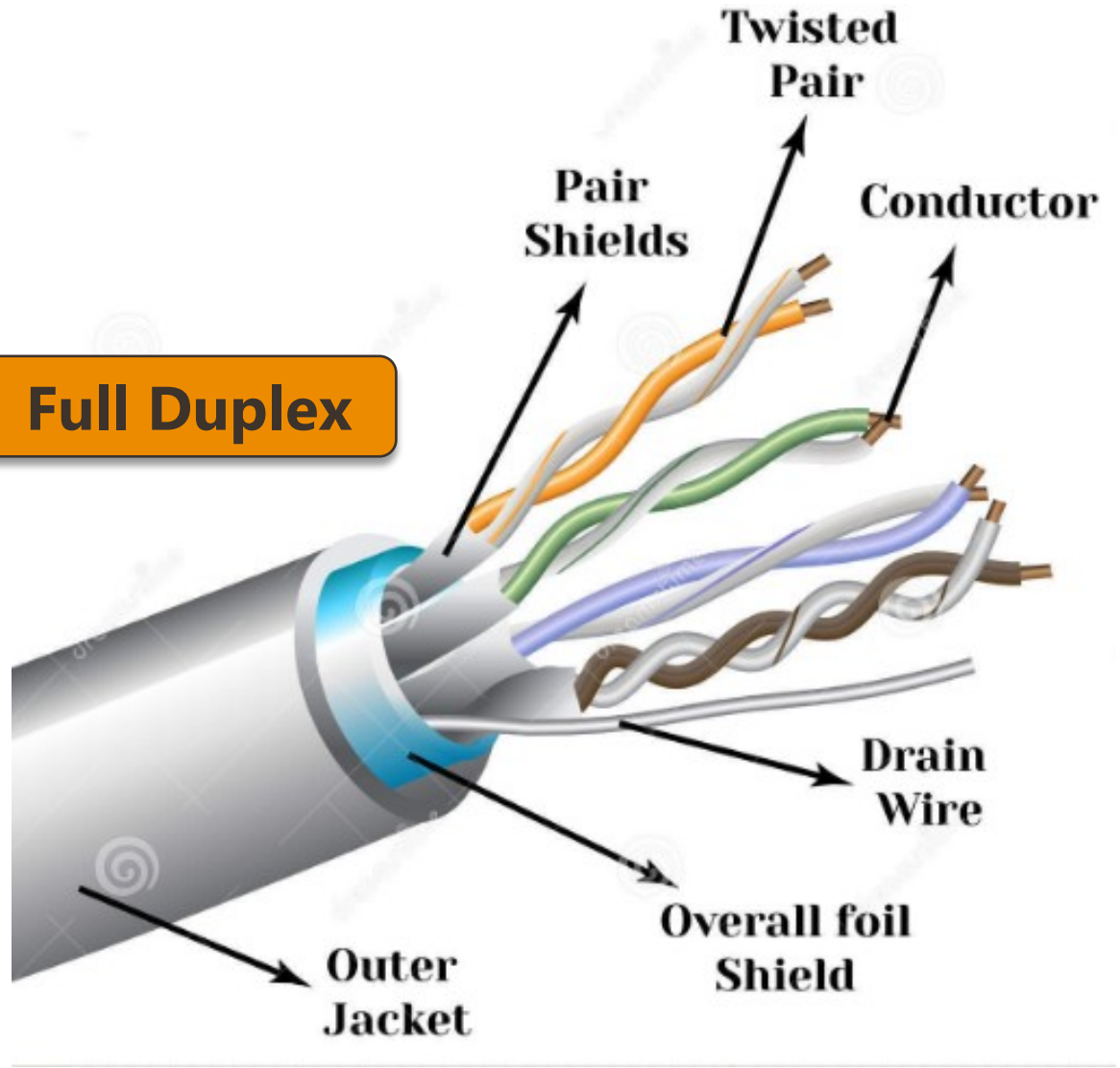

Full Duplex

- Oldest and still **common** transmission media
- Can transmit **analog or digital** signals
- Most common is **UTP** (Unshielded Twisted Pair)
- Uses **repeaters** for long distance connection
- Less expensive

Coaxial Cable

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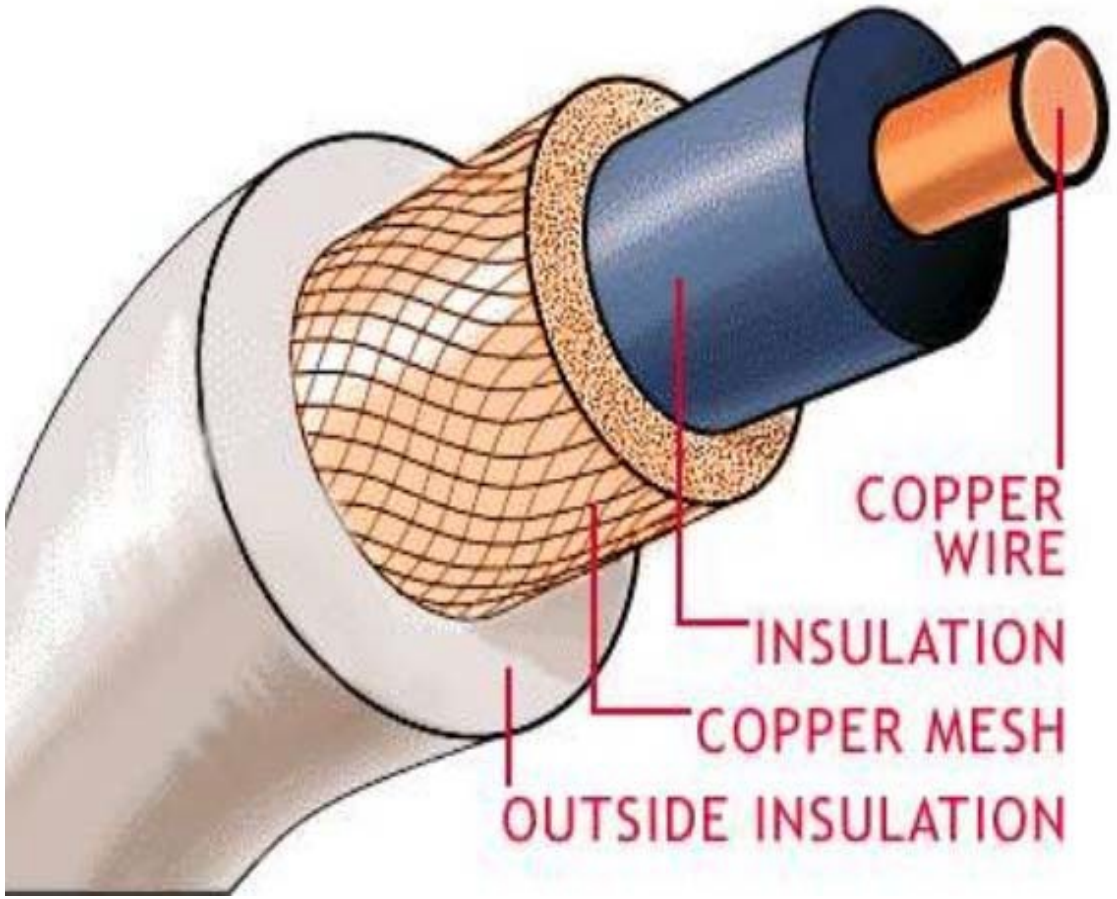
Half Duplex

- **Better shielding** than twisted pairs
- **Not flexible**
- Two kinds:
  - ✓ 50-ohm cable (digital transmission)
  - ✓ 76-ohm cable (analogy transmission & cable television)



Fiber Optic

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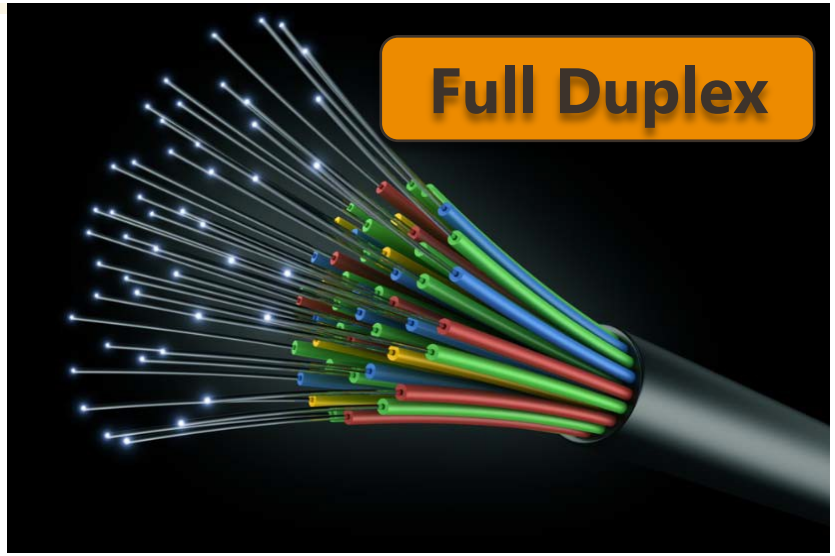
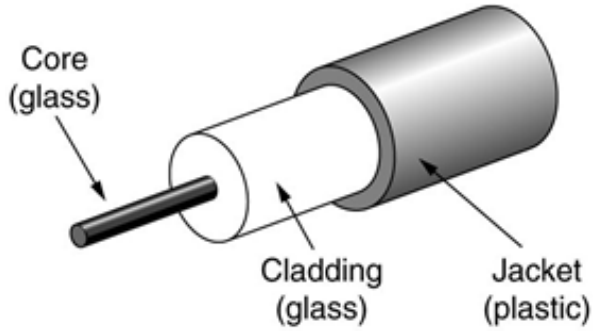
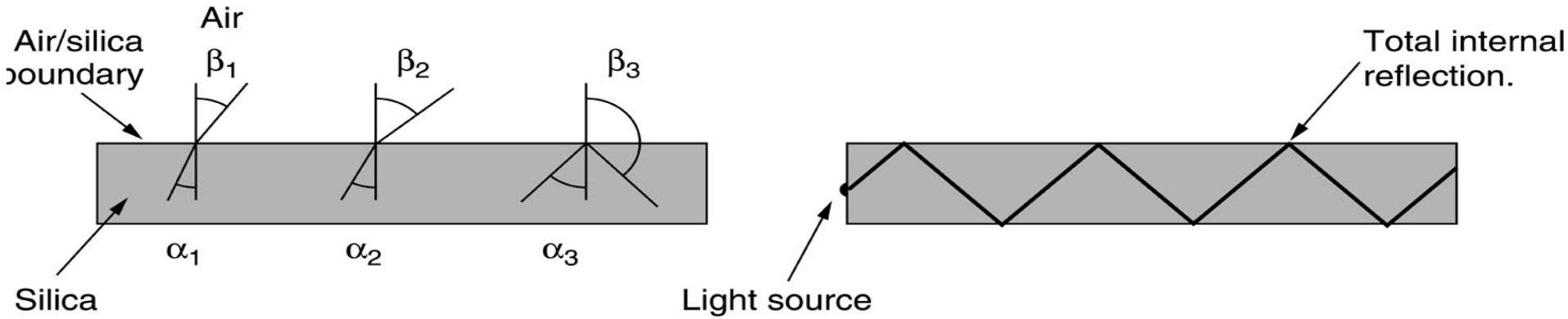
- Light source (speed of light)
- Transmission medium (ultra-thin fiber of glass)
- Detectors







Unguided: Electromagnetic Spectrum

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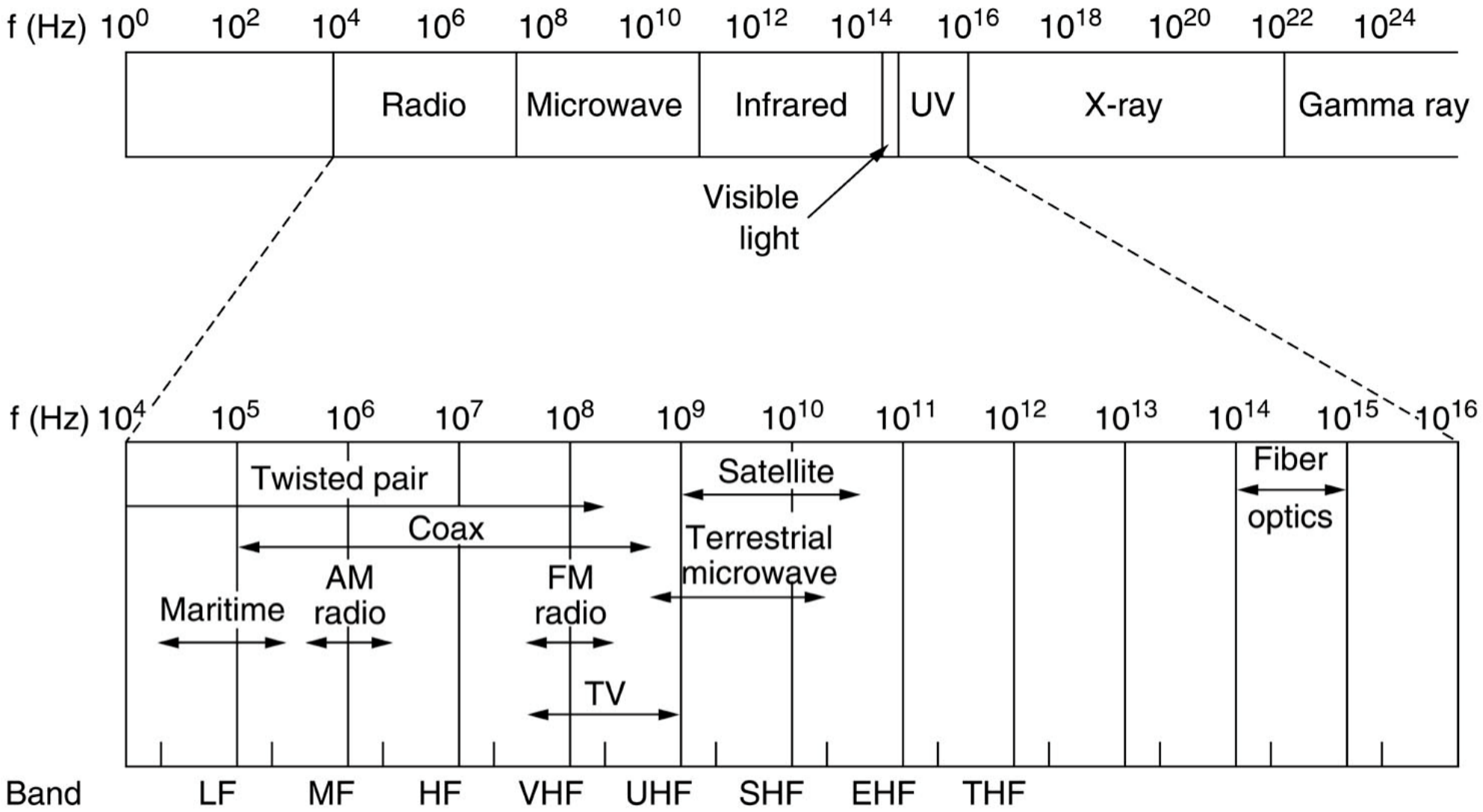

Radio Transmission

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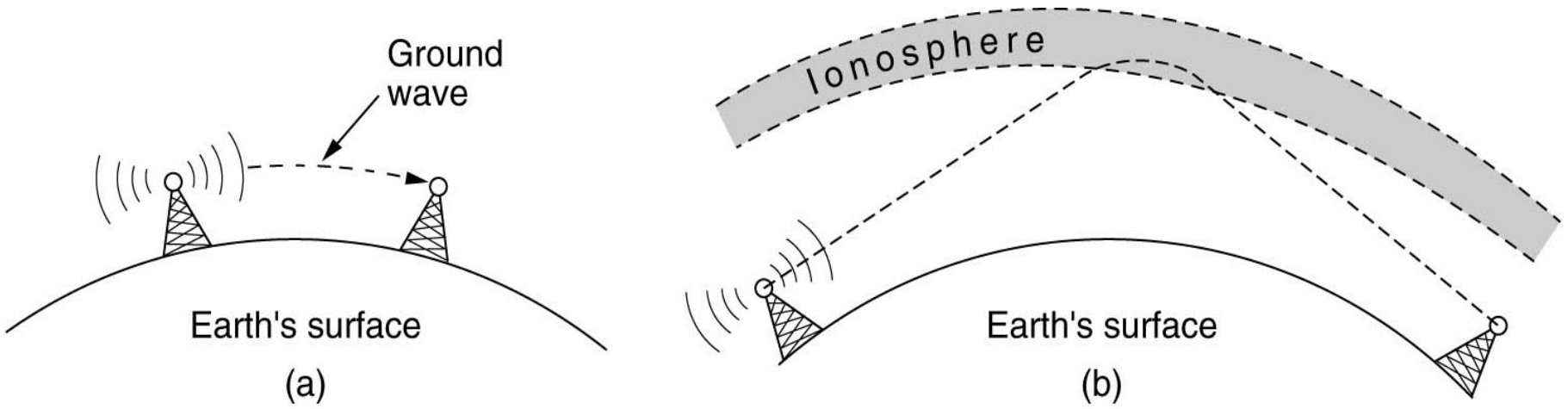
- Easy to generate & travel long distance
- Omni-directional



*(a) VLF, LF & MF bands, radio waves **follow the curvature** of the earth.*

*(b) HF band **bounced off** the ionosphere. (Tanenbaum)*

Microwave Transmission

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- Travel in **straight line**
- Used for:
  - ✓ Long-distance telephone communication
  - ✓ Television distribution
  - ✓ Etc.

Infrared & Millimeter Waves

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- **Short-range** communication
  - Remote controls
- **Cheap** and easy to built
- **Cannot penetrate** solid objects

Light Wave Transmission

- **Laser or Light**
- **Unidirectional**
- Offer **high bandwidth** & very low cost
- **Cannot penetrate** rain or thick fog

Wireless Signals

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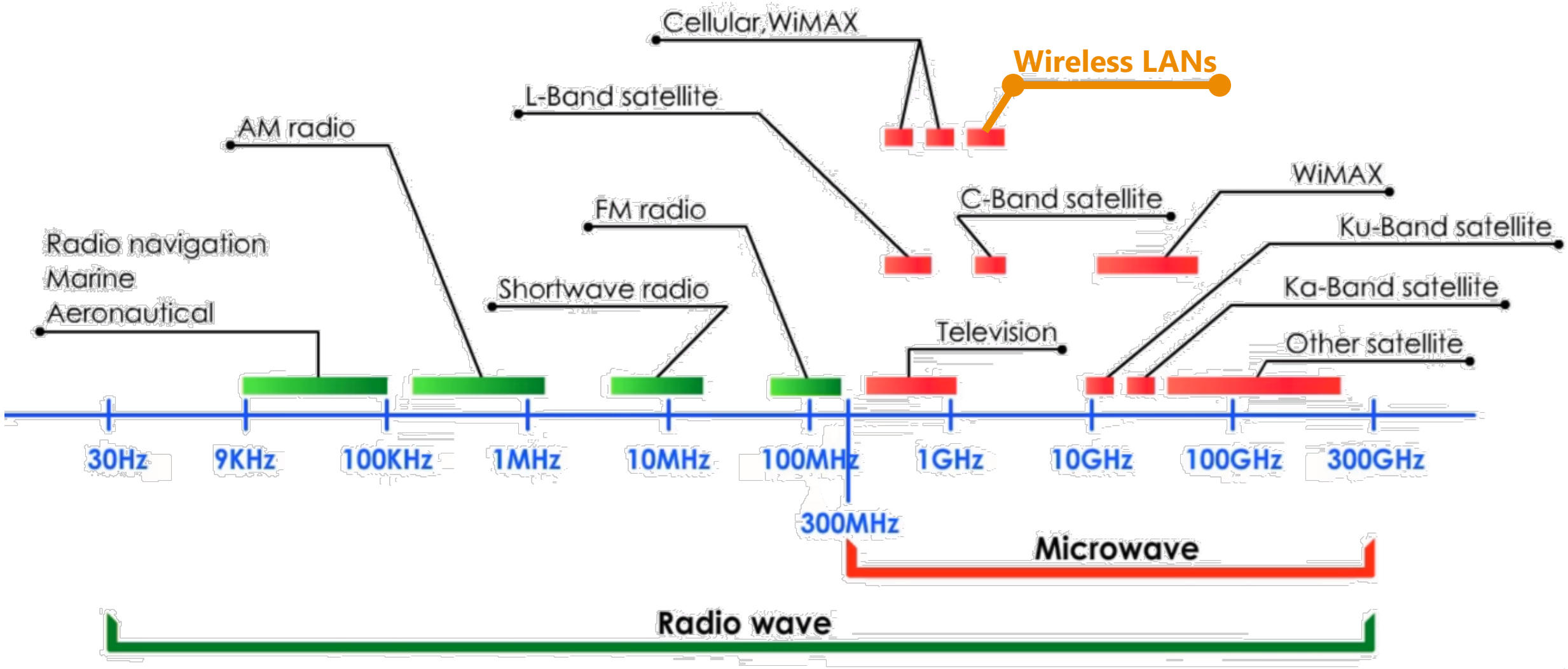

Wireless Signal Attenuation?

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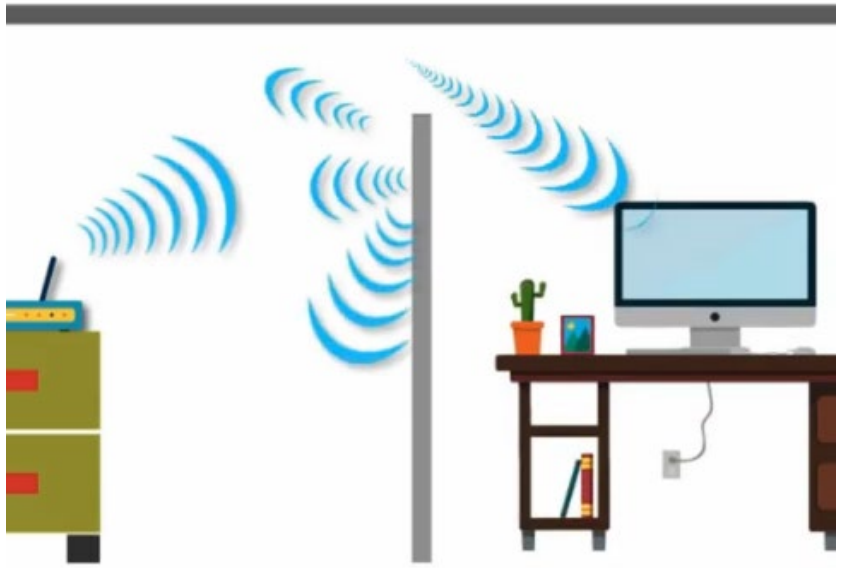
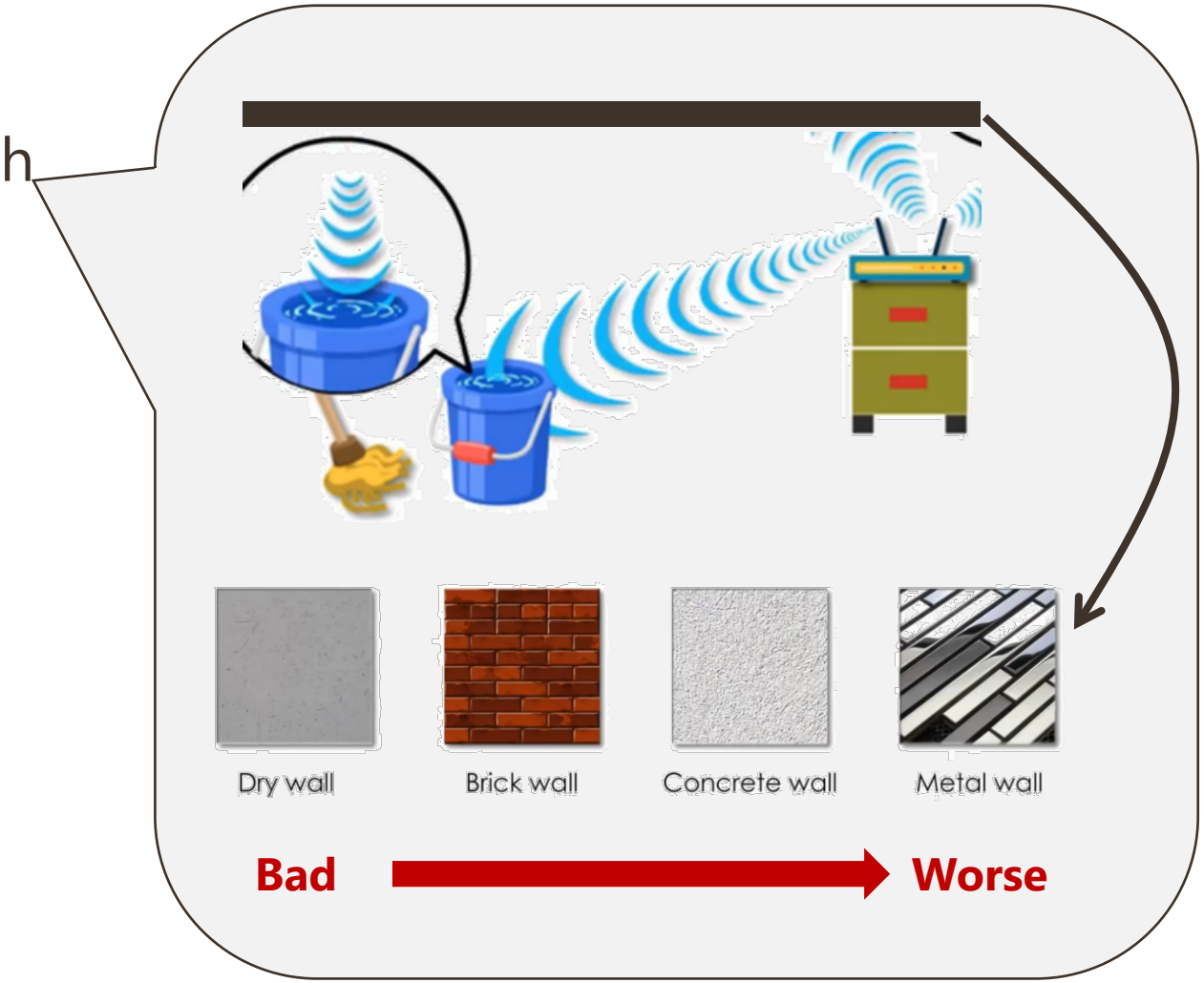
- **Absorption**
  - Some materials absorb signal's strength
- **Reflection**
  - Some absorbed, some reflected
  - Not necessarily bad





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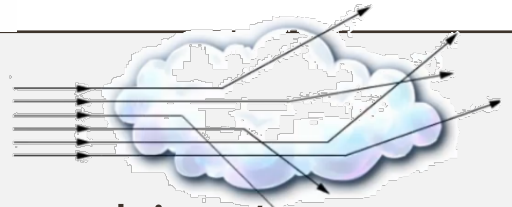
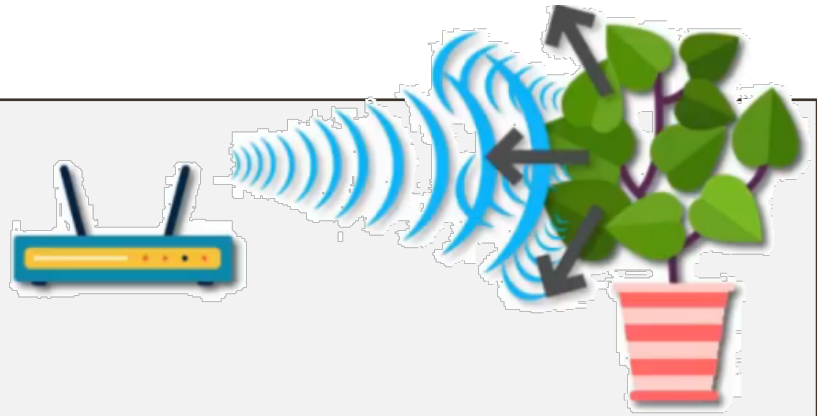
Diffraction

- Sharp edges, corners, etc





Scattering

- Diffusion of wireless signal at an object's uneven surface
- i.e. plant leaves, **dust**, **smoke**, or micro **drops of water**

Interference

- Devices operating on same 2.4Ghz

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Last Mile Technologies

- Dial-up
- ISDN
- DSL/ADSL
- NBN

Last Mile Technologies

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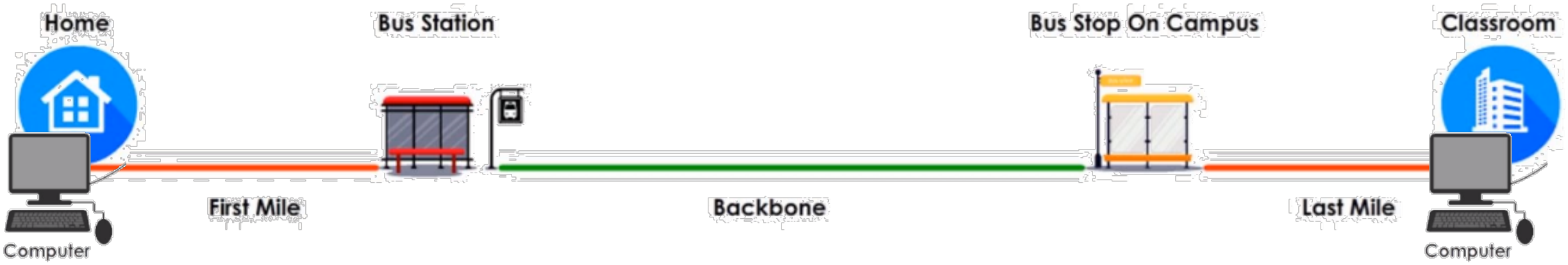
- Refers to any **telecommunication methods, devices** and **media** that **carry signals over the last/first mile**
- **E.g.**
  Network backbone use Fibre Optics but the last mile still use copper wires
- **Typically the speed bottleneck**



Network Backbone

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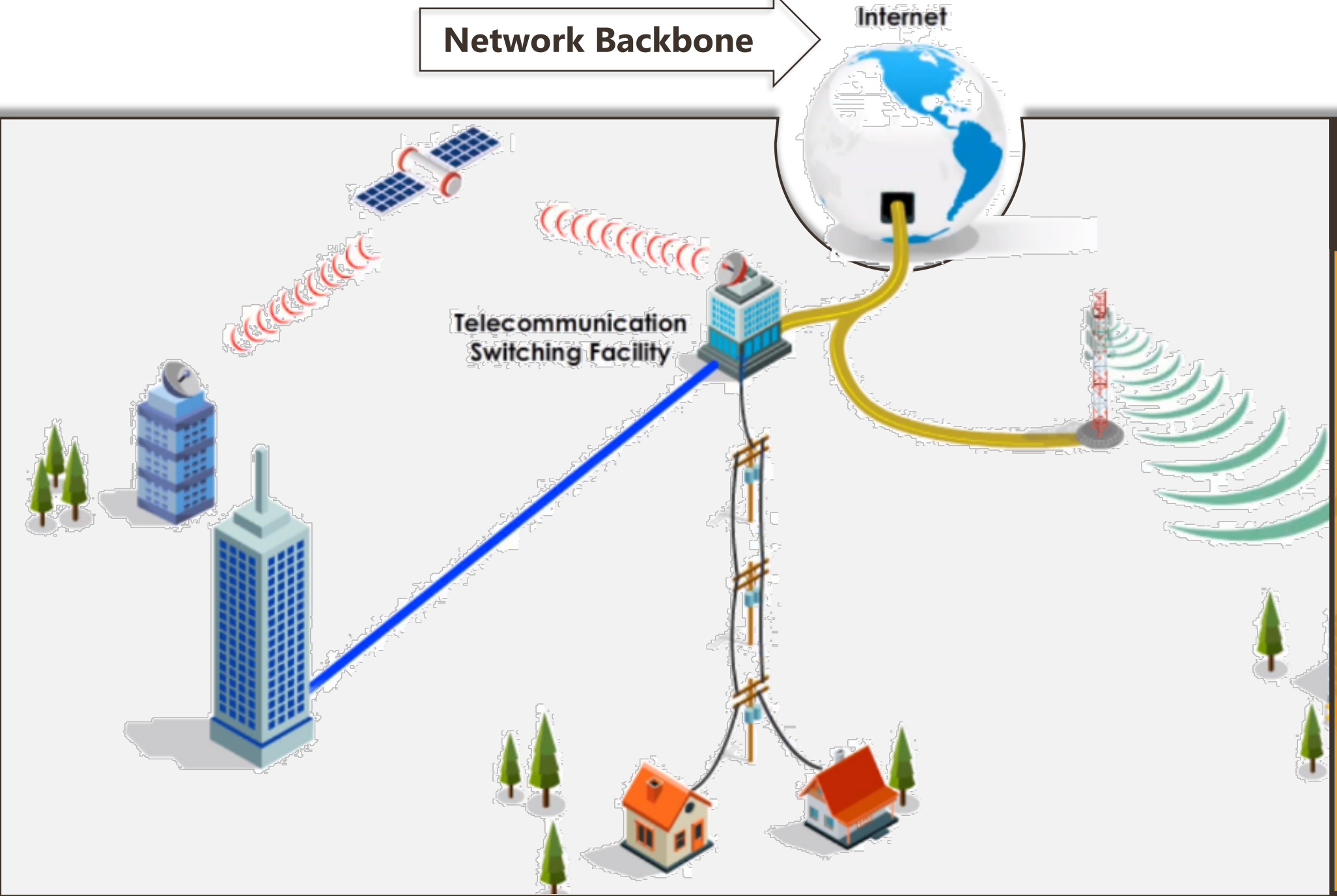

LAST MILE TECHNOLOGY

- Dial-up
- DSL
- Cable modem
- Broadband
- WiMax
- Cellular
- Fibre Optics
- Satelite

Dial-up

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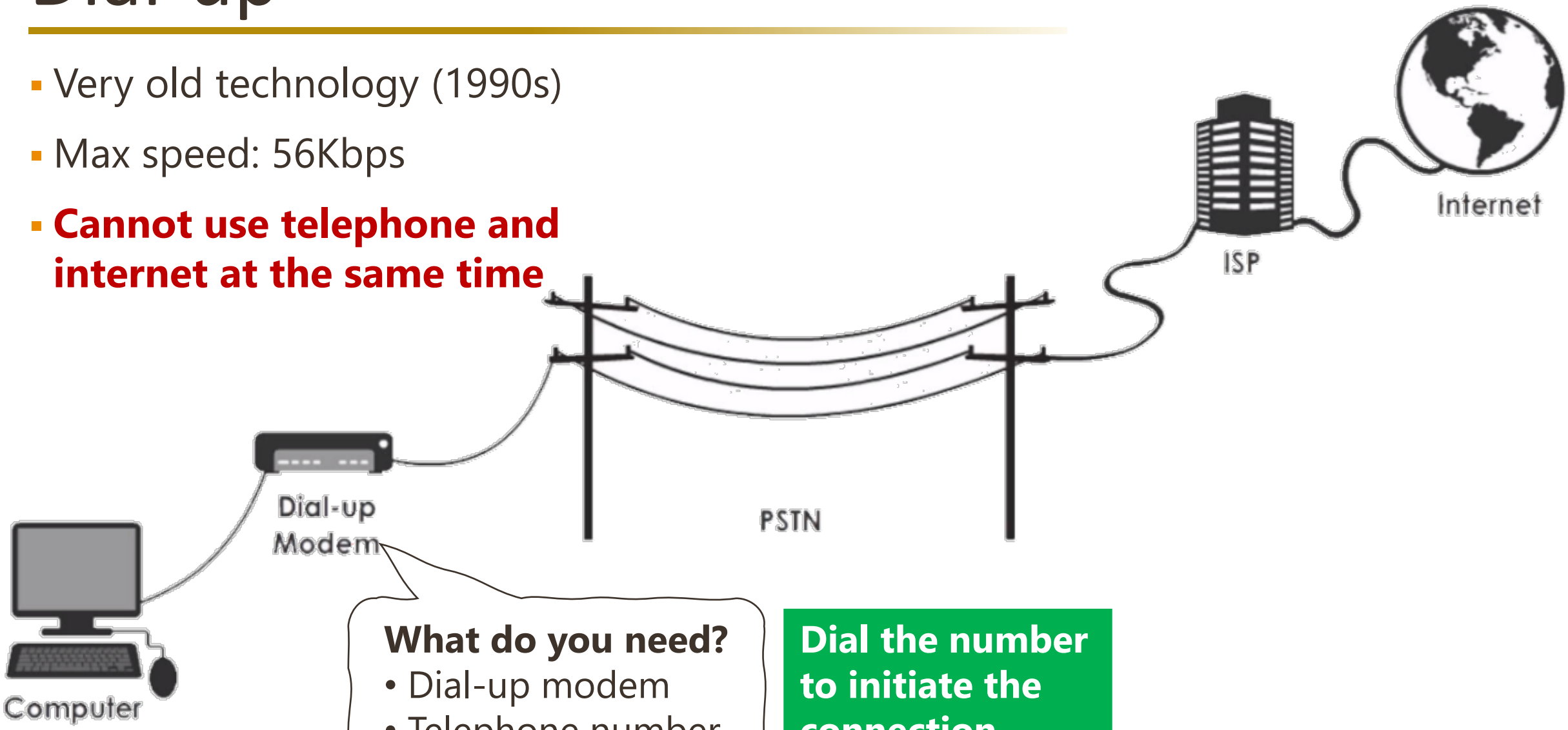
- Very old technology (1990s)
- Max speed: 56Kbps
- **Cannot use telephone and internet at the same time**



What do you need?
- Dial-up modem
- Telephone number

Dial the number to initiate the connection

Dial-up: PSTN

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- PSTN or Public Switched Telephone Network is most commonly known as a **'telephone line'**
- Users need to use **one line** for one conversation at a time using only one **phone number (=one phone line)**
- Circuit-switched copper phone lines are used to transmit **analogue voice data**
- As a **dedicated service**, a PSTN line cannot be used for any other purpose while a call is being made

ISDN

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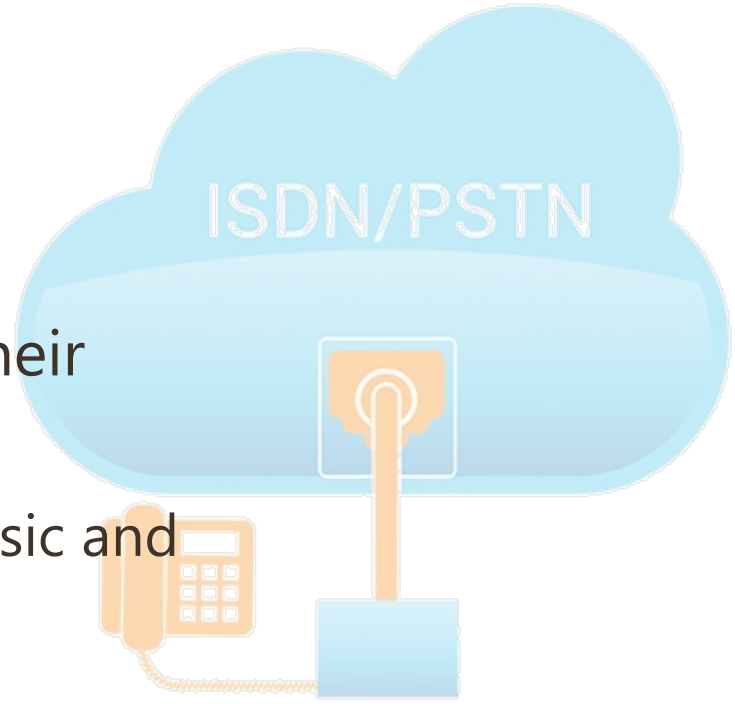
- Integrated Services Digital Network (ISDN) provides **digital transmission of voice and data** services
- ISDN supports **multiples channels** for voice and data.
- Medium to Large Businesses: Option of integrating with their phone systems (PABX) to enable **multiple features**
  - ✓ Like using a 100-number range, groups, queues, on hold music and RVAs, etc.



With **NBN** (National Broadband Network), PSTN and ISDN will be phased out.

Digital Subscriber Line (DSL)

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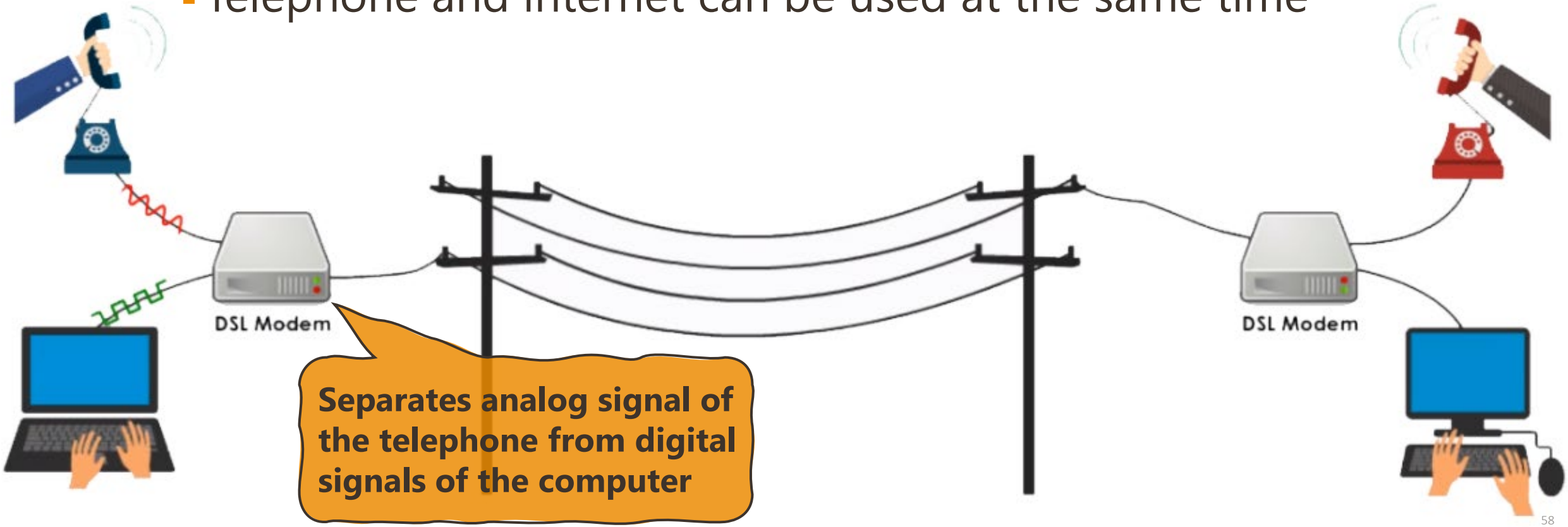
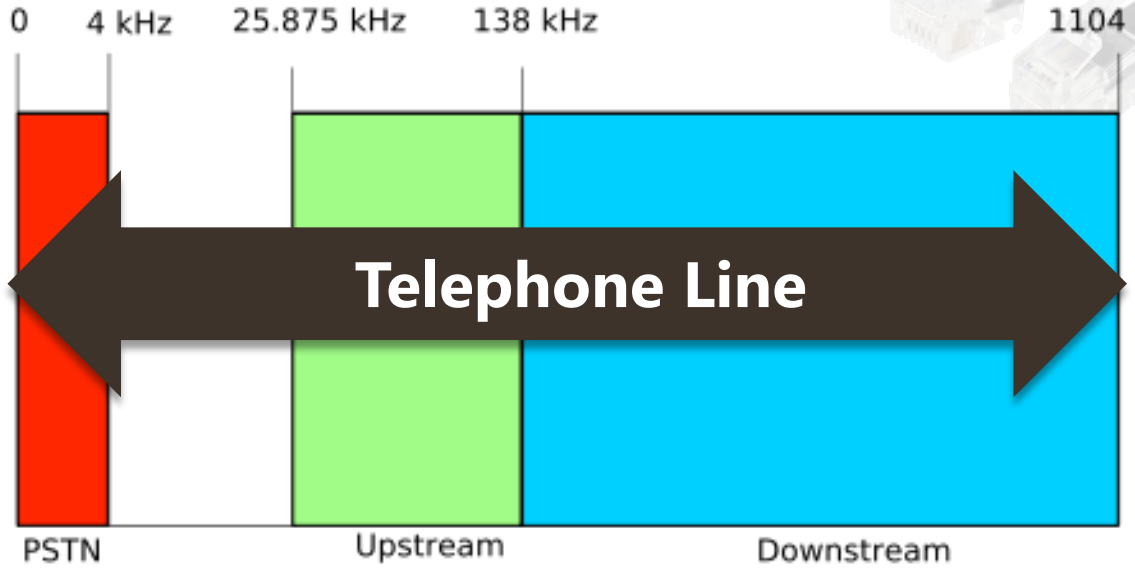
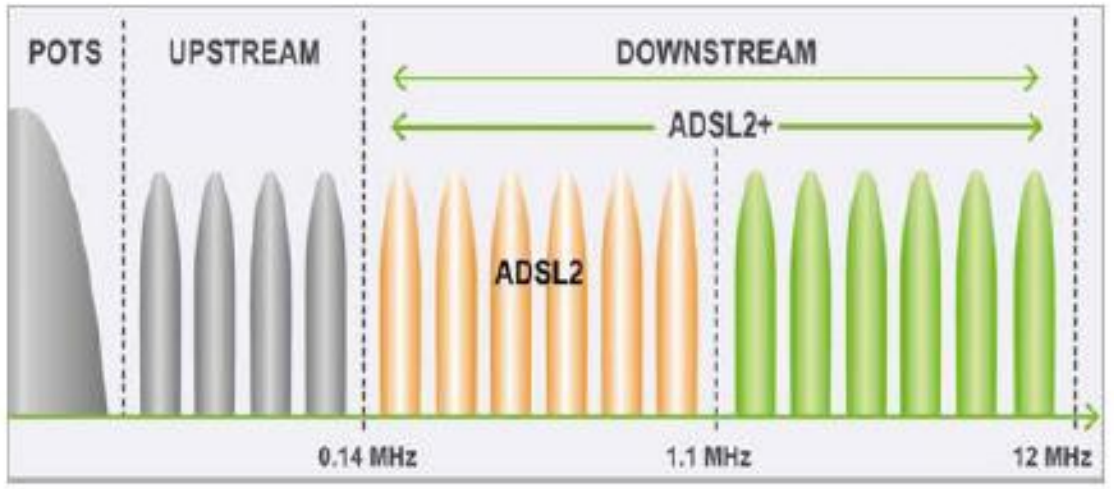
- Faster data transfer over PSTN
- Always on connection (No dialing required)
- Telephone and internet can be used at the same time



DSL

- **ADSL (Asymmetric DSL)**
  - Downstream is faster than upstream
- **For business use:**
  - **SDSL (Symmetric DSL)**
    - i.e. video conferencing
  - **HDSL (High bit-rate DSL)**
  - **VDSL (Very high bit-rate DSL)**





National Broadband Network (NBN)

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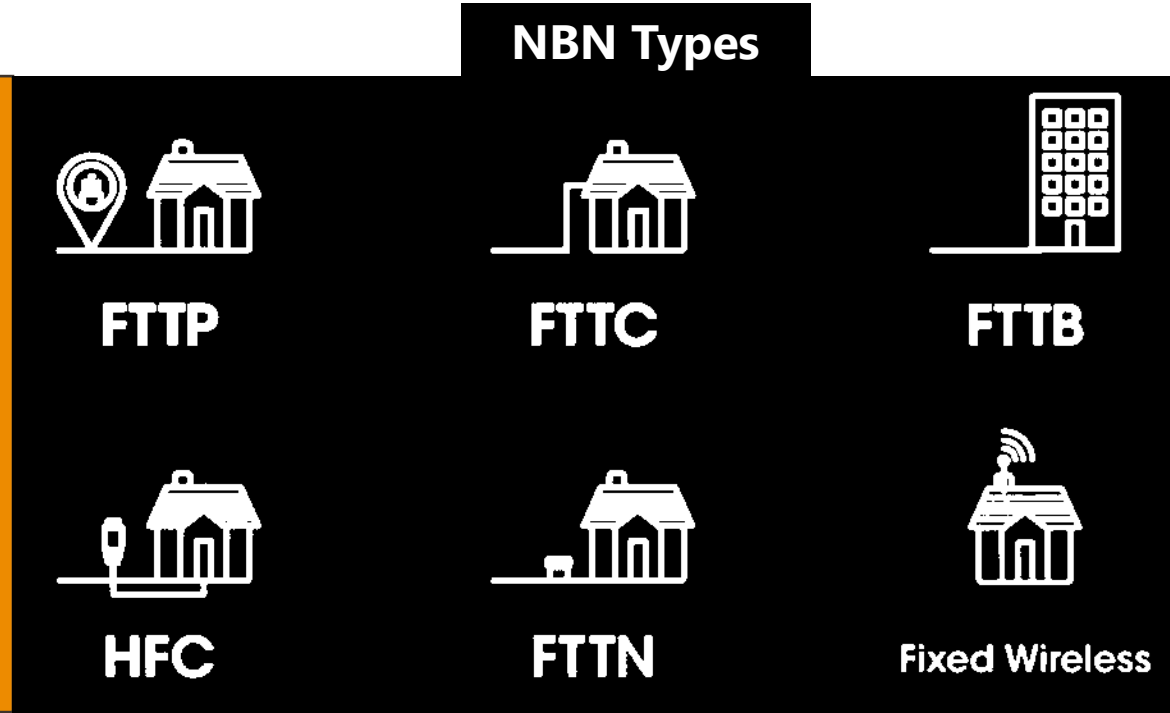
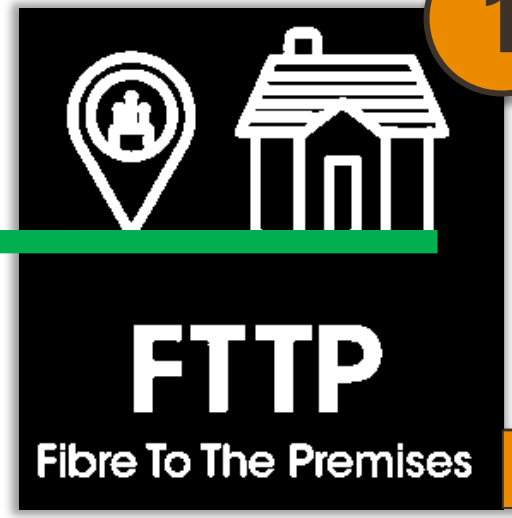
- National network of communication infrastructure currently being built on behalf of federal government
- **For internet and phone *(voip)***
- Aims to deliver network speed of **50Mbps – 1Gbps**

- Broadband Network via Fibre Optics, Fixed Wireless, Satellite Technology for home users
  - **Always on** connection *(no dialing)*



NBN Types

1

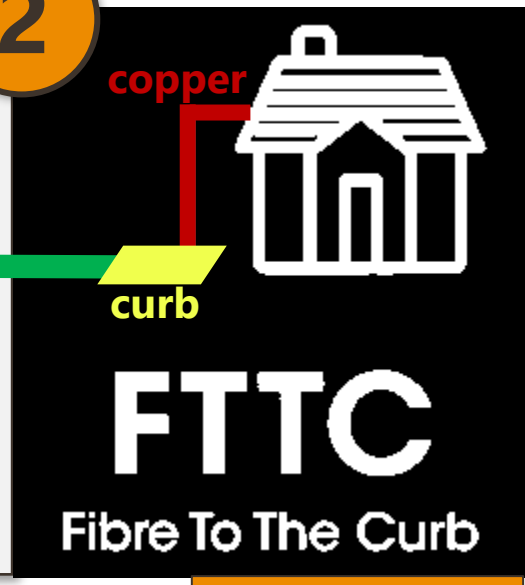


- Fibre is connected all the way from exchange to office/house
- **GOLD** standard in NBN

`<= 1 Gbps`

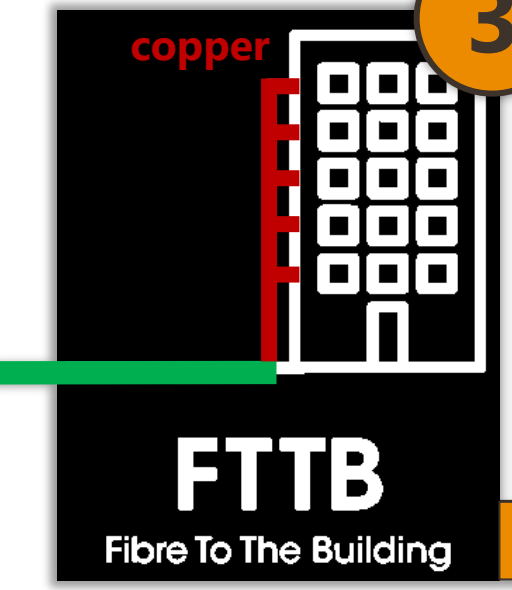
2

- Fibre to curb or driveway
- Existing copper lines from curb to premises



`<= 100 Mbps`

3

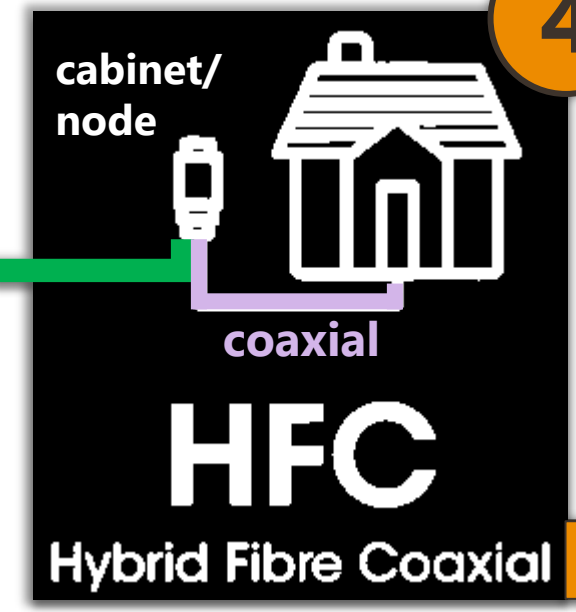


- Fibre to central point in the building
- Copper to each socket

`<= 100 Mbps`

NBN Types

4

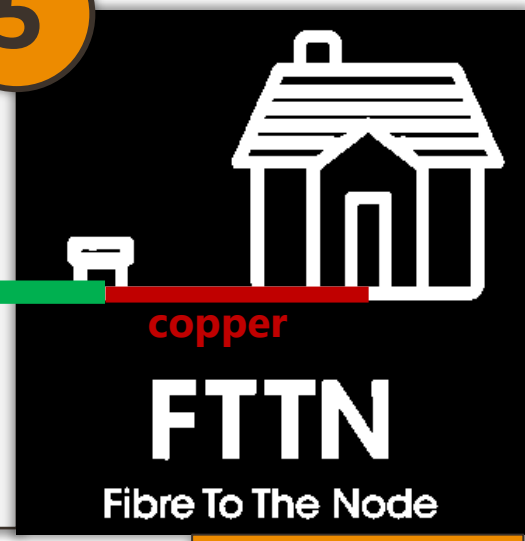


- Fibre to cabinet (a.k.a node) near your premises
- Existing coaxial cable from cabinet to premises

<= 100 Mbps

5

- Fibre to node near your premises
- Existing copper lines (50m-1.5km) from node to premises



25-100 Mbps

6

Remote areas

- Fixed antenna to receive the signal from the tower
- Wireless can be affected by many factors

12-50 Mbps

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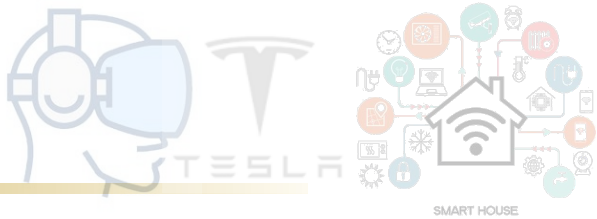
Last Mile Technologies – Cellular Networks

- 1G, 2G, 3G, 4G, **5G**
- 5G Technologies
  - Millimetre Wave
  - Massive MIMO
  - Small Cell
  - Beamforming
  - NOMA (non-orthogonal multiple access)
  - MEC (Mobile Edge Computing)

Cellular Networks



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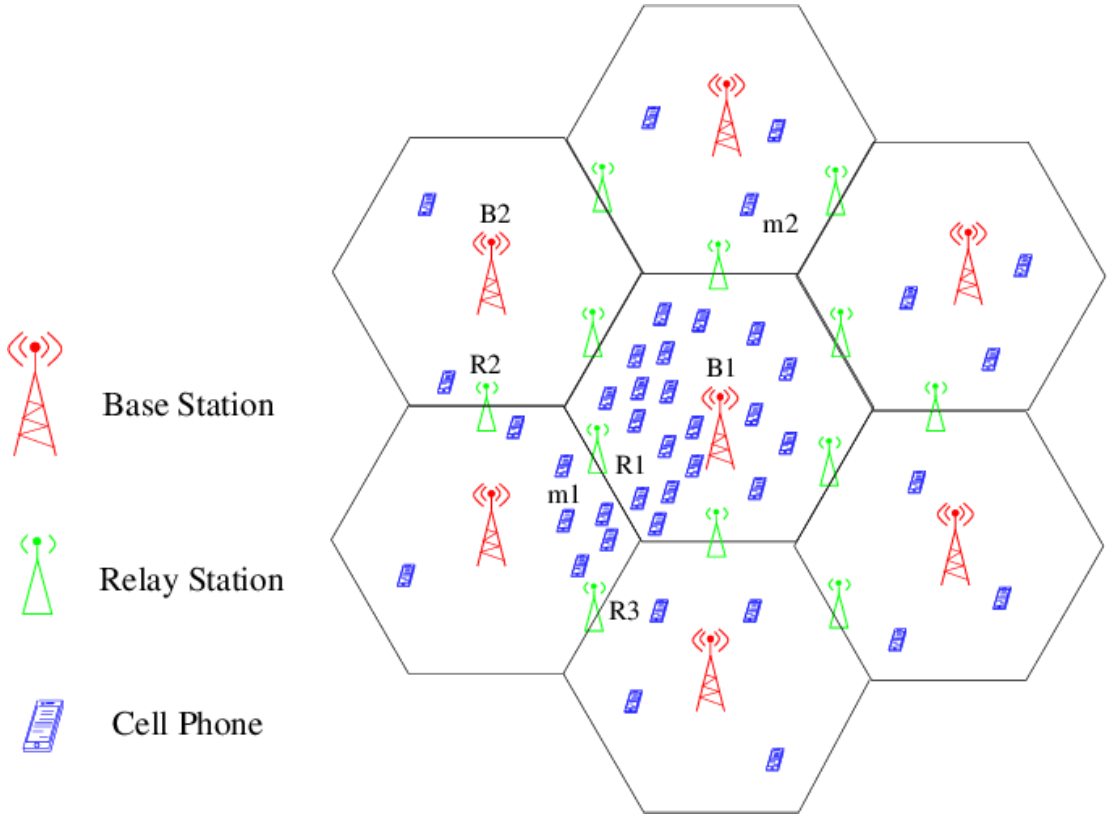
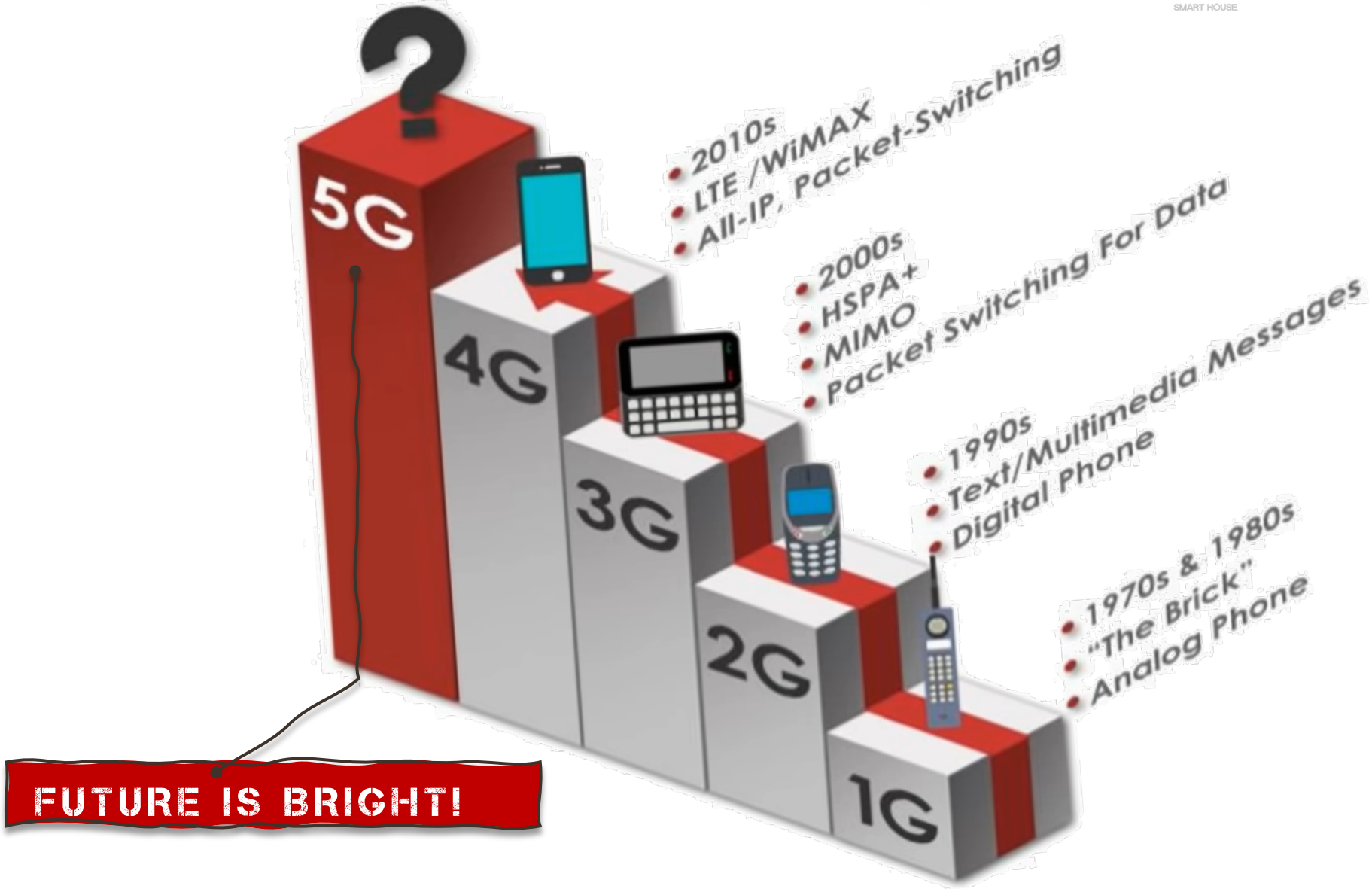
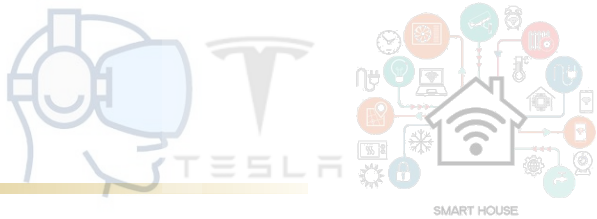
- High-speed, high-capacity voice and data communication networks
- Enhanced multimedia and seamless roaming capabilities for supporting cellular devices.



Cellular Networks



Cellular Networks



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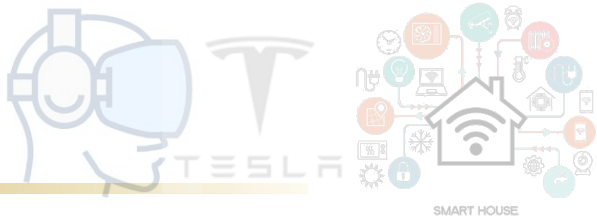
- **1G**: Analog signals only: voice calls
- **2G**: Ran on digital signals. SMS (and MMS).
- **3G**: Still in use today. Greater voice and data capacity and speed. Mobile phones are no longer just about making calls, but hubs of social connectivity.
- **4G**: Much faster than 3G (Up to 100Mbps). Offer connectivity for tablets and laptops as well as smartphones.

Cellular Networks



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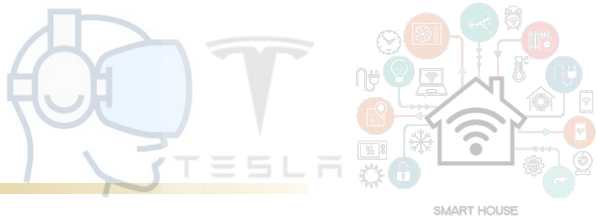
- **2020s: 5G era**
- High speed, low latency, and high connectivity
- 3 major categories:
  1. **Machine-to-machine communication: IoT**
  2. **Ultra-reliable low latency communications**
  3. **Enhanced mobile broadband**

5G Technologies



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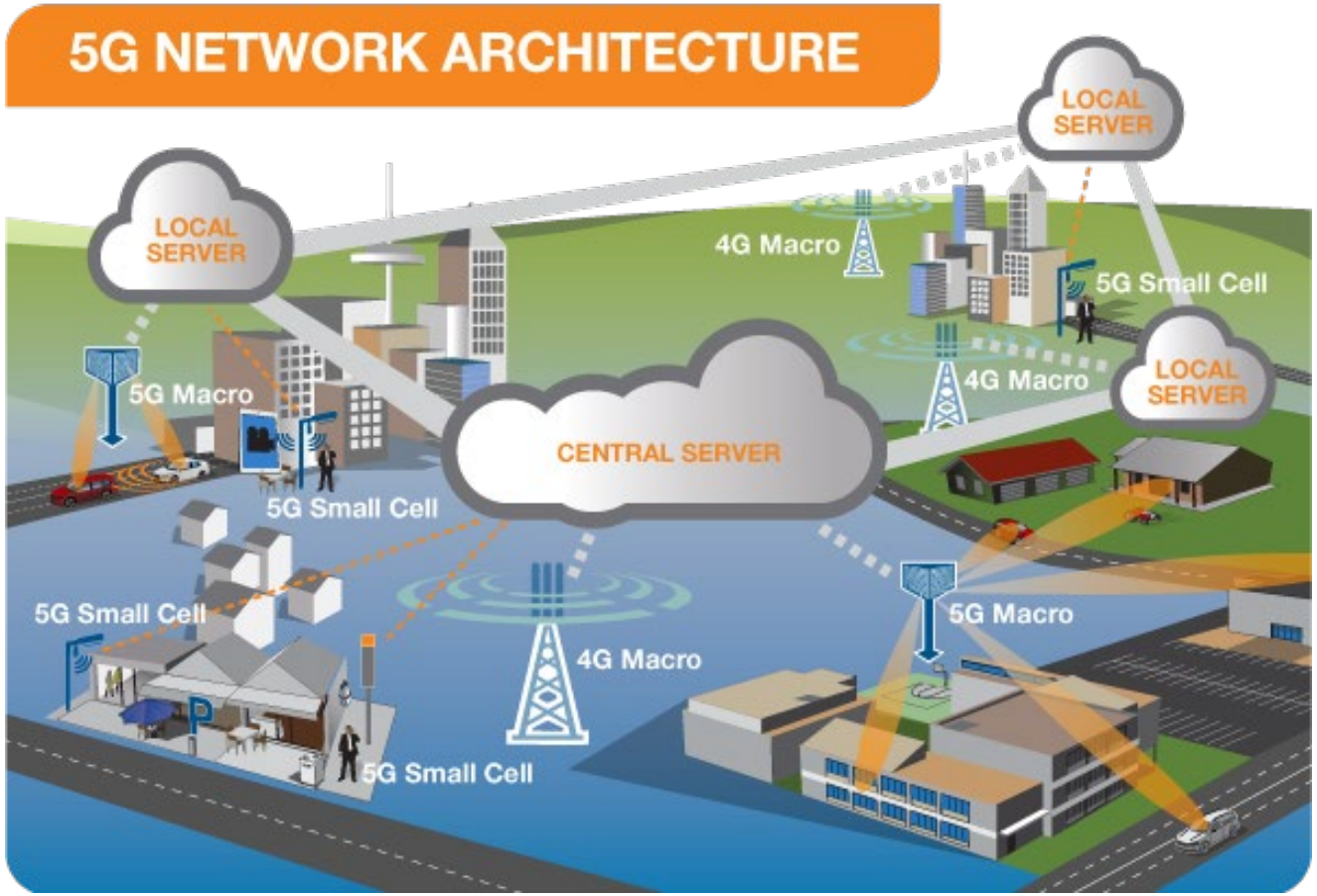
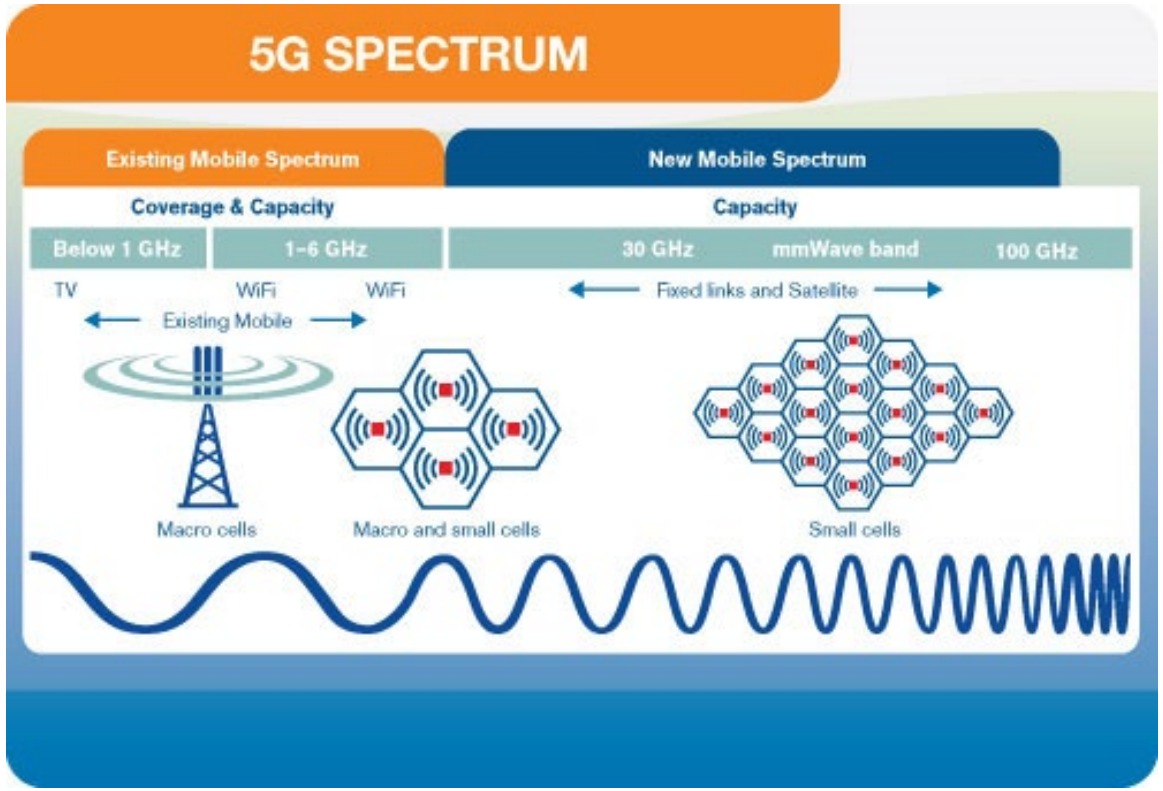
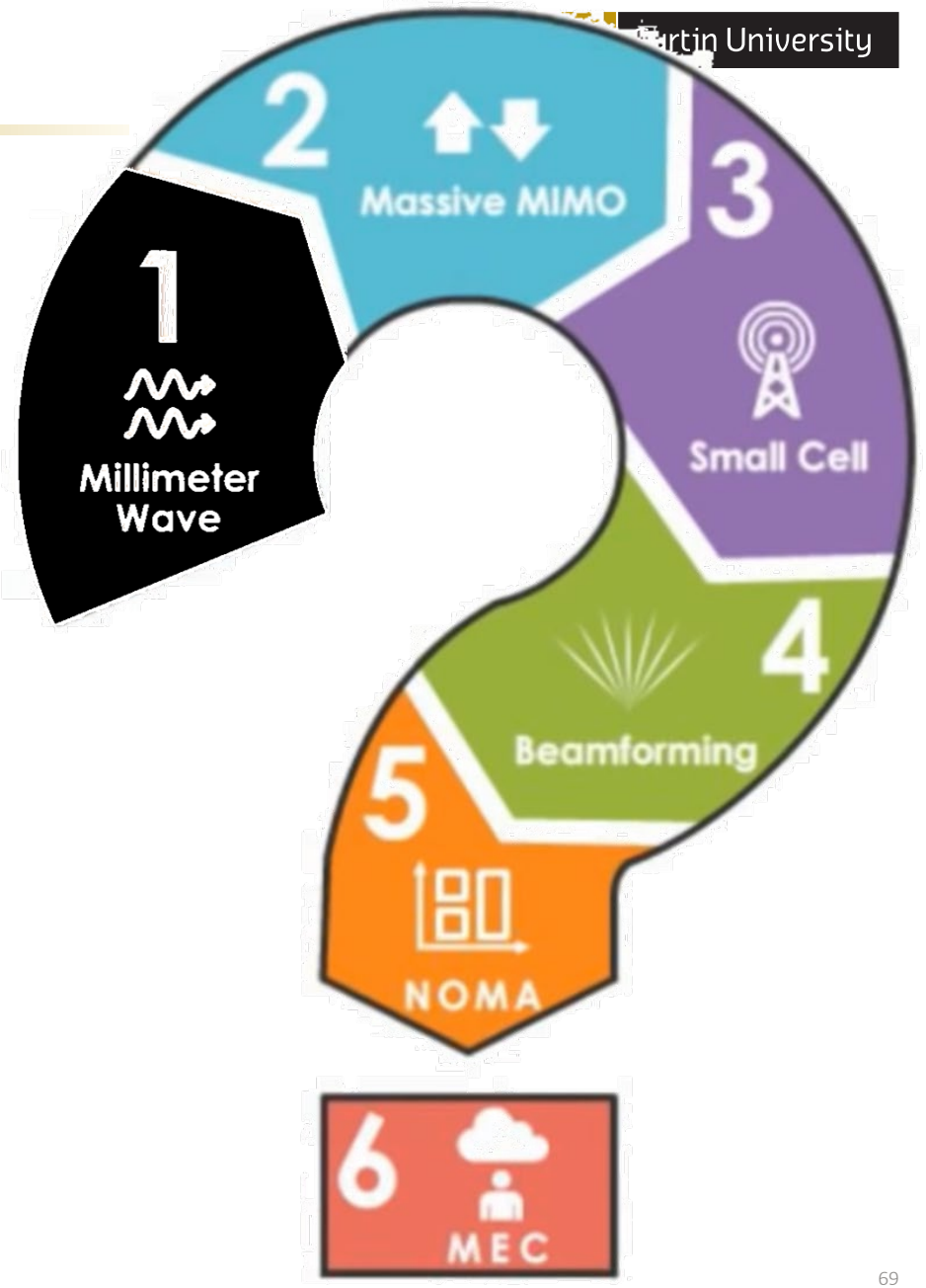
1. **Millimeter Wave**
2. **Massive MIMO**
3. **Small Cell**
4. **Beamforming**
5. **NOMA**
6. **MEC**



Millimeter Wave

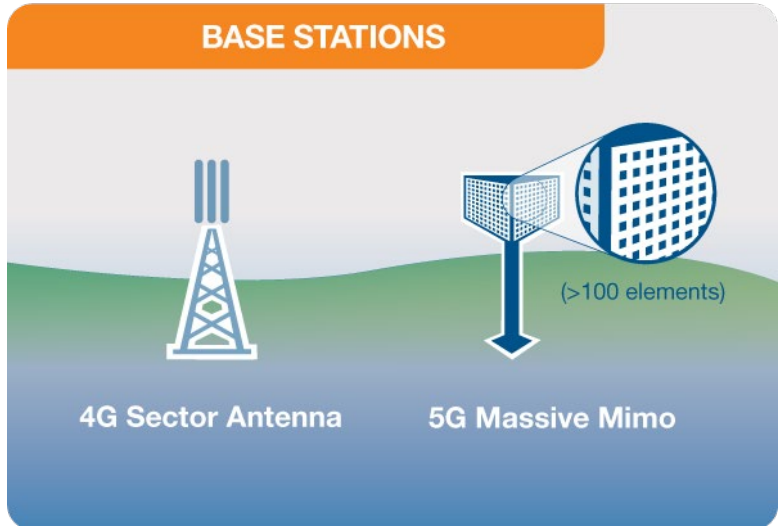
- New and less used band
- Higher frequency wave carry more data
- Supports having a massive MIMO antenna

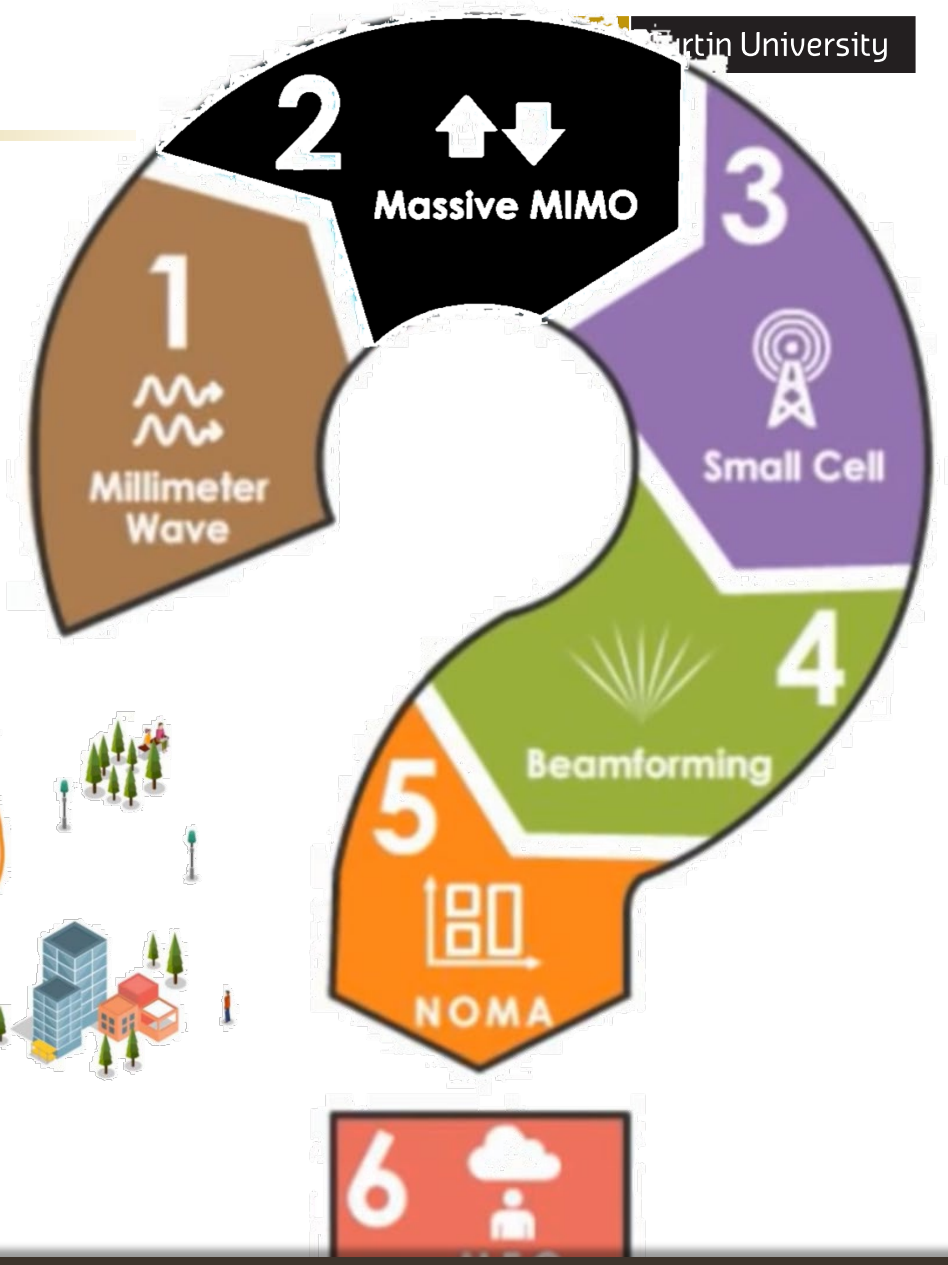




Massive MIMO

- A lot of transmitters and receivers installed on a small size cell or panel

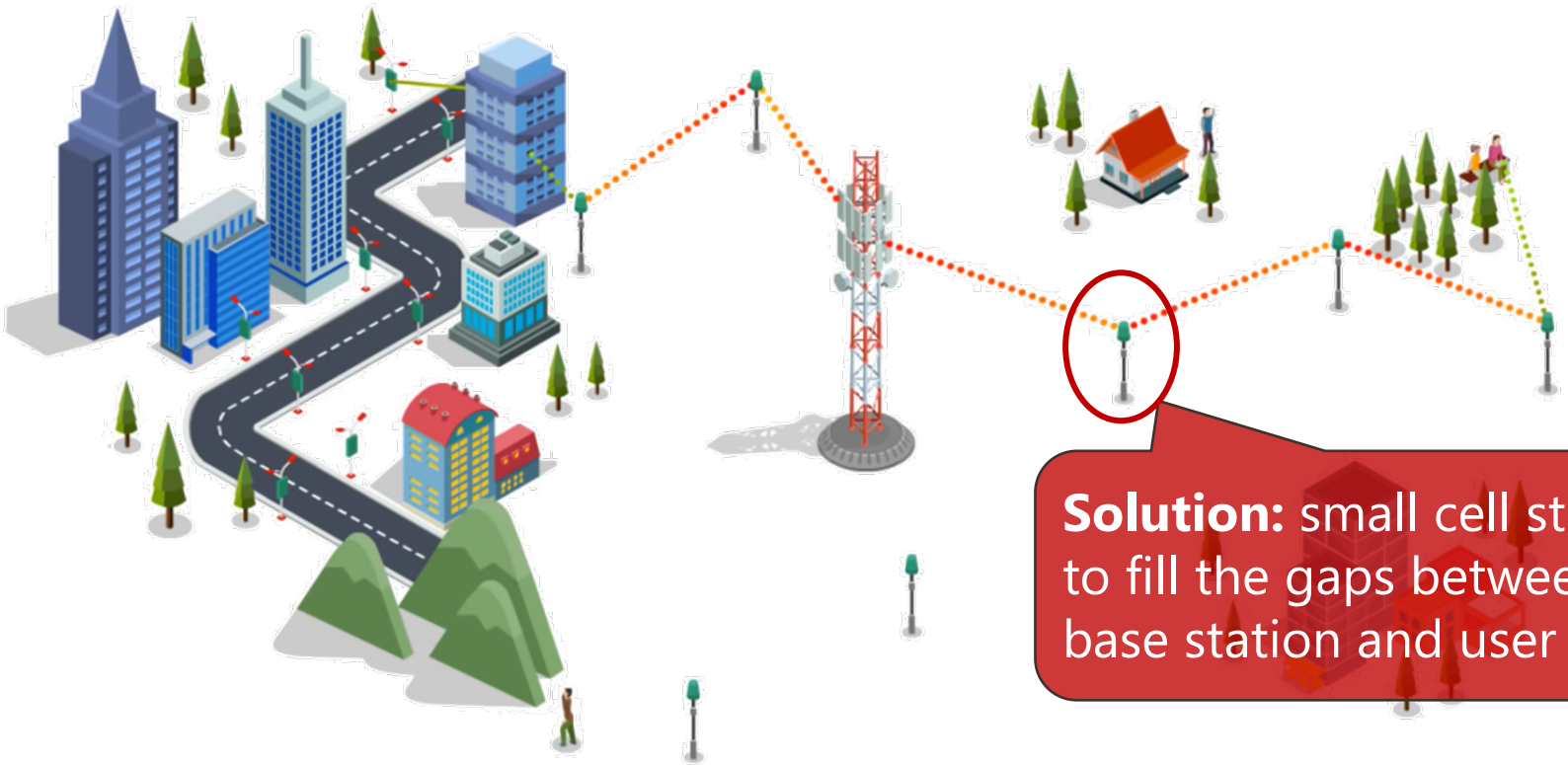




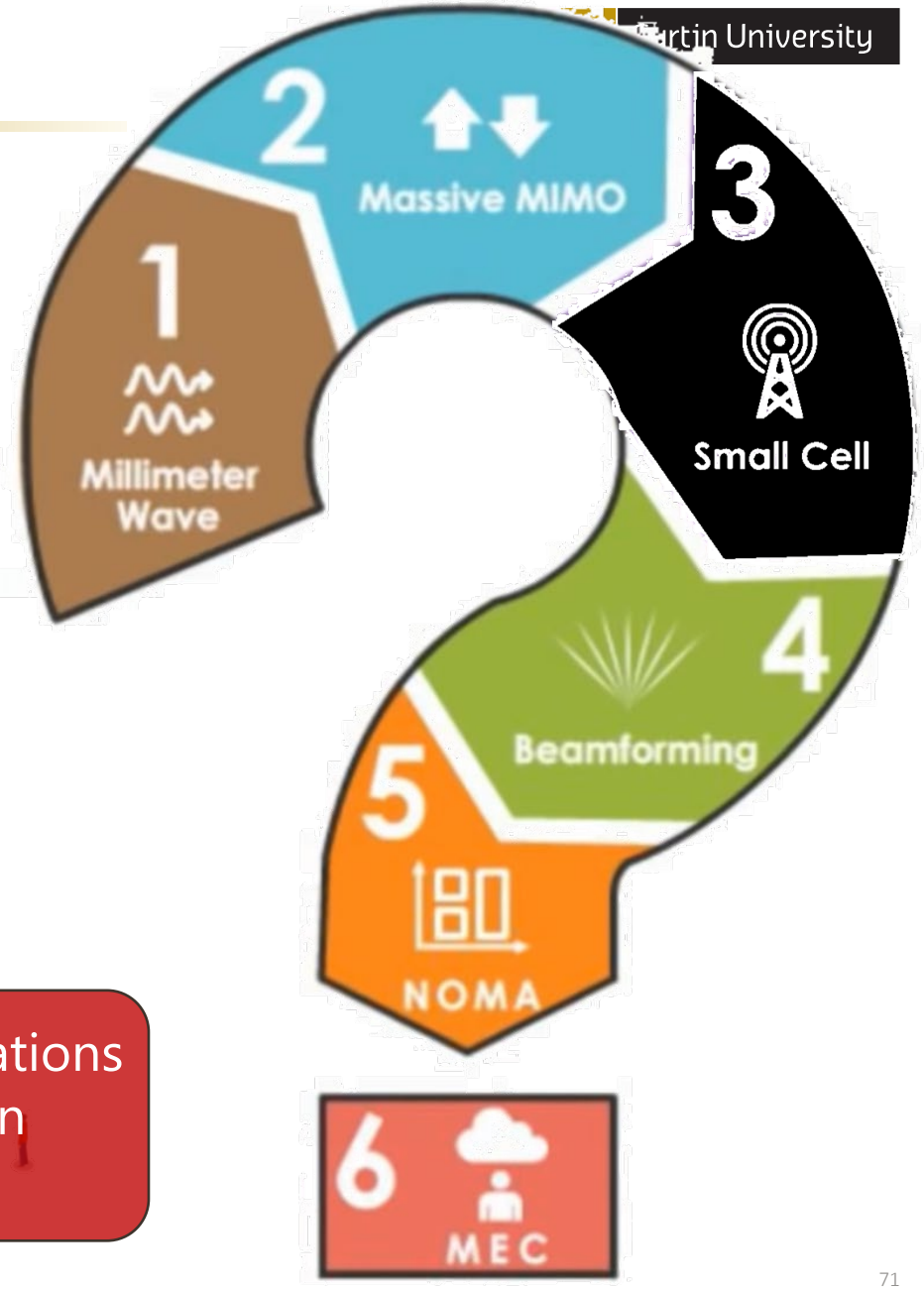
MIMO: Multiple Input Multiple Output

Small Cell

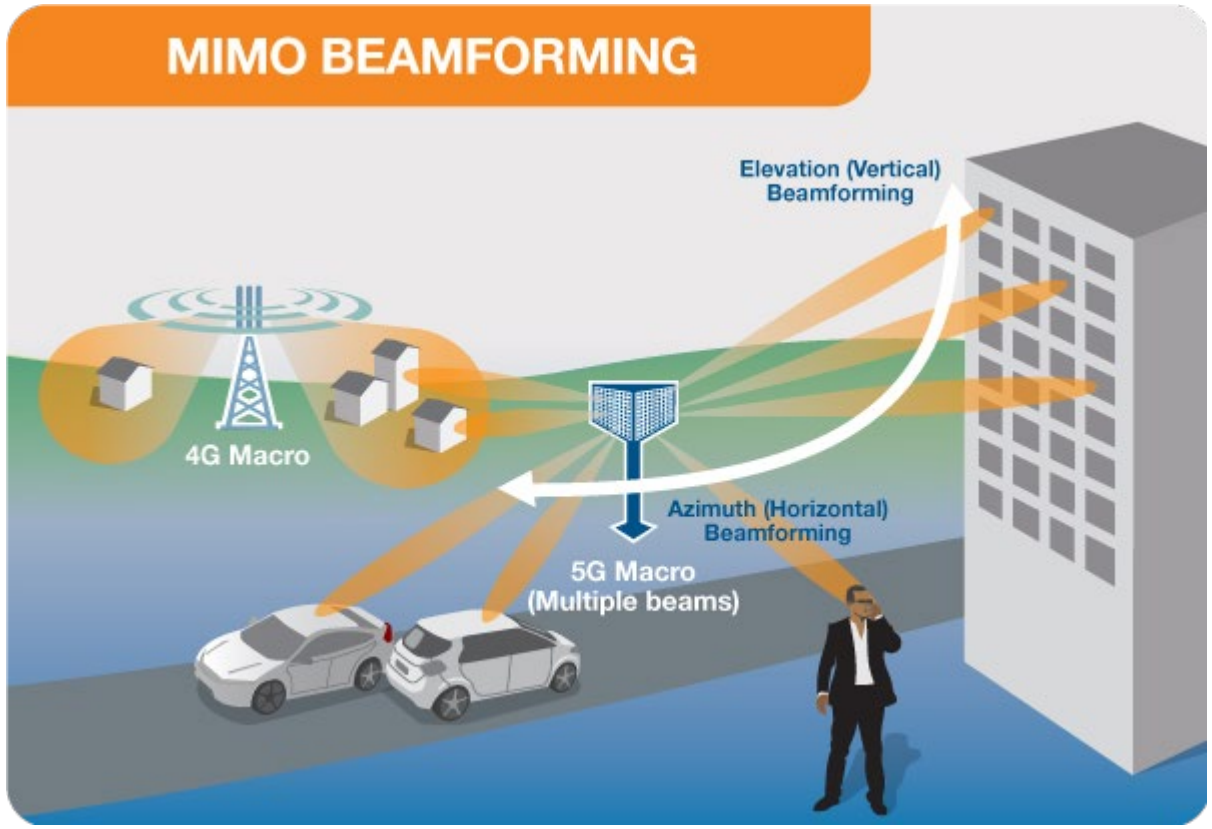
- **High freq. signals** have **more collisions** with obstacles in the air/on the ground
- Thus able to **cover shorter distance**



Solution: small cell stations to fill the gaps between base station and user

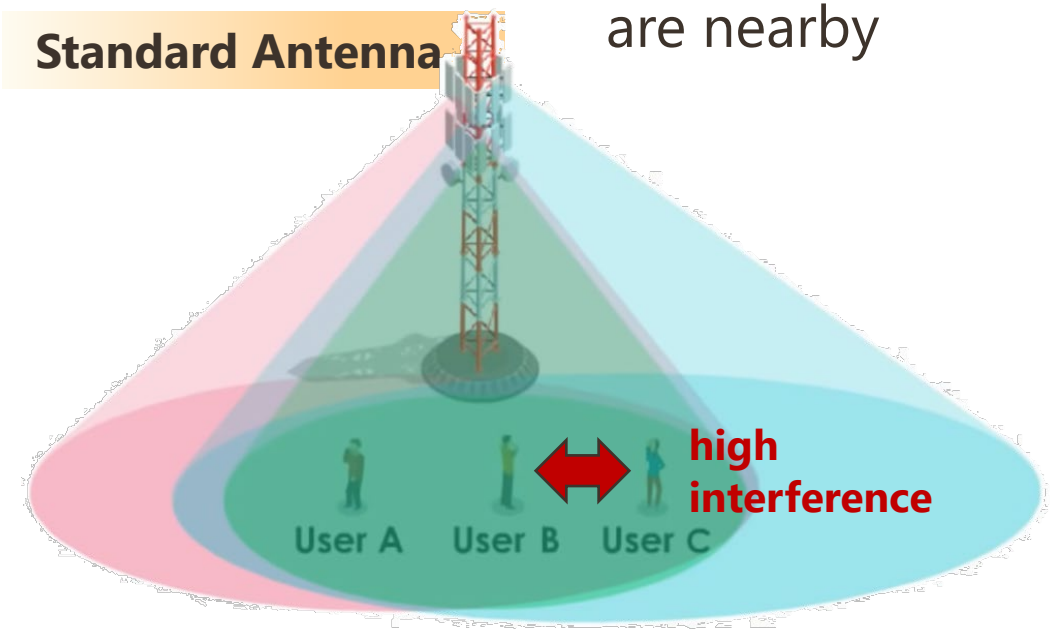


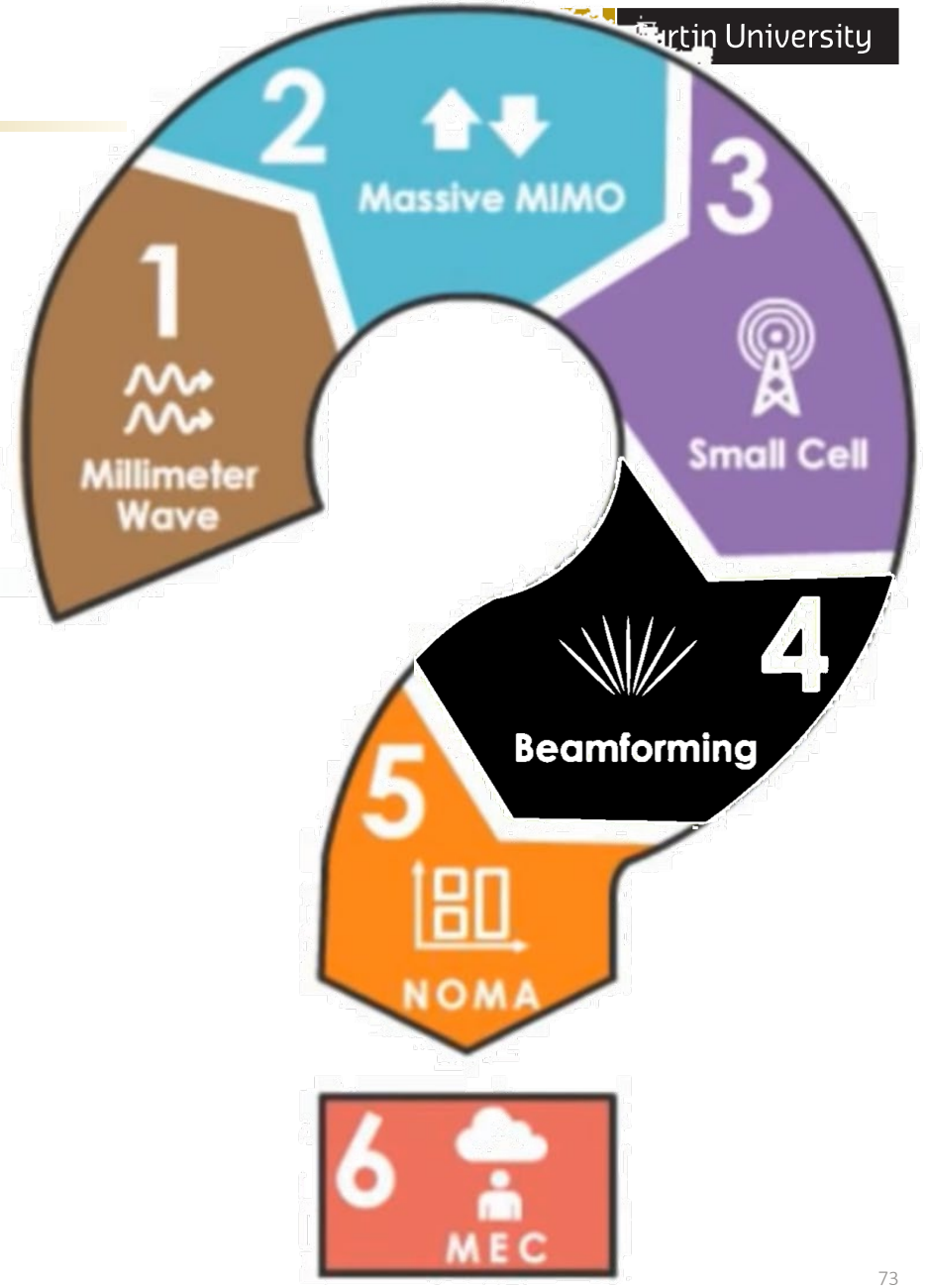
Beamforming



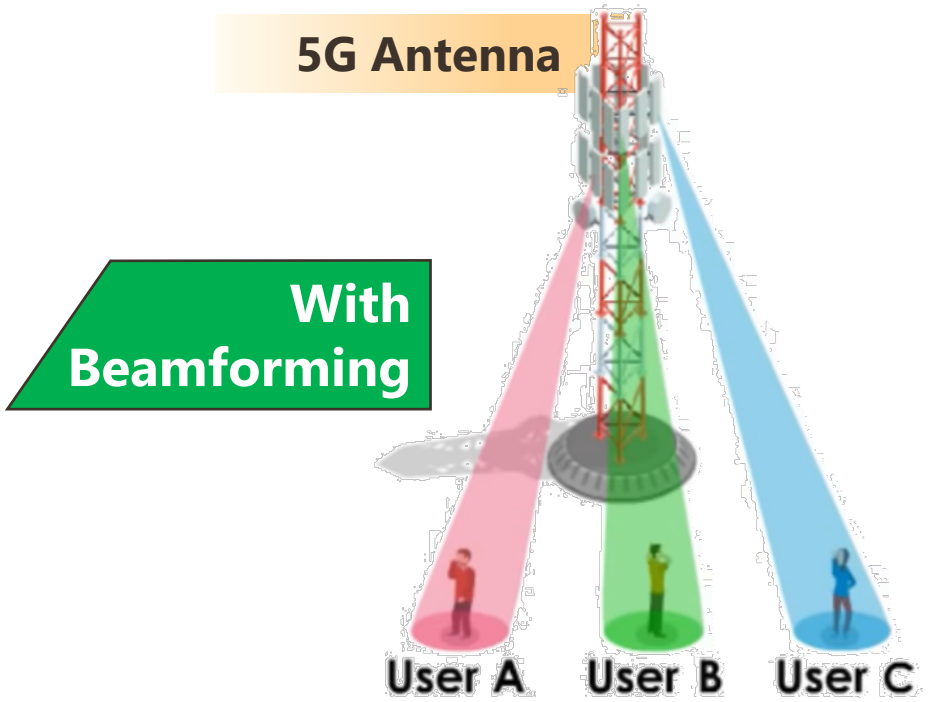
Beamforming

- **4g signals are omni directional** spreads over large area as they travel – lose energy
- **Interference is worse** when users are nearby





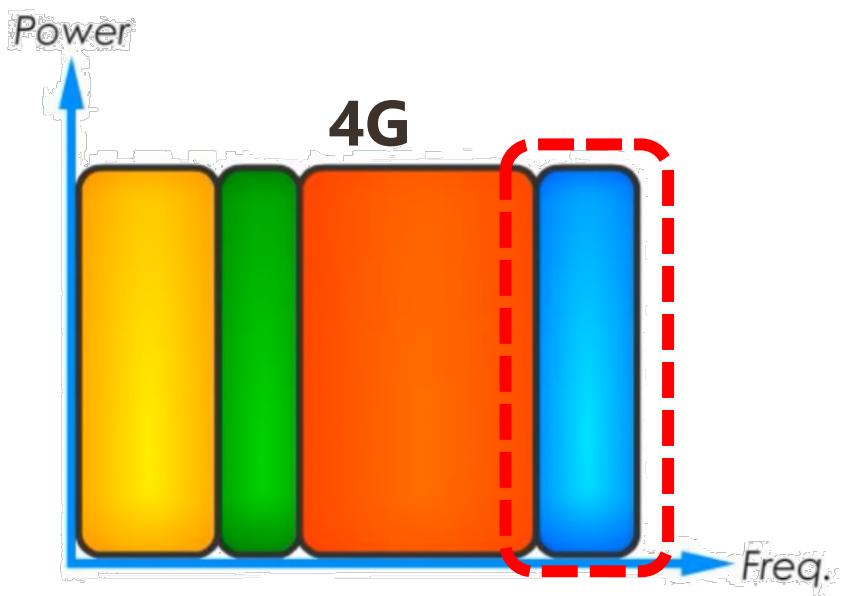
Beamforming



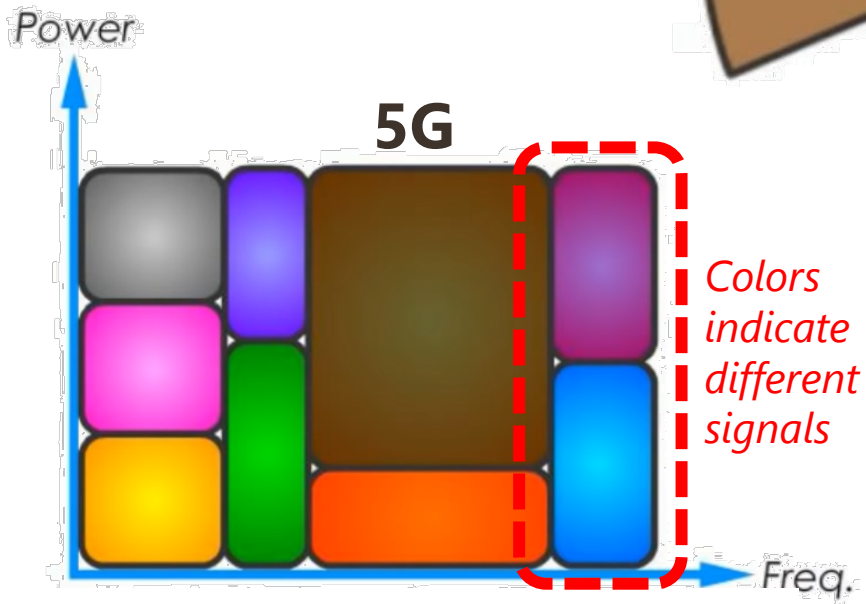
- ✓ Transmission between user and base/cell station **more directional** (i.e. laser beam)
- ✓ Less interference, less energy consumption

NOMA

- Non-Orthogonal Multiple Access
- Allow **different signals share** the **same channel simultaneously**

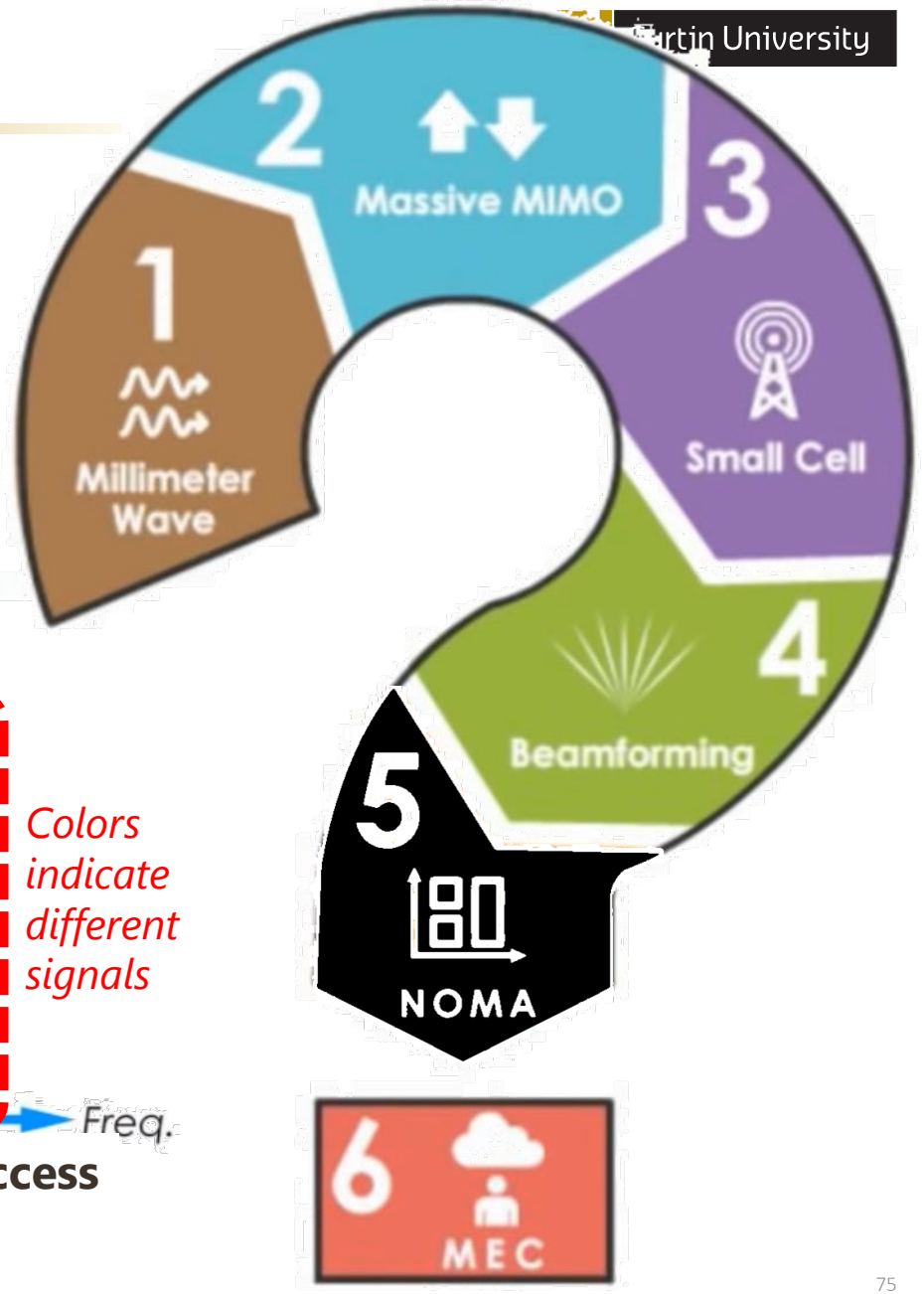


Orthogonal Multiple Access



Colors indicate different signals

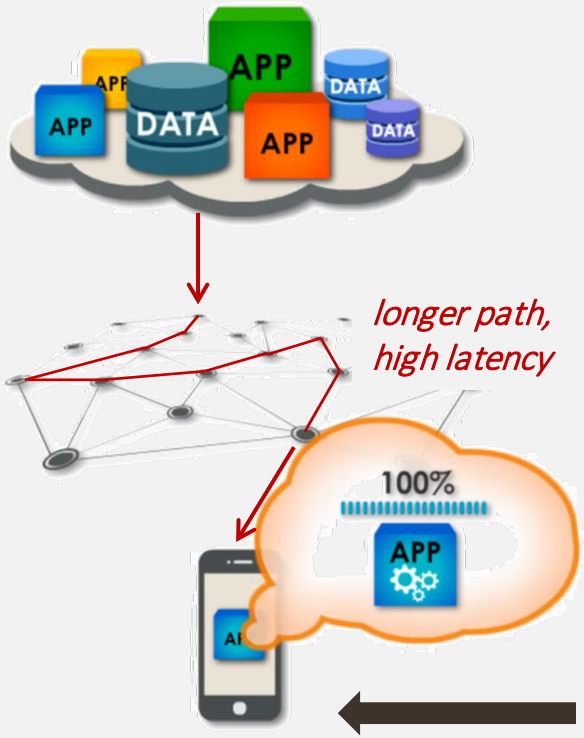
Non-Orthogonal Multiple Access



Mobile Edge Computing (MEC)

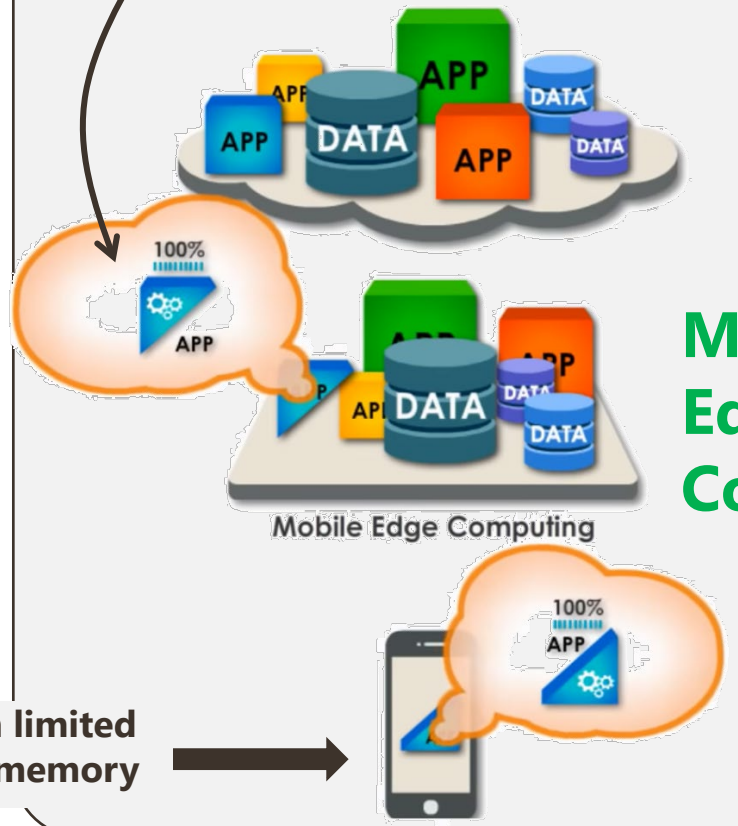
Cloud Computing

- Cloud is far away from users
- Users required to download many data and apps

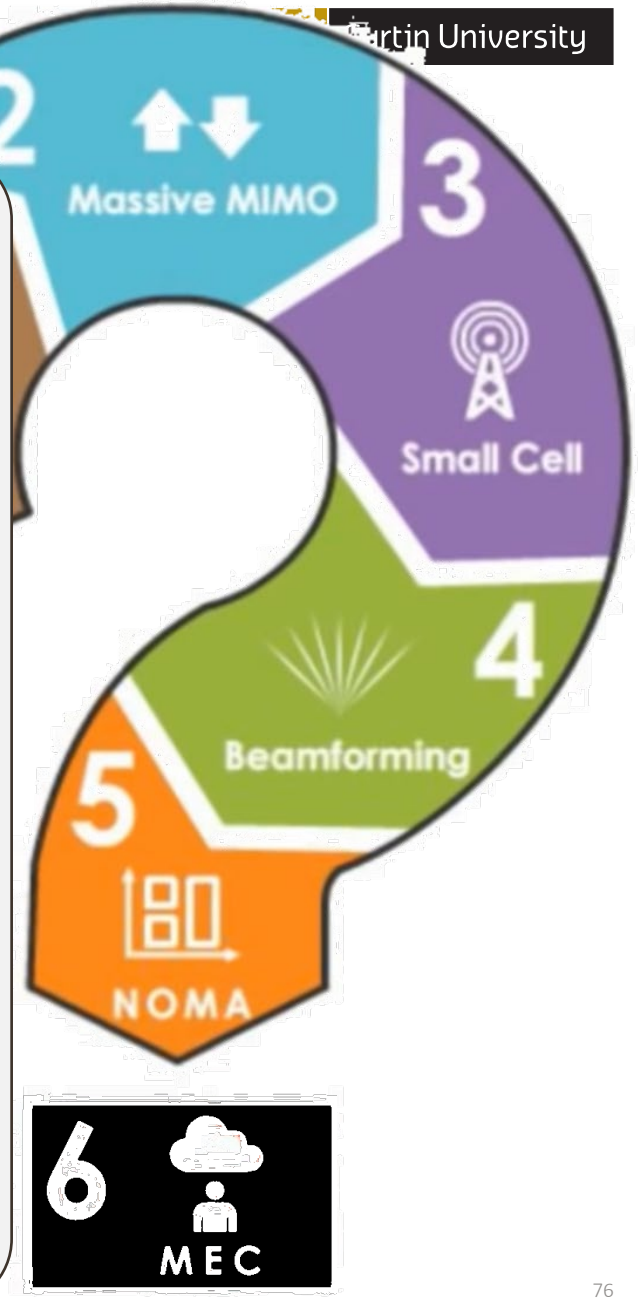


Move cloud computing and **services** closer to the device (**edge of the** local **network**)

Application splitting (some tasks performed at device and some at the cloud)



Mobile Edge Computing



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- **Physical Layer**
  - Fundamentals
  - Services
- **Signals**
  - Analog vs Digital
  - Analog to Digital vice versa
  - Signal Attenuation and Amplification
- **Digital Encoding**
  - Bit Encoding
  - Manchester Encoding
  - Differential Manchester Encoding
  - MLT-3
- **Medium Capacity**
  - Bandwidth, Speed, Lag, Throughput
  - Multiplexing
    - FDM
    - TDM
- **Network Topologies**
  - Physical topology
  - Logical topology
  - Hybrid topology
- **Transmission Media**
  - Transmission Modes
  - Simplex, Half-Duplex, Full-Duplex
  - Guided Media
  - Unguided Media
- **Last Mile Technologies**
  - Dial-up
  - ISDN
  - DSL
  - NBN
  - Cellular Networks
    - 1G, 2G, 3G, 4G, 5G
    - 5G Technologies


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THANK YOU
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