Access and Core Networks

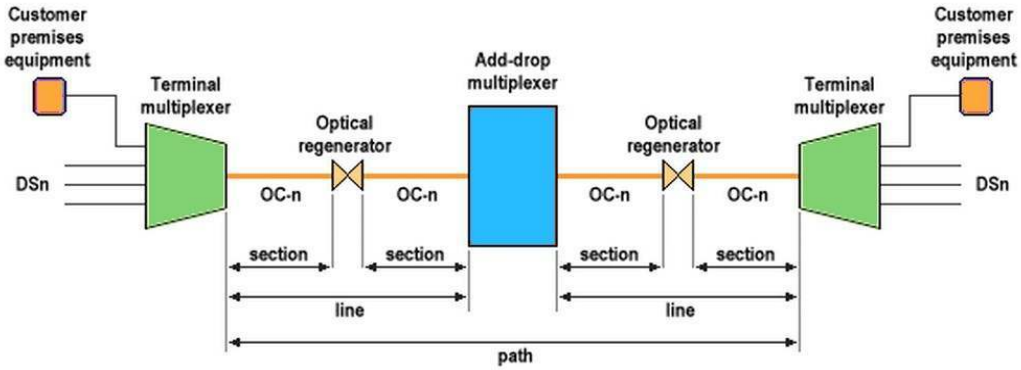
universidade de aveiro
deti.ua.pt

SONET/SDH

- Synchronous Optical NETwork (SONET) – North America
  - TDM physical layer standard for optical fiber communications.
    - Compatible with US and Canada PDH - 8000 frames/sec - T frame = 125 µsec.
    - Point-to-point (linear) or ring Optical Carriers (OC)
  - ITU version = Synchronous Digital Hierarchy (SDH) – Rest of the World
    - Small differences, but interoperable at higher speeds.
  - Direct mapping of lower levels into higher ones
  - SONET frames: STS. SDH frames: STM.
    - Transport all PDH types in one universal hierarchy.
    - Also transports ATM cells and general packet data.
  - SONET Add-Drop Multiplexing
    - Allows taking individual channels in and out without full demultiplexing.

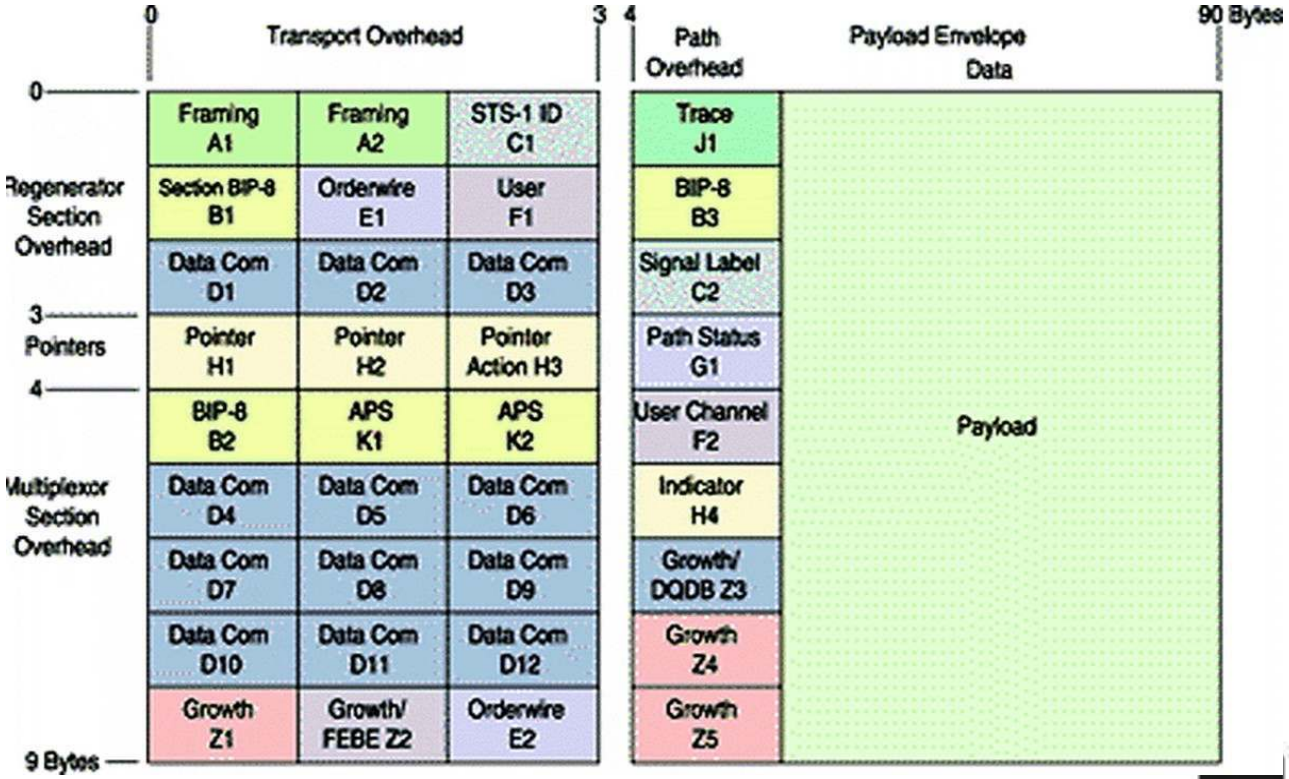
SONET/SDH Designations and bandwidths

SONET Optical Carrier Level	SONET Frame Format	SDH level and Frame Format	Payload bandwidth[nb 3] (Kbit/s)	Line Rate (Kbit/s)
OC-1	STS-1	STM-0	50,112	51,840
OC-3	STS-3	STM-1	150,336	155,520
OC-12	STS-12	STM-4	601,344	622,080
OC-24	STS-24	–	1,202,688	1,244,160
OC-48	STS-48	STM-16	2,405,376	2,488,320
OC-192	STS-192	STM-64	9,621,504	9,953,280
OC-768	STS-768	STM-256	38,486,016	39,813,120
OC-3072	STS-3072	STM-1024	153,944,064	159,252,480



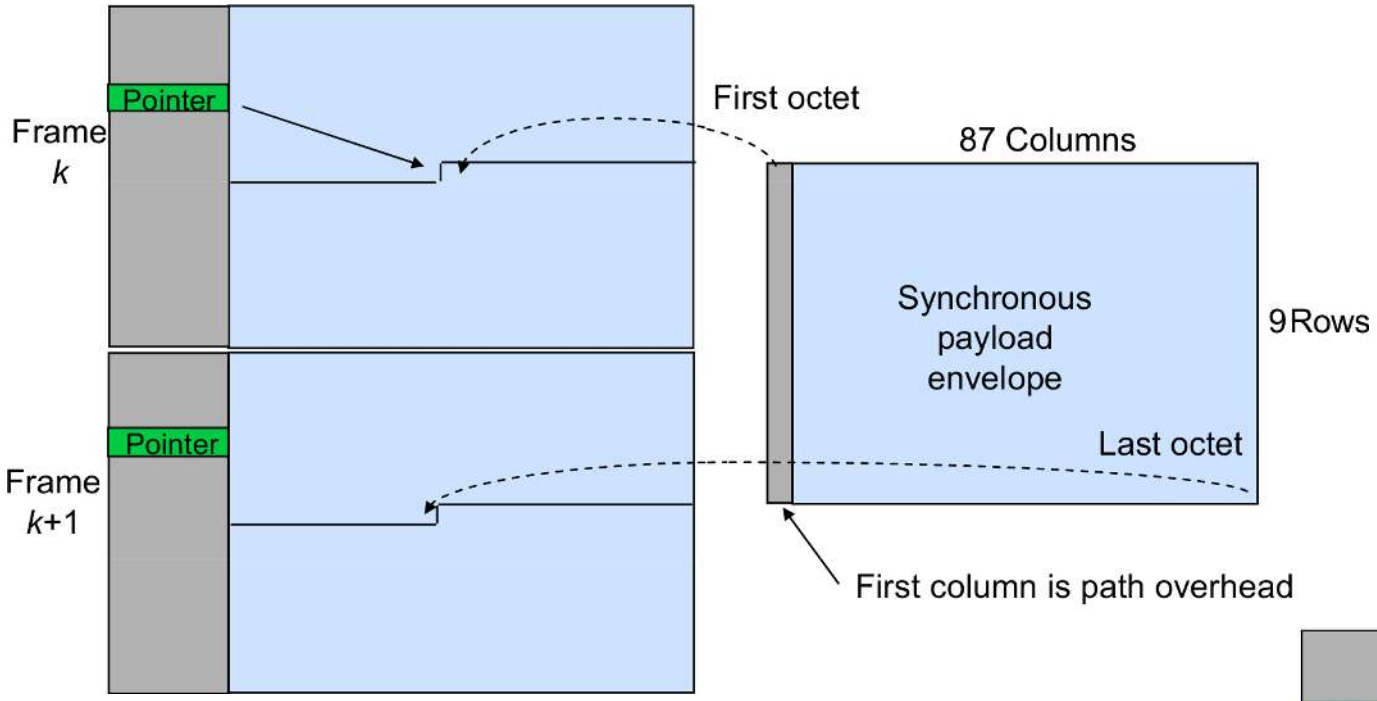
STS Frames

- Transport Overhead (TOH):
  - Processed at every SONET node.
  - Occupies a portion of each SONET frame.
  - Carries management and link integrity information.
- Synchronous Payload Envelope (SPE):
  - Path Overhead (POH),
    - Inserted & removed at the ends.
  - Data/Payload.
- STS-1 Frame: 9 rows x 90 cols.
  - 810 bytes per frame, 8000 frames/sec → 51.84Mbps
  - 810x64kbps → 51.84Mbps
- Special OH bytes
  - H1, H2, H3: Pointer Action

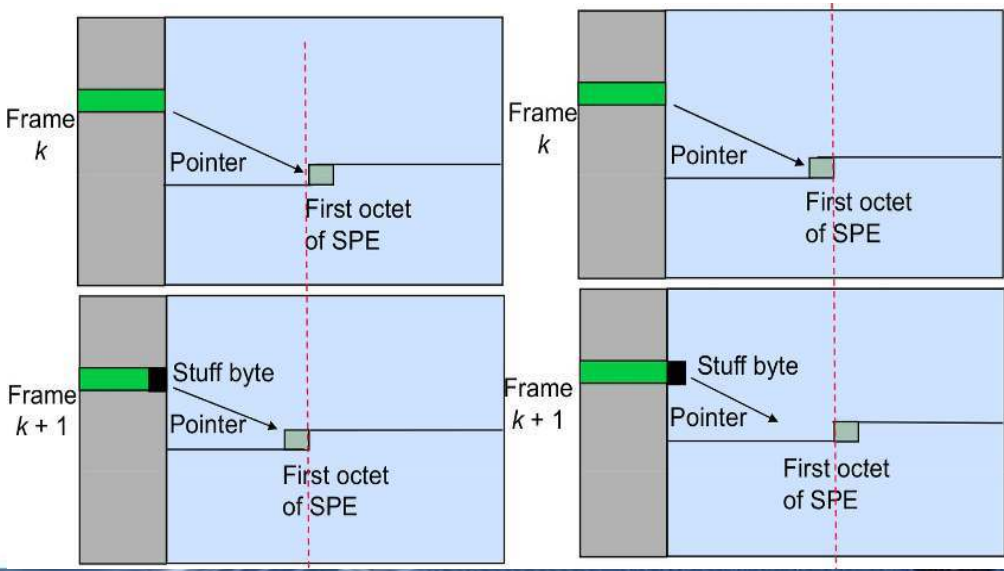


SPE Over Consecutive Frames

- Pointer indicates where SPE begins within a frame

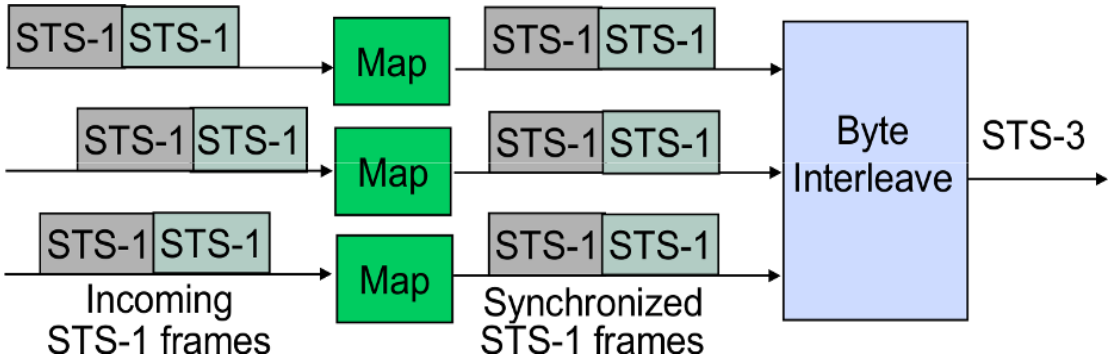


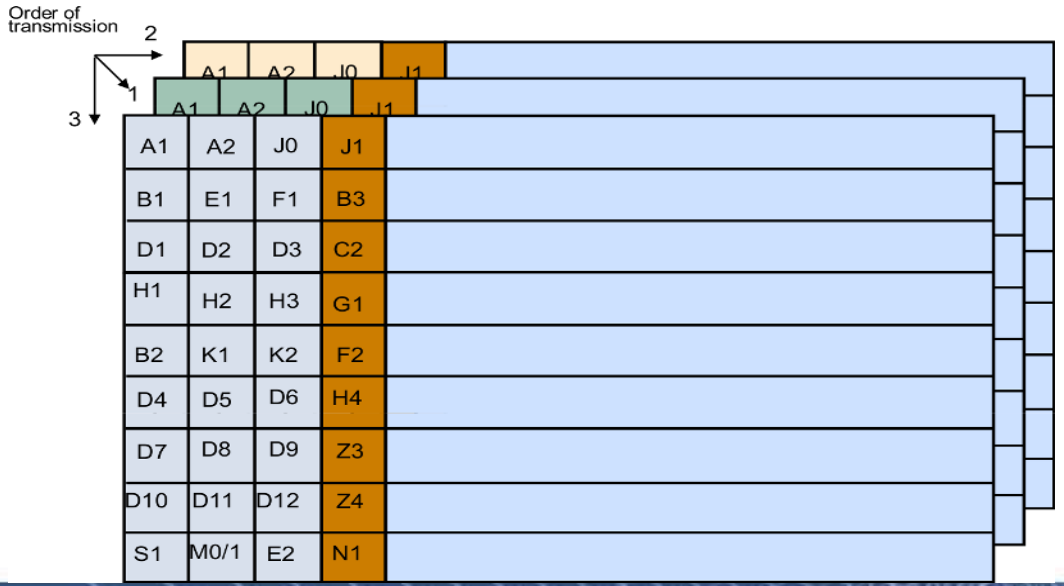
- Pointer enables add/drop capability
  - Positive/negative byte stuffing.



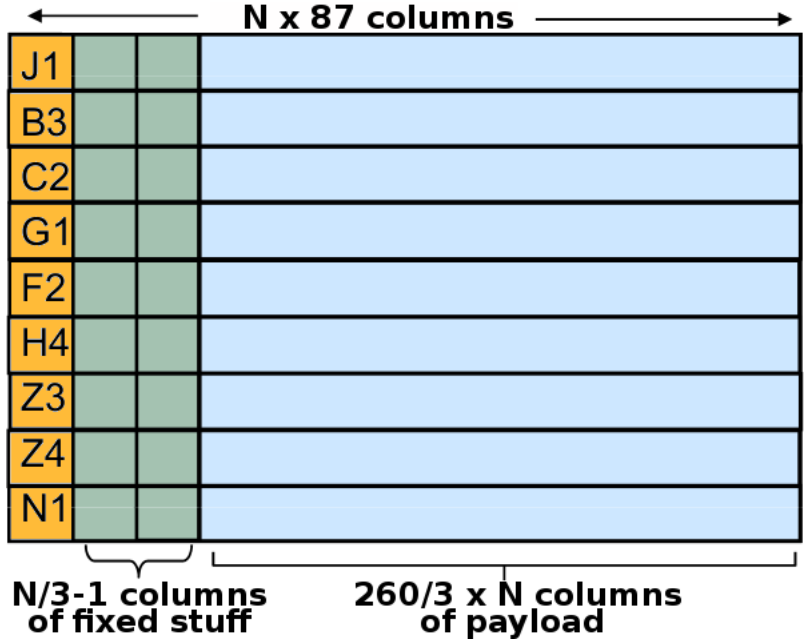
STS Multiplexing

- Synchronous/Channelized
  - Synchronize each incoming STS-1 to local clock → STS-1s.
  - All STS-1s are byte interleaved to produce STS-n.



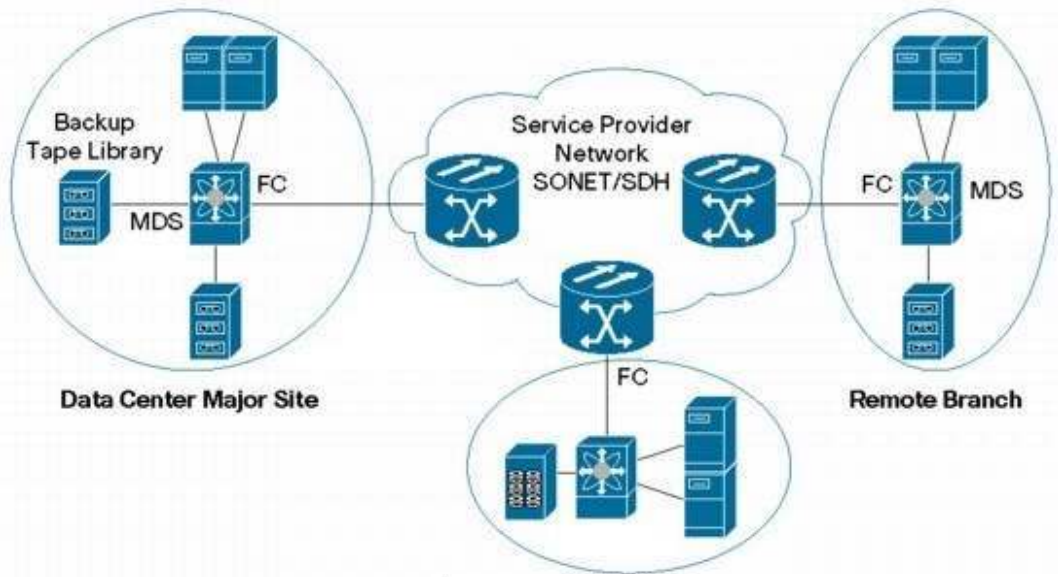


- Concatenated Payload
  - H1,H2,H3 tell us if there is concatenation
  - STS-3c has more payload than 3 STS-1s
  - STS-Nc payload = Nx260/3x9 bytes
  - Payload rates
    - OC-3c = 149.760 Mbps, OC-12c = 599.040 Mbps, OC-48c = 2.3961 Gbps, OC-192c = 9.5846 Gbps
- OC-Nc Concatenated Payload

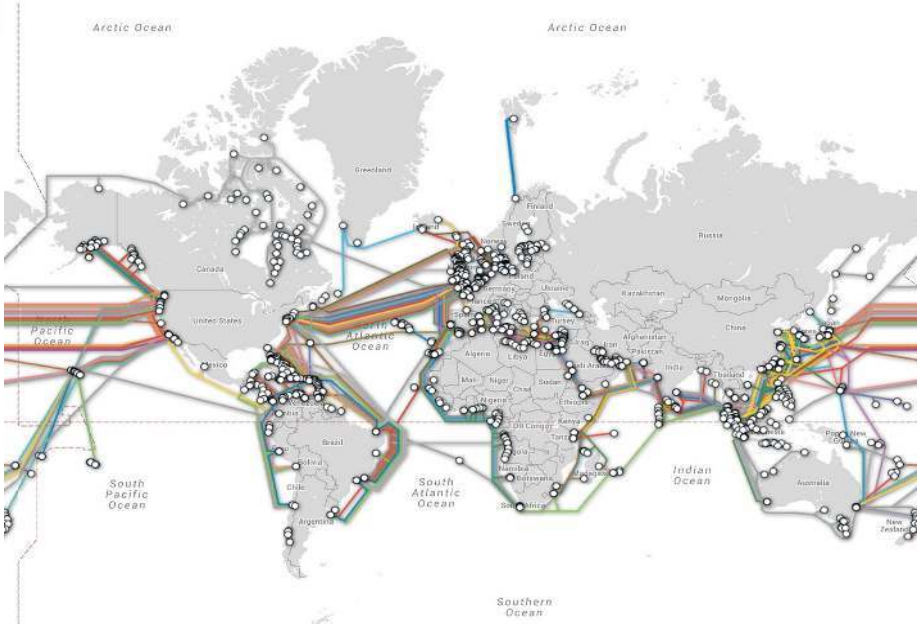


SONET/SDH Usage

Network/ISP Core

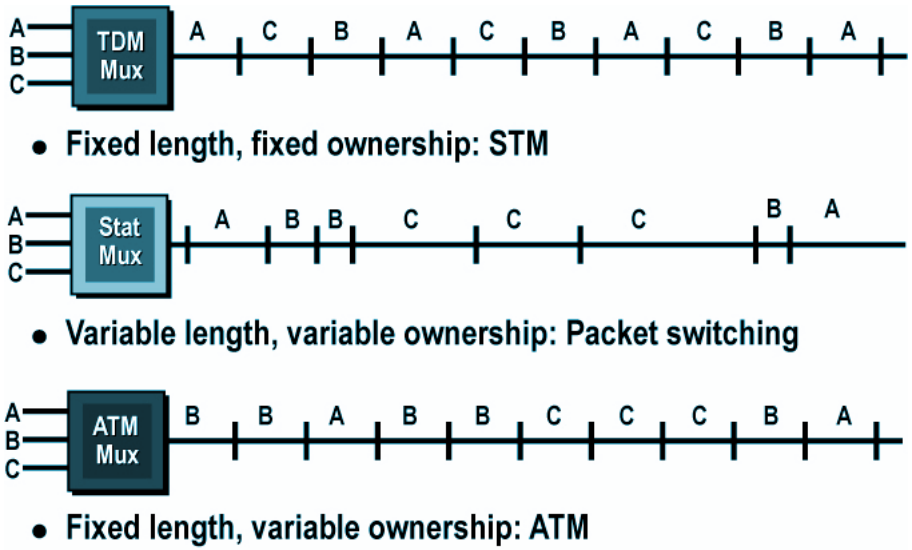


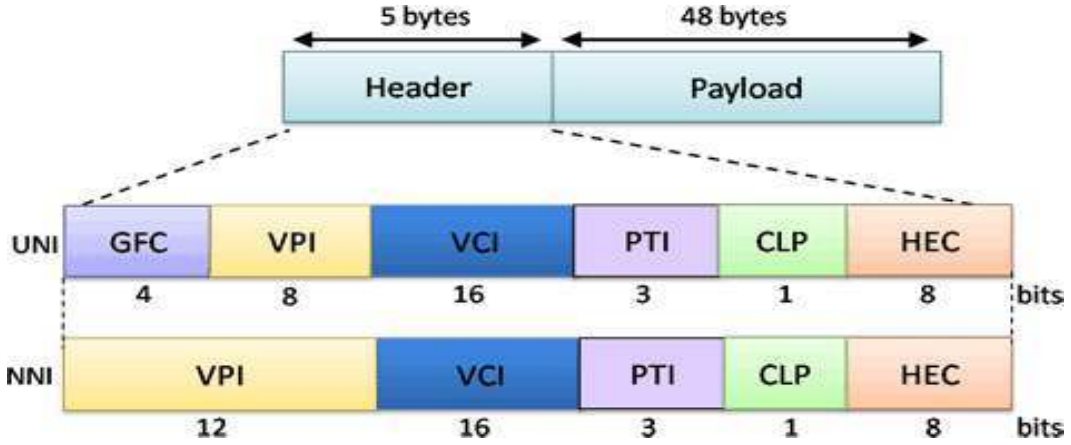
Long-range point-to-point links



Asynchronous Transfer Mode (ATM)

- ATM is a blend of Synchronous Transfer Mode (STM) and packet switching.
  - It has variable assignment, based on the arrival rate and delay sensitivity of the traffic.
  - However, after the assignment occurs, uses fixed-length time slots called cells.
    - Delay-sensitive traffic has immediate assignment
    - Data traffic can be temporarily buffered before being transmitted.
- Is a form of cell switching using small fixed-sized data units called cells.
  - 53 bytes: 5 header and 48 data.



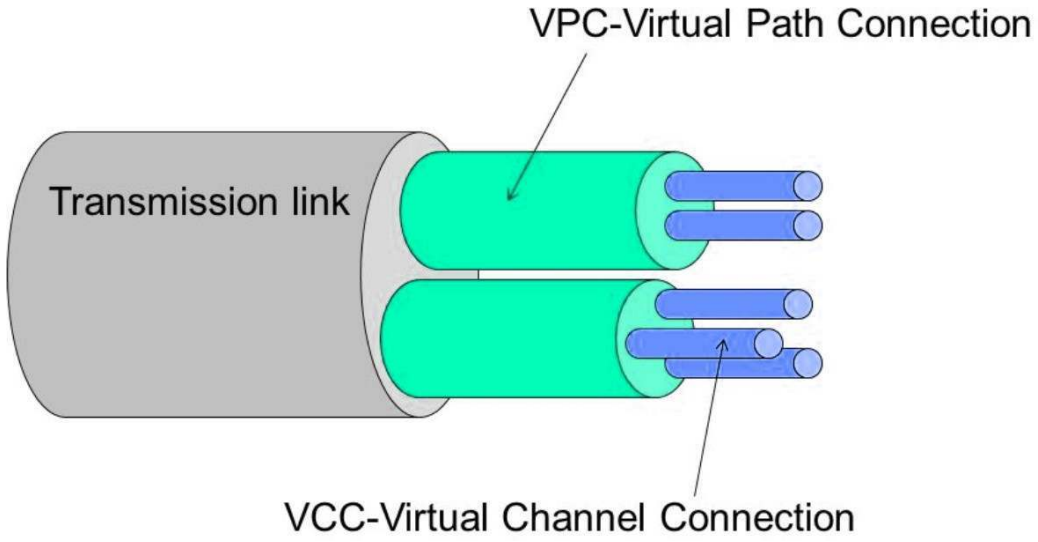


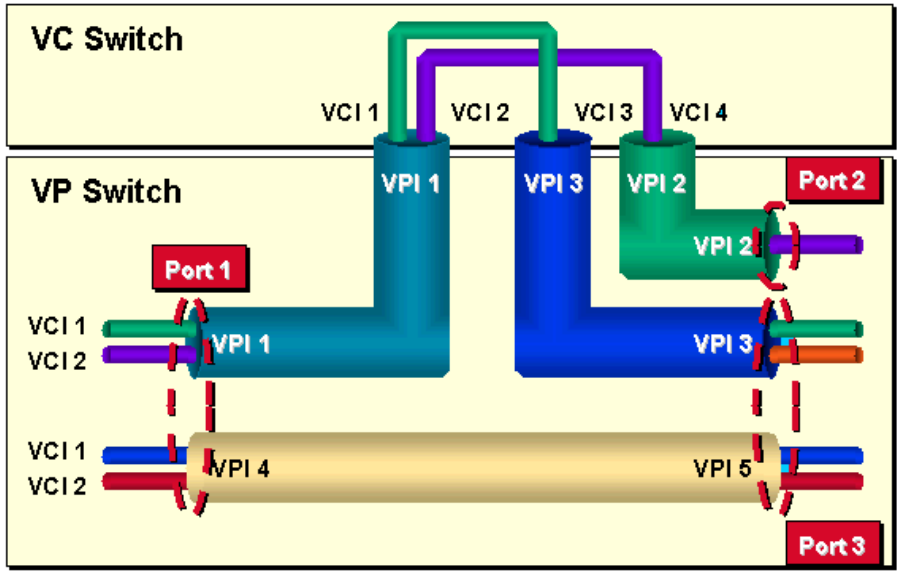
UNI (User-Network Interface).
NNI (Network-Network Interface).

ATM Connections and Switching

- ATM is connection-oriented.
  - A connection (an ATM channel) must be established before any cells are sent.
  - Two levels of ATM connections:
    - Virtual path connections.
    - Virtual channel connections.
    - Indicated by two fields in the cell header:
    - Virtual Path Identifier: VPI.
    - Virtual Channel Identifier: VCI.
- Switching based on VPI/VCI.

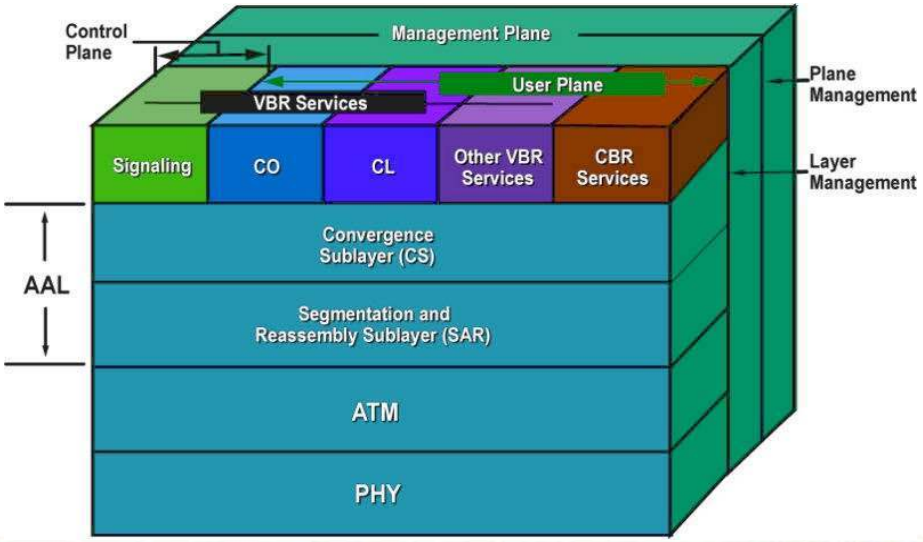
Port in	VPI/VCI	Port out	VPI/VCI
1	1/1	2	2/4
1	1/2	2	3/3
1	4/1	3	5/1
1	4/2	3	5/2





ATM Adaptation Layer (AAL)

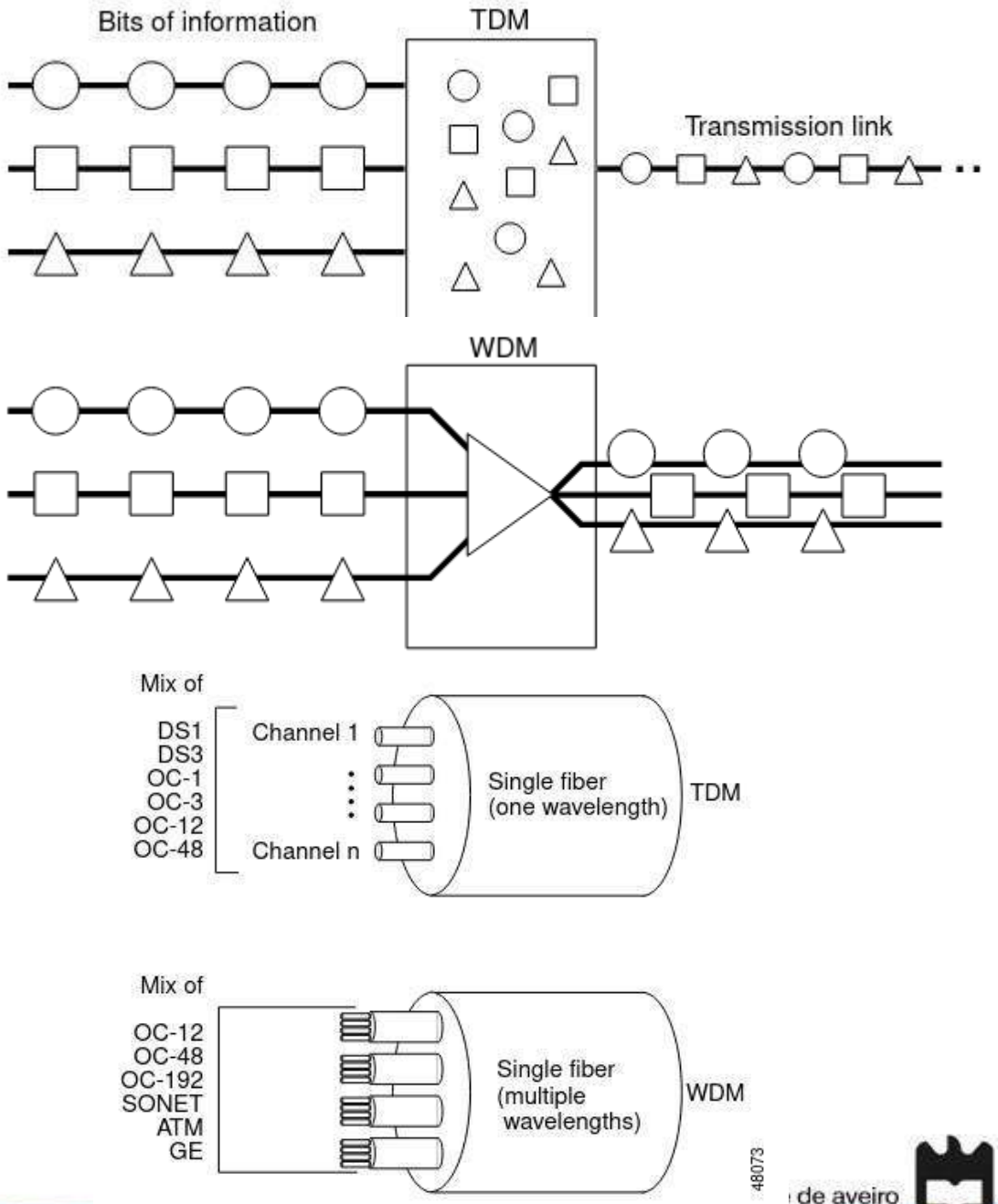
- AAL is responsible for providing specific transport services to the higher layer protocols.
- The AAL is divided into:
  - Convergence Sublayer (CS) - manages the flow of data to and from SAR sublayer.
  - Segmentation and Reassembly Sublayer (SAR) - breaks data into cells at the sender and reassembles cells into larger data units at the receiver.
- ITU-T has defined four AAL service classes based on combinations of these three characteristics
  - Class A is a constant bit rate (CBR), delay-sensitive, connection-oriented service or a circuit emulation service.
  - Class B is a variable bit rate (VBR) service requiring time synchronization between sender and receiver (e.g., real-time compressed audio and video).
  - Classes C and D are delay-insensitive VBR services.
- Four AAL protocol types were defined to support the four service classes.
  - AAL 1 and AAL 5; And not in use anymore: AAL 2 and AAL 3/4.
  - Each type describes the format of the SAR-PDU (or the cell Payload field) and related operational procedures.



Service Class	A	B	C	D
Connection Mode	Connection-Oriented			Connectionless
Bit Rate	Constant	Variable		
End-to-End Timing Relationship	Required		Not Required	
Users	Circuit Emulation (e.g., Voice)	Packet Video and Compressed Voice	Connection-Oriented Data (e.g., Frame Relay)	Connectionless Data (e.g., SMDS, IP)
Sugested AAL Type	1	2	3/4, 5	3/4, 5

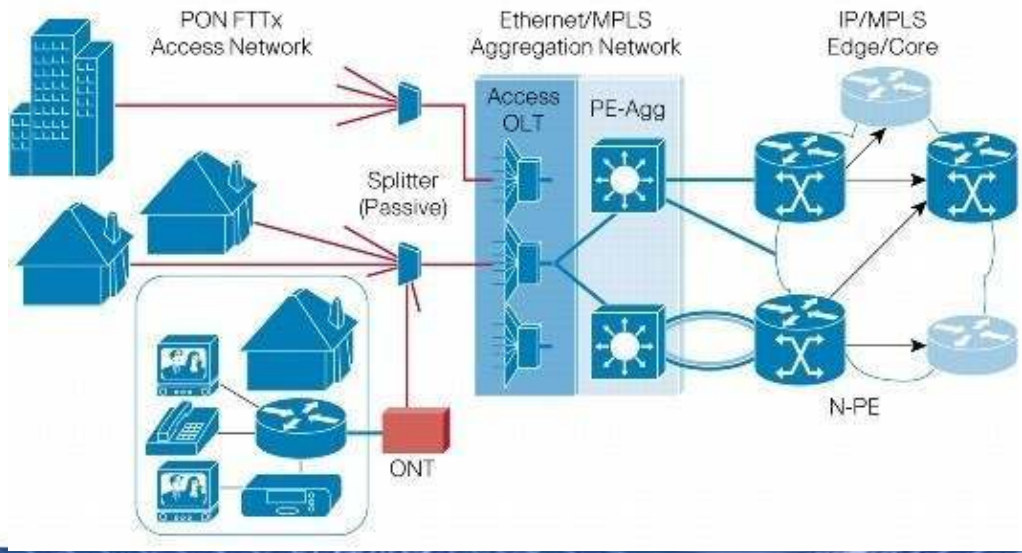
TDM, WDM and DWDM

- Time-division multiplexing (TDM).
  - E.g., SONET/SDH.
- Wavelength Division Multiplexing (WDM).
- Dense Wavelength Division Multiplexing (DWDM)
  - Optical fiber multiplexing technology that is used to increase the bandwidth of existing fiber networks.
    - Supports a higher number of wavelengths over the optical fiber.
  - Is a physical layer architecture, it can transparently support both TDM and data formats such as ATM, Gigabit Ethernet, etc…



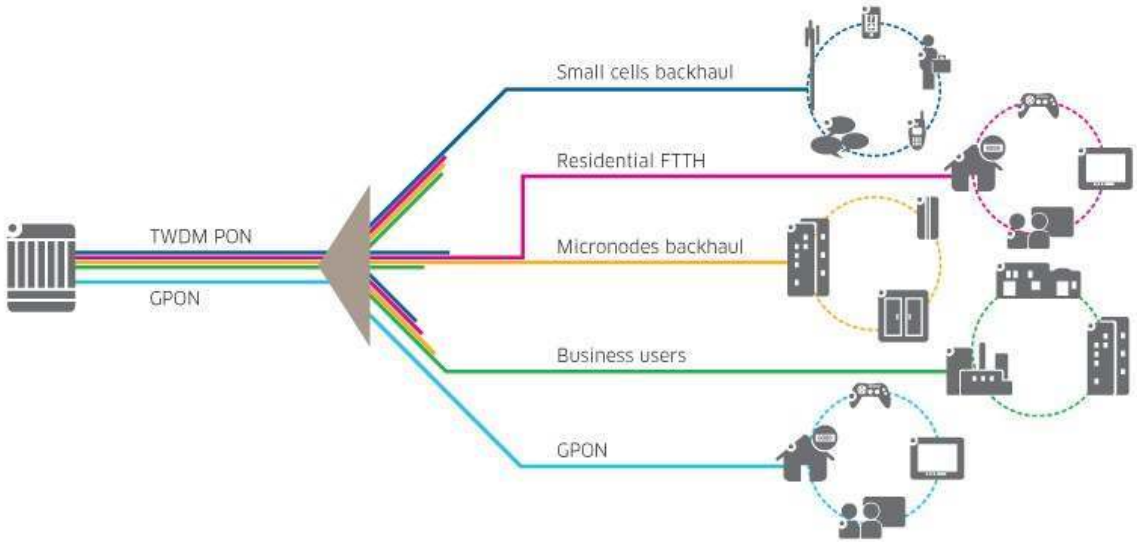
Passive Optical Network (PON)

- Is "passive" since it uses unpowered splitters to route data sent from a central location to multiple destinations.
- Based on TDM transmission.
- Variants
  - GPON - a "gigabit-capable PON" that supports 2.488 Gbps downstream and 1.244 Gbps upstream; follows the ITU G.984 standard.
  - EPON - the most popular PON implementation; transmits data as Ethernet frames at up to 10 Gbps downstream and upstream; also known as GEPON or the IEEE 802.3 standard.
- Focused on fiber connectivity to the home and other types of final network users (hotels, hospitals, and high-density residential buildings).



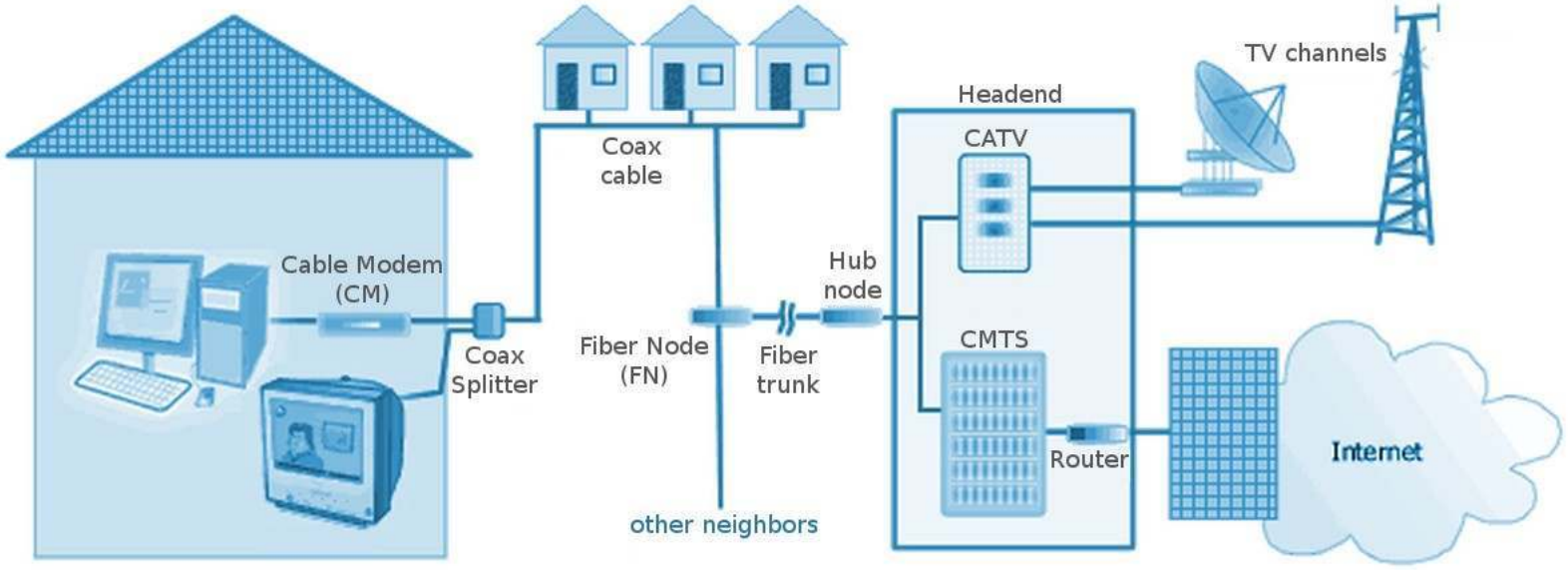
DWDM-PON and TWDM-PON

- The evolution of PON technologies are:
  - Time and Wavelength Division Multiplexed Passive Optical Network (TWDM-PON).
  - Dense Wavelength Division Multiplexed Passive Optical Network (DWDM-PON).
  - Adds flexibility by supporting the overlay of multiple services, user groups or organizations on the same fiber.
  - Can coexist with, and expand on, current PON deployments.
    - Ensures that operators' investments will keep providing value in the long term.



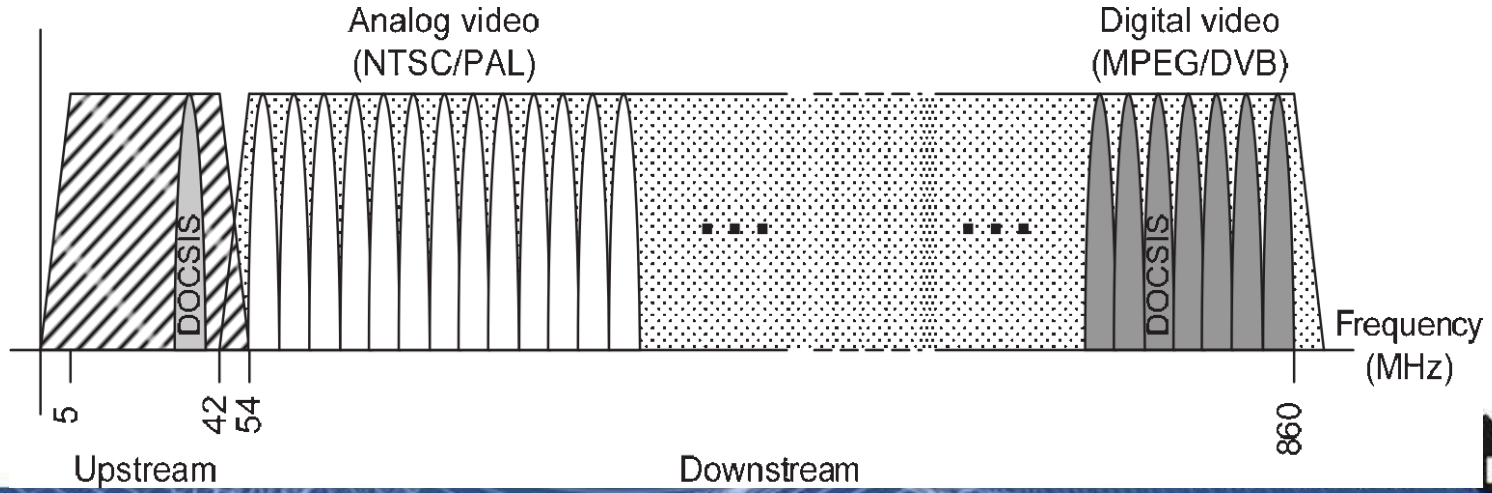
Community Access Television (CATV) "Cable" TV

- Hybrid Fiber Access (HCF)
  - Copper/Coax from Fiber Nodes and clients.
  - Fiber core (FN-Hub + Hub-Hub + some Hubs-Headend).
- Cable Modem (CM)
- Cable Modem Terminating System (CMTS)
- Fiber Node (FN)



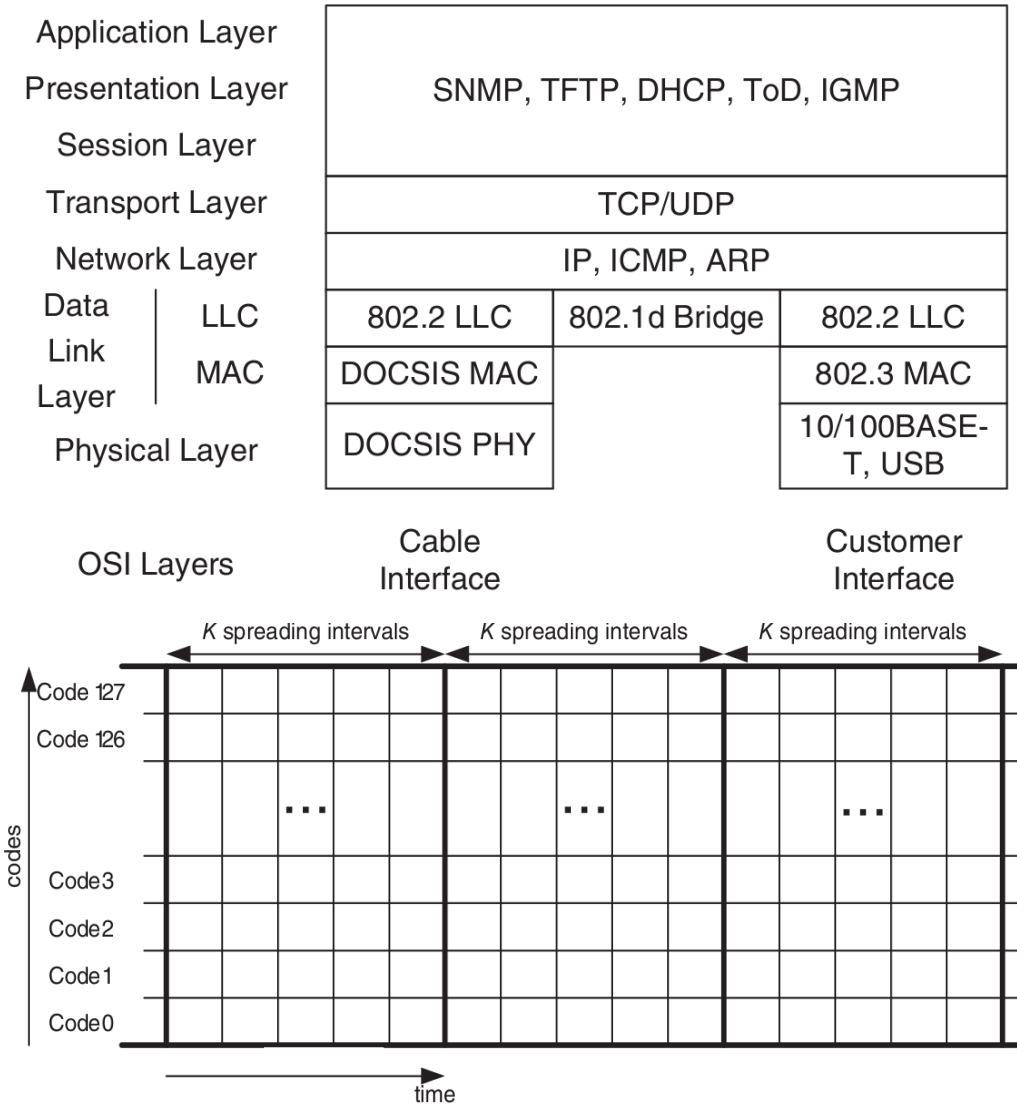
Data Over Cable Service Interface Specification (DOCSIS)

- Versions 1.0 and 1.1
  - D/U: up to 50Mbps/9Mbps. Speed in Europe, 8MHz channels.
- Version 2.0
  - Adds A-TDMA which is a direct extension of the DOCSIS 1.x concepts and new synchronous CDMA (S-CDMA) → Upstream speed improvement.
  - D/U: up to 50Mbps/27Mbps.
- Version 3.0
  - Adds bonding of individual physical channels.
  - Using 4 channels – D/U: up to 200Mbps/108Mbps.
  - Using 8 channels – D/U: up to 400Mbps/108Mbps.
- In US, 6MHz channels → Lower speeds.
- Spectrum allocation



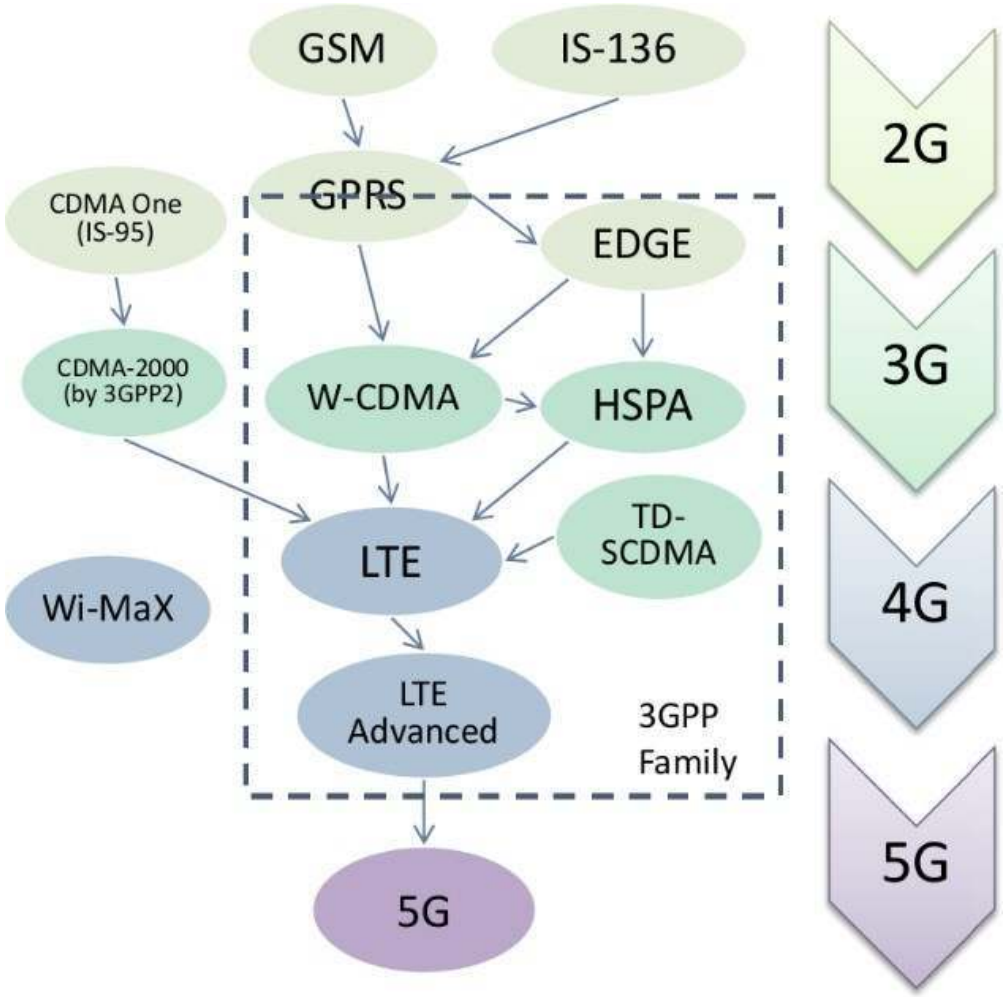
DOCSIS Transmission

- Downstream Transmission
  - Digital Video Broadcast (DVB) standards.
  - Signal is a continuous stream of 188-byte long MPEG packets, that contain:
    - An MPEG video payload, or
    - a DOCSIS MAC payload.
- Upstream Transmission
  - TDMA Transmission Mode (from version 1.0).
    - Transmissions are separated only in time.
  - Synchronous CDMA (S-CDMA) Transmission Mode (from version 2.0).
    - Transmissions are separated by both time and CDMA spreading code.
      - CDMA - Code division multiple access.
    - DOCSIS MAC payloads transmited in one or more mini-slots (time/code divided mini slots).



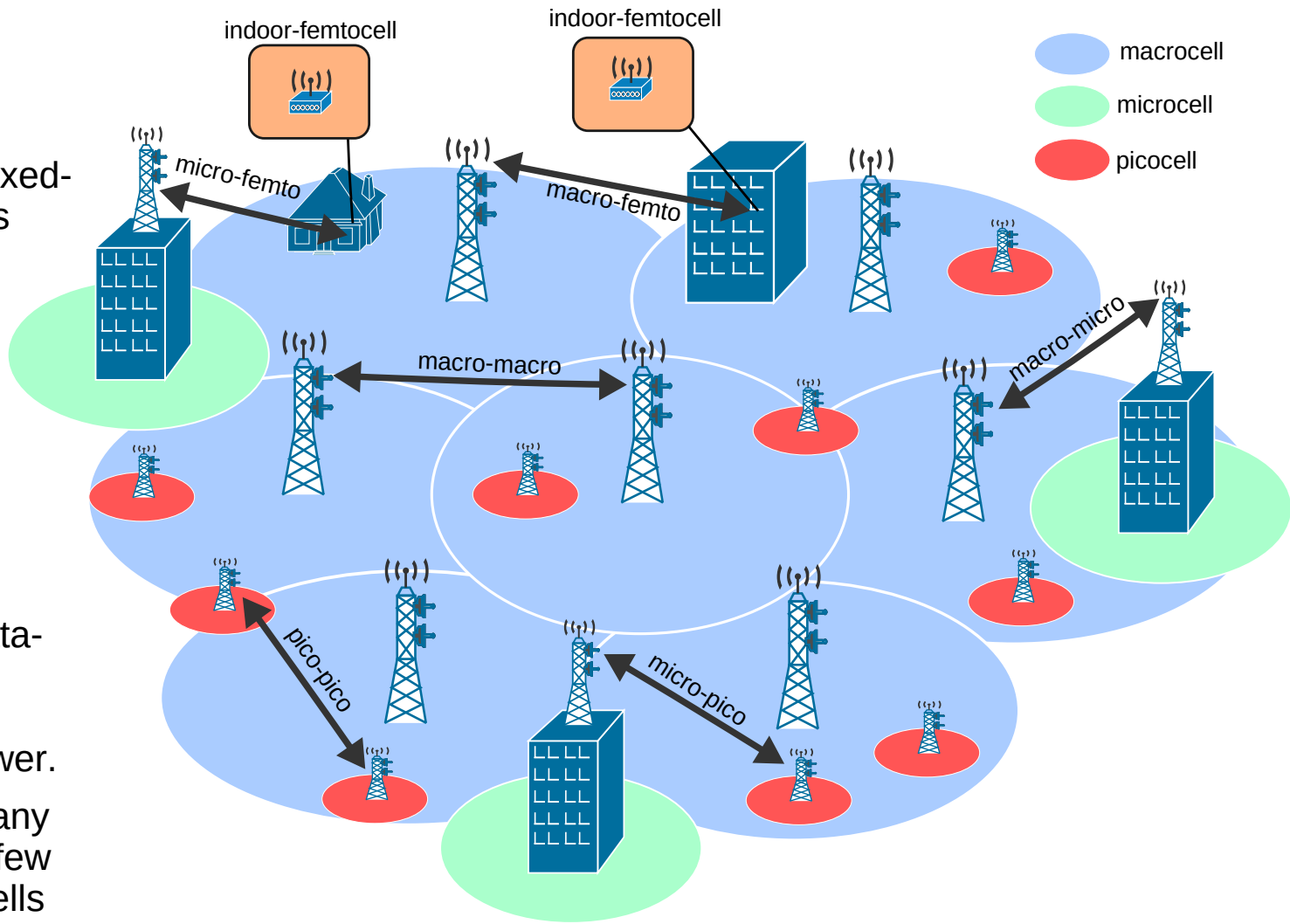
Mobile Networks

- 2G:
  - GSM (Global System for Mobile)
  - GSM Packet Radio System (GPRS)
  - Enhanced Data-rates for GSM Evolution (EDGE)
  - Based on TDMA
- 3G:
  - Universal Mobile Telecommunication System (UMTS)
  - Based on Wideband-CDMA (W-CDMA)
  - High Speed Packet Access (HSPA)
  - High-Speed Downlink Packet Access (HSDPA)
  - High-Speed Uplink Packet Access (HSUPA)
  - CDMA2000
- 4G:
  - LTE
  - LTE-Advanced
  - IEEE 802.16e (WiMax) and IEEE 802.16m
  - Based on OFDA and MIMO
- 5G:
  - Based on MIMO
  - Small cells
  - NFV Core
  - Integrated Wired and Wireless IP networks

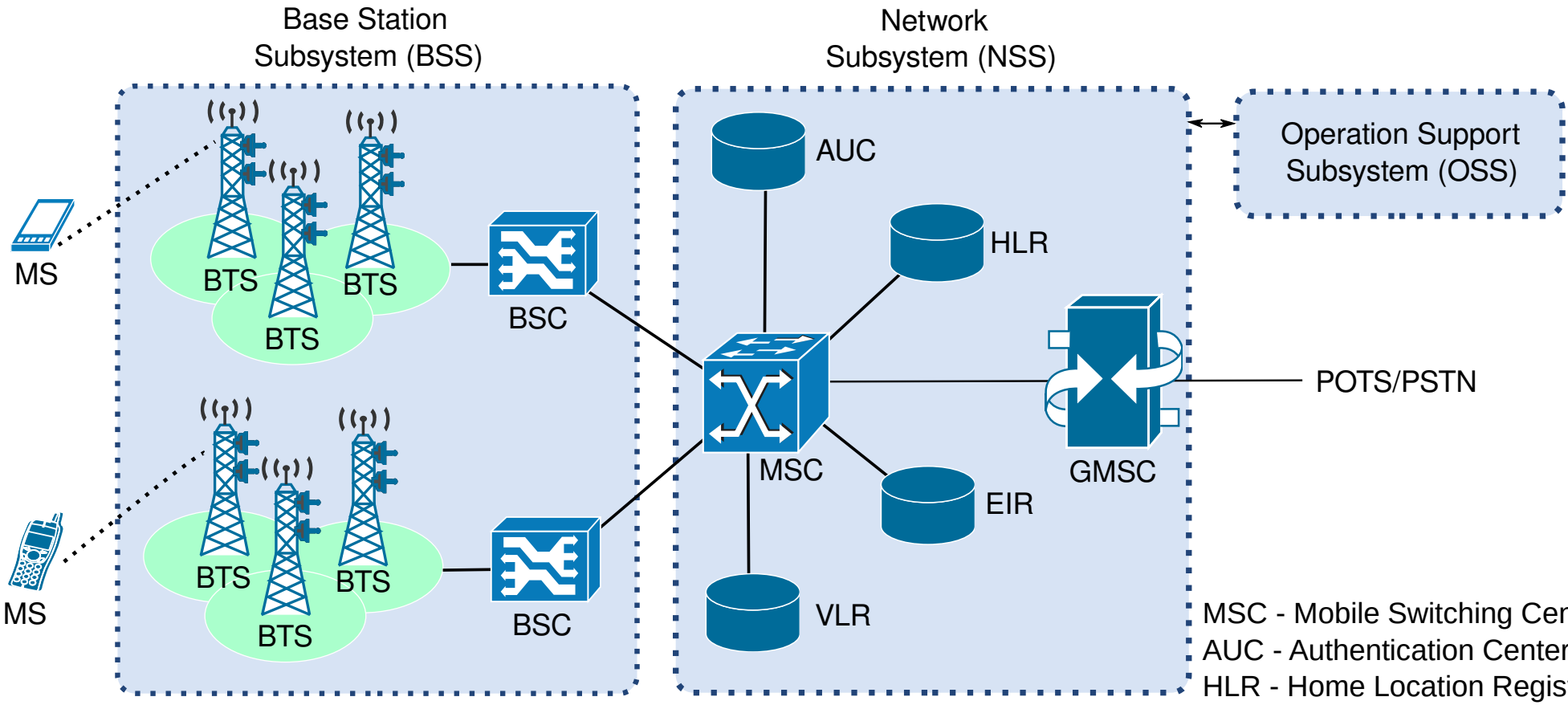


Cellular Network Concept

- Concept used on Public Land Mobile Networks (PLNM).
- Network is distributed over land areas called cells.
  - Each served by at least one fixed-location transceiver, known as base station.
- Macrocells are mainly used to provide a widespread coverage area.
- Smaller micro, pico or femtocell structures can be used for high data-rate.
  - Able to sustain high speed data-traffic by reducing the propagation distance, hence reducing the transmission power.
  - Micro/picocells can handle many devices within the range of a few hundred meters while femtocells are mostly used for indoor or home area.



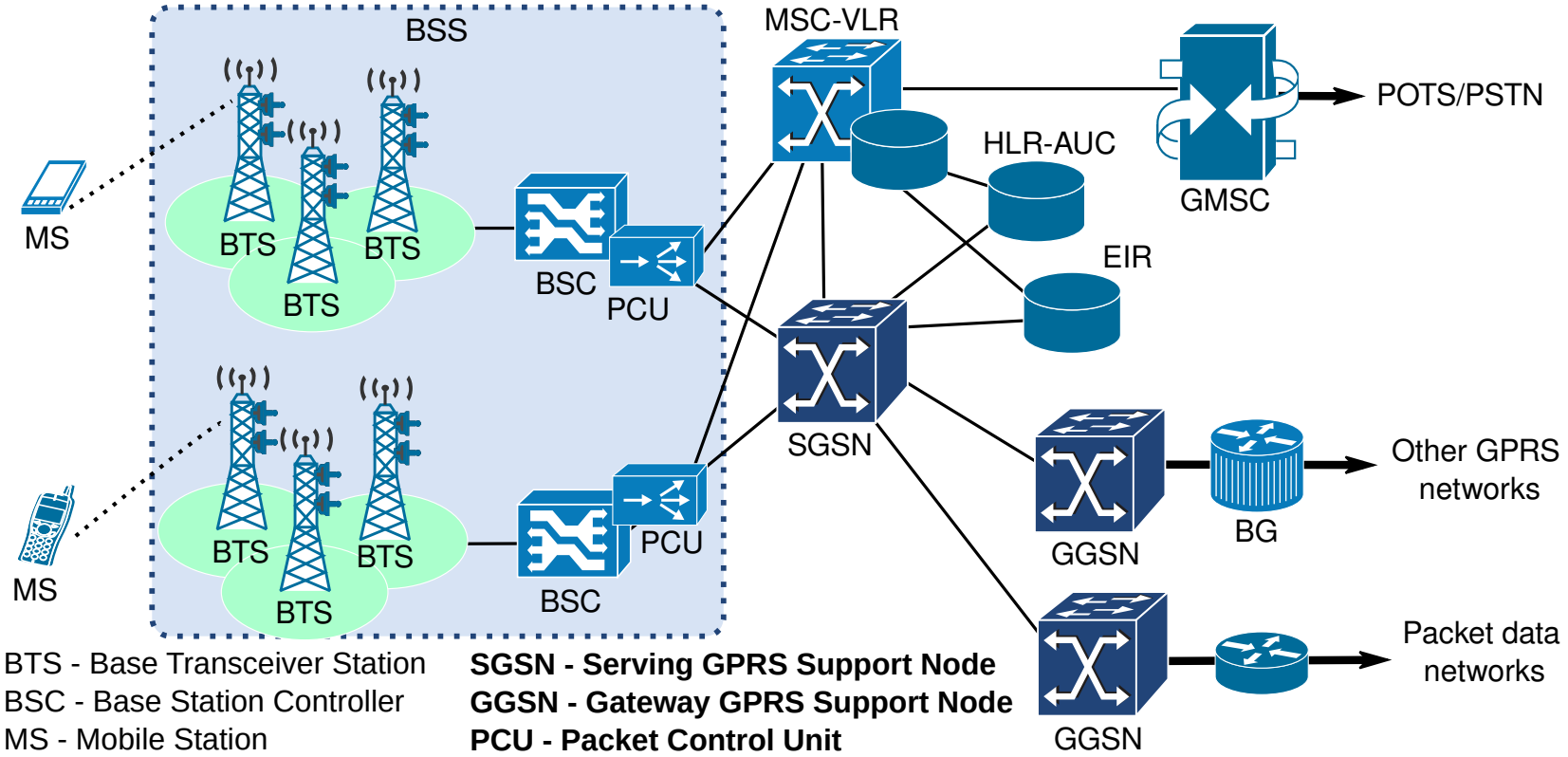
Global System for Mobile (GSM)



BTS - Base Transceiver Station
BSC - Base Station Controller
MS - Mobile Station

MSC - Mobile Switching Center
AUC - Authentication Center
HLR - Home Location Register
GMSC - Gateway MSC
EIR - Equipment Identity Register
VLR - Visitor Location Register

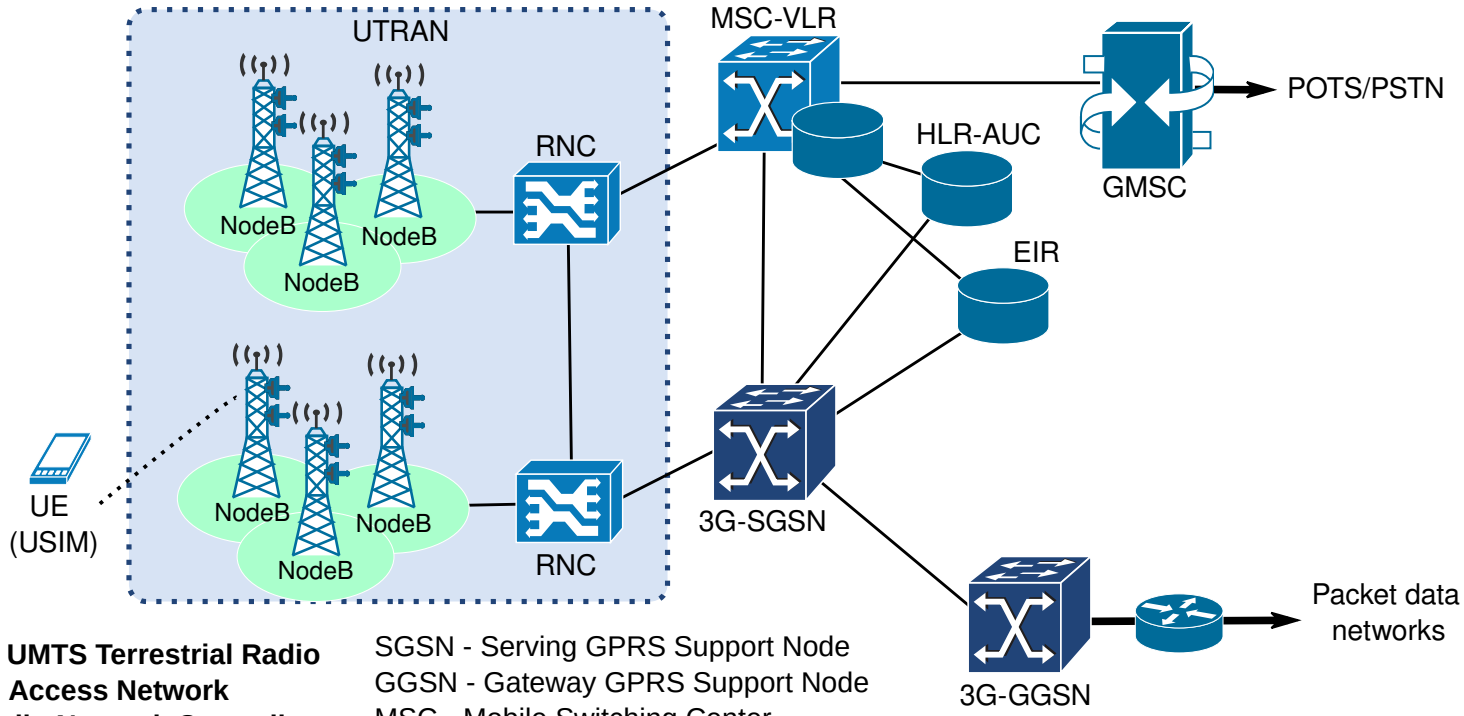
GSM Packet Radio System (GPRS)



BTS - Base Transceiver Station
BSC - Base Station Controller
MS - Mobile Station

SGSN - Serving GPRS Support Node
GGSN - Gateway GPRS Support Node
PCU - Packet Control Unit
BG - Border Gateway
MSC - Mobile Switching Center
AUC - Authentication Center
HLR - Home Location Register
GMSC - Gateway MSC
EIR - Equipment Identity Register
VLR - Visitor Location Register

Universal Mobile Telecommunication System (UMTS)



UTRAN - UMTS Terrestrial Radio Access Network
RNC - Radio Network Controller
UE - User Equipment
USIM - UMTS Subscriber Identity Module

SGSN - Serving GPRS Support Node
GGSN - Gateway GPRS Support Node
MSC - Mobile Switching Center
AUC - Authentication Center
HLR - Home Location Register
GMSC - Gateway MSC
EIR - Equipment Identity Register
VLR - Visitor Location Register

- 3rd Generation Partnership Project (3GPP) standard.
- Novel radio access network called Universal Terrestrial Radio Access Network (UTRAN)
- Core network remains largely unchanged from GPRS/EDGE.

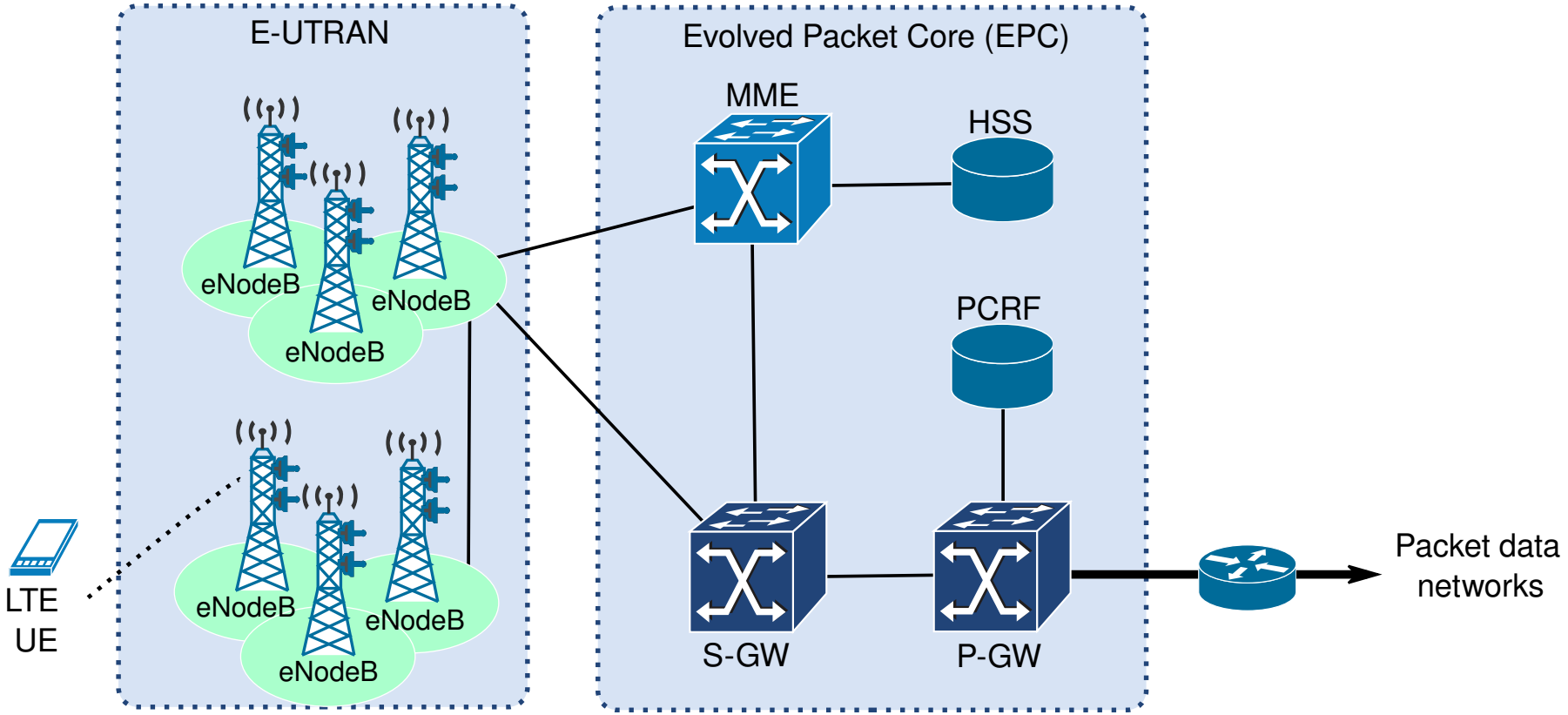
High Speed Packet Access (HSPA)

- Upgrade to W-CDMA networks to provide **higher bit rates** and **lower delays**.
- High-Speed Downlink Packet Access (HSDPA)
  - To be able to make faster decisions on radio channel allocation (adapting to varying channel quality) and reduces delays, new functions were added closer to the radio interface (NodeB):
    - Scheduling, select which UE(s) is/are to use the radio resources at each Transmission Time Interval (TTI), where one TTI is 2 ms.
    - Link adaptation, setting of channel coding rate and modulation (QPSK or 16QAM), in order to utilize the resources effectively.
- High-Speed Uplink Packet Access (HSUPA)
  - Uses a packet scheduler that operates on a request-grant principle where the UEs request a permission to send data and the scheduler decides when and how many UEs will be allowed to do so.
  - However, unlike HSDPA, uplink transmissions are not orthogonal to each other.
- Evolved High Speed Packet Access (HSPA+)
  - Further increase bit rates.
  - New functions are added:
    - Higher order modulation 64QAM (DL) and 16QAM (UL),
    - Multiple Input Multiple Output (MIMO) used only in the DL.

Long Term Evolution (LTE)

- LTE standard has been developed by 3GPP
  - Extension of UMTS (based on 3GPP standard)
  - and CDMA200 1xEV-DO (based on 3GPP2 standard).
- Designed for high speed data applications both in the uplink and downlink.
  - Offers about 300Mbps data rate in the downlink and about 75 Mbps in the uplink.
- LTE is an all IP based network, supporting both IPv4 and IPv6.
  - Possibility of supporting voice over LTE (VoLTE).
- Uses a different form of radio interface from UMTS.
  - Instead of CDMA it uses OFDMA (Orthogonal Frequency Division Multiple Access is used in the downlink; and SC-FDMA(Single Carrier - Frequency Division Multiple Access) is used in the uplink.
- Uses MIMO (Multiple Input Multiple Output).
  - Requires the use of multiple antennas (antenna matrices).
- LTE has been defined to accommodate both FDD and TDD operation.

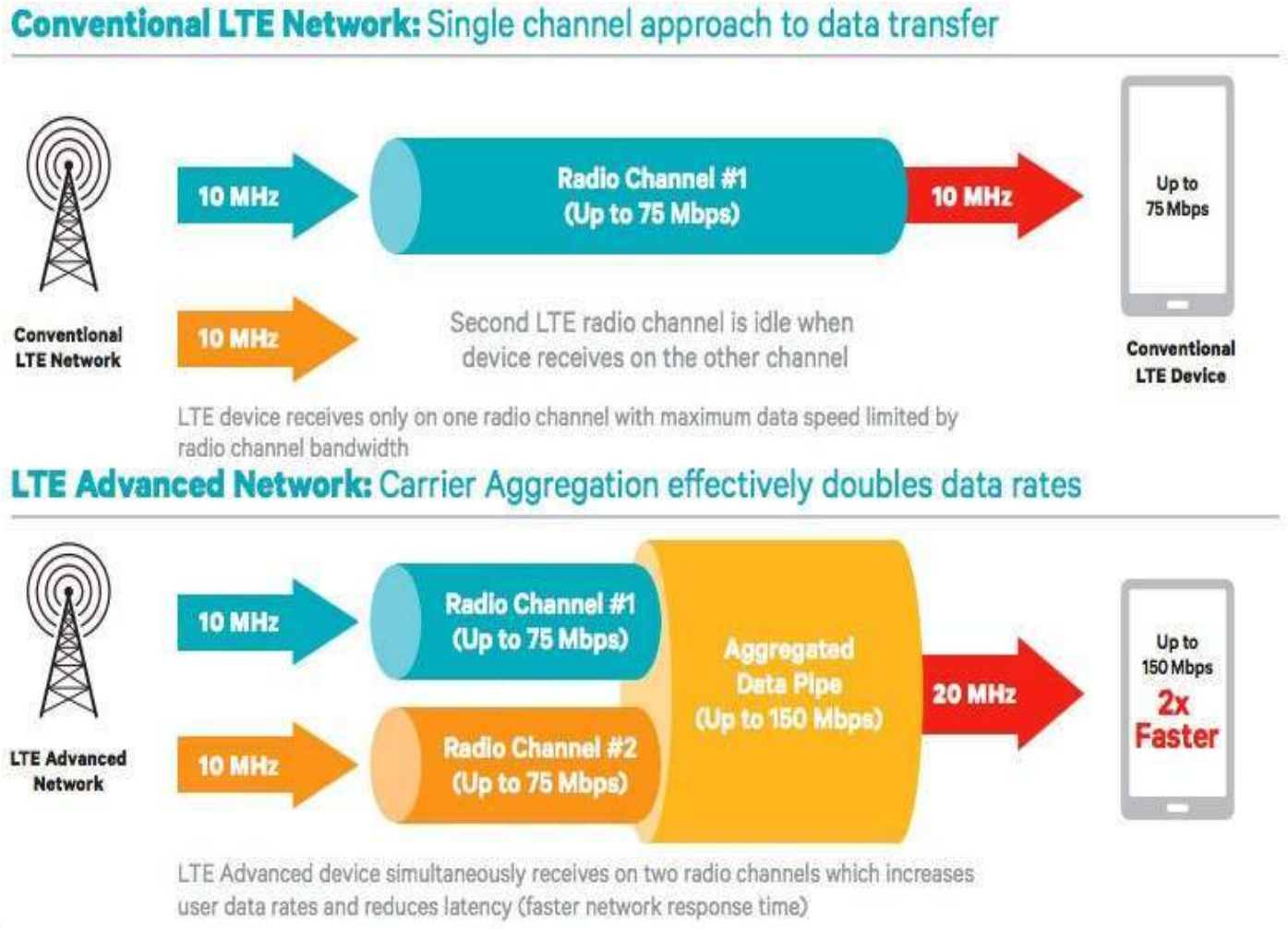
Long Term Evolution (LTE)



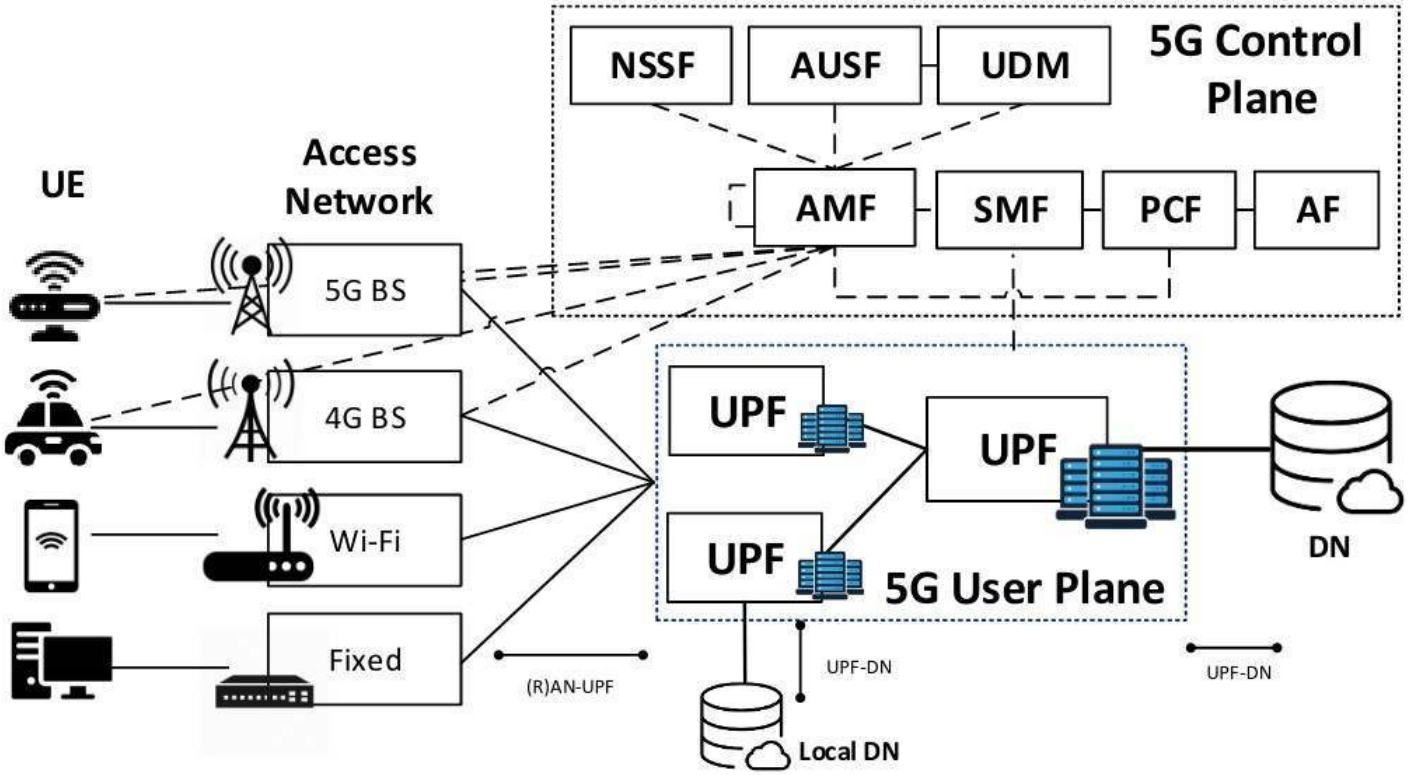
S-GW - Serving Gateway
P-GW - Packet data network Gateway
MME - Mobility Management Entity
HSS - Home Subscriber Server
PCRF - Policy and Charging Rules Function

LTE-Advanced

- LTE-Advanced is the upgraded version of LTE.
  - Increases the peak data rates to about 1GBPS in the downlink and 500MBPS in the uplink.
- Utilizes higher number of antennas and added carrier aggregation feature.
  - Carrier aggregation can be used for both FDD and TDD.

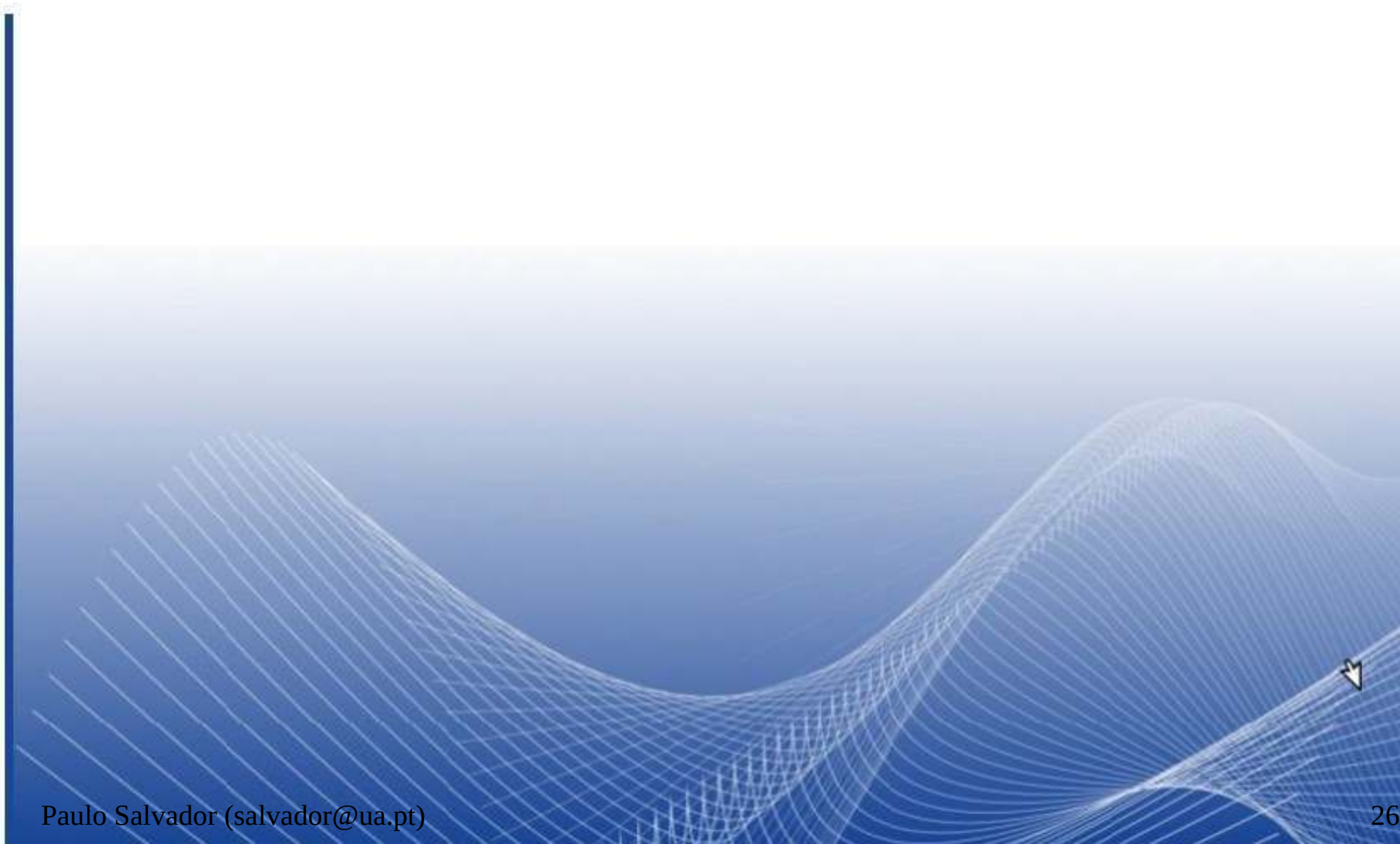


5G



- Architecture incorporates
  - Network Function Virtualization (NFV) at the core,
  - Edge Computing (EC),
  - Software Defined Networks (SDNs).
- Uses a high frequency range (30 GHz and 300 GHz) of the radio spectrum,
  - Higher frequency → Higher bandwidth, Lower range → Smaller cells.
- Integrated Wired and Wireless IP networks.

WPAN and Sensor Networks

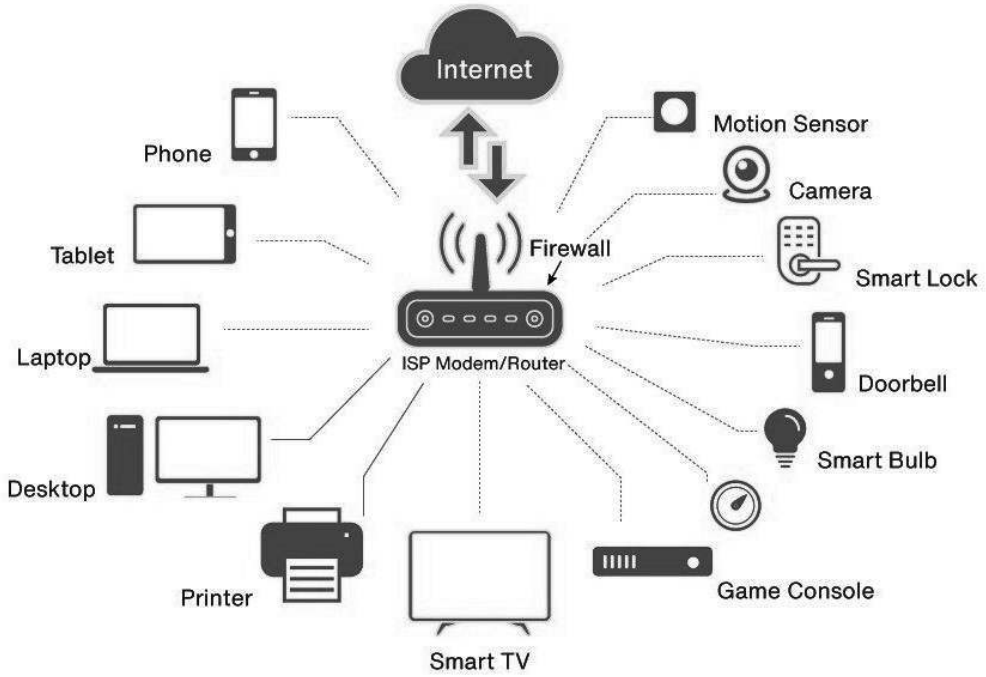


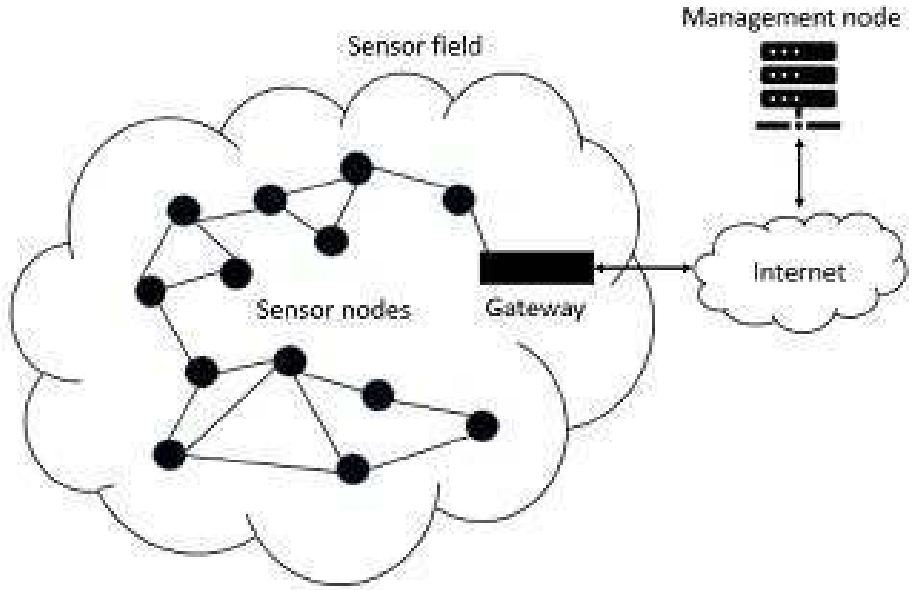
Wireless Personal Area Network (WPAN)

- Span a small area (e.g.,a private home or an individual workspace)
  - Communicate over a short distance.
  - Low-powered communication.
  - Primarily uses ad-hoc networking.
  - Could be wireless or wired.

Internet of Things / Sensor Networks

- Composed by small and medium devices
  - Usually battery powered.
  - May not allow battery replacement.
  - Low computational resources.
- Network requirements
  - Simplicity
    - Easy to deploy and with low computational requirements.
    - Low cost devices.
  - Security
    - Node access should be controlled.
    - Data should be encrypted.
  - Reliability
    - Limited failures and integrated recovery features.
  - Efficiency (low-power)
    - Battery life should be measured in months or years.
  - Scalability
    - Should support an high number of connected devices.





IEEE 802.15

- Standard for low-data-rate physical and medium access control layer specifications for wireless personal area networks (WPAN).
- Evolved over time:
  - IEEE 802.15.4-2003 ; IEEE 802.15.4-2006, IEEE 802.15.4-2011 IEEE 802.15.4-2015.
- IEEE 802.15.4 is a wireless access technology for
  - Low-cost and low-data-rate devices.
  - Devices powered by batteries.
  - Enables easy installation using a compact protocol stack.
  - Several network communication stacks use this technology in both the consumer and business markets.

Communication Standards

- Wi-Fi
  - Range: ~50 meters
  - Data Rate: 23-144Mbps
  - Frequency: 2.4GHz/5GHz
  - Max. Devices: 250
- Bluetooth
  - Range: 10 meters (class 2/3), 100 meters (class 1)
  - Data Rate: 1-3Mbps
  - Frequency: 2.4GHz
  - Max. Devices: 7

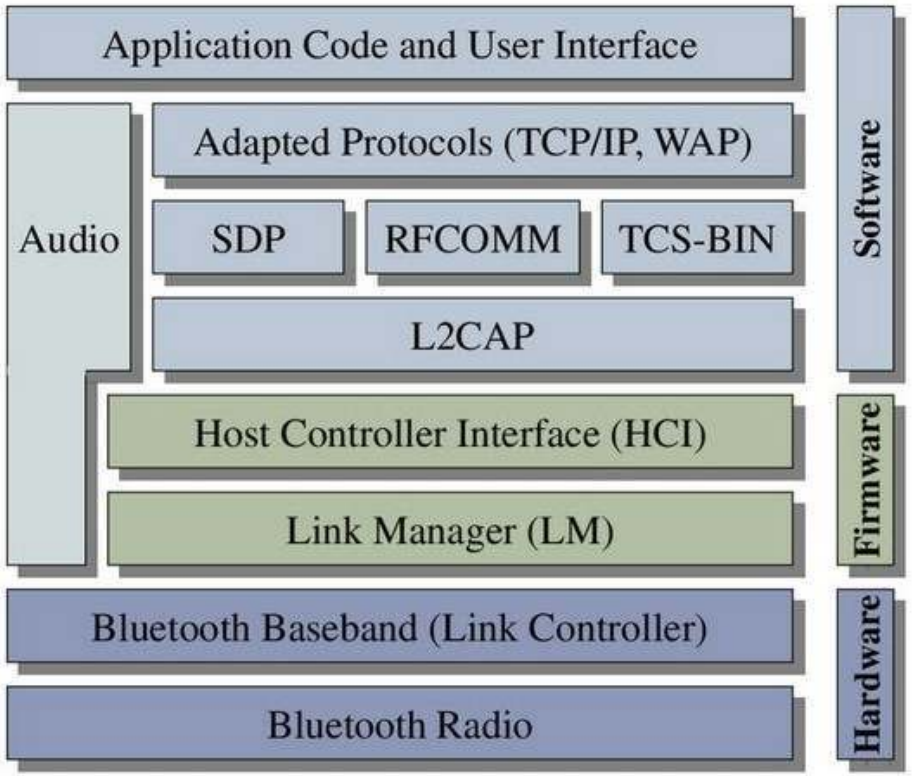
- Zigbee
  - Range: 50-70 meters
  - Data Rate: 20-250 kbps
  - Frequency: 915MHz to 2.4GHz
  - Max. Devices: ~1000 (realistically)
- Z-Wave
  - Range: ~100 meters
  - Data Rate: 100 kbps
  - Frequency: 915MHz
  - Max. Devices: 232
- Thread (newest and trending)
  - Range: ~30 meters
  - Data Rate: 250 kbps
  - Frequency: 2.4GHz
  - Max. Devices: 300

Wi-Fi

- Star topology.
- Current consumption: ~250mA (very high)
- Wi-Fi is an alternative only for always or frequently powered devices.

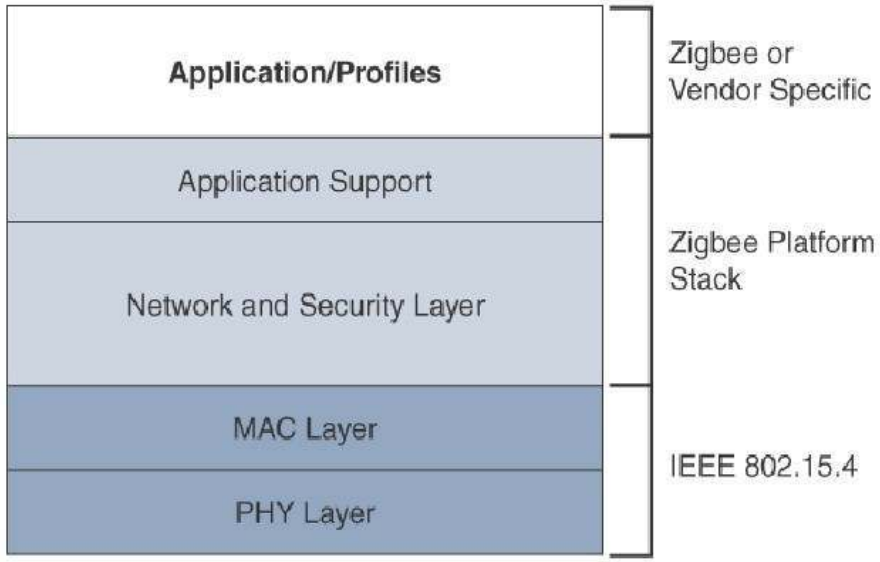
Bluetooth

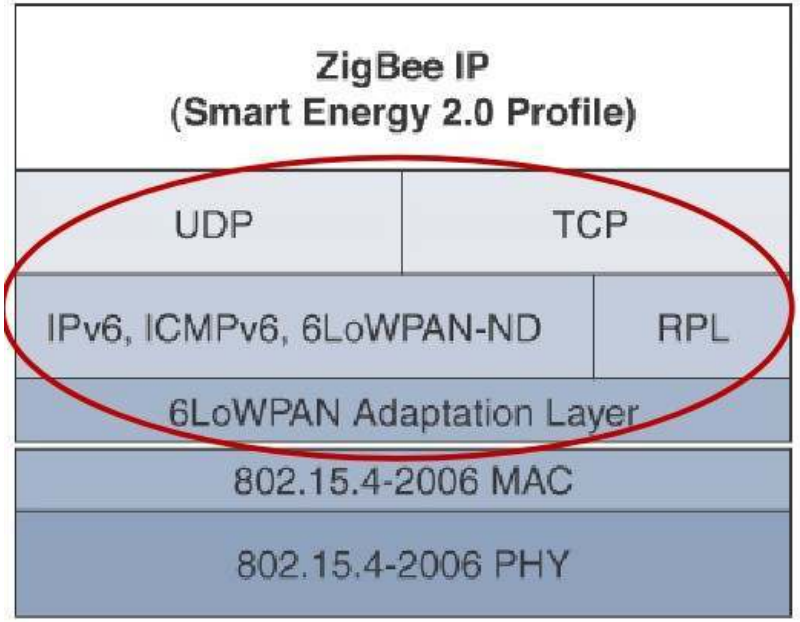
- Mesh and Star topology.
- Current consumption:
  - Bluetooth: ~30mA.
  - Bluetooth LE: less than 15mA.
- Bluetooth has classes that define indicate the power output and wireless range of a device:
  - Class 1: 100 mW (20 dBm), 100 meter
  - Class 2: 2.5 mW (4 dBm), 10 meter
  - Class 3: 1 mW (0 dBm), 1 meter
- Bluetooth Low Energy (LE) is a power-conserving variant of PAN technology.
- Frequency Hopping Spread Spectrum



ZigBee

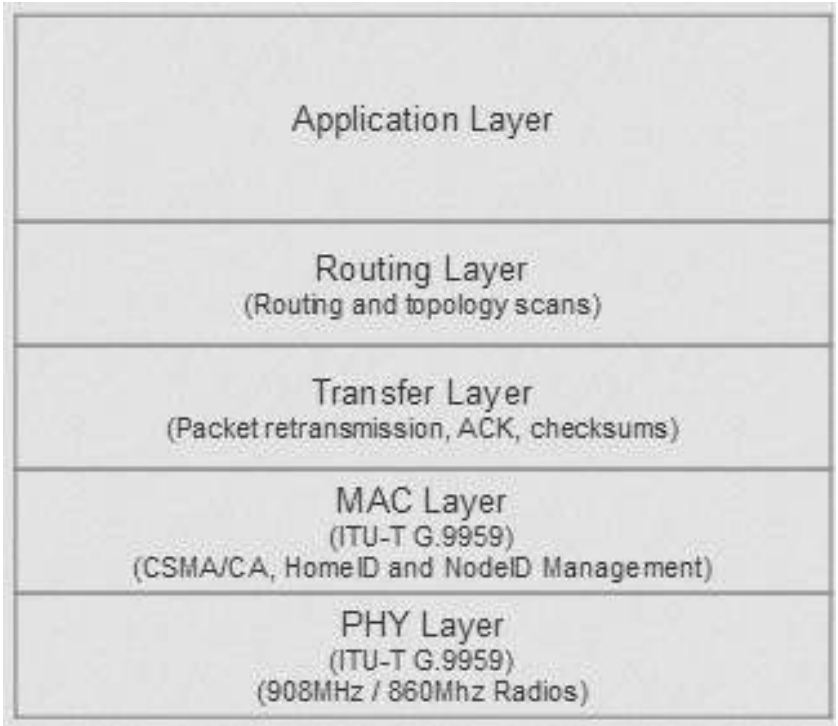
- Star, Tree or Mesh topology.
- Current consumption: ~50mA.
- ZigBee has not provided interoperability with other IoT solutions or open standards
- ZigBee IP was created to embrace the open standards at the network and transport layers
- Based on IEEE 802.15.4.
- And, based on 6LoWPAN
  - Defines encapsulation and header compression to send and receive IPv6 packets over IEEE 802.15.4 networks.





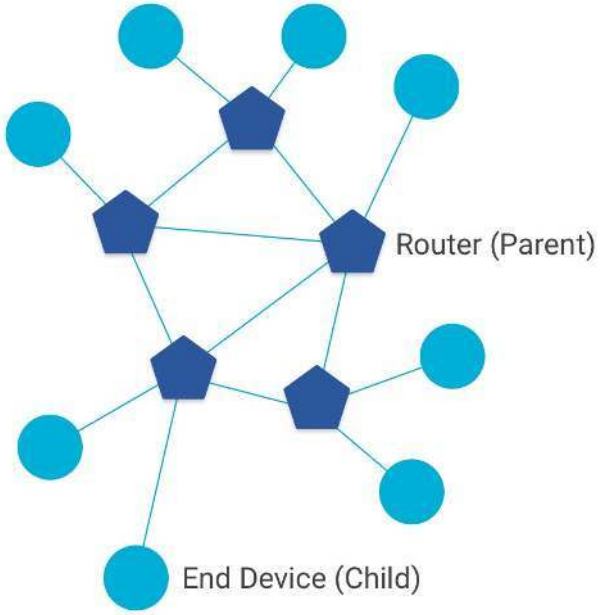
Z-Wave

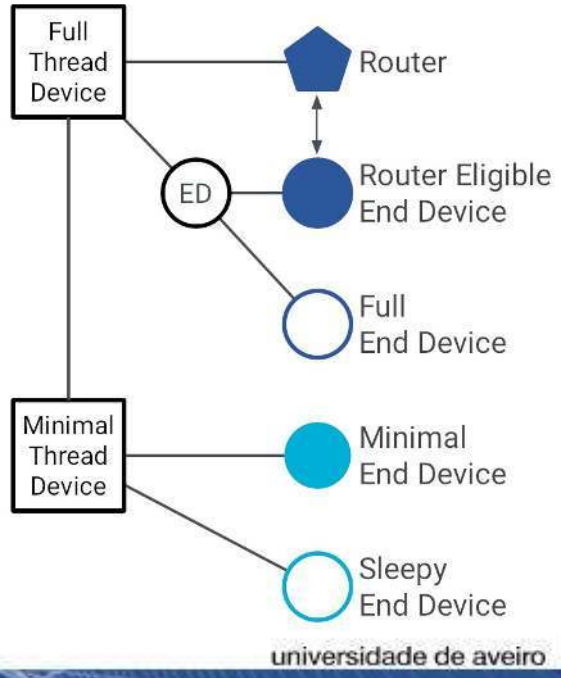
- Mesh topology.
- Current consumption: ~2.5mA.
- Defined by ITU-T G.9959 Standard.
  - Closed standard until 2020.



Thread

- Defined for all but the application layer and all of the layers are pre-existing protocols.
  - At the physical and link layer, IEEE 802.15.4 protocol is used just like with ZigBee.
  - At the network and transport layers, Thread uses a combination of IPv6, 6LowPAN. UDP, and DTLS (Datagram Transport Layer Security).
- Mesh topology.
- IPv6-based networking protocol.
- Independent of other mesh networking protocols, such a ZigBee, Z-Wave, and Bluetooth LE.
- Nodes are split into two forwarding roles: router and end-device.
- Nodes comprise a number of types:
  - Full Thread Device - always has its radio on and subscribes to the all-routers multicast address
    - Router, Router Eligible End Device (REED), Full End Device (FED)
  - Minimal Thread Device - does not subscribe to the all-routers multicast address
    - Minimal End Device (MED) - radio always on
    - Sleepy End Device (SED) – radio normally disabled, wakes on occasion to poll for messages from its parent





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Low Power Wide Area Network (LPWAN)

- Wireless telecommunication wide area network designed to allow long-range communications at a low bit rate, low power consumption and low cost.
- SigFox
  - Supports millions of end devices.
  - Proprietary.
    - Access infrastructure (built with operators) and software.
    - Open market for the endpoints.
  - 30-50km range in rural areas, and 3-10km range in urban areas.
  - Ultra narrow band, 868MHz (EU) or 902Mhz (US).
  - Low energy consumption.
  - Dedicated network.
- LoRaWAN
  - Stands for “Long Range”.
  - To be used in long-lived battery-powered devices scenarios.
  - Semi-proprietary
    - Parts of the protocol are well documented, others not
    - They own the radio part (but sub-licensing is on the way)
    - You can install your own gateways
  - LoRa usually means two different things:
    - LoRa: a physical layer that uses Chirp Spread Spectrum (CSS) modulation.
    - LoRaWAN: a MAC layer protocol.