Lecture 4: Local Loop Technologies, Internet Access & Leased Lines

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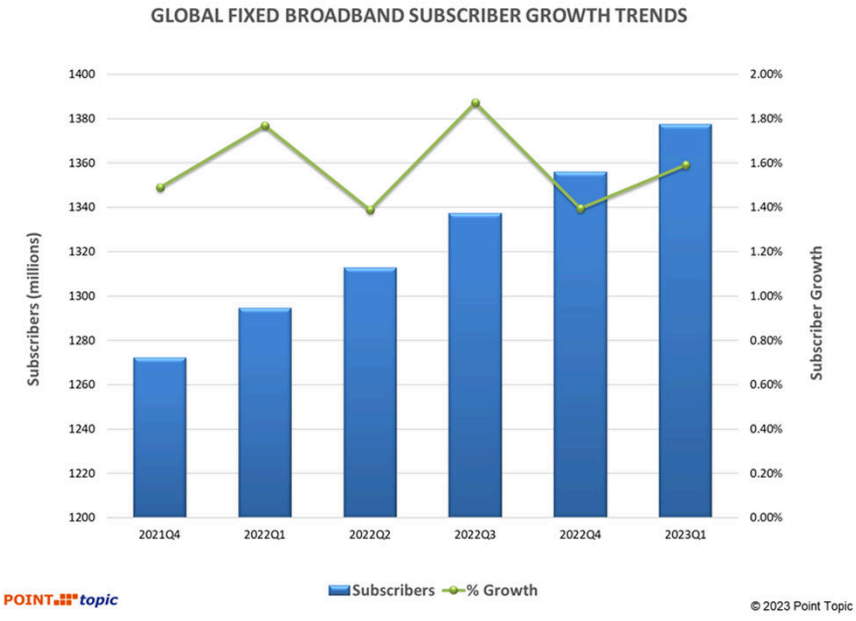
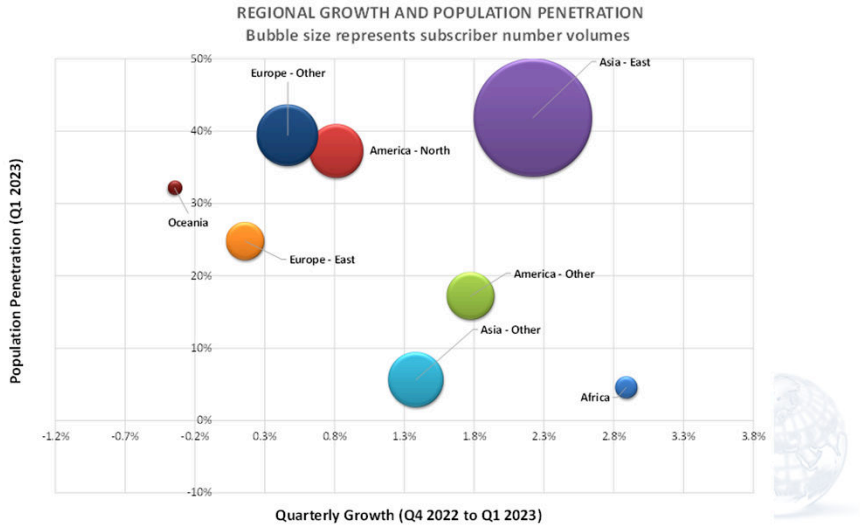
Internet Access Technologies

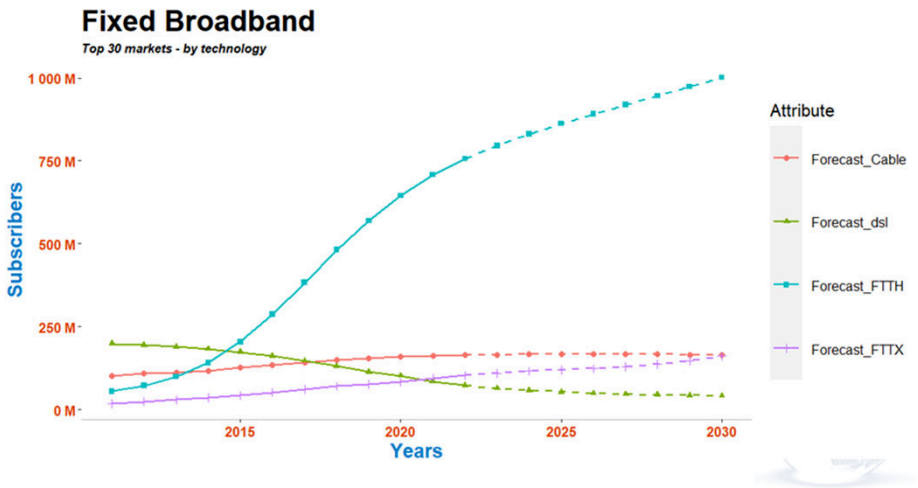
- *Old* Dial-up Modem
- Digital Subscriber Line (xDSL)
- Fiber (FTTx)
- Cable TV (CATV) Networks
- Power line communication (PLC)
- Leased Lines
- Cellular

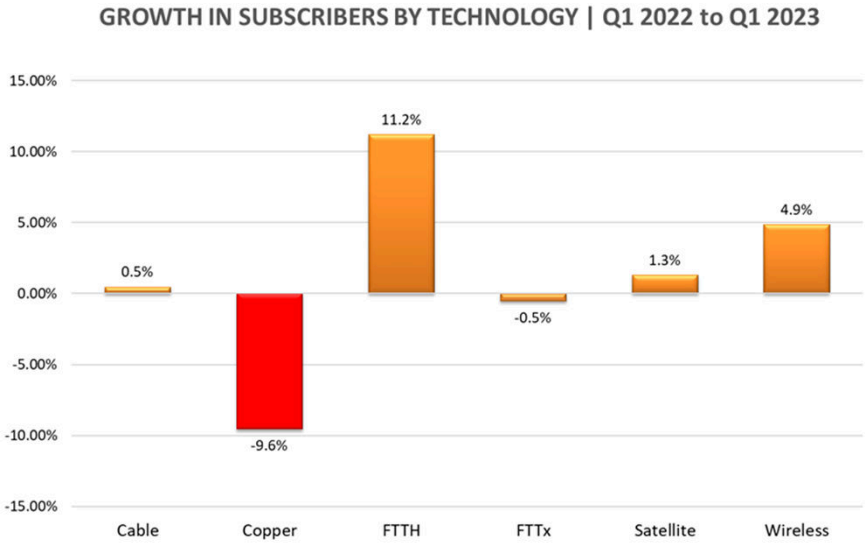


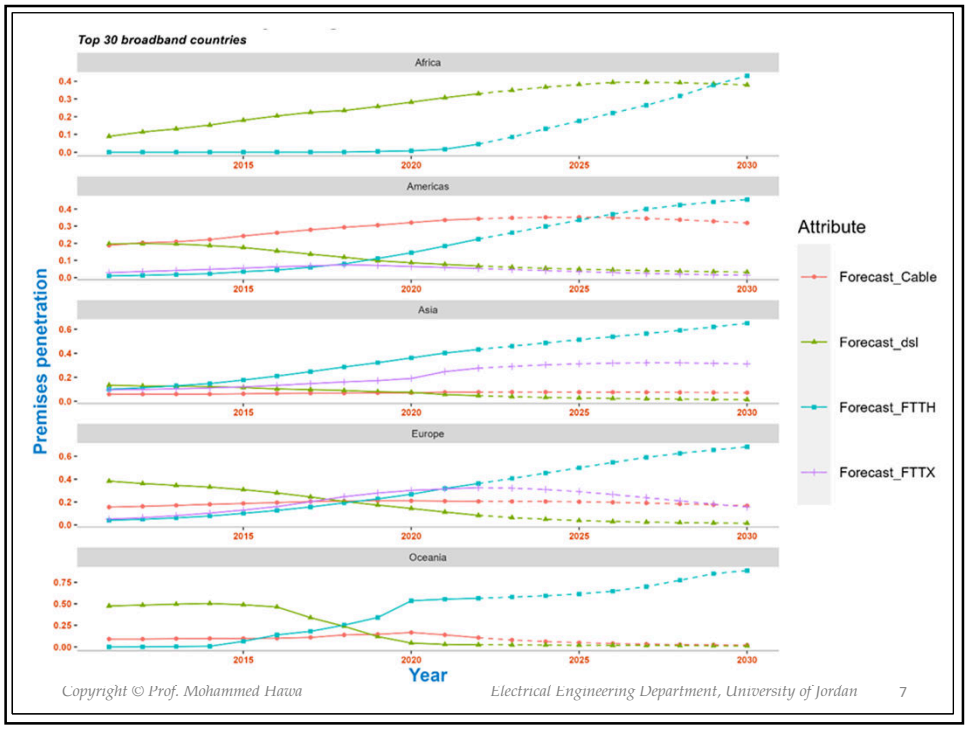
Broadband in Different Regions

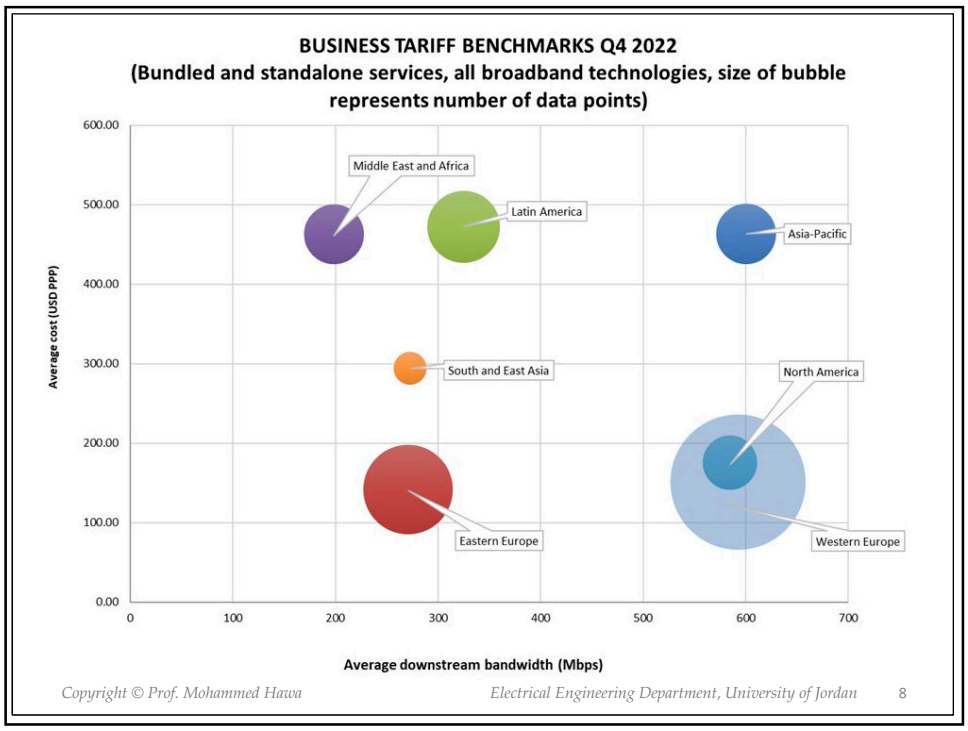


Fixed Broadband Technologies

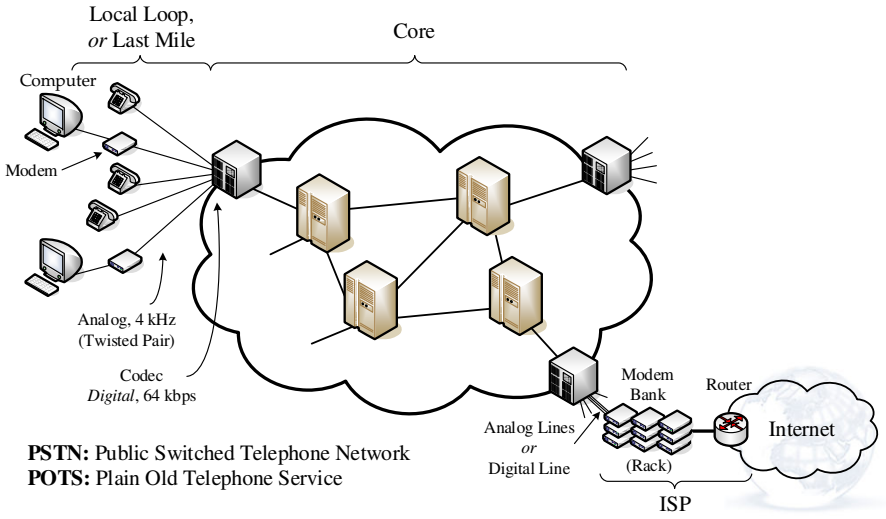





Top 30 broadband countries
Africa
Americas
Asia
Europe
Oceania
Premises penetration
Year
Attribute
Forecast_Cable
Forecast_dsl
Forecast_FTTH
Forecast_FTTX


BUSINESS TARIFF BENCHMARKS Q4 2022
(Bundled and standalone services, all broadband technologies, size of bubble represents number of data points)
Middle East and Africa
Latin America
Asia-Pacific
South and East Asia
North America
Eastern Europe
Western Europe
Average cost (USD PPP)
Average downstream bandwidth (Mbps)

Dial-up Modem vs. xDSL Modem

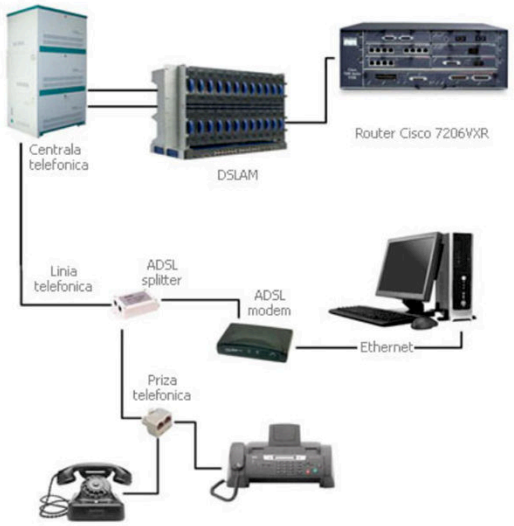


PSTN: Public Switched Telephone Network
POTS: Plain Old Telephone Service

Dial-up Modems

- Transmission is limited by the 4 kHz anti-aliasing LPF at the L.E. line card.
- Disadvantages:
  - Limited bandwidth means limited data rate (best was ITU-T V.92 56kbps downstream/48kbps upstream).
  - Expensive path reserved by circuit-switching to ISP.
  - Cannot make a phone call and connect to the Internet at the same time.
- Advantages:
  - Re-use of the existing local loop (no need for new very expensive infrastructure).

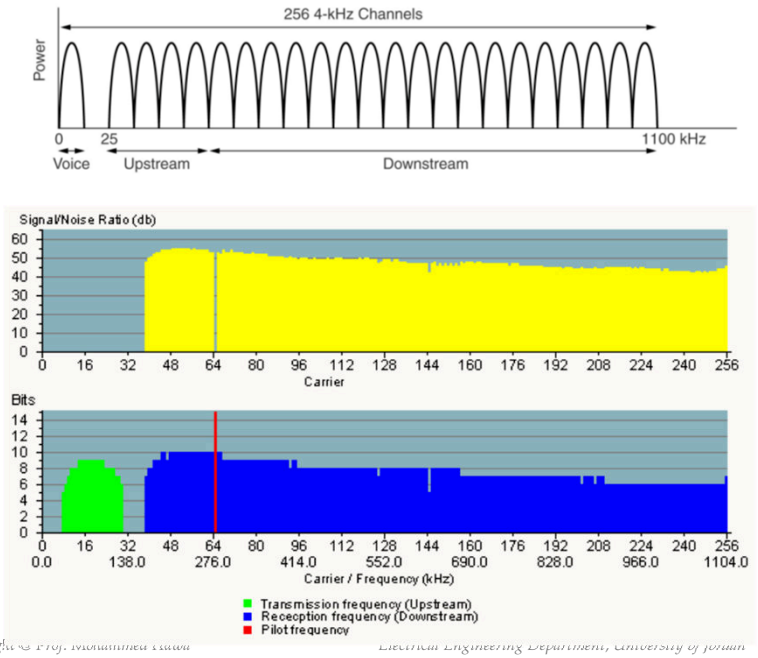
Digital Subscriber Line (xDSL)



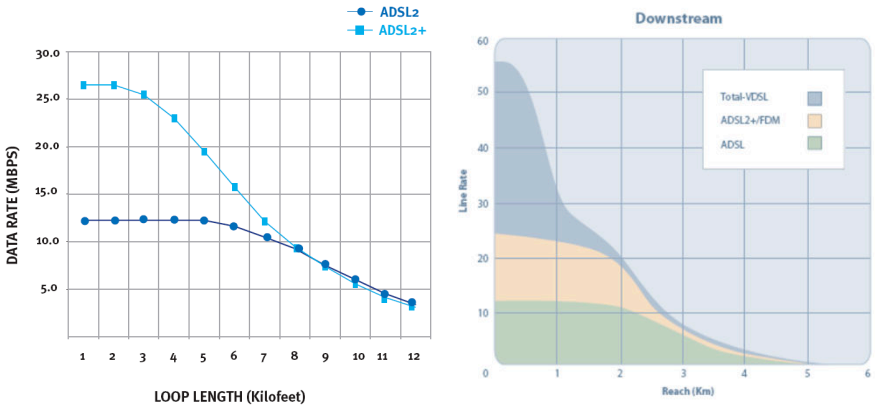
xDSL Standards

- Different variants of DSL technologies exist: ADSL/ADSL2/ADSL2+ (Asymmetric DSL), SDSL (Symmetric DSL), HDSL (High-bit-rate DSL), VDSL/VDSL2 (Very High Rate DSL), RADSL (Rate-Adaptive DSL), GDSL (Gigabit DSL).

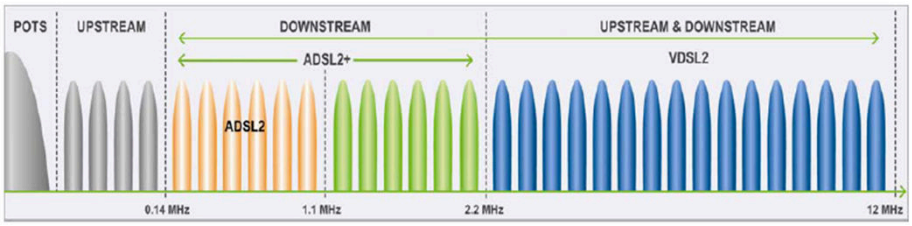
Name	Standard Name	Downstream rate	Upstream rate
ADSL	ANSI T1.413-1998 Issue 2	8 Mbit/s	1.0 Mbit/s
ADSL2	ITU-T G.992.3 Annex J	12 Mbit/s	3.5 Mbit/s
ADSL2+M	ITU-T G.992.5 Annex M	24 Mbit/s	3.3 Mbit/s
VDSL	ITU-T G.993.1	55 Mbit/s	3 Mbit/s
VDSL2-Vplus	ITU-T G.993.2 Amendment 1	300 Mbit/s	100 Mbit/s
G.fast	ITU-T G.9700 & G.9701	1 Gbit/s	100 Mbit/s



Above Data Rates are *Maximum*



Use bandwidth *above* 4 kHz



G. fast Service rate performance targets over 0.5 mm straight loops

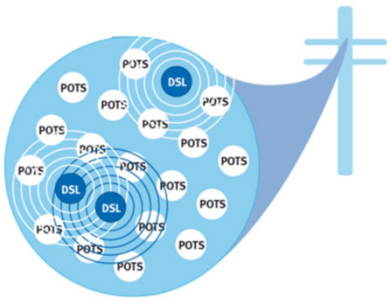
Distance	Performance target
<100 m, FTTB	500–1000 Mbit/s
100 m	500 Mbit/s
200 m	200 Mbit/s
250 m	150 Mbit/s
500 m	100 Mbit/s

G.fast and Vectoring

- G.fast provides up to 1 Gbit/s aggregate uplink and downlink data rate at 100m distance.
- Approved in December 2014, deployments in 2016.
- G.fast uses DMT. It modulates up to 12 bit per DMT frequency carrier, reduced from 15 in VDSL2 to reduce complexity.
- G.fast uses 106 MHz bandwidth, with 212 MHz profiles planned for future amendments.
- Compared to 8.5, 17.664, or 30 MHz profiles in VDSL2.
- G.fast uses TDD, as opposed to ADSL2 and VDSL2, which use FDD, with symmetry ratios of 90/10 up to 10/90, including 50/50.
- Performance in G.fast systems is limited by crosstalk between multiple wire pairs in a single cable (called Self-FEXT: far-end crosstalk).

Vectoring

- Vectoring coordinates line signals to reduce crosstalk (noise cancellation).
- Vectoring was previously specified for VDSL2 by the ITU-T in G.993.5, called G.vector.
- The first version of G.fast will support an improved version of the linear precoding scheme found in G.vector.
- Non-linear precoding planned for a future amendment.

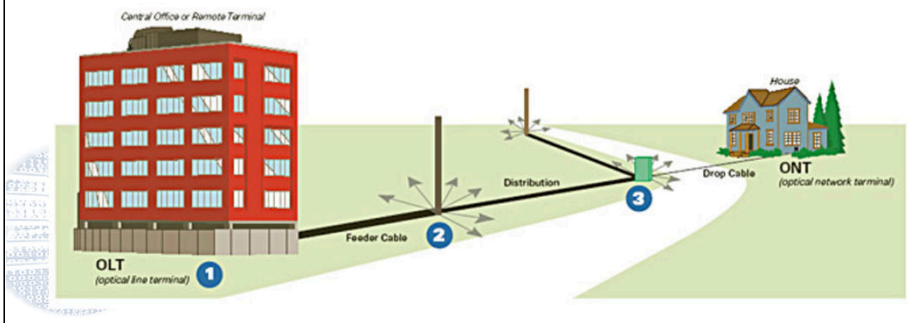


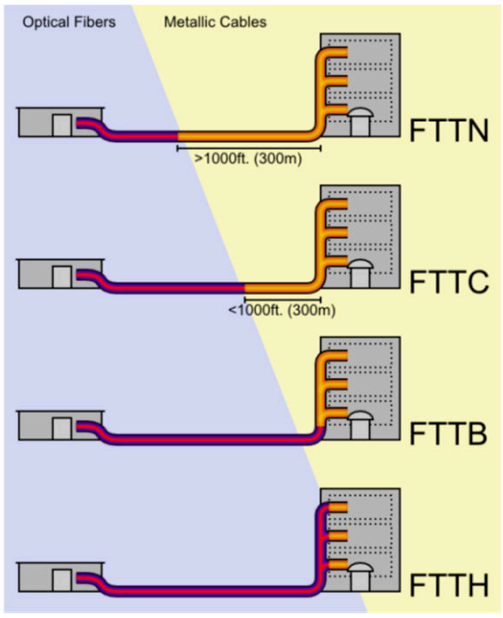
G.fast Deployment

- **FTTdp** (fiber to the distribution point) is commonly associated with G.fast, similar to how FTTN is associated with VDSL2.
- FTTdp is in between FTTC and FTTH.
- In FTTdp, a limited number of subscribers at a distance of up to 200–300 m are attached to one fiber node (can be mounted on a pole or underground), which acts as a DSLAM.
- Compared to ADSL2 where the DSLAM is located in the Local Exchange at a distance of up to 5 km from the subscriber, while in some VDSL2 the DSLAM is located in a street cabinet and serves hundreds of subscribers at distances up to 1 km.

Fiber to the x (FTTx)

- Telephony networks consist of a large distribution network of copper wires.
- Fiber to the node / Fiber to the neighborhood (FTTN)
- Fiber to the curb (FTTC) / Fiber to the kerb (FTTK)
- Fiber to the distribution point (FTTdp)
- Fiber to the building (FTTB)
- Fiber to the home (FTTH)





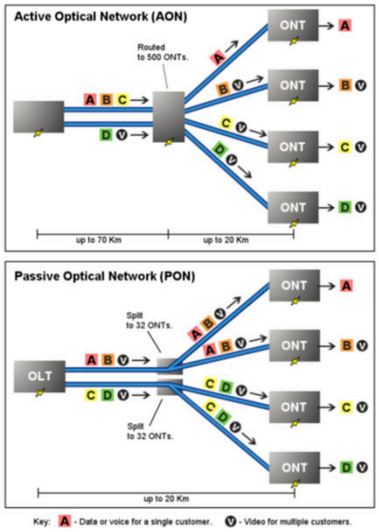
Equipment

FTTC

FTTH

FTTx

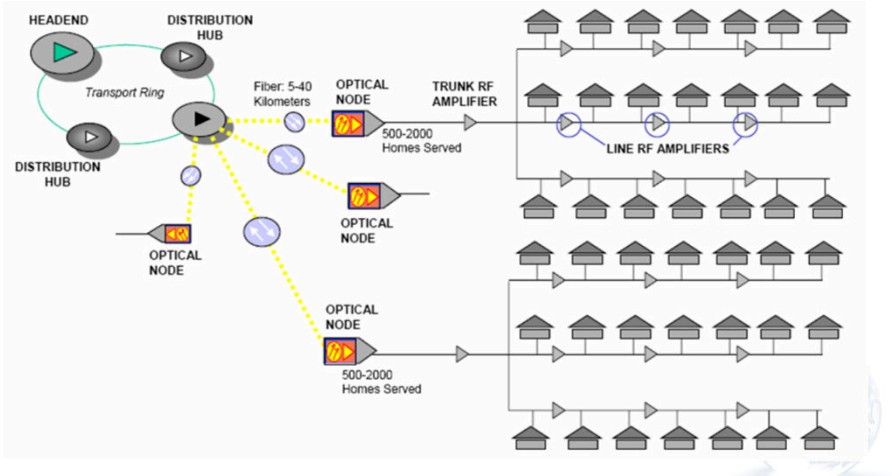
- The two main technologies to support FTTx architectures are:
- **VDSL2 and G.fast:** used along with FTTN, FTTC and FTTdp deployments.
- **Passive optical network (PON):** used in FTTH and in some FTTB deployments. Also in FTTN, FTTC, FTTdp along with VDSL2 and G.fast.



Name	Standard	Maximum Split ratio	Downstream Capacity*	Upstream Capacity*	Layer 2 encapsulation
GPON (Gigabit PON)	ITU-T G.984	1:64	2.5 Gbps	1.25 Gbps	ATM & Ethernet
10G-PON (10 Gigabit PON)	ITU-T G.987	1:128	10 Gbps	2.5 Gbps	Ethernet
NG-PON2 (or TWDM-PON)	ITU-T G.989	1:128	40 Gbps	40 Gbps	Ethernet
EPON (Ethernet PON)	IEEE 802.3ah	1:32	1.25 Gbps	1.25 Gbps	Ethernet
10G-EPON (10 Gigabit Ethernet PON)	IEEE 802.3av	1:64	10 Gbps	1.25 Gbps	Ethernet
50G-EPON (50 Gigabit Ethernet PON)	IEEE 802.3ca	1:64	50 Gbps	50 Gbps	Ethernet

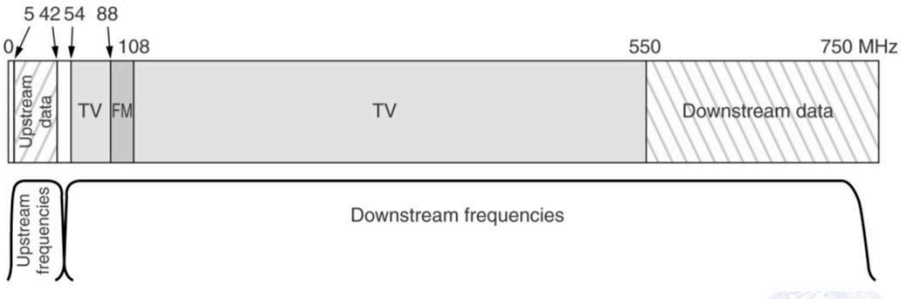
(*) before being divided by the number of splits

Cable TV (CATV) Networks



Cable Modems

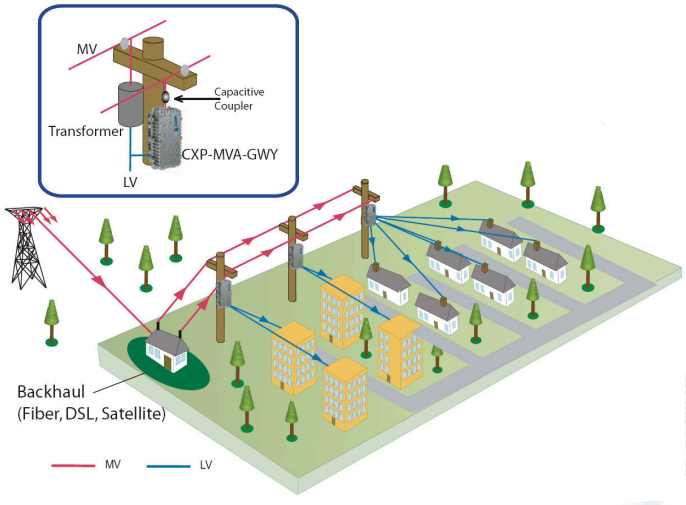
Coaxial Cable Bandwidth



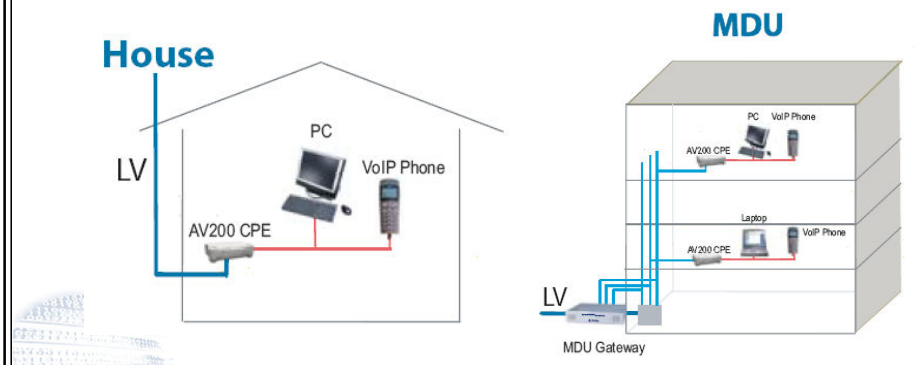
DOCSIS (Data Over Cable Service Interface Specifications)

CableModem Standard Name	Ratified as ITU-T Standard	DOCSIS (6 MHz channels)		EuroDOCSIS (8 MHz channels)	
		Downstream rate	Upstream rate	Downstream rate	Upstream rate
DOCSIS 1.1	J.112 Annex B	42.88 Mbit/s	10.24 Mbit/s	55.62 Mbit/s	10.24 Mbit/s
DOCSIS 2.0	J.122	42.88 Mbit/s	30.72 Mbit/s	55.62 Mbit/s	30.72 Mbit/s
DOCSIS 3.0 8 channel	J.222	343.04 Mbit/s	122.88 Mbit/s	444.96 Mbit/s	122.88 Mbit/s
DOCSIS 4.0 OFDM	J.481	10 Gbit/s	6 Gbit/s		

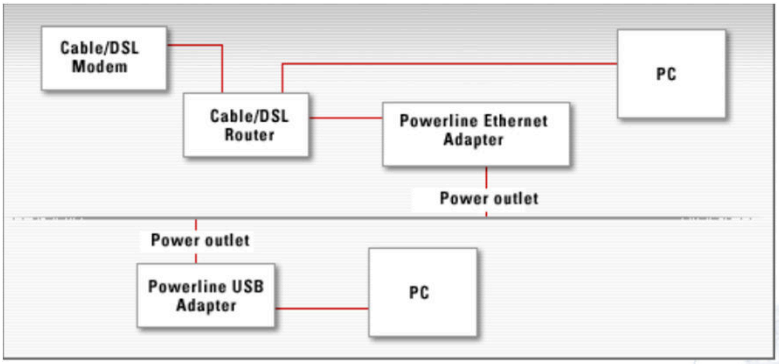
Power Line Communication (PLC)



Split data stream at home



Also for Home Networking

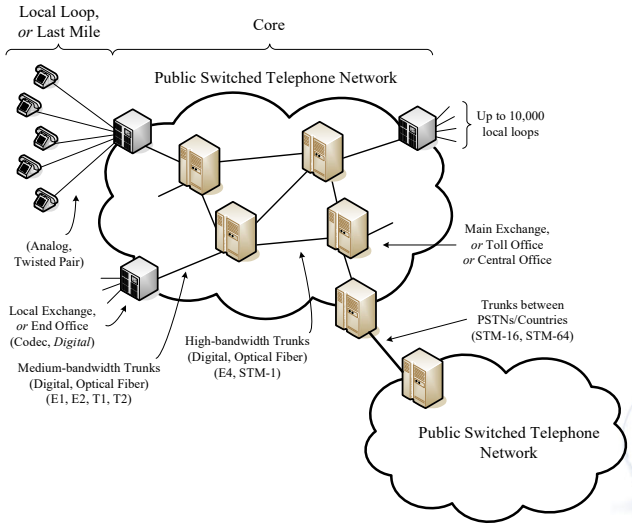


Powerline Adapter

PLC Standards Groups

- High Definition PLC (HD-PLC), led by Panasonic;
- HomePlug Powerline Alliance (HomePlug); various power line communications specifications that support networking over existing home electrical wiring (HomePlug 1.0 (14 Mbit/s), HomePlug AV (200 Mbs) and HomePlug AV2 (1 Gbps and 1.3 Gbps)).
- IEEE 1901 supports both HomePlug and HD-PLC.
- ITU-T G.hn/G.9960 as a standard for high-speed power line, coax and phone line communications (1 Gbps).

Leased Lines from Telephony



Plesiochronous Digital Hierarchy (PDH)

European Standard:

Carrier	Multiplex …	Data Rate	MUX Level
E0	1 channel (voice or signaling)	64 kbps	
E1	30 speech + 1 framing + 1 signaling channels	2.048 Mbps	1st Level
E2	Four E1 carriers + framing	8.448 Mbps	2nd Level
E3	Four E2 carriers + framing	34.368 Mbps	3rd Level
E4	Four E3 carriers + framing	139.264 Mbps	4th Level
E5	Four E4 carriers + framing	565.148 Mbps	5th Level

U.S. Standard:

Carrier	Multiplex …	Data Rate	MUX Level
T0	1 channel (voice and signaling combined)	64 kbps	
T1	24 PCM channels + framing	1.544 Mbps	1st Level
T2	Four T1 carriers + framing	6.312 Mbps	2nd Level
T3	Seven T2 carriers + framing	44.736 Mbps	3rd Level
T4	Six T3 carriers + framing	274.176 Mbps	4th Level

SDH (Synchronous Digital Hierarchy) / SONET (Synchronous Optical NETwork)

European Standard:

Optical Carrier	Multiplex …	Data Rate
STM-1	Basic	**155.52 Mbps**
STM-4	Four STM-1 carriers	**622.08 Mbps**
STM-16	Four STM-4 carriers	**2.48832 Gbps**
STM-64	Four STM-16 carriers	**9.95328 Gbps**
STM-256	Four STM-64 carriers	**39.813 Gbps**
STM-1024	Four STM-256 carriers	**159.252 Gbps**

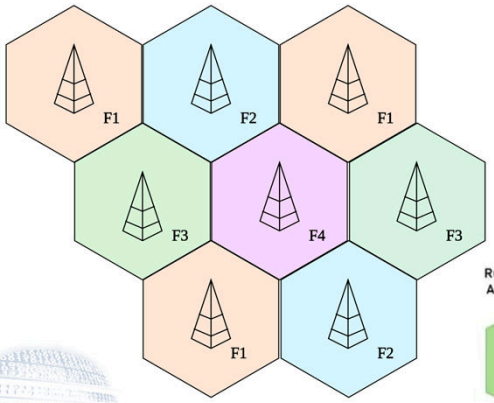
U.S. Standard:

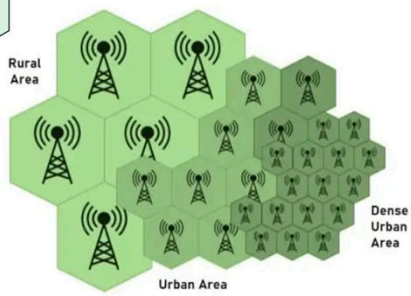
Optical Carrier	Electrical Carrier	Multiplex …	Data Rate
OC-1	STS-1	Basic	**51.84 Mbps**
OC-3	STS-3	Three OC-1 carriers	**155.52 Mbps**
OC-12	STS-12	Four OC-3 carriers	**622.08 Mbps**
OC-48	STS-48	Four OC-12 carriers	**2.48832 Gbps**
OC-192	STS-192	Four OC-48 carriers	**9.95328 Gbps**
OC-768	STS-768	Four OC-192 carriers	**39.813 Gbps**
OC-3072	STS-3072	Four OC-768 carriers	**159.252 Gbps**

Remember…

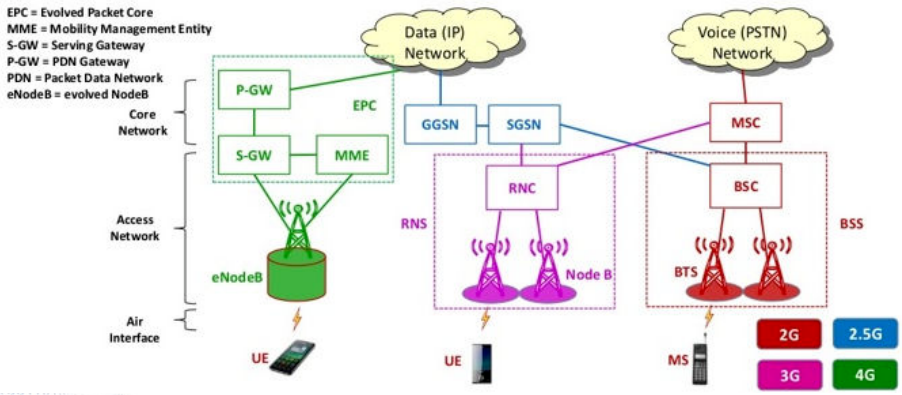
- SDH is an ITU-T standard (G.707, G.708, G.709)
- STM-n stands for: Synchronous Transport Module – Level n
- STS-n stands for: Synchronous Transport Signal – Level n
- OC-n stands for: Optical Carrier – Level n
- Benefits of SDH/SONET over PDH: simpler and a more flexible multiplexing at high data rates. Huge capacity of extra bits dedicated for network management and maintenance functions to allow protection rings.

Cellular (Wireless)





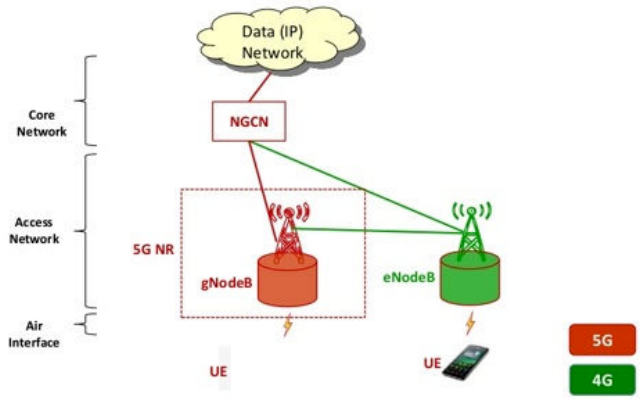
Network Architecture



Homework: MS, BTS, BSC, MSC, UE, RNC, GGSN, SGSN.

Network Architecture: 5G

NGCN = Next Generation Core Network
gNodeB = next generation NodeB
NR = New Radio



Cellular Telephony (3GPP & ITU-T)

	Standard	Name (Technology)	Data Rate
2.5G	GPRS	General Packet Radio Service (TDMA)	54 kbps
3G	UMTS	Universal Mobile Telecommunications System (CDMA)	384 kbps
	HSPA	High Speed Packet Access (OFDMA)	7.2 Mbps
3.75G	HSPA+ (Rel. 6)	Evolved High Speed Packet Access Release 6 (OFDMA + MIMO)	14.4 Mbps
	LTE	Long Term Evolution (OFDMA + MIMO)	100 Mbps
4G	LTE Advanced (Rel. 10)	Long Term Evolution Advanced (OFDMA + MIMO)	500 Mbps
4.75G	LTE Advanced Pro (Rel. 13)	256-QAM, Massive MIMO, LTE-Unlicensed & LTE IoT	1 Gbps
5G	5G Evolution (Rel. 17)	100 MHz bandwidth @ 3.5 GHz, Beam Management	10 Gbps

