Electronics and Electrical Communications Eng. dept.
Faculty of Engineering
Cairo University

قسم هندسة الإلكترونيات والاتصالات الكهربية
كلية الهندسة
جامعة القاهرة

Communications Engineering (ELC 3251) Part 2

1

Communications Engineering (ELC 325a)

This part of the course mainly defines the basic parameters of typical communication systems. It gives examples of most used systems such as POTS/PSTN system, and satellite communications system. It also gives examples of communications access media (wired and wireless). A brief introduction to Traffic and Queuing theories is also included.

2

Main Course Objective(in Brief)

- to introduce computer engineering students to the fundamentals of Communications engineering,
- to familiarize students with communications principles such as modulation theory, etc.
- to familiarize students with the design and analysis of telecom systems.

3

Learning Outcomes

1.Examine the basic concepts of communication theory,

2. Analyze a typical communication systems,

3.Calculate network quality of service using traffic and queuing theories to analyze a communication network.

4

Assignments & Quizzes

- ➤ You may have a 5 minutes quiz during the lecture.
- ➤ You will receive the assignment at least one week before the submission due date.
- ➤ Notice: that it is an individual assignment.
- ➤ Grades:
  - No Mid term Exam for this part (for the time being…!)

5

Course Guidelines

- This is a course dealing with fundamentals of communications systems; pace is fast, material is demanding.
- This part is highly descriptive with some mathematical exercises.
- Every lecture is based on material covered in previous lectures.
- Interactive lectures; if you have any question, interrupt the instructor anytime and ask…, however, you should not talk between you during the lectures!
- Mobile phones should be kept either switched-off or be kept on silent-mode

6

Suggested Reading

There is no single textbook for this subject. However, the following are good references :

1. John C. Bellamy, "Digital Telephony", 3rd Ed., 2002,Wiley series in telecommunications and signal processing.
2. R. Freeman, "Telecommunication System Engineering", 3rd ed., 1996, J.Wiley,
3. "Satellite Communications", Dennis Roddey, McGraw Hill, 1996.
4. "LEO Satellites for Personal Communication Network", A. Jamalpour, Artech House, 1998.

7

Suggested Reading Cont'd

5. Lecture notes, S Paker, K.Has Uni., Electronics Eng. Program., 2004.
6. S. Haykan, Comm. Systems, 3rd Ed., 1994
7. "Networking", Jeffrey Beasley, PEARSON, Prentice Hall, 2004.
8. Several web sites ….

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8

Unit 1:

Access Networks and Transmission Media

Reference: Computer Communications, William Stallings, 9th Edition, Prentice Hall, 2011

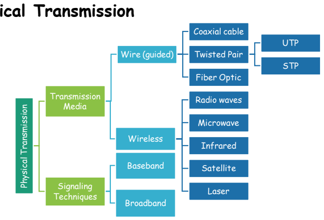
9

Overview

- Guided - wire such as fiber-optic cable, twisted-pair copper wires, and coaxial cables)
- Unguided - wireless (such as wireless LAN or a digital satellite channel)
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important as well as interference
- Key concerns are data rate and distance

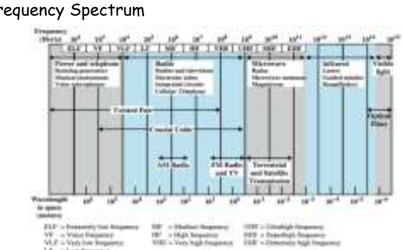
10

Physical Transmission



11

Frequency Spectrum



12

Design Factors Determining Data Rate and Distance

bandwidth
- higher bandwidth gives higher data rate

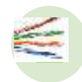
transmission impairments
- impairments, such as attenuation, limit the distance

interference
- overlapping frequency bands can distort or wipe out a signal

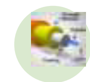
number of receivers
- more receivers introduces more attenuation

13

Guided Transmission Media


TWISTED PAIR


COAXIAL CABLE


OPTICAL FIBER

14

Twisted Pair Wire

- **Types**
  - Unshielded twisted pair (UTP)
  - Shielded twisted pair (STP)

Twisting: Minimizes the effect of electromagnetic interference

Shielding (Conductive material)

Insulation (Non-conductive material).
- Casing (Plastic material)

15

Twisted Pair

- **Types**
  - Unshielded twisted pair (UTP)
  - Shielded twisted pair (STP)

Twisting: Minimizes the effect of electromagnetic interference

Shielding (Conductive material)

Insulation (Non-conductive material).
- Casing (Plastic material)

Can be used for analog and digital transmission

analog
- needs amplifiers every 5km to 6km

digital
- can use either analog or digital signals
- needs a repeater every 2km to 3km

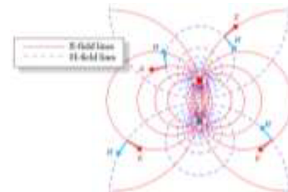
limited:
- distance
- bandwidth (1MHz)
- data rate (100MHz)

16

Unshielded and Shielded TP

- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive
  - Harder to handle (thick, heavy)
- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference

17



Electromagnetic waves around two parallel wires in free space
Source Course EETS8320, Fall 2005 at , School of Eng., Southern Methodist University

18

Advantages of TP

- Cheap
- Easy to install
- Compared to coaxial cables, twisted pair wires have a lower bandwidth, but recent improvements have contributed to an increase in bandwidth and hence an increase in speed.

Areas of Applications

Most common medium:
- Telephone network
  - Between house and local exchange (subscriber loop)
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)
  - 10Mbps or 600Mbps--->

19

Examples of UTP Categories

Category	Description	Bandwidth/Data Rate
Category 3 (CAT3)	Telephone Installation class C	Up to 16 Mbps
Category 5 (CAT5)	Computer Network	Up to 100 MHz/100Mbps-100 m length
Category 5 (CAT5e)	Computer Networks	100MHz/1000Mbps applications with improved noise performance
Category 6 (CAT6)	Higher speed computer Networks	Up to 200 MHz
Category 7 (Cat7)	STP, More expensive, harder to work with. Sometimes called SSTP, shielded screen TP, the shield decreased the effect of x-talk and increases data rate	Up to 600 MHz/data up to 10Gbps

20

Transmission Lines Parameters

For transverse EM waves we can determine four "lumped" parameters that approximately describe the properties of the section of wire/cable:

- *R*. Longitudinal resistance (ohm/meter)
- *L*. Loop inductance (henry/meter)
- *G*. Parallel insulation conductance (mho/meter or 1/ohm•meter)
- *C*. Parallel wire pair capacitance (farad/meter)

Derived parameters:

- Characteristic impedance or surge impedance, Z_0 :

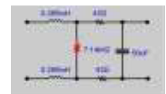
$$Z_0 = \sqrt{(R + jL2\pi f)/(G + jC2\pi f)}$$

- Wave speed (phase velocity)

$$c_m = 1/\sqrt{(R + jL2\pi f)\bullet(G + jC2\pi f)}$$

Example of Lumped Element Model for Transmission Line

This represents a 1 km loop of 0.91 mm diameter copper wire, with typical plastic insulation.



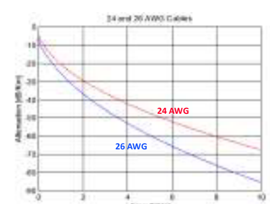
Wire "Gauge"

- In North America, wire diameter is described by "gauge" (AWG) number
- Most other countries list actual diameter (in mm)

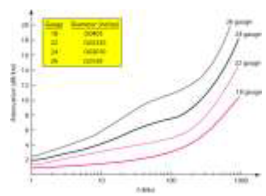
[notice: dc resistance stated in table]

B&S or AWG Copper Wire Gauge	Diameter (inches)	Diameter (mm)	Ω per km (at dc, 0 Hz) [loop Ω is twice the resistance of one wire]
12	0.08	2.053	10.42 Electric power uses
14	0.064	1.628	16.56 Electric power uses
19	0.036	0.91	51.6 Telephone history interest
22	0.025	0.644	103.8 Telephone use today
24	0.020	0.511	164.4 Telephone use today

Attenuation vs. frequency



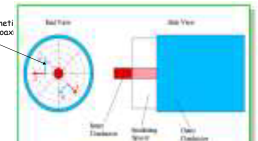
Attenuation vs. frequency for various AWG



25

Coaxial Cable

Electromagneti waves in a coaxi cable



Category	Impedance	Use
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

Source Course EETS8320, Fall 2005 at , School of Eng., Southern Methodist University

26

Types of Coaxial Cables

- Thin coaxial
  - Lighter version
  - Thin Ethernet cable
- Thick coaxial
  - Original version
  - Standard Ethernet cable

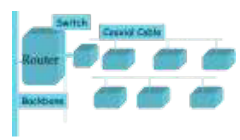
Areas of Applications

- Ethernet bus LANs
- Telephone trunks
- Mainframe networks
- Cable TVs

27

Examples of Thin and Thick Coaxial Cables Used in LAN

- Standardized
- 10Base2 cable
  - 10M bps over baseband
  - Ethernet
  - Thin coaxial cable
  - Bus topology
- Standardized
- 10Base5
  - 10M bps
  - Ethernet
  - Thick coaxial cable
  - Bus topology



28

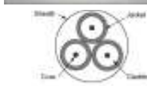
Overall Characteristics of the Coaxial Cables

- Relatively cheap compared to fiber-optic cables
- Wider bandwidth compared to twisted pair wires
- Good transmission characteristics
- Used in high-speed synchronous transmission
- Supports broadband communications
- Can be tapped for multi-drop connection

29

Optical Fibers (Fiber Optic Cables)

- Light travels along the path of a fiber strand by bouncing around its edges
- Carry data over long distances and at very high speeds
- Fiber cannot be bent or twisted



30

Fiber optic technology

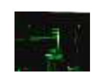
- Sources
- Transmission medium
- Detectors

Fig: The fiber optic communication system

31

Sources of light

- Light emitting diodes
- Lasers



Transmitter

- Modulate electrical signals into optical signals
- Light is used as the carrier of information
- Mostly modulate at 850nm, 1300nm and ~~1550 nm~~
- Lasers give high intensity, high frequency light
- LEDs are economical

Hint: The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation.

32

Physics of optical fibers

- Speed of light changes as it across the boundary of two media.
- Refraction of light : bending of light as it travels from one media to another. It happens when a ray of light is passing from a medium of higher refractive index, n_1 into a medium of lower refractive index, n_2.
- ~~Refraction of light : bending of light as it travels from one media to another. It happens when a ray of light is passing from a medium of higher refractive index, n_1 into a medium of lower refractive index, n_2.~~

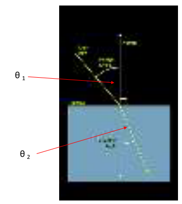
33

Refraction of light

Snell's Law , formulated in 1621

Snell's Law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$



- **Critical angle: Angle of incidence at which angle of refraction = 90°**
- **For θ_1 greater than critical angle, total internal reflection occurs with no losses at the boundary.**

- Angles w.r.t normal

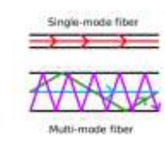
34

Refraction Indices

Vacuum……1.00000 (exactly)	Air ……1.00029	Alcohol ……1.329	Diamond …… 2.417
Glass …… 1.5	Ice …… 1.309	Sodium Chloride (Salt) …. 1.544	Sugar Solution (80%) …… 1.49
	Water (20 C) …………… 1.333		

35

Types of optical fibers



- Single mode
  - only one signal can be transmitted
  - use of single frequency
- Multi mode
  - Several signals can be transmitted
  - Several frequencies used to modulate the signal

36

Losses in optical fibers

- Attenuation loss
- Dispersion loss
- Waveguide loss

37

Advantages of Optical Fibers

- Very broad bandwidth, so higher transmission speeds are possible
- Signals travel a longer distance (low attenuation)
- No Electro-magnetic field
  - No interference
  - Signals are difficult to tap
- Smaller size
  - Multiple fiber strands can be included in a cable of very small diameter

Areas of Applications

- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- LANs

38

Comparison of Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
~~Twisted pair (with loading)~~	~~0 to 3.5 kHz~~	~~0.2 dB/km @ 1 kHz~~	~~50 μs/km~~	~~2 km~~
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	To THz	0.2 to 0.5 dB/km	5 μs/km	40 km

39

Wireless Transmission

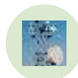
Transmission and reception are achieved by means of an antenna

Directional (higher frequencies)
- transmitting antenna puts out focused beam
- transmitter and receiver must be aligned

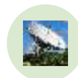
Omnidirectional (lower frequencies)
- signal spreads out in all directions
- can be received by many antennas

42

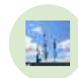
Examples of Wireless Transmission Technologies



Terrestrial microwave transmission



Satellite transmission



Radio (broadcasting, mobile, wireless networks,..)

43

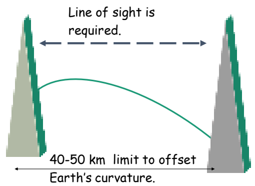
1-Terrestrial Microwave

- uses the radio frequency spectrum, commonly from 2 to 40 Ghz
- parabolic dish transmitter, mounted high as possible
- used by common carriers as well as private networks
- requires unobstructed line of sight between source and receiver
- curvature of the earth requires stations (called repeaters) to be ~50 km apart

44

No obj

Line-of-Sight Requirement



45

Microwave Applications

- long-haul telecommunications service for both voice and television transmission
- short point-to-point links between buildings for closed-circuit TV or link between LANs
- bypass application
  - e.g. bypass local telephone company to reach long-distance carrier

46

Microwaves Electromagnetic Spectrum

Electromagnetic spectrum			
Name	Wavelength	Frequency (Hz)	
Gamma ray	< 0.02 nm	> 15 EHz	Microwaves occupy a place in spectrum with frequency above ordinary radio waves, and below infrared light; Some sources classify microwaves as radio waves, a subset of the radio wave band; while others classify microwaves and radio waves as distinct types of radiation.
X-ray	0.01 nm - 10 nm	30 EHz - 30 PHz	
Ultraviolet	10 nm - 400 nm	30 PHz - 750 THz	
Visible light	390 nm - 750 nm	770 THz - 400 THz	
Infrared	750 nm - 1 mm	400 THz - 300 GHz	
Microwave	1 mm - 1 m	300 GHz - 300 MHz	
Radio	1 mm - 100 km	300 GHz - 3 kHz	

47

Microwave Data Rates

Examples of Digital Microwave Performance

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

48

Microwave

❑ Advantages
- no cabling needed between sites
- wide bandwidth
- multichannel transmissions

❑ Disadvantages
- line of sight requirement
- expensive towers and repeaters
- subject to interference - e.g., passing airplanes, rain

49

2-Satellite Transmission

- a microwave relay station in space
- can relay signals over long distances
- geostationary satellites
  - remain above the equator at height of 35,863 km (geosynchronous orbit)
  - travel around the earth in exactly the time the earth takes to rotate

36K

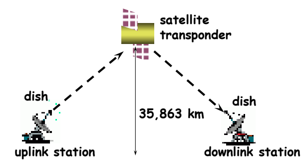
50

Satellite Transmission Links

- earth stations communicate by sending signals to the satellite on an *uplink*
- the satellite then repeats those signals on a *downlink*
- the broadcast nature of the downlink makes it attractive for services such as the distribution of television programming

51

Satellite Transmission Process (e.g., Geo Sat)



52

Satellite Applications

- television distribution
  - a network provides programming from a central location
  - direct broadcast satellite (DBS)
- long-distance telephone transmission
  - high-usage international trunks
- private business networks
- global positioning
- Internet connectivity

53

Main Satellite Bands

- C band: 4(downlink) - 6(uplink) GHz
  - the first to be designated
- Ku band: 12(downlink) -14(uplink) GHz
  - smaller and cheaper earth stations used
  - rain interference is the major problem
- Ka band: 20(downlink) - 30(uplink) GHz
  - More smaller and cheaper receivers
  - Much more attenuation

54

Satellite

Advantages
- can reach a large geographical area
- high bandwidth
- cheaper over long distances

Disadvantages
- high initial cost
- susceptible to noise and interference
- propagation delay (e.g., 1/4 second in Geo Sat))

3-Radio Transmission

Omnidirectional and easily received
- Broadcast radio
  - 30 MHz to 1 GHz - FM, VHF, UHF television
- Mobile telephony including 5G
  - several bands below 1GHz and in the 2-5 GHz band, and 26-86 GHz (mmWave).
- Wireless LAN
  - 2.4 GHz range for 11 MB up to 200 meters, and 6GHz for higher bit rates.

4- Wireless Networks

a- WiFi

IEEE 802.11 standard – nicknamed WiFi
- Short for "*Wireless Fidelity*"
- A trademark of the Wi-Fi Alliance
- Commonly used for "wireless local area network" (WLAN)
- Operates in unlicensed frequency bands, Permitted if limited transmission power, 902-928 MHz, 2.4-2.5 GHz, 5.725-5.825 GHz, and 60 Ghz.

WiFi Family

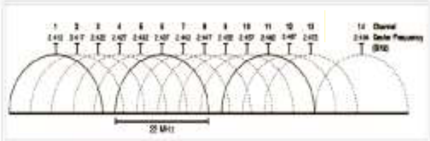
	802.11 (legacy)	802.11a	802.11b	802.11g	802.11n	802.11ac
Max Speed	1.2 Mbit/s	54 Mbit/s	11 Mbit/s	54 Mbit/s	150 Mbit/s	800 Mbit/s
MIMO	no	no	no	no	up to 4	up to 8
Frequency	2.4 GHz	5.8 GHz	2.4 GHz	2.4 GHz	2.4 & 5 GHz	5 GHz
Year	1997	1999	1999	2003	2009	2013

WiFi Several Network Topology

- LAN extension Access points (base stations) connected via wired LAN
- Cross-building interconnect – point-to-point wireless
- Ad-hoc network – peer-to-peer without access point (Mesh Network)

61

2.4 GHz IEEE 802.11b/g/n Channels



Graphical representation of 2.4 GHz band channels overlapping

62

IEEE 802.11ac Gigabit Wi-Fi

Wi-Fi standard provides Very High Throughput, VHT data up to 1 Gbps within the 5.8 GHz ISM band.

IEEE 802.11ad Microwave Wi-Fi / WiGig

Microwave Wi-Fi standard to provide data throughput rates of up to 6Gbps at frequencies around 60 GHz with speed up to 7Gbps.

64

Examples of Future Versions

802.11 ah

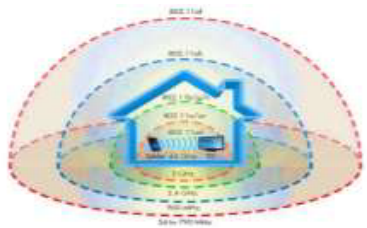
802.11ah standard, also known as WiFi HaLow, is designed to reach up to 1 km providing that certain conditions are met.
To achieve greater coverage, 802.11ah is transmitted at just 900 MHz, a much lower frequency than the existing 2.4 GHz and 5 GHz WiFi technologies.

802.11 af

802.11af also been dubbed White-Fi or Super WiFi and uses television spectrum frequencies between 54 MHz and 790 MHz, potentially making this the longest range WiFi technology yet, with miles of coverage.

65

Current and Future 802.11 versions



66

Wi-SUN

- Wi-SUN (Wireless Smart Utility Network) is a wireless communication standard that enables seamless connectivity between smart-grid devices.
- This wireless communication technology is based on the IEEE 802.15.4g standard for the physical layer (PHY) and the IEEE 802.15.4e standard for the MAC layer.
- The PHY layer is responsible for managing the hardware that modulates and demodulates the RF bits. Whereas, the MAC layer is responsible for sending and receiving RF frames

67

Technical Specifications of Wi-SUN

Coverage	**Up to 4 km**
Frequency	868 MHz (EU), 915 MHz (USA), 2.4 GHz ISM bands (Worldwide)
Datarate	Up to 300 kbps
Latency	0.02 seconds
Power Efficiency	Less than 2 uA when resting; 8 mA when listening
Scalability	Networks with up to 5,000 devices; 10 Million Endpoints Worldwide

68

4- Wireless Networks Contd.
b-Bluetooth

- Wireless Personal Area Networks (WPAN)
- Design objectives
  - Cable replacement
  - Low cost
  - Low power
  - Small size
  - For mobile devices
- Standard: IEEE 802.15.1

69

Technical Specification

- *Classes*
  - *Class 1 (100mW, 100m range)*
  - ***Class 2 (2.5mW, 10m range)***
  - *Class 3 (1mW, 1m range)*
- RF
  - ISM band between 2.4-2.485GHz
  - Frequency hopping over 79 channels, 1600 hops/second

Bluetooth Version

Version	Data rate	Feature
1.2	721 kb/s	
2.0 + EDR	3 Mb/s	Enhanced Data Rate (EDR)
3.0 + HS	24 Mb/s	High-Speed
4.0	1 Mb/s (BLE)	Bluetooth Low Energy (BLE)

WiFi vs. Bluetooth

	Bluetooth	Wifi
Specifications authority	Bluetooth SIG	IEEE, WECA
Year of development	1994	1991
Bit rate	Low (800 Kbps)	High (11 Mbps)
Hardware requirement	Bluetooth adaptor on all the devices connecting with each other	Wireless adaptors on all the devices of the network, a wireless router and/or wireless access points
Cost	Low	High
Power Consumption	Low	High
Frequency	2.4 GHz	2.4 GHz
Security	It is less secure	It is more secure
Range	10 meters	100 meters
Primary Devices	Mobile phones, mouse, keyboards,office and industrial automation devices	Notebook computers, desktop computers, servers
Ease of Use	Fairly simple to use. Can be used to connect to seven devices at a time. It is easy to switch between devices or find and connect to any device.	It is more complex and requires configuration of hardware and software.

4- WIRELESS Networks
c-ZigBee

- Design objectives
  - Low power consumption
  - Simple Design
  - Few costs
- History
  - ZigBee-style networks began in around 1998
  - IEEE 802.15.4 was first completed in 2003
  - ZigBee Alliance was established in 2002

ZigBee Core Market

- **Industrial and Commercial**
  - Monitors
  - Movement Sensors
  - Automation
- **Personal Healthcare**
  - Patient monitors
  - Remote Diagnosis
  - Data loggers
- **Building Automation**
  - Security
  - Lighting
  - Fire and Safety systems
- **Automotive**
  - Service controls
  - Inventory tracking

74

Device Type

- **Full Function Device (FFD)**
  - Network router function
  - Any Topology

- **Reduced Function Device (RFD)**
  - Easy and cheap to implement
  - Limited to star topology
- **Personal Area Network (PAN) Coordinator**
  - Maintains overall network knowledge
  - Needs most memory and computing
  - power

75

Bluetooth vs. ZigBee

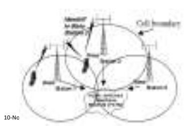
	Bluetooth (v1)	ZigBee
Protocol Stack	250 kb	< 32 kb (4kb)
Range	10 - 100 meters	30 - 100 meters
Link Rate	1 Mbps	250 kbps
Battery	rechargeable	non-rechargeable
Devices	8	2^16
Air Interface	FHSS	DSSS
Usage	frequently	infrequently
Network Join Time	long	short
Extendibility	no	yes
Security	PIN, 8-128 Bit configurable	128 bit, AES

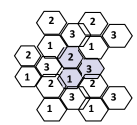
76

5- Wireless Networks Contd.

d- Cellular (Mobile) Network

- Base stations transmit to and receive from mobiles at the assigned spectrum
  - Multiple base stations use the same spectrum (spectral reuse)
- The service area of each base station is called a cell
- Each mobile terminal is typically served by the 'closest' base stations
  - Handoff when terminals move





77

Mobile Evolution from 1G to 5G

- 1G (1980/1990)
- 2G/2.5G (Late 90'S)
- 3G (2001)
- 4G (2010)
- 5G (more than 82 commercial 5G networks in the world, more than 180M users, 100 models of commercial 5G devices available worldwide)

78

1'st Generation (1G)

- 1G refers to 1st generation of mobile telecommunication.
  1. Advanced Mobile Phone Services (AMPS), Deployed in US , Japan : 1983
  2. Nordic Mobile Telephony (NMT), Sweden, Denmark, Norway, Finland : 1981
  3. Total Access Communication System (TACS), British System, similar to AMPS : 1985
- It provides a speed up to 2.4kbps.
- It is based on analog system.
- It allows user to make call in one country.
- It has low capacity, unreliable handoff, and poor voice links.

79

2'nd Generation (2G)

- It was developed in late 1980s and completed in late 1990s.
- It is based on digital system.
- It provides a speed of up to 64 kbps.
- It provides services like voice and sms with more clarity.
- Major prominent technologies were GSM, CDMA, and IS95

1- Global system for Mobile (GSM)
- Based on TDMA ; Europe
- 900 Mhz, 1800 Mhz. Later 850 Mhz and 1900 Mhz in Americas
- Quad Band ; World Phones

80

2'nd Generation (2G) Contd.

2- Code Division Multiple Access
- cdmaOne or IS-95
- All users use same freq band ; 800 Mhz
- Major success in Korea, Used by Verizon and Sprint
- Easy Migration to 3G

2.5 G GPRS (General Packet Radio Service)

- An Overlay technology on top of the existing GSM systems with data rate = 56 – 114Kbps.
- 4 MCS (Modulation and coding schemes) used.
- Factors affecting downlink/uplink speed:
  - TDMA slots
  - Multi-slot class
  - Channel Encoding used

81

2.75 G GPRS EDGE (Enhanced Data rate for GSM)

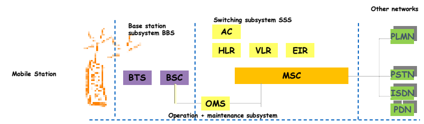
Superset of GPRS.

Data rate = 4 times GPRS.

9 MCS (Modulation and coding schemes) used – Gaussian min shift keying and 8PSK.

82

GSM Architecture



Value added services
AC Authentication Center
BSC Base Station Controller
BTS Base Tranceiver Station
EIR Equipment Identification Register
HLR Home Location Register

MSC Mobile Services Switching Center
OMS Operation Maintenance Subsystem
VLR Visitor Location Register

Source: M. Edris, Senior Eng., Siemens

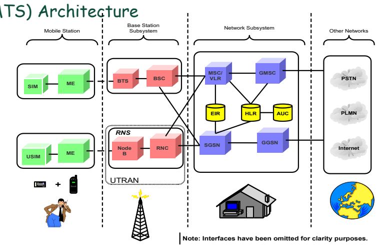
83

Third Generation (3G)

- UMTS - Universal Mobile Telecommunications System. Also known as W-CDMA.
- W-CDMA uses the DS-CDMA and TDD channel access method with a pair of 5 MHz channels.
- Requires new cell towers & frequency allocations.
- Data rate = 1Mbps(theoritical)
- Frequency bands:
- Uplink 1885-2025 MHz (mobile-to-base), Downlink 2110-2200 MHz (base-to-mobile).
- NTT DoCoMo launched the first commercial 3G network on 1 October 2001, using the WCDMA technology
- The current trend in mobile systems is to support the high bit rate data services at the downlink via High Speed Downlink Packet Access (HSDPA)

84

3G (UMTS) Architecture



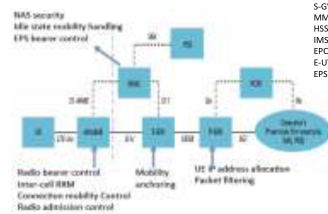
Note: Interfaces have been omitted for clarity purposes.

85

4'th Generation (4G)

- It was developed in the year 2010.
- It is faster and more reliable.
- It provides speed up to 100 Mbps.
- It provides high performance like uploading and downloading speed.
- It provides easy roaming as compared to 3G.
- Use of a higher Layer Protocol (IP) as transport medium affords intelligence at every stage within the network relative to a service

LTE Architecture



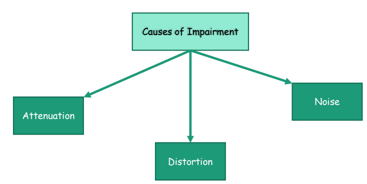
P-GW PDN Gateway
S-GW Serving Gateway
MME Mobility Management Entity
HSS Home Subscriber Server
IMS . IP Multimedia Subsystem
EPC Evolved Packet Core
E-UTRAN Evolved UTRAN
EPS Evolved Packet System.

5'th Generation (5G)

It is a new phase of mobile telecommunication & wireless system.

- Pilots Trials started in 2017.
- Peak data rate (downlink) 20 Gbps
- User-experienced data rate 100Mbps
- Latency 1 ms
- Mobility 500 Km/h
- Connection density 1,000,000 devices /sq.km

Transmission Impairment



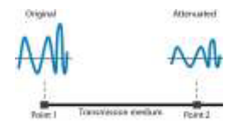
Attenuation

- Means loss of energy -> weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

Measurement of Attenuation

- To show the loss or gain of energy the unit "decibel" is used;

$dB = 10\log_{10} P_2/P_1$
Where P_1 is input signal,
And P_2 is output signal

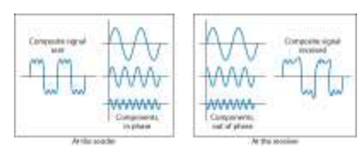


Hint: Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as dB_m = 10 log10 P_m , where P_m is the power in milliwatts.

Distortion

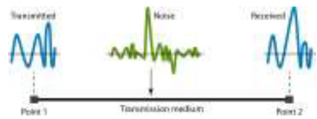
- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

Distortion



Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lightning, etc.
  - Induced



96

Signal to Noise Ratio (SNR)

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as $SNR_{dB.}$

97

Example

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Solution
The values of SNR and SNR_{dB} can be calculated as follows:

$$\mathrm{SNR} = \frac{10{,}000\ \mu\mathrm{W}}{1\ \mathrm{mW}} = 10{,}000$$
$$\mathrm{SNR_{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

98

Is there a limit on the transmission rate over a communication channel?

99

Case Study: Telephone Channel

Telephone Transmission

A baseband voice signal where the frequency range optimized for voice signals

Direct transmission of digital data not possible
Long sequences of 1's or 0's look like a signal with Frequency -- 0
Frequency for 9600bps sequences of alternating 0's and 1's > 3400Hz.

***Modulate* an audio-frequency *carrier signal* with digital data**
Carrier always above low cutoff.
To get high data rates at <3400Hz, squeeze multiple bits into a signal element.

Baud Rate

Each signal element is a "baud" (after its inventor Baudot (1845-1903)
Number of **signal elements /s** is called the **baud rate.**

Theoretical Limitations on Transmission Rate, Nyquist Theorem:

Max Bit Rate = 2 x carrier bandwidth x $\log_2$(possible values/signal element)

no of bits encoded by a signaling element

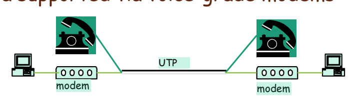
e.g., for an 8 levels for signal element (i.e., 3 bit/signal element) in a voice channel;

Max bit rate = 2 x 3000 x $\log_2(8)$ = 18000bps

Fixed by legacy technology

for voice grade lines and 8 possible values per baud

Data supported via voice-grade modems



To send data, it is converted into 4 kHz audio (modem)

Data rate is determined by *Shannon's capacity theorem.*

- *There is a maximum data rate (bps) called the "capacity", that can be reliably sent through the communications channel.*
- *The capacity depends on the BW and SNR.*

In Shannon's days it worked out to about 25 kbps, and with V.34 modem it is about 35 kbps (33.6 kbps).

Shannon-Hartley Law

This law takes noise into account;

Max bit rate = bandwidth x $\log_2(1 + S/N)$

Where S/N is the signal to noise ratio.

S/N for analogue PSTN with multiple exchanges is ~1000

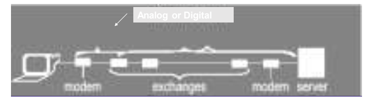
(It depends on complexity of connection)

Max bit rate = 3000 x $\log_2(1000)$ = 30000bps

33.3kbps modems reached this limit

104

HOW COULD OLD MODEMS RUN AT 56K?



56.6kbps modems was "expected" to be used with mainly digital PSTNs

only 1 analog link - user's modem to local exchange

S/N ratio better than 1000

In fact, they often fail to achieve 56.6kbps

105

How to make use of existing telephone networks to transmit higher data rates?

109

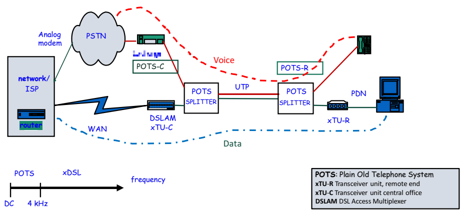
Digital Subscriber Line (DSL)

Why we use DSL?

- Need higher speed digital connection to subscribers
- Not feasible to replace UTP in the ***last mile***
- DSL modems don't assume either the 4 kHz analog line or 64 kbps digital line.
- Use whatever the physics of the UTP allows

110

xDSL System Reference Model (x=A, H,V,..)



111

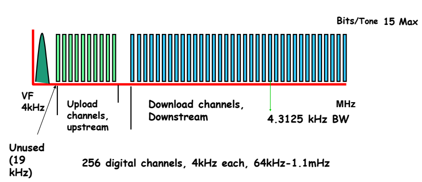
ADSL Example

Asynchronous: Download speed and upload speeds differ

Basic Technology
Extends the useful life of POTS copper wires
Bandwidth increased from 3kHz to 1.1MHz
Divided into separate frequency bands ,Discrete Multitone signaling (DMT), and DMT uses 256 "tones" to carry data bits for ADSL, and 4096 for VDSL2
Each frequency band has its own carrier, coded using QAM (2 phase values, 4 amplitudes), each "tone" can carry up to 15 bits and each tone has a 4.3125 KHz passband
System adapts to S/N ratio across the frequency range
Variable Upload/download channel allocation (in practice, 26 upstream channels)

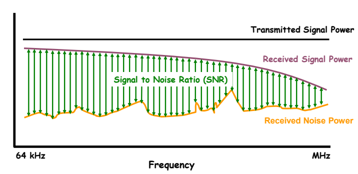
112

ADSL Frequency Spectrum



113

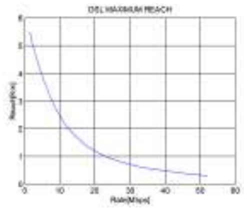
Signal Attenuation



SNR is responsible for the performance

114

xDSL - Maximum Reach



115

ADSL Standards

modem	speed	reach	main applications
ADSL	6 Mbps DS 640 Kbps US	3.5-5.5 km	residential Internet, video-on-demand
ADSL2	8 Mbps DS 800 Kbps US	> ADSL	Internet access, VoIP
ADSL2+	16 Mbps DS 800 Kbps US	< 2 km	"

116

More xDSL flavors

117

VDSL Standards

Version	Standard name	Common name	Downstream rate	Upstream rate	Approved on
VDSL	ITU G.993.1	VDSL	55 Mbit/s	3 Mbit/s	2001-11-29
VDSL2	ITU G.993.2	VDSL2	200 Mbit/s	100 Mbit/s	2006-02-17
VDSL2-Vplus	ITU G.993.2 Amendment 1 (11/15)	VDSL2 Annex Q VPlus/35b	300 Mbit/s	100 Mbit/s	2015-11-06

VDSL2 permits the transmission of asymmetric and symmetric aggregate data rates up to 300+ Mbit/s downstream and upstream

118