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WORK INTEGRATED
LEARNING PROGRAMMES
Mobile Networks
PPT Booklet

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Course Information

- This course will cover physics of semiconductor material and semiconductor devices.
- Correlate semiconductor material physics fundamentals with semiconductor device physics.
- It aims at making the basic physical concepts behind microelectronic devices clear and imparts modeling information about these devices for their use as circuit elements in integrated circuits.
- The course covers the basic technology, models, properties, fabrication and concepts associated with Semiconductors and Semiconductor devices.

Reading Material

Text Book

- **T1:** Wireless and Mobile Networks, Concepts and Protocols, 2ed, Sunilkumar S. Manvi, Mahabaleshwar S. Kakkasageri, Wiley, ISBN: 9788126558551

Reference Book

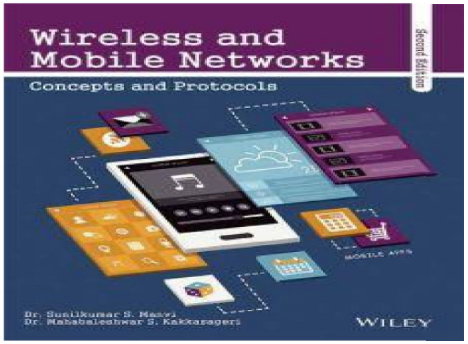
- **R1:** Internet of Things for Architects: Architecting IoT Solutions by Implementing Sensors, Communication Infrastructure, Edge Computing, Analytics, and Security; Perry Lea; Packt Publishing Ltd; 2018
- **R2**: Ad Hoc Wireless Networks: Architectures and Protocols; C. Siva Ram Murthy and B.S. Manoj; Pearson
- **R3**: Relevant specifications/RFCs

Additional Material

- Time to time additional material in the form of research papers, video links and lecture slides etc. will be provided.

Preferred Book

Wireless and Mobile Networks, Concepts and Protocols, 2ed, Sunilkumar S. Manvi, Mahabaleshwar S. Kakkasageri, Wiley, ISBN: 9788126558551



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Outline

- Overview of a Communication System
- Digital vs. Analog Communications
- Examples of Wireless Communication Systems
- Why Wireless is Different ?
- Wireless System Architecture
- Multiple Access Techniques
- Evolution of Cellular Networks (1G ~ 3G)
- Wireless Local Area Networks (WLANs), Bluetooth and Personal Area Networks (PANs)
- Ad hoc networks
- Topics to be covered in the course

Components of a Communication System (1)

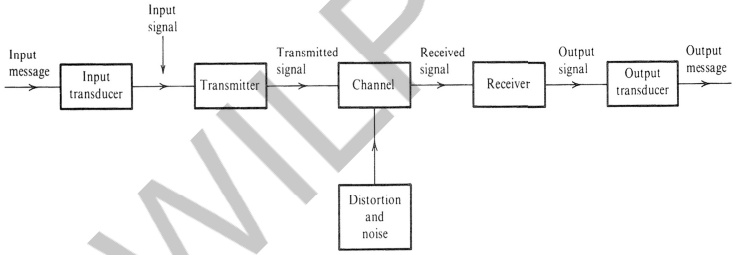

Figure 1: Communication Systems

Components of a Communication System (2)

- The **source** originates a message, which could be a human voice, a television picture or data. The source is converted by an **input transducer** into an electrical waveform referred to as the baseband signal or message signal.
- The **transmitter** modifies the baseband signal for efficient transmission. The transmitter generally consists of one or more of the following subsystems: a pre-emphasizer, a sampler, a quantizer, a coder and a modulator.
- The **channel** is a medium through which the transmitter output is sent, which could be a wire, a coaxial cable, an optical fiber, or a radio link, etc. Based on the channel type, modern communication systems are divided into two categories: **wireline communication** systems and **wireless communication** systems.

Components of a Communication System (3)

- The **receiver** reprocessed the signal received from the channel by undoing the signal modifications made at the transmitter and the channel. The task of the receiver is to extract the message from the distorted and noisy signal at the channel output. The receiver may consist of a demodulator, a decoder, a filter, and a de-emphasizer.
- The receiver output is fed to the **output transducer**, which converts the electrical signal to its original form.
- Transmitters and receivers are carefully designed to overcome the distortion and noise.
- The Goal of Physical layer Communication System is to **transmit information accurately and efficiently** (power and spectrum).

Digital vs. Analog Communications (1)

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- Analog and Digital Signals
  - Messages are digital or analog.
    - Digital messages are constructed with a finite number of symbols. For example, a text file is a digital message constructed from 50 symbols, consists of 26 letters, 10 numbers, a space and several punctuation marks. Similarly, a Morse-coded telegraph is a binary message, implying only two symbols – mark and space.
    - Analog messages are characterized by data whose values vary over a continuous range. For example, a speech waveform has amplitudes that vary over a continuous range. A picture is also an analog message.

Noise immunity of digital signals

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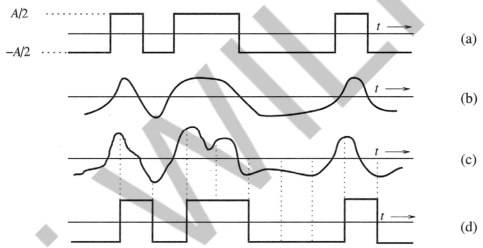

Figure 1.3 (a) Transmitted signal. (b) Received distorted signal (without noise). (c) Received distorted signal (with noise). (d) Regenerated signal (delayed).

Digital vs. Analog Communications (2)

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- **Noise immunity of digital signals** – digital data can be recovered without any error as long as the distortion and noise are within limits. On the other hand, for an analog message, even a slight distortion or interference in the waveform will cause an error in the received signal.
- **Regenerative repeaters**—Based on this "noise immunity", when transporting a bit stream over a long distance, regenerative repeaters or repeater stations are placed along the path of a digital system at distances short enough to ensure that noise and distortion remain within a limit. The viability of regenerative repeaters is the main reason for the superiority of digital systems over analog ones.
- **Every possible communication can be carried on with a minimum of two symbols**, i.e., by using a proper binary sequence. In the last 20 years, digital communication gradually replace its analog competitors, and the revolution is now nearly complete.

Interface of Analog and Digital Systems -- A/D and D/A Conversion

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- **Sampling Theorem** A meeting ground exists for analog and digital signals: conversion of analog signals to digital signals. The backbone that supports the interface is Shannon's Sampling Theorem, which states that if the highest frequency in the signal spectrum is B (in hertz), then the signal can be recovered from its samples, taken at a rate not less than 2B samples per second.
- **Quantization** each sample is approximated, or round off to the nearest quantized level, the information is thus digitalized. The quantized signal is an approximation of the original one. We can improve the accuracy of the quantized signal to any desired degree by increasing the number of levels.
- **Coding**
  - **Source coding** Convert the quantized signal into binary sequences.
  - **Channel coding** Introduce redundancy in a controlled manner to overcome the effects of noise and interferences.
- **Mapping** Map binary sequence into symbols.
- **Transmission** Symbols are applied to a transmitter filter, which produces a continuous signal for transmission over a continuous channel.

Examples of Wireless Communication Systems

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- Codeless telephones --- use radio to connect a portable handset to a dedicated base station over a distance of a few tens of meters.
- Paging systems --- Communication systems that broadcast a page from every base station in the network and send brief messages to a subscriber.
- Cellular telephone systems --- provide a wireless connection to the PSTN (Public Switched Telephone Network) for any user location within the radio range of a system.
- Garage car opener
- Remote controllers for home entertainment equipment
- Hand-held walkie-talkies
- Wireless keyboard and mouse
- Wireless Lan router and adapter
- …..

Wireless Vs. Wireline Communications

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---- Challenges in Wireless Communication Systems

- **Wireless channel**
  - Have time varying and multipath propagation properties.
  - Communicate over a medium significantly less reliable than wired physical layer.
  - Are unprotected from outside signals and interceptions. Multiuser interference (MUI) is a significant problem in wireless communications.
  - Has neither absolute nor readily observable boundaries outside of which stations are known to be unable to receive network frames.
- **User Mobility**
  - Destination address does not equal to a fixed destination location.
  - Power management --- performance, interference lever and power consumption.
  - Hand-off --- A mobile switches its serving base station while moving from cell to cell.
  - Location management --- tracks the user's movement, support users roaming delivers calls to the user at its current location.

Introduction to wireless communication systems

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- It is the Transfer of data between 2 points that aren't connected by an electrical conductor.
- They typically use electromagnetic waves.
- Transmitting voice and data using electromagnetic waves in open space (atmosphere)
- The information from the sender to the receiver is carried over a well-defined frequency band.
- Each Channel has a fixed bandwidth. Different channels can be used to transmit information in parallel and independently.

Why Wireless Communication

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- Mobility

  - Radio waves travel freely through the air, wireless modes of communication give a great deal of mobility.

- Freedom from wires

  -Wired networks can be inflexible in terms of mobility.
  - Extra cables and switches to connect a device to the network and use in different location
  - Installation can be lengthy and complex
  - Maintenance costly.

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Why Wireless Communication

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- Global Coverage
- Communication can reach where wiring is infeasible or costly(e.g. hazardous areas, long distances etc.).
- Scalability
  - Problems with a wired network is coping with expansion and can be expensive.
  - Addition of new users is fast and relatively convenient in wireless communication.
- Stay Connected any where any time.

Challenges of wireless communication system

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– High costs for setting up the infrastructure
– Security vulnerabilities.
– Efficient use of Finite Radio Spectrum
– Efficient Hardware
– *Low power* transmitter, receivers
-Many devices are battery operated. We need to have low power transmitters and receivers
– *Low power* signal processing tools

Challenges of wireless communication system

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– Multipath propagation and fading

Fading is caused by destructive interference of two or more versions of the transmitted signal arriving at the receiver in different times with different amplitude and phases

– Integrated services
- Voice, data, *multimedia* over a single network

Challenges of wireless communication system

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- wireless communication is influenced by
- Physical obstructions
- climatic conditions
- Interference from other wireless devices

- Maintaining quality of service over unreliable links

Summary

- Wireless communication is the transmission of voice and data in free space(atmosphere)
- Stay connected any where any time, mobility, scalability, wide coverage are some of the advantages of wireless network and hence preferred.
- Challenges of wireless communication in terms of security of the data transferred, setting up of the infrastructure, efficient use of radio spectrum etc need to be addressed.

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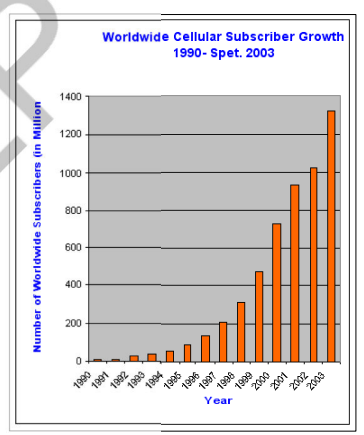
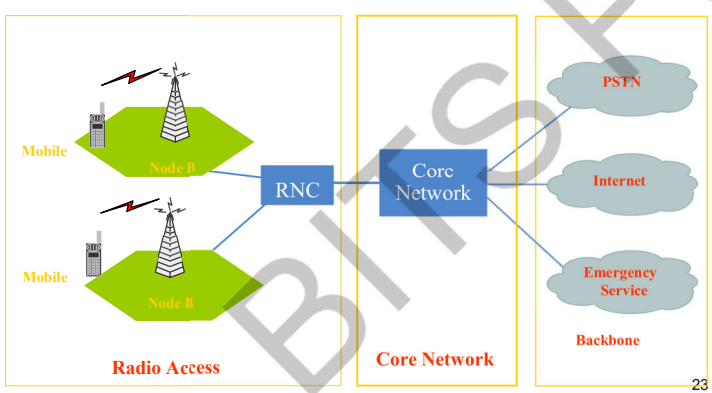
Trends on Wireless Communications

- **Rapid growth** In the last few decades, new and cheaper wireless services are emerging continuously, due to advances in:
  - Digital signal processing
  - Digital and RF circuit fabrication
  - Large scale circuit integration
  - Digital switching techniques -> large scale deployment of radio communication networks
- **Convergence of wireless and Internet ---- Broadband communications**
  - 3G cellular and PCS networks
  - WLAN networks
  - Ad-hoc Networks (military)



Cellular System Architecture



Cellular System Architecture

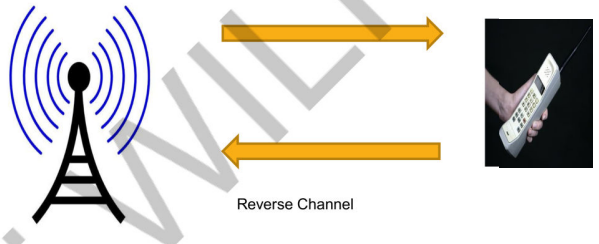
- **Radio Access**: RF related signal processing and radio resource management. Mobile => base station => BSC or RNC => MSC.
- **Core Network**: Main part is MSC (mobile switching center), performs user authentication, admission control, traffic control, roaming, billing, network support and maintenance etc.
- **Backbone networks**: Providing voice services (PSTN, Public Switched Telephone Network), data services (through Internet), and emergency services. Wireless networks need to be connected to backbone networks to extend its service capabilities and geographic coverage.

Wireless Communication System Definitions

- Handoff: The process of transferring a mobile station from one channel or base station to another.
- Mobile Station : A station in the cellular radio service intended for use while in motion at unspecified locations.
- Mobile Switching Center : coordinates the routing of calls in a large Center service area. An MSC is also called a mobile telephone switching office (MTSO).

Forward and Reverse Channel

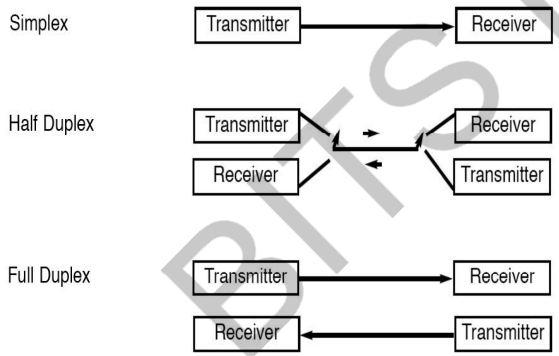
Radio channel used for transmission of information from the base station to the mobile.



Radio channel used for transmission of information from the mobile to base stations

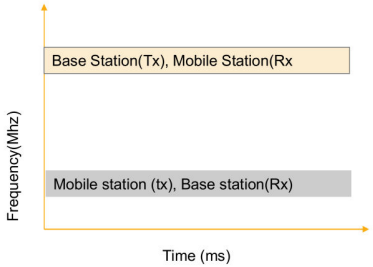
Classification of Mobile Radio Transmission

Classification of mobile radio transmission system



Forms of Full Duplexing

- Two forms of Full Duplexing
- Frequency division duplexing uses two radio channel
  - Forward channel: base station to mobile user
  - Reverse channel: mobile user to base station



Forms of Full Duplexing

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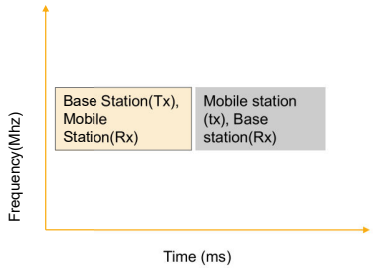
- **Time division duplexing shares a single radio channel in time.**
- **Receives for half the frame and transmits for half the frame.**



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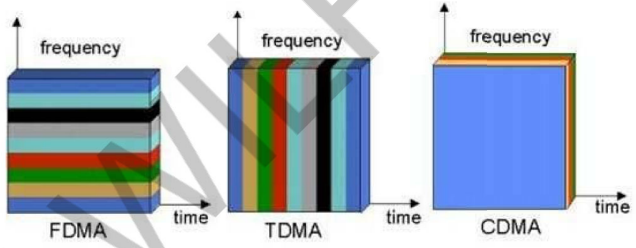
Multiple Access Techniques



Wireless Communication

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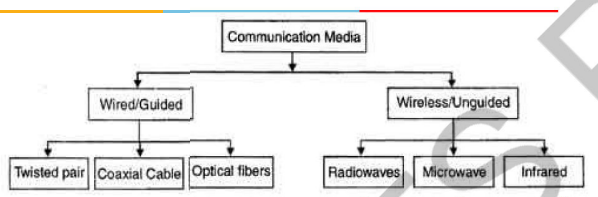

- Easily generated, Omni-directionally travel long distances, easily penetrate buildings

Used for long distance communication, high SNR, point to point-line of sight

Short range communication, unable to pass through solid objects

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Multiple Access Techniques

- **FDMA** (Frequency Division Multiple Access) each user is allocated a unique frequency band or channel, no other user can share the same frequency band.
- **TDMA** (Time Division Multiple Access) divides the radio spectrum into time slots, and in each slot, only one user is allowed to either transmit or receive.
- **CDMA** (Code Division Multiple Access) each user is assigned a special code sequence (signature) to modulate its message signal, all users are allowed to transmit over the same channel simultaneously and asynchronously.
- **SDMA** (Space Division Multiple Access) controls the radiated energy for each user in space. SDMA serves different users by using spot beam antennas.

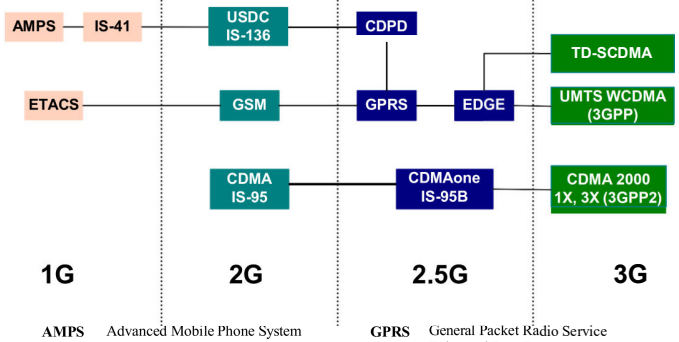
How a cellular telephone call is made?

- **Receiving a call**
  - Turn on a cellular phone
  - The cellular phone scan the control channels to determine the one with the strongest signal, it then monitors the signal drops below a usable level. At his point, it starts to search of strongest base station again.
  - If a phone call is placed to a mobile user, the MSC dispatches the request to all the base stations in the system, the MIN (mobile identification number, i.e. the mobile's phone number) is broadcast as a paging message through the forward control channel.
  - The mobile receives the signal through the base station it monitors and responds by identifying itself through the reverse control channel.
  - The base station informs the MSC of the handshake.
  - The MSC instructs the base station to move the call to an unused voice channel within the cell.
  - The base station signals the mobile to change frequencies to the unused unused forward and reverse voice channel pair.
  - The base station instructs the mobile phone to ring, thereby to instruct the user to answer the phone.

How a cellular phone call is made (continued)

- **Initiating a call**
  - The mobile sends a call initiation request through the reverse control channel, with this the unit transmits its MIN, ESN (electronic serial number) and the phone number of the called party.
  - Base station receives the request and sends it to the MSC.
  - The MSC validates the request, making connection to the called party through PSTN.
  - The MSC instructs the base station and mobile user to move to an unused forward and reverse voice channel pair.
- **Roaming**
  - All cellular systems provide a service called *roaming*. This allows subscribers to operate in service areas other than the one from which the service is subscribed.
  - The MSC issues a global command every several minutes, asking all unregistered mobiles to report their subscription information.
  - Mobiles report back upon receiving the request.
  - If the mobile has roaming authorization for billing purpose, the MSC registers the subscriber as a *roamer*.

Wireless System Evolution: Cellular Networks



AMPS Advanced Mobile Phone System
ETACS European Total Access Communication System
USDC United States Digital Cellular
GSM Global Systems for Mobile
CDPD Cellular Digital Packet Data
GPRS General Packet Radio Service
EDGE Enhanced Data Rates for GSM Evolution
UMTS Universal Mobile Telecommunications System
3GPP 3rd Generation Partnership Project

1G Wireless Systems

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- Appeared in late 1970s and deployed in early 1980s.
- All based on analog techniques, all used FDMA and FM modulation.
- System capacity is low. Data rate: 8~10 kbps
- Representative Standards:
  - **AMPS:** Advanced Mobile Phone System, developed by AT&T Bell Labs in late 1970s. First deployed in 1983. The first AMPS system **used large cells and omni-directional base station antennas, therefore, the number of users that can be supported was quite limited.** AMPS is used all over the world and is esp. popular in US, South America, China and Australia.
  - **ETACS:** European Total Access Communication Systems. Almost identical to AMPS except that the channel bandwidth is scaled to 25kHz instead of 30 kHz as in AMPS.

2G Wireless Systems: Characteristics

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- Deployed in mid 1990s, 2G wireless systems all use digital voice coding and digital modulation.
- Can provide advanced call capabilities and at least a 3- times increase in overall system capacity.
- Was designed before the widespread of the Internet, mainly supported voice-centric services and limited date-service, like short messages, FAX,etc.
- Date rate: on the order of 10 kbps

2G Wireless Systems: Representative Standards

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- **GSM** (Global Systems for Mobile communications)
  - A TDMA system, serves as the pan-European cellular service, provides a wide range of network service, including phone service, FAX, short message service. Support 24.7kbps data rate.
- **USDC IS-136** (United States Digital Cellular)
  - A TDMA system which is compatible with AMPS, it supports more users (6 times) with improved performance. It shares the same frequencies, frequency reuse plan and base stations as AMPS. Provides access to VPN, supports short messages. Support 48.6kbps data rate.
- **IS-95** (United States Digital Cellular Standard)
  - A CDMA standard also designed to be compatible with AMPS through using of CDMA/AMPS dual mode phones and base stations. Capacity is 8~10 times that of AMPS. Support 14.4kbps data rate.

2.5G Wireless System

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Compared to 2G systems, 2.5G systems enables high speed data communications, provides continuous connection to internet.

- **CDPD** (Cellular Digital Packet Data), a data service for 1st and 2nd generation US cellular systems without additional bandwidth requirement, packet channels are dynamically assigned to idle voice channels. Support 48.6kbps data rate as in IS-136.
- **GPRS** (General Packet Radio Service), based on GSM by allowing multiple slots of a GSM radio channel be dedicated to an individual user, promises data rate from 56 kbps to 114kbps--- continuous connection to the Internet for mobile phone and computer users, easy access to VPN (Virtual Private Network).
- **EDGE** (Enhanced Data Rates for GSM Evolution), providing 384kbps rate by using improved modulation (8-PSK instead of GMSK in GSM) and relaxed error control. Also referred to as EGPRS.
- **CDMA one (IS-95B)**: Providing high speed data access on a common CDMA radio channel by dedicating multiple orthogonal user channels for specific users or specific purposes. Support 115.2kbps.

3G Wireless Systems: Features

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- Features:
  - **High transmission rate and the support of multimedia services.**
    - Multiple-megabit internet services, and simultaneous voice and data access with multiple parties at the same time using a single mobile handset.
    - Date rate: around 2Mbps. Bandwidth: in the order of MHz
  - Seamless global roaming: wireless access from anywhere on the earth. Obviously, it will include the satellite networks.
- 3GPP and 3GPP2
  - Worldwide standardization organizations established to gather global expertise, participated by almost all the big companies.
  - 3GPP: based on backward compatibility to GSM, IS-136, GPRS, EDGE etc.
  - 3GPP2: based on backward compatibility to IS-95, and CDMAone.

3G Wireless Systems: Challenges

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- **Impact of high transmission rate --- frequency selective fading**
  - High transmission rate implies that the signal bandwidth is much wider than the coherence bandwidth of the channel, different frequency components in the signal will experience different fading characteristic.
  - **Solution**: Modulate each signal components onto a different subcarrier and send them over the channel in parallel, so that each component will experience flat fading. => multicarrier systems.
- **System capacity and user mobility**
  - Enlarged capacity and higher transmission rate requires more efficient deployment of the available bandwidth, which implies that the system needs to be reused more often.
  - Higher degree of frequency reuse implies more complex mobile management.
  - How to increase spectrum efficiency is the ultimate goal of communication research.

3G Wireless Systems: Representative Standards

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- **3GPP UMTS** (Universal Mobile Telecommunications System) A wideband CDMA (5MHz) standard based on the network fundamentals of GSM/EDGE, is designed to provide backward compatibility with GSM, IS- 136, GPRS and EDGE. Can support 2Mbps data rate. New RF equipment needed.
- **3GPP2 CDMA 2000 3G 1X-3X** Use one (same bandwidth as IS-95) or three adjacent 1.25MHz channels (3-times bandwidth as that of IS-95) to provide instantaneous packet data access at 144kbps or 2Mbps. No additional RF equipment needed, changes are all made in software or baseband hardware.
- **TD-SCDMA** (Time-division Synchronous CDMA) A standard proposed by CATT (China Academy and Telecommunications Technology) and Siemens Corporation. Relies on the existing GSM infrastructure and allows 3G data access by adding high data rate equipment (smart antennas) at each GSM station. Support up to 384kbps of packet data.

Wireless Local Area Networks (WLANs) and Personal Area Networks (PANs, Bluetooth)

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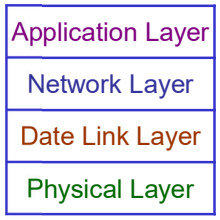
- WLANs and PANs, provide broadband telecommunications access in the local exchange, driven by demand for broadband Internet access from business and homes due to the rapid growth of the Internet.
- Provide high speed, high performance wireless connections between computers and the wireless access points, between laptops, between laptops and printers, scanners, video cameras and other electronics in local area or at home. => Replace the cumbersome cords that connect devices to one another.
- Operate at low power and license free spectrum,
  - North America: IEEE 802.11x series, example: Wi-Fi.
  - Europe: HIPERLAN/2
  - Both IEEE 802.11a and HIPERLAN/2 support up to 54Mbps.
  - Use spread spectrum and OFDM technologies
- Bluetooth: provides convenient and flexible low power short range wireless connections in personal area networks. First a manufacture, then extended to an open standard.

Mobile Ad-Hoc Networks

- Cellular networks have a fixed infrastructure, in which each mobile access the network and communicating to other mobiles through the base station. That is, base station is the fixed infrastructure which performs centralized administration.
- **Ad-Hoc networks are infrastructureless and have no fixed routers**. Each node (mobile) in the ad-hoc network can set up as and play the role of a base station in that it can transmit to and receive from other nodes in the network.
- A node in an ad-hoc network to other nodes if they are within line-of-sight.
- Non-line-of-sight-nodes are called *hidden nodes*. Communication between a pair of hidden nodes needs to hop over one or more intermediate nodes, in this sense, it is called multihop networks.
- A system with a fixed infrastructure is basically a two-hop system.
- Ad-hoc networks are highly dynamic and are generally used for military services.

Conceptual Layers in a Wireless Network

- **Physical layer** --- involves the actual signal transmission and reception over the propagation channel.
- **Datalink Link layer** --- deals with signal at the output of the base station receiver, performs radio resource management, power control, rate allocation, call admission, error control etc.
- **Networks layer**: a protocol stack that includes handoff management, location management, traffic management and traffic control.
- **Application layer**: communicating, distributed processes running in end systems (hosts), e.g., e-mail, Web, P2P file sharing, instant messaging



Definition of WiMAX

WiMAX – **W**orldwide **I**nteroperability for **M**icrowave **Acc**ess.

It is a new telecommunication technology aimed at providing wireless data over long distances.

This wireless technology is designed to provide the last mile of high speed internet access as well as nomadic service.

It is based on IEEE 802.16-WirelessMAN

Scenario

- The user would pay the provider monthly fee for using the service. Lower cost + better speed.
- The WiMAX protocol is designed to accommodate several different methods of data transmission, one of which is Voice Over Internet Protocol (VoIP)
- Almost anyone with a laptop could make VoIP calls

Technical Details

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WiMAX is a term coined to describe standard, interoperable implementations of **IEEE 802.16** wireless networks.

Standards

- Range- 30 miles from base station
- Speed- 70 Megabits per second
- Frequency bands- 2 to 11 GHz for licensed band and 10 to 66 GHz for unlicensed bands.
- Defines both MAC and Physical (PHY) layer and allows multiple PHY layer specifications.

MAC layer/ data link layer

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- WiMAX uses a scheduling algorithm for which the subscriber station need to compete only once for initial entry into the network.
- A time slot is allocated to the subscriber by the base station.
- The time slot can change but remains assigned to the subscriber station
- Stability is achieved by allowing the base stations to control QoS parameters by balancing the time-slot assignments wrt application needs.

Architecture

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Fixed WiMAX has two types of architectures:

- Point-to-Point (P2P) Architecture
- Point-to-Multipoint (P2MP) Architecture.

Architecture
Point-to-point

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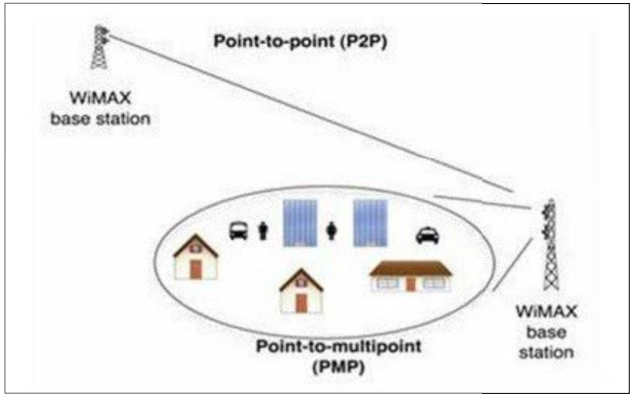

Architecture

Point-to-Multipoint

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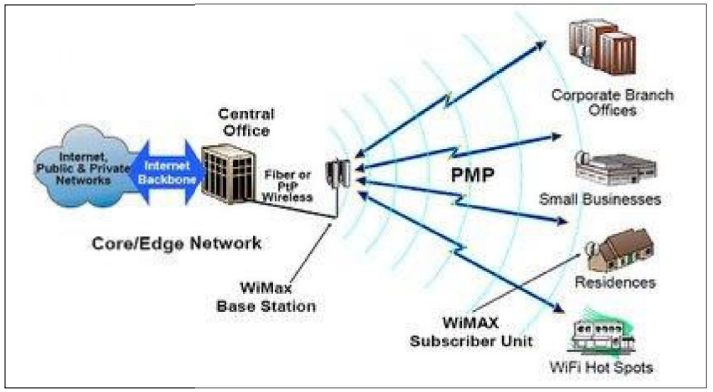

Outline

- Overview of a Communication System
- Digital vs. Analog Communications
- Examples of Wireless Communication Systems
- Why Wireless is Different ?
- Wireless System Architecture
- Multiple Access Techniques
- Wireless network architecture
- Wireless Local Area Networks (WLANs), Bluetooth and Personal Area Networks (PANs)
- Ad hoc networks
- Topics to be covered in the course

Components of a Communication System (1)

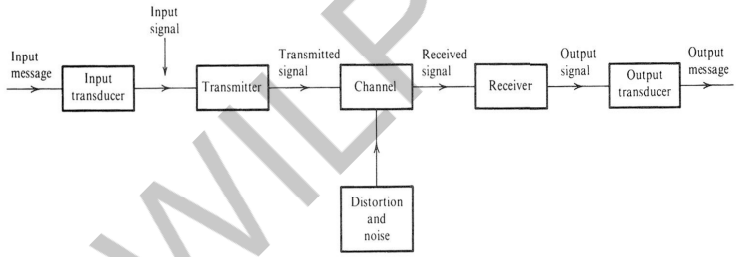

Figure 1: Communication Systems

Components of a Communication System (2)

- The **source** originates a message, which could be a human voice, a television picture or data. The source is converted by an **input transducer** into an electrical waveform referred to as the baseband signal or message signal.
- The **transmitter** modifies the baseband signal for efficient transmission. The transmitter generally consists of one or more of the following subsystems: a pre-emphasizer, a sampler, a quantizer, a coder and a modulator.
- The **channel** is a medium through which the transmitter output is sent, which could be a wire, a coaxial cable, an optical fiber, or a radio link, etc. Based on the channel type, modern communication systems are divided into two categories: **wireline communication** systems and **wireless communication** systems.

Components of a Communication System (3)

- The **receiver** reprocessed the signal received from the channel by undoing the signal modifications made at the transmitter and the channel. The task of the receiver is to extract the message from the distorted and noisy signal at the channel output. The receiver may consist of a demodulator, a decoder, a filter, and a de-emphasizer.
- The receiver output is fed to the **output transducer**, which converts the electrical signal to its original form.
- Transmitters and receivers are carefully designed to overcome the distortion and noise.
- The Goal of Physical layer Communication System is to **transmit information accurately and efficiently** (power and spectrum).

Digital vs. Analog Communications (1)

- Analog and Digital Signals
  - Messages are digital or analog.
    - Digital messages are constructed with a finite number of symbols. For example, a text file is a digital message constructed from 50 symbols, consists of 26 letters, 10 numbers, a space and several punctuation marks. Similarly, a Morse-coded telegraph is a binary message, implying only two symbols – mark and space.
    - Analog messages are characterized by data whose values vary over a continuous range. For example, a speech waveform has amplitudes that vary over a continuous range. A picture is also an analog message.

Noise immunity of digital signals

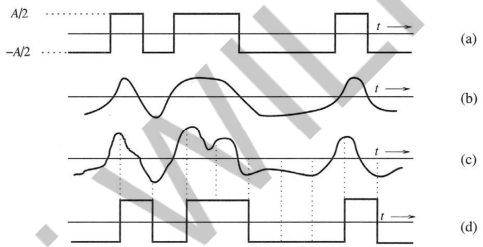

Figure 1.3 (a) Transmitted signal. (b) Received distorted signal (without noise). (c) Received distorted signal (with noise). (d) Regenerated signal (delayed).

Digital vs. Analog Communications (2)

- **Noise immunity of digital signals** – digital data can be recovered without any error as long as the distortion and noise are within limits. On the other hand, for an analog message, even a slight distortion or interference in the waveform will cause an error in the received signal.
- **Regenerative repeaters**—Based on this "noise immunity", when transporting a bit stream over a long distance, regenerative repeaters or repeater stations are placed along the path of a digital system at distances short enough to ensure that noise and distortion remain within a limit. The viability of regenerative repeaters is the main reason for the superiority of digital systems over analog ones.
- **Every possible communication can be carried on with a minimum of two symbols**, i.e., by using a proper binary sequence. In the last 20 years, digital communication gradually replace its analog competitors, and the revolution is now nearly complete.

Interface of Analog and Digital Systems -- A/D and D/A Conversion

- **Sampling Theorem** A meeting ground exists for analog and digital signals: conversion of analog signals to digital signals. The backbone that supports the interface is Shannon's Sampling Theorem, which states that if the highest frequency in the signal spectrum is B (in hertz), then the signal can be recovered from its samples, taken at a rate not less than 2B samples per second.
- **Quantization** each sample is approximated, or round off to the nearest quantized level, the information is thus digitalized. The quantized signal is an approximation of the original one. We can improve the accuracy of the quantized signal to any desired degree by increasing the number of levels.
- **Coding**
  - **Source coding** Convert the quantized signal into binary sequences.
  - **Channel coding** Introduce redundancy in a controlled manner to overcome the effects of noise and interferences.
- **Mapping** Map binary sequence into symbols.
- **Transmission** Symbols are applied to a transmitter filter, which produces a continuous signal for transmission over a continuous channel.

Examples of Wireless Communication Systems

- Codeless telephones --- use radio to connect a portable handset to a dedicated base station over a distance of a few tens of meters.
- Paging systems --- Communication systems that broadcast a page from every base station in the network and send brief messages to a subscriber.
- Cellular telephone systems --- provide a wireless connection to the PSTN (Public Switched Telephone Network) for any user location within the radio range of a system.
- Garage car opener
- Remote controllers for home entertainment equipment
- Hand-held walkie-talkies
- Wireless keyboard and mouse
- Wireless Lan router and adapter…..

Wireless Vs. Wireline Communications

---- Challenges in Wireless Communication Systems

- **Wireless channel**
  - Have time varying and multipath propagation properties.
  - Communicate over a medium significantly less reliable than wired physical layer.
  - Are unprotected from outside signals and interceptions. Multiuser interference (MUI) is a significant problem in wireless communications.
  - Has neither absolute nor readily observable boundaries outside of which stations are known to be unable to receive network frames.
- **User Mobility**
  - Destination address does not equal to a fixed destination location.
  - Power management --- performance, interference lever and power consumption.
  - Hand-off --- A mobile switches its serving base station while moving from cell to cell.
  - Location management --- tracks the user's movement, support users roaming delivers calls to the user at its current location.

Introduction to wireless communication systems

- It is the Transfer of data between 2 points that aren't connected by an electrical conductor.
- They typically use electromagnetic waves.
- Transmitting voice and data using electromagnetic waves in open space (atmosphere)
- The information from the sender to the receiver is carried over a well-defined frequency band.
- Each Channel has a fixed bandwidth. Different channels can be used to transmit information in parallel and independently.

Why Wireless Communication

- Mobility

- Radio waves travel freely through the air, wireless modes of communication give a great deal of mobility.

- Freedom from wires

-Wired networks can be inflexible in terms of mobility.

- Extra cables and switches to connect a device to the network and use in different location

- Installation can be lengthy and complex

- Maintenance costly.

Why Wireless Communication

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- Global Coverage
- Communication can reach where wiring is infeasible or costly(e.g. hazardous areas, long distances etc.).
- Scalability
  - Problems with a wired network is coping with expansion and can be expensive.
  - Addition of new users is fast and relatively convenient in wireless communication.
- Stay Connected any where any time.

Challenges of wireless communication system

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– High costs for setting up the infrastructure
– Security vulnerabilities.
– Efficient use of Finite Radio Spectrum
– Efficient Hardware
– *Low power* transmitter, receivers
-Many devices are battery operated. We need to have low power transmitters and receivers
– *Low power* signal processing tools

Challenges of wireless communication system

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– Multipath propagation and fading
- Fading is caused by destructive interference of two or more versions of the transmitted signal arriving at the receiver in different times with different amplitude and phases

– Integrated services
- Voice, data, *multimedia* over a single network

– wireless communication is influenced by
  - Physical obstructions
  - climatic conditions
  - Interference from other wireless devices

– Maintaining quality of service over unreliable links

Wireless Communication System Definitions

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- Handoff: The process of transferring a mobile station from one channel or base station to another.
- Mobile Station : A station in the cellular radio service intended for use while in motion at unspecified locations.
- Mobile Switching Center : coordinates the routing of calls in a large Center service area. An MSC is also called a mobile telephone switching office (MTSO).

Quiz 1

1. What is wireless communication?
   a) Sending data from one location to with the use of physical medium
   b) Sending data from one location to another without the use of physical medium
   c) Sending data from one location to another without the use of virtual medium
   d) None of the mentioned

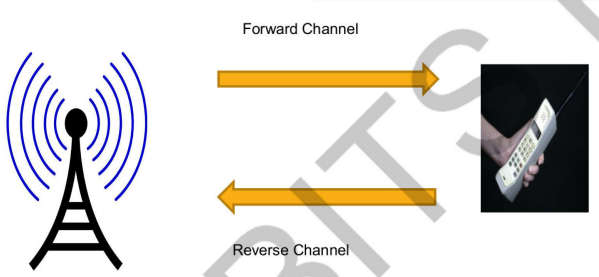
Quiz 1

1. What is wireless communication?
   a) Sending data from one location to with the use of physical medium
   b) Sending data from one location to another without the use of physical medium
   c) Sending data from one location to another without the use of virtual medium
   d) None of the mentioned

Answer: b
Explanation: Wireless communication is a way of sending data from one location to another without the use of wires, cables, or any other physical medium.

Forward and Reverse Channel

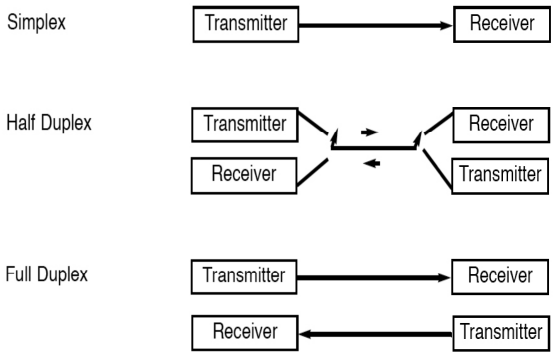
Radio channel used for transmission of information from the base station to the mobile.



Radio channel used for transmission of information from the mobile to base stations

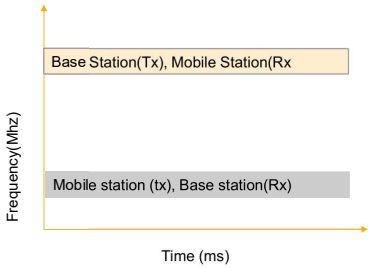
Classification of Mobile Radio Transmission

Classification of mobile radio transmission system



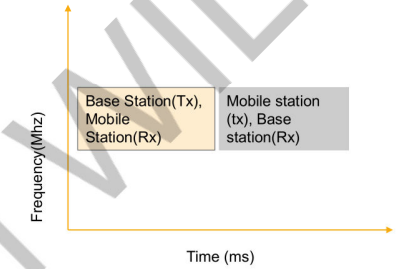
Forms of Full Duplexing

- Two forms of Full Duplexing
- Frequency division duplexing uses two radio channel
  - Forward channel: base station to mobile user
  - Reverse channel: mobile user to base station



Forms of Full Duplexing

- **Time division duplexing shares a single radio channel in time.**
- **Receives for half the frame and transmits for half the frame.**



Quiz-2

- Which of the following is not a TDMA standard of 2.5G network?
  - a) GPRS
  - b) GSM
  - c) HSCSD
  - d) EDGE

Quiz-2

- Which of the following is not a TDMA standard of 2.5G network?
  - a) GPRS
  - b) GSM
  - c) HSCSD
  - d) EDGE

- Answer: b
- Explanation: GSM (Global System for Mobile) is a TDMA standard for 2G network. HSCSD (High Speed Circuit Switched Data), GPRS (General Packet Radio Service) and EDGE (Enhanced Data rates for GSM Evolution) are TDMA standards of 2.5G technology.

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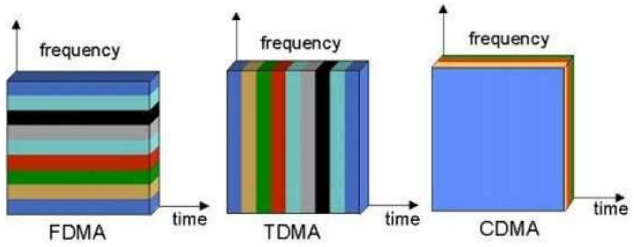
Multiple Access Techniques



Quiz-3

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- In ..... multiple access is achieved by allocating different time slots for the different users.
  - a) TDMA
  - b) FDMA
  - c) CDMA
  - d) FGMA

Quiz-3

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- In ..... multiple access is achieved by allocating different time slots for the different users.
  - a) TDMA
  - b) FDMA
  - c) CDMA
  - d) FGMA
- Answer : a) TDMA

Wireless Communication

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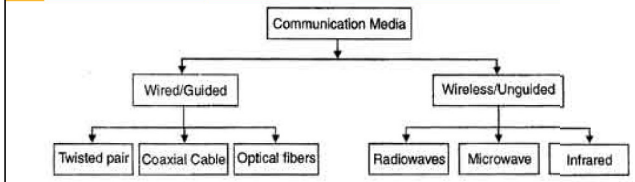
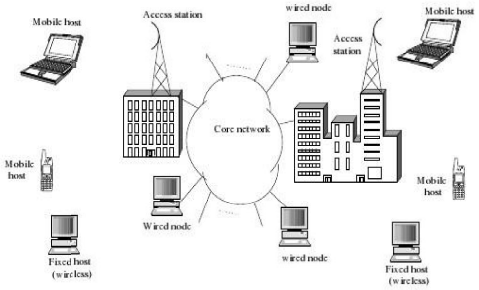


- Easily generated, Omni-directionally travel long distances, easily penetrate buildings

Used for long distance communication, high SNR, point to point- line of sight

Short range communication, unable to pass through solid objects

Wireless network architecture



It consists of mobile hosts, fixed hosts, access stations (BS), core network to support mobility and switching.

Wireless network architecture (Contd..)

Mobile host

- Laptop, mobile phone, PDA, notebook, etc. can move from one place to another place while maintaining connection with wireless network.

Fixed wireless host

- Cannot move but the medium is radio waves.
- Example: wireless web servers, printers, etc.

Access Network

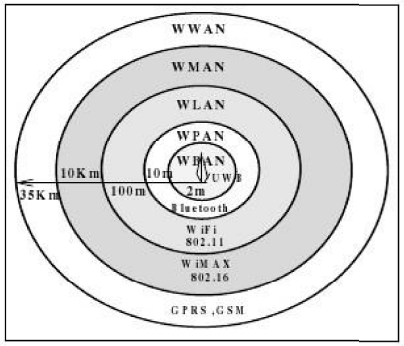
- Consists of access stations (BS) which provide services to hosts reachable from it.

Wireless network architecture (Contd..)

Core Network

- Consists of active components that perform data switching between access stations (BS), and provide location and mobility services.
- Facilitates communication from mobile host to mobile host, mobile host to wired node, fixed host to wired node, fixed host to mobile host, etc.

Classification of wireless networks (Contd..)



Quiz-4

Which of the following is a type of wireless communication?

a) LAN
b) WAN
c) PAN
d) All of the mentioned

Quiz-4

Which of the following is a type of wireless communication?

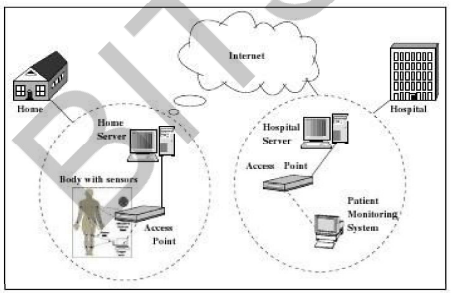
a) LAN
b) WAN
c) PAN
d) All of the mentioned

Answer: d
Explanation: The three different types of wireless networks:
i) WWAN – Wireless Wide Area Networks
ii) WLAN – Wireless Local Area Network
iii) WPAN – Wireless Personal Area Network

Classification of wireless networks (Contd..)

Wireless Body Area Network (WBAN)

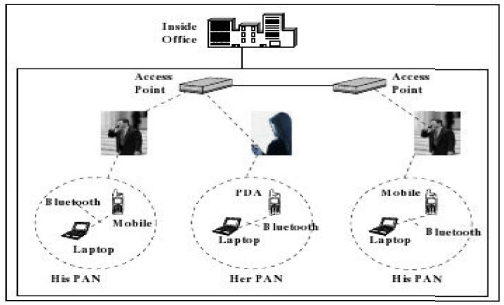
- Max. signal range 2 meters
- Interconnecting respective devices within the surface of the body



Classification of wireless networks (Contd..)

Wireless Personal Area Network (WPAN)

- Max. signal range of 10 meters



Classification of wireless networks (Contd..)

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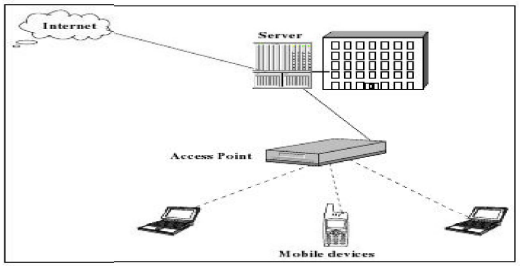
Wireless Local Area Network (WLAN)

- Also called the Wireless Fidelity (Wi-Fi or IEEE 802.11)
- Signal range is ≈100 meters.



Recall: an example of wired LAN

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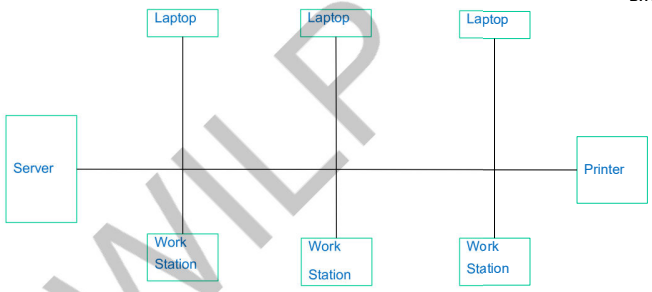

An example of wireless LAN

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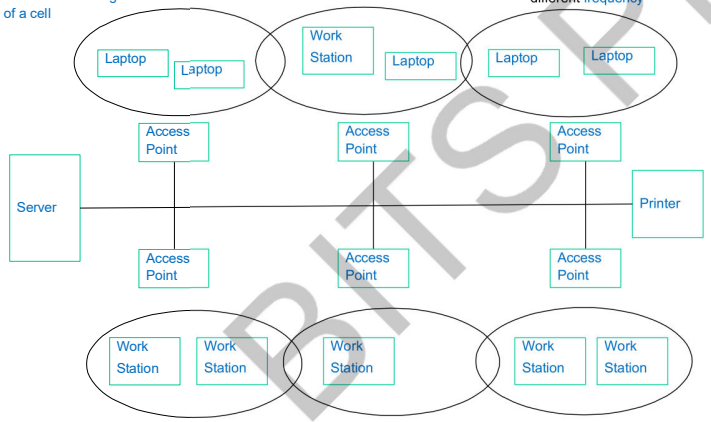
A user is connected if he/she is in the coverage area of a cell

Each cell operates at a different frequency



Classification of wireless networks

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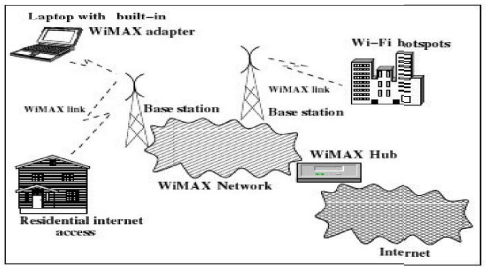
Wireless Metropolitan Area Network (WMAN)

- Signal range of approximately 5 km to 20 km (recently up to 50 km)
- Often called Worldwide Interoperability for Microwave Access (WiMAX or IEEE802.16)

WiMAX BS

Mobile devices might have built in WiMAX adapter or may be externally plugged



Wi-Fi users may be connected to the WiMAX network

WMAN might be owned and operated by organizations or public institutions

Classification of wireless networks

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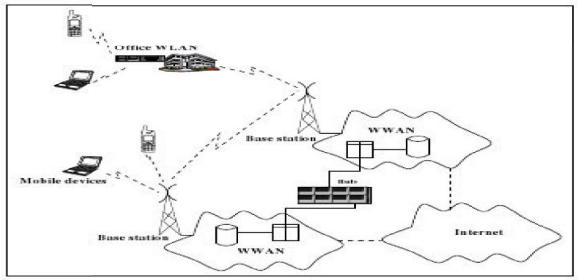
Wireless Wide Area Network (WWAN)

- Use cellular network Technologies such as W-Max, GSM, GPRS, 3G and others
- Use network infrastructure of mobile operators.
- Cover wide area much wider than groups mentioned above.



Wireless switching technology

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Packet switching is the basic type of wireless switching technology

- Uses short bursts of information, uses channels only for short periods of time.
- Standard routing protocols

Recall: Packet switching

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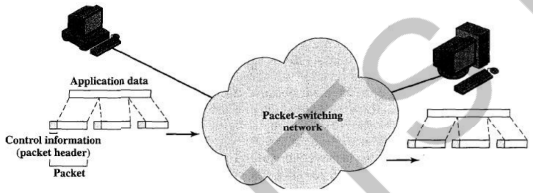

From W. Stallings, Wireless Communications and Networks, 2nd Edition

Recall: Packet switching (Contd..)

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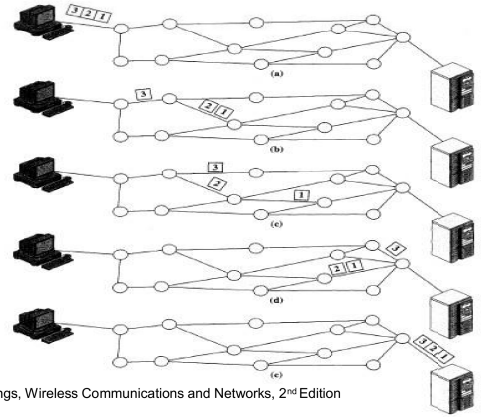


From W. Stallings, Wireless Communications and Networks, 2nd Edition

Quiz-5

A local telephone network is an example of a _____ network.

a) Packet switched
b) Circuit switched
c) Bit switched
d) Line switched

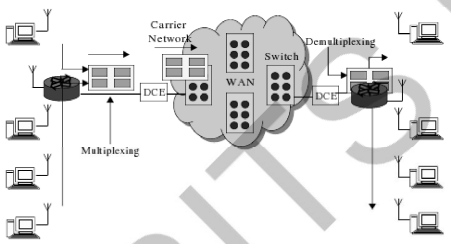
Quiz-5

A local telephone network is an example of a _____ network.

a) Packet switched
b) Circuit switched
c) Bit switched
d) Line switched

Answer: b
Explanation: Circuit switching is connection oriented switching technique, whereas in the case of packet switching, it is connectionless. Circuit switching is implemented in the Physical layer, whereas packet switching is implemented in the Network layer. Internet too is based on the concept of circuit switching.

Wireless switching technology (Contd..)



- Packets are routed and pipelined using multiplexing
- Bandwidth is used only when data is transmitted

Wireless switching technology (Contd..)

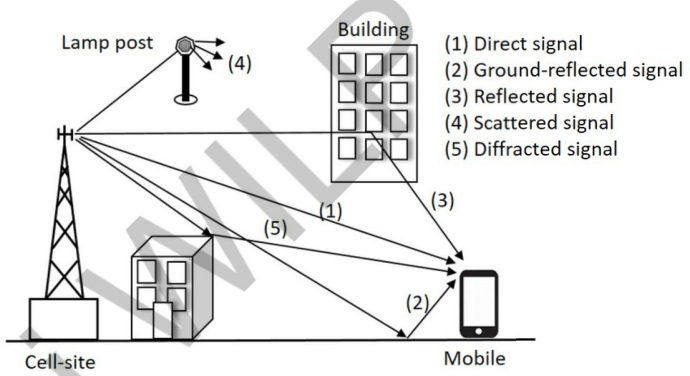
Virtual circuit

- Switched virtual circuits (SVCs)
- Established dynamically on demand
  - 3 phases – circuit establishment, data transfer, circuit termination
- Permanent virtual circuits (PVCs)
  - Only one mode i.e., data transfer

Wireless communication problems

- Increased bit error rate
- Lower transmission power
- Scattering
- Reflection
- Diffraction
- Path loss
- Multipath propagation

Wireless communication problems



Wireless communication problems

Increased bit error rate

Wireless network media is more prone to errors due to

- obstacles between Tx and Rx
- Interference from neighbor nodes

One can observe

- Annoying to voice and video clients
- Frequent disconnections causing to data loss

Wireless communication problems (Cont

Lower transmission power

- Mobile units powered by battery have scarce energy resources
- Limited transmission power to avoid interference
- Attenuation

Capture power at the receiver side is $P_r = P_t / (4 \pi d / l)_2$

Where P_t is the transmitter power, d the distance between the transmitter and the receiver, and l is the wavelength of the signal.

$L_p = (4 \pi d / l)_2$ is the path loss.

Scattering

- Occurs when signal pass through the object whose dimension is smaller than the wavelength.
- Scattered waves are produced by rough surfaces, small objects, irregularities in the channel. Need proper deployment strategies to reduce it.

Wireless communication problems (Contd..)

Reflection

- Occurs when electromagnetic wave strikes an object which has very large dimension compared to the wave length. Ex: walls, furniture, buildings, etc.

Diffraction

- Occurs when radio path between Tx and Rx is obstructed by surfaces that have sharp irregularities(edges) causing secondary waves, which will be present in space and behind the obstacle.

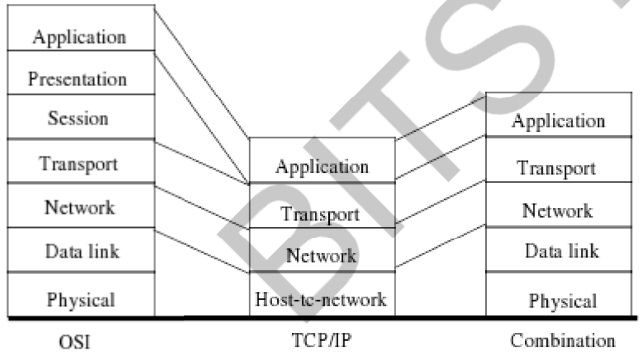
Wireless communication problems (Contd..)

Multipath Propagation

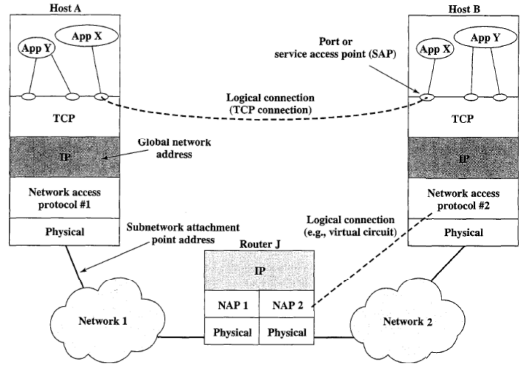
- Caused by reflection and scattering directions with varying delays
- Radio waves arrive at the Rx from different
- Final signal is the summation of all signals
- Antenna diversity methods are used to overcome this problem.

Wireless network reference model

- The TCP/IP architecture is functionally equivalent to the OSI reference model.



Recall: TCP/IP Concepts



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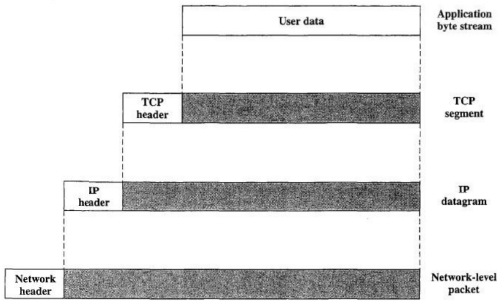
Protocol Data Units in the TCP/IP Architecture



Examples:

TCP header includes destination port, sequence number, checksum
IP header includes destination host address (B in previous example)

Network header includes destination subnetwork address

From W. Stallings, Wireless Communications and Networks, 2nd Edition

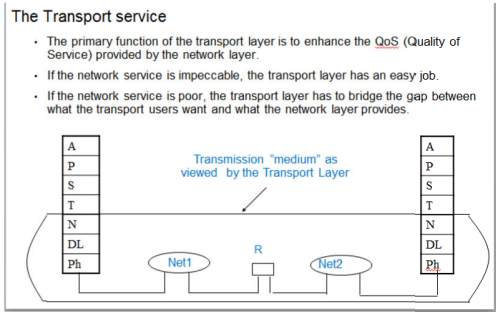
Wireless network reference model (Contd..)

- Major similarities and differences between TCP/IP and the OSI reference models are
  - Both models have an application, a transport, and a network/Internet layer
  - The TCP/IP model does not have a session layer
  - Lower layers connects the upper layers to the actual physical network

Wireless network reference model (Contd..)

- Application layer functions
  - This is the layer where end user applications such as remote login, mail transfer, file transfer, network management, and web browsers run
- Transport layer functions
  - Its job is to provide reliable communication from application to application (end-to-end) regardless of the lower-layer protocols and communication links
    - It encapsulates application layer data and deliver it to the network layer

Illustration of the transport service



Wireless network reference model (Contd..)

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- Data link layer functions
- This includes the logical link control (LLC) sublayer and the MAC (media access control) sublayer.
- It does segmenting the bit stream into frames, error handling, flow control, and access control.
- MAC is responsible for accessing and sharing of the wireless channel and reliable delivery by using acknowledgments.

Illustration of data link layer

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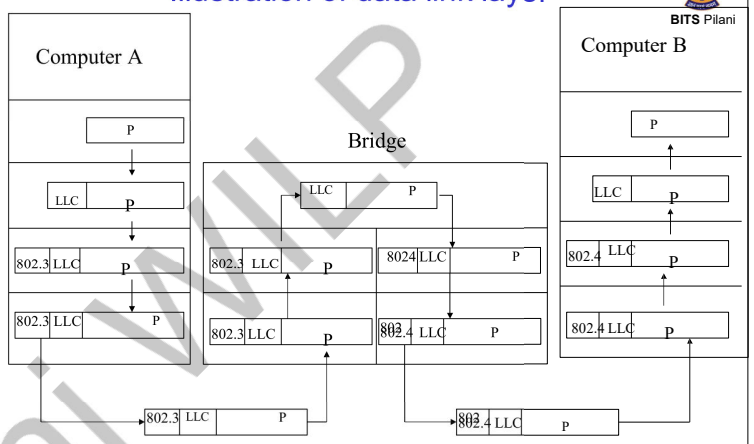

Wireless network reference model (Contd..)

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- Physical layer functions
- This layer transports encapsulated data from the data link layer and transmits it wirelessly to the distant network.
- The wireless features and functionality (modulation type, data rate, and so on) take place at this layer.

Wireless Local Area Networks (WLANs) and Personal Area Networks (PANs, Bluetooth)

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- WLANs and PANs, provide broadband telecommunications access in the local exchange, driven by demand for broadband Internet access from business and homes due to the rapid growth of the Internet.
- Provide high speed, high performance wireless connections between computers and the wireless access points, between laptops, between laptops and printers, scanners, video cameras and other electronics in local area or at home. => Replace the cumbersome cords that connect devices to one another.
- Operate at low power and license free spectrum,
  - North America: IEEE 802.11x series, example: Wi-Fi.
  - Europe: HIPERLAN/2
  - Both IEEE 802.11a and HIPERLAN/2 support up to 54Mbps.
  - Use spread spectrum and OFDM technologies
- Bluetooth: provides convenient and flexible low power short range wireless connections in personal area networks. First a manufacture, then extended to an open standard.

Mobile Ad-Hoc Networks

- Cellular networks have a fixed infrastructure, in which each mobile access the network and communicating to other mobiles through the base station. That is, base station is the fixed infrastructure which performs centralized administration.
- **Ad-Hoc networks are infrastructureless and have no fixed routers**. Each node (mobile) in the ad-hoc network can set up as and play the role of a base station in that it can transmit to and receive from other nodes in the network.
- A node in an ad-hoc network to other nodes if they are within line-of-sight.
- Non-line-of-sight-nodes are called *hidden nodes*. Communication between a pair of hidden nodes needs to hop over one or more intermediate nodes, in this sense, it is called multihop networks.
- A system with a fixed infrastructure is basically a two-hop system.
- Ad-hoc networks are highly dynamic and are generally used for military services.

Definition of WiMAX

WiMAX – **W**orldwide **I**nteroperability for **M**icrowave **Acc**ess.

It is a new telecommunication technology aimed at providing wireless data over long distances.

This wireless technology is designed to provide the last mile of high speed internet access as well as nomadic service.

It is based on IEEE 802.16-WirelessMAN

Scenario

The user would pay the provider monthly fee for using the service. Lower cost + better speed.

The WiMAX protocol is designed to accommodate several different methods of data transmission, one of which is Voice Over Internet Protocol (VoIP)

Almost anyone with a laptop could make VoIP calls

Technical Details

WiMAX is a term coined to describe standard, interoperable implementations of **IEEE 802.16** wireless networks.

Standards

- Range- 30 miles from base station
- Speed- 70 Megabits per second
- Frequency bands- 2 to 11 GHz for licensed band and 10 to 66 GHz for unlicensed bands.
- Defines both MAC and Physical (PHY) layer and allows multiple PHY layer specifications.

WiMAX uses a scheduling algorithm for which the subscriber station need to compete only once for initial entry into the network.

A time slot is allocated to the subscriber by the base station.

The time slot can change but remains assigned to the subscriber station

Stability is achieved by allowing the base stations to control QoS parameters by balancing the time-slot assignments wrt application needs.

Fixed WiMAX has two types of architectures:

- Point-to-Point (P2P) Architecture
- Point-to-Multipoint (P2MP) Architecture.

Multiple Access Techniques

- **FDMA** (Frequency Division Multiple Access) each user is allocated a unique frequency band or channel, no other user can share the same frequency band.
- **TDMA** (Time Division Multiple Access) divides the radio spectrum into time slots, and in each slot, only one user is allowed to either transmit or receive.
- **CDMA** (Code Division Multiple Access) each user is assigned a special code sequence (signature) to modulate its message signal, all users are allowed to transmit over the same channel simultaneously and asynchronously.
- **SDMA** (Space Division Multiple Access) controls the radiated energy for each user in space. SDMA serves different users by using spot beam antennas.

How a cellular telephone call is made?

- **Receiving a call**
  - Turn on a cellular phone
  - The cellular phone scan the control channels to determine the one with the strongest signal, it then monitors the signal drops below a usable level. At his point, it starts to search of strongest base station again.
  - If a phone call is placed to a mobile user, the MSC dispatches the request to all the base stations in the system, the MIN (mobile identification number, i.e. the mobile's phone number) is broadcast as a paging message through the forward control channel.
  - The mobile receives the signal through the base station it monitors and responds by identifying itself through the reverse control channel.
  - The base station informs the MSC of the handshake.
  - The MSC instructs the base station to move the call to an unused voice channel within the cell.
  - The base station signals the mobile to change frequencies to the unused unused forward and reverse voice channel pair.
  - The base station instructs the mobile phone to ring, thereby to instruct the user to answer the phone.

How a cellular phone call is made (continued)

- **Initiating a call**
  - The mobile sends a call initiation request through the reverse control channel, with this the unit transmits its MIN, ESN (electronic serial number) and the phone number of the called party.
  - Base station receives the request and sends it to the MSC.
  - The MSC validates the request, making connection to the called party through PSTN.
  - The MSC instructs the base station and mobile user to move to an unused forward and reverse voice channel pair.
- **Roaming**
  - All cellular systems provide a service called *roaming*. This allows subscribers to operate in service areas other than the one from which the service is subscribed.
  - The MSC issues a global command every several minutes, asking all unregistered mobiles to report their subscription information.
  - Mobiles report back upon receiving the request.
  - If the mobile has roaming authorization for billing purpose, the MSC registers the subscriber as a *roamer*.

QUIZ-6

Which of the following is/are the main part(s) of basic cellular system.

a) A mobile Unit
b) A cell Site
c) A mobile Telephone Switching Office
d) All of the above

QUIZ-6

Which of the following is/are the main part(s) of basic cellular system.

a) A mobile Unit
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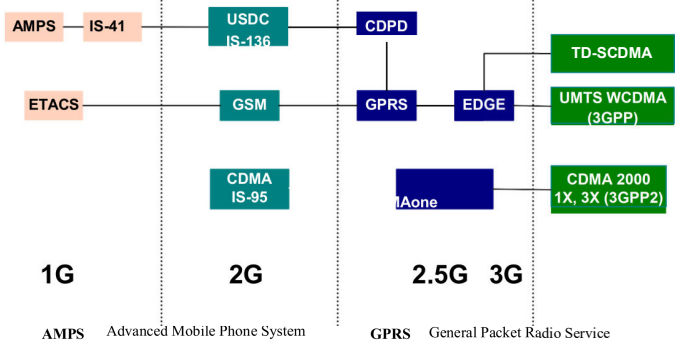
d) All of the above

Answer: d) All of the above

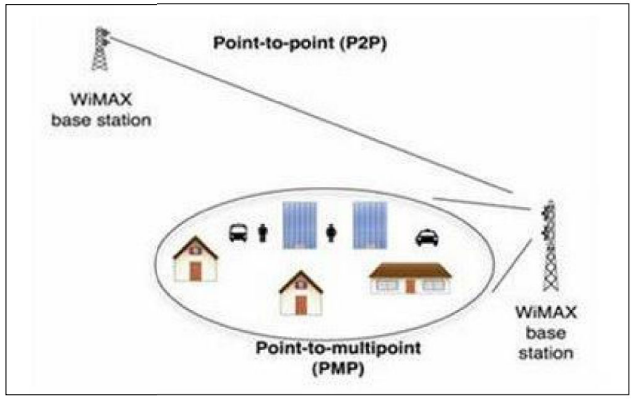
Wireless System Evolution: Cellular Networks



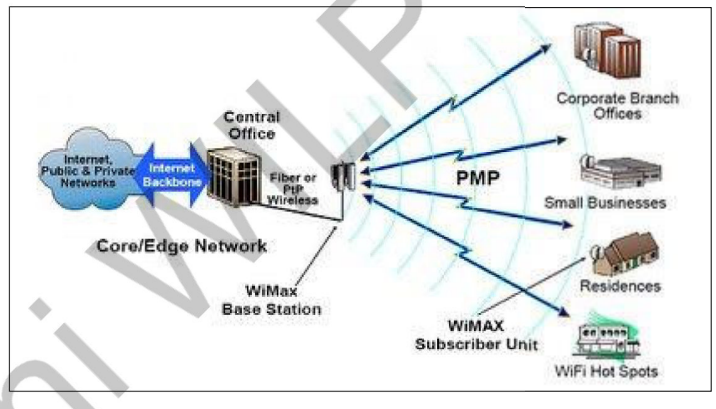
AMPS Advanced Mobile Phone System
ETACS European Total Access Communication System
USDC United States Digital Cellular
GSM Global Systems for Mobile
CDPD Cellular Digital Packet Data

GPRS General Packet Radio Service
EDGE Enhanced Data Rates for GSM Evolution
UMTS Universal Mobile Telecommunications System
3GPP 3rd Generation Partnership Project

Point-to-point



Point-to-Multipoint



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Course Objective

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CO1: Explain the issues/challenges in wireless networks
CO2: Describe the architecture of WPANs, WLANs and wireless ad-hoc networks, and compare specific protocol with respect to their strengths and weaknesses
CO3:Explain the evolution of cellular technologies, and the characteristics of LTE and 5G networks
CO4: Solve network design problems, by identifying the requirements and challenges, comparing different protocols, choosing the right elements for the design solution.

Text Books and Reference Books

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Text Books:

T1: Wireless and Mobile Networks, Concepts and Protocols, 2ed, Sunilkumar S. Manvi, Mahabaleshwar S. Kakkasageri, Wiley, ISBN: 9788126558551

Reference Books

Internet of Things for Architects: Architecting IoT Solutions by Implementing Sensors, Communication Infrastructure, Edge Computing, Analytics, and Security; Perry Lea; Packt Publishing Ltd; 2018

Contact Session 3 and 4

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CH	List of Topics	Text
3-4	Wireless Personal Area Networks • Overview of Wireless Personal Area Network (WPAN) • WPAN Technologies and Protocols • 802.15.4 Network Architecture • 802.15.4 Network Components • Bluetooth Network Architecture • Bluetooth Network Components • WPAN Applications	Text-1

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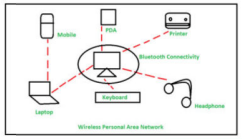
Wireless Personal Area Networks (WPAN) - Overview

WPAN : A small-scale wireless network that requires little or no infrastructure and operates within a short range.
Connect devices within a very small geographical area which is usually within few meters (10m – 100m).
This network is created spontaneously and unobtrusively as and when the portable devices need to communicate with one another.
Wireless Personal Area Network (WPAN) is connected through Bluetooth, IrDA, Zigbee, RFID, NFC



Wireless Personal Area Networks (WPAN) - Overview

The IEEE 802.15 is standard for Wireless Personal Area Networks was formed to develop standards for short range wireless PANs

- Main characteristics of a WPAN:
- Short-range communication
- Low power consumption
- Low cost
- Small personal networks
- Communication of devices within a personal space

Wireless Personal Area Networks (WPAN) - Overview

WPAN devices have to discover one another and also each other's capabilities.
Discovery is achieved using specific self-configuration mechanisms and service discovery protocols.
Mechanisms are also needed to authenticate devices to one another and establish keys for encrypted communications.

Comparison of WPAN technologies

Standard	Frequency	Operating Range	Important Feature
IrDA	875nm wavelength	1-2 meters	Requires line-of-sight communication
Bluetooth	2.4 GHz	10 meters to 100 meters	Automatic device discovery, can communicate through physical obstacles.
IEEE 802.15	2.4 GHz	10 meters to 100 meters	Uses Bluetooth as the foundation, coexists with 802.11 devices

WPAN Technologies and Protocols

As per IEEE, Wireless Personal Area Network is classified into 3 classes:

High-rate WPAN (HR-WPAN) :
- It is defined in the IEEE 802.15.3 standard.
- Data throughput is > 20 Mbps.

Medium-rate WPAN (MR-WPAN) :
- It is defined in the IEEE 802.15.1 standard.
- Data throughput is 1 Mbps.

Low-rate WPAN (LR-WPAN) :
- It is defined in the IEEE 802.15.4 standard.
- Data throughput is < 0.25 Mbps.

Technologies used in WPAN :
- Bluetooth
- ZigBee
- IrDA
- Wireless Body Area Network (WBAN)

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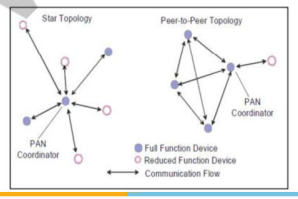
WPAN Technologies - IEEE 802.15.4

- IEEE 802.15.4 is a low-cost, low-data-rate wireless access technology for devices that are operated or work on batteries. This describes how low-rate wireless personal area networks (LR-WPANs) function.
- IEEE 802.15.4 provides for very low cost communication of nearby devices with little to no underlying infrastructure.
- Two different device types can participate in an LR-WPAN network;
- **Full Function Device (FFD)**
  - This kind of devices can be either a coordinator, a coordinator of a WPAN or a simple device.
  - It works under all topologies and communicates with all types of devices.
- **Reduced Function Device (RFD)**
  - An RFD can't be a WPAN coordinator.
  - It can be defined as a final device which can communicate only with an FFD.

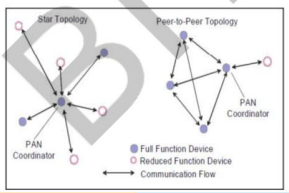
WPAN Technologies - IEEE 802.15.4

- **IEEE 802.15.4 network topologies**
  - There are two main forms of network topology that can be used within IEEE 802.15.4.
  - These network topologies may be used for different applications and offer different advantages.
- The two IEEE 802.15.4 network topologies are:
- **Star topology:**
  - As the name implies the star format for an IEEE 802.15.4 network topology has **one central node** called the **PAN coordinator** with which all other nodes communicate.



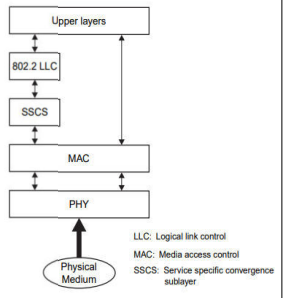
WPAN Technologies - IEEE 802.15.4

- **Peer to Peer network topology:**
  - In this form of network topology, there is still a PAN coordinator, but communications may also take place between different nodes and not necessarily via the coordinator.
  - FFDs are able to route data, while the RFDs are only able to provide simple communication.



802.15.4 Network Architecture

- 802.15.4 Network Architecture basically comprises
  - A **physical layer (PHY),** which contains the RF transceiver along with its low-level control mechanism.
  - A **MAC sublayer** provides access to the physical channel for all types of transfer.
  - The **upper layers** consist of a network layer, which provides network configuration, manipulation, and message routing.
- An IEEE 802.2 logical link control (LLC) can access the MAC through the service specific convergence sublayer (SSCS).



LR-WPAN device architecture

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802.15.4 Network Architecture

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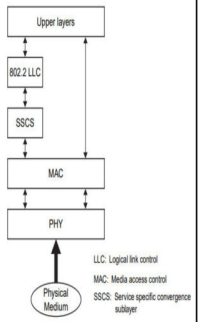
- **Physical layer (PHY)**
  - The PHY provides two services: the **PHY data service** and **PHY management** service interfacing to the physical layer management entity (PLME).
  - The PHY data service enables the **transmission and reception** of **PHY protocol data units (PPDUs)** across the physical radio channel.
  - The PHY management services are activation and deactivation of the radio transceiver, energy detection (ED), link quality indication (LQI), channel selection, clear channel assessment (CCA) and transmitting as well as receiving packets across the physical medium.
  - To maintain a common simple interface with MAC, both PHY data service and management service share a single packet structure.
  - The 2.4 GHz PHY uses a 16-ary quasi-orthogonal modulation technique based on DSSS methods with QPSK modulation.



LR-WPAN device architecture

802.15.4 Network Architecture

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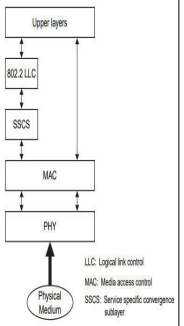
- **Data link Layer**
  - The data link layer is divided into two sublayers, the MAC and LLC sublayers.
  - The MAC provides services to an IEEE 802.2 type logical link control through the service-specific convergence sublayer (SCCS), or a proprietary LLC can access the MAC services directly without going through the SCCS.
  - The features of the MAC are **association** and **disassociation**, **acknowledged frame delivery**, **channel access mechanism**, **frame validation**, **guaranteed time slot management**, and **beacon management**.
  - An important function of the MAC is to confirm **successful reception of a received frame**. Successful reception and validation of a data or MAC command frame is confirmed with an **acknowledgment.**
  - Three levels of security are provided: no security of any type; access control lists (non-cryptographic security); and symmetric key security, using AES-128.



LR-WPAN device architecture

802.15.4 Network Architecture

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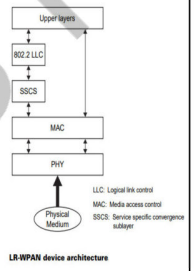
- **Network Layer**
  - The network layer of Zigbee (IEEE 802.15.4) is responsible for **topology construction** and maintenance as well as naming and binding services, which include the tasks of addressing, routing, and security.

IEEE 802.15.4 supports multiple network topologies, including **star, peer-to-peer, and cluster tree.**



LR-WPAN device architecture

IEEE 802.15.4 PHY Layer

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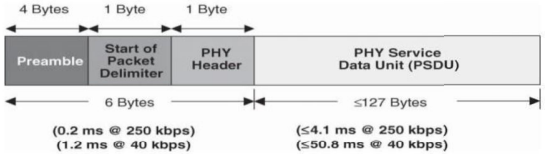
- PHY layer provides an interface between the MAC layer and the physical radio channel.
- It provides two services, accessed through two service access points (SAPs). These are the **PHY data service** and the **PHY management service.**
- **IEEE 802.15.4 Physical layer Packet structure**



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IEEE 802.15.4 PHY Layer

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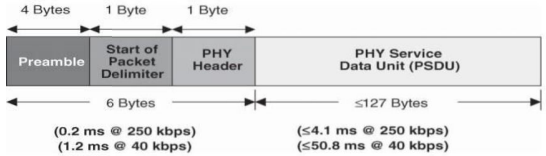
- **IEEE 802.15.4 Physical layer Packet structure**
- Each PPDU contains a synchronization header (preamble plus start of packet delimiter), a PHY header to indicate the packet length, and the payload, or PHY service data unit (PSDU).
- The 32-bit preamble is designed for the acquisition of symbol and chip timing, and in some cases may be used for coarse frequency adjustment.
- Within the PHY header, 7 bits are used to specify the length of the payload (in bytes).
- Typical packet sizes for home applications such as monitoring and control security, lighting, air conditioning, and other appliances are expected to be of the order of 30–60 bytes
- More demanding applications such as interactive games and computer peripherals, or multihop applications with more address overhead, may require larger packet sizes.



IEEE 802.15.4 Media Access Control (MAC) Layer

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- The Media Access Control (MAC) layer, specified by IEEE 802.15.4, is located between the physical and network layers. The MAC layer performs the following functions:
  - Transfers data to the network layer and vice versa; transfers data to the physical layer and vice versa
  - End device association and disassociation
  - In the coordinator, offers **optional guaranteed time slot** (GTS) for each device accessing the network
  - Generates the **beacon frame** in a coordinator
  - Supports device security
  - Provides carrier-sense multiple access with **collision avoidance** (CSMA/CA) as the access method for the network
  - Provides a **reliable connection** between two MAC layers by using an acknowledgment ...

IEEE 802.15.4 Media Access Control (MAC) Layer

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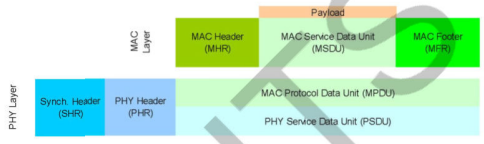
IEEE 802.15.4 MAC Overview

General Frame Structure



4 Types of MAC Frames:

- Data Frame
- Beacon Frame
- Acknowledgment Frame
- MAC Command Frame

IEEE 802.15.4 Media Access Control (MAC) Layer

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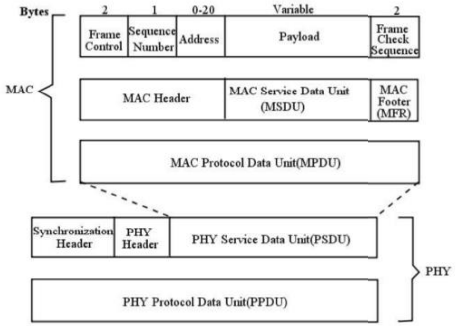
IEEE 802.15.4 MAC Overview

General Frame Structure



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