for 4th Year (Datas)

Wireless Communication and Mobile Computing

CS Program

Wollega University

Chapter 1

Introduction to Wireless Communication Systems

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Objectives

- At the end of this chapter you should be able to:
  - Define wireless communication
  - Describe the four major types of wireless networks
  - Describe the basic elements of a wireless network

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Outline

- Overview of wireless communications
- Cellular Communications from 1G to 5G
- WLAN; WPAN; WMAN
- Future Wireless Networks

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Introduction

- Wireless Communication System:
  - Wireless communications is a type of data communication that is performed and delivered wirelessly.
  - Any electrical communication system that uses a naturally occurring communication channel, such as air, water, earth.
- Examples:
  - Cell phone, Sonar(system for detecting underwater objects)
  - Broadcast: (one way)
    - Radio, TV, pagers, satellite TV, etc.
  - Two Way:
    - Walkie-talkie, cell phones, satellite phones, wireless local area networks, etc.
- Wireless communications is the fastest growing segment of the communications industry.

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Introduction(cont'd)

- Wireless systems consist of
  - wireless wide-area networks (WWAN)[i.e., cellular systems],
  - Wireless local area networks (WLAN),
  - Wireless personal area networks (WPAN)
  - Wireless metro area networks(WMAN)
- Applications: wireless sensor networks, automated highways and factories, smart homes, remote telemedicine, etc.
- The handsets used in all of these systems possess complex functionality, yet they have become small, low-power consuming devices that are mass produced at a low cost, which has in turn accelerated their widespread use.

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Introduction(cont'd)

- Fundamentally different from wired networks
- Different wireless applications have different requirements
  - Voice systems
    - have relatively low data rate requirements (around 20 Kbps)
    - can tolerate a fairly high probability of bit error
    - but the total delay must be less than around 30 msec or it becomes noticeable to the end user.
  - Data systems
    - require much higher data rates (1-100 Mbps) and very small bit error rates but do not have a fixed delay requirement.
  - Real-time video systems have high data rate requirements coupled with the same delay constraints as voice systems
  - Paging and short messaging have very low data rate requirements and no delay constraints.

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Introduction(cont'd)

- These diverse requirements for different applications make it difficult to build one wireless system that can efficiently satisfy all these requirements simultaneously.
- For these reasons, at least in the near future, wireless systems will continue to be fragmented, with different protocols tailored to support the requirements of different applications.

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Introduction (cont'd)

Short Range: Low Power, Wireless Personal Area Network (WPAN)
- Bluetooth (1 Mbps)
- Ultra Wideband (UWB) (>100 Mbps)
- Sensor Networks
- IEEE 802.15.4, Zigbee

Long Distance: High Power, Wireless Wide Area Networks (WWAN)
- 2G
  - GSM (9.8 kbps)
  - PDC
  - GPRS (114 kbps)
  - PHS (64 kbps, up to 128 kbps)
- 3G (cdma2000, WCDMA) (384 kbps to 2 Mbps)

Middle Range: Medium Power, Wireless Local Area Network (WLAN)
- Home RF (10 Mbps)
- IEEE802.11a,b,g (108 Mbps) (802.11a based proprietary 2x mode)

Wireless Networks

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Cellular Networks

- Extremely popular. There are billions of cellular system users worldwide. Indeed cellular phones have become a critical business tool and part of everyday life
- Ignited the wireless revolution
- Provide two-way voice and data communication
- Initially designed for mobile terminals inside vehicles with antennas mounted on the vehicle roof
- Today these systems have evolved to support lightweight handheld mobile terminals

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Cellular Networks (cont'd)

- Cellular Network Organization
  - Multiple low power transmitters(100W or less)
  - The service area is divided into cells
    - Each with own antenna
    - Each with own range of frequencies
    - Served by base station, consisting of transmitter, receiver, control unit
    - Adjacent cells on different frequencies to avoid interference
  - A combination of multiple cells is called a cellular structure
- Cell radii can vary from 10m in buildings up to tens of kilometers in the countryside
- Operate in licensed frequency bands roughly between 900 MHz and 2 GHz

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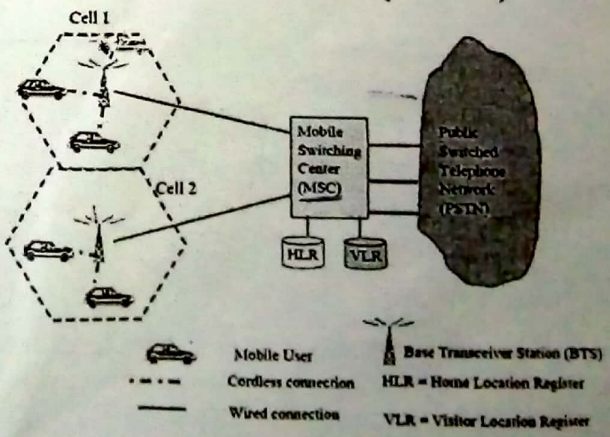
Cellular Networks (cont'd)



A Cellular Communication Network

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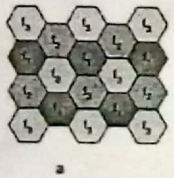
Cellular Networks (cont'd)

- The basic premise behind cellular system design is frequency reuse.
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells. Objective is to reuse frequency in nearby cells
  - 10-50 channels (TDM, FDM or CDMA) assigned per cell
- A cell of any size can support roughly the same number of users



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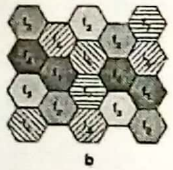

b

a) Cellular system with three cell clusters

b) Cellular system with seven cell clusters

Frequency Reuse(cont'd)

- is a method used by service providers to improve the efficiency of a cellular network and to serve millions of subscribers using a limited radio spectrum
- is based on the fact that after a distance a radio wave gets attenuated and the signal falls bellow a point where it can no longer be used or cause any interference
- a transmitter transmitting in a specific frequency range will have only a limited coverage area
- beyond this coverage area, that frequency can be reused by another transmitter

Network Cells

- the entire network coverage area is divided into cells based on the principle of frequency reuse
- a cell = basic geographical unit of a cellular network; is the area around an antenna where a specific frequency range is used; is represented graphically as a hexagonal shape, but in reality it is irregular in shape
- when a subscriber moves to another cell, the antenna of the new cell takes over the signal transmission
- a cluster is a group of adjacent cells, usually 7 cells; no frequency reuse is done within a cluster
- the frequency spectrum is divided into sub bands and each sub band is used within one cell of the cluster
- in heavy traffic zones cells are smaller, while in isolated zones cells are larger

Network Cells(cont'd)

- The shape of cells are never perfect circles or hexagons. It depend on:
  - The environment (buildings, mountains, valleys etc.),
  - on weather conditions, and
  - sometimes even on system load
- Well known from mobile networks (GSM, UMTS)
- A procedure inside a cellular network controls the switching process between the cells and end devices(more on the 2nd chapter)

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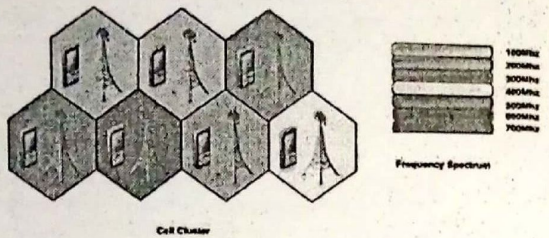

Cell Cluster

Frequency Spectrum

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Types of Cells

- macro cell – their coverage is large (aprox. 6 miles in diameter); used in remote areas, high-power transmitters and receivers are used
- microcell – their coverage is small (half a mile in diameter) and are used in urban zones; low-powered transmitters and receivers are used to avoid interference with cells in another clusters
- Pico cell – covers areas such as building or a tunnel

* macro cell = their coverage is large
* micro cell = their coverage is small
* pico cell = covers areas

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Other Cellular Concepts

- handover = moving a call from one zone (from the transmitter-receiver from one zone) to another zone due to subscriber's mobility
- roaming = allowing the subscriber to send/receive calls outside the service provider's coverage area

handover = call from one zone to another zone due to subscriber's mobility

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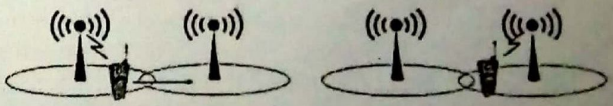
Other Cellular Concepts(cont'd)

- Handover/Handoff
  - Is switch from one channel to another as the mobile moves from one cell area to another.



- Reasons for handovers are:
  - leaving the transmission range of a cell
  - overloading or breakdown of the used cell
  - loss of connection quality

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zone

Increasing Capacity of cells

- Increasing Capacity In time, as more customers use the system, traffic may build up so that there are not enough frequencies assigned to a cell to handle its calls.
- A number of approaches have been used to cope with this situation, including the following:

❖ **Adding new channels**: Typically, when a system is set up in a region, not all of the channels are used, and growth and expansion can be managed in an orderly fashion by adding new channels.

❖ **Frequency borrowing**: In the simplest case, frequencies are taken from adjacent cells by congested cells.

- The frequencies can also be assigned to cells dynamically.

Con't

❖ **Cell splitting**: In practice, the distribution of traffic and topographic features is not uniform, and this presents opportunities for capacity increase. Cells in areas of high usage can be split into smaller cells.

- Generally, the original cells are about 6.5 to 13 km in size. The smaller cells can themselves be split; however, 1.5-km cells are close to the practical minimum size as a general solution

❖ **Cell sectoring:** With cell sectoring, a cell is divided into a number of wedge shaped sectors, each with its own set of channels, typically three or six sectors per cell.

- Each sector is assigned a separate subset of the cell's channels, and directional antennas at the base station are used to focus on each sector.

Cellular Networks (cont'd)

- Advantages of cellular systems with small cells
  - **Higher capacity** - allows frequency reuse(higher number of users per unit area)
  - **Less transmission power**
    - Receiver far away from a base station would need much more transmit power
    - Power aspects are not a big problem for base stations.
    - Energy is a serious problem for mobile handheld devices
  - **Local interference only**
    - With small cells, mobile stations and base stations only have to deal with 'local' interference
  - **Robustness:**
    - Cellular systems are decentralized and so, more robust against the failure of single components

Cellular Networks (cont'd)

- Disadvantages:
  - Infrastructure needed: Cellular systems need a complex infrastructure to connect all base stations.
  - Handover needed: The mobile station has to perform a handover when changing from one cell to another.
  - Frequency planning: To avoid interference between transmitters using the same frequencies, frequencies have to be distributed carefully.

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Evolution of Cellular Networks

- Cellular networks ranging from 1G to 5G
- 1G: First-generation wireless cellular
  - It was introduced in 1979 in the United States.
  - The 1G also called Advanced Mobile Phone System (AMPS), was invented at Bell Labs and first installed in 1982.
  - During the early 1980s, several incompatible cellular systems (TACS, NMT, C450, etc.) were introduced in Western Europe.
  - The deployment of these incompatible systems resulted in mobile phones being designed for one system that could not be used with another system, and
  - roaming between the many countries of Europe was not possible.
  - The first-generation systems were designed for voice applications.

Con't

- At the introduction of 1G services, the mobile device was large in size, and would only fit in the trunk of a car.
- Use analog transmission, and are primarily intended for voice service and low rate(about 9.6 kbps)circuit switched data service . Analog cellular phones are insecure.
- These networks are very slow (less than 1 kilobits per second).
- The 1G systems used FDMA and analog Frequency Modulation(FM).

Evolution of Cellular Networks (cont'd)

- 2G: Second-generation wireless cellular
  - Introduced in the late 1990s
  - These systems use digital transmission and are also intended primarily for speech.
  - Groupe Special Mobile (GSM), renamed Global System for Mobile communications, was established for harmonization.
    - ✓ To solves incompatibility problems of 1G and
    - ✓ roaming was possible with the use of Subscriber Identity Module (SIM) roaming, between them and with all other GSM-based systems.
  - These systems, most prevalent at present, operate at 9.6 Kbps.
  - The 2G systems based on TDMA and CDMA technologies

Con't

- The primary differences between 1G and 2G are:
  - **Digital traffic channels** – 1G systems are almost purely analog; 2G systems are digital.
  - **Encryption** – all 2G systems provide encryption to prevent eavesdropping. Simple to encrypt digital traffic
  - **Error detection and correction** – second-generation digital traffic allows for detection and correction, giving clear voice reception.
  - **Channel access** – second-generation systems allow channels to be dynamically shared by a number of users via TDMA and CDMA

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Evolution of Cellular Networks (cont'd)

- 2.5G Systems
  - Are essentially 2G systems that have evolved to medium-rate (around 100 Kbps) data.
  - 2G systems with added data capabilities
  - As part of the 2.5G initiative, GSM is being extended by the General Packet Radio System (GPRS) to support data rates up to a maximum of 160 Kbps.
  - GPRS can be added to GSM infrastructures quite readily. It doe not require new radio spectrum.
  - GPRS basically overlays a packet-switching network on the existing circuit switched GSM network.
  - This gives the user an option to use a packet-based data service.
  - The phase after GPRS is called Enhanced Data Rates for GSM Evolution (EDGE), can deliver maximum data rates up to 500 Kbps

Evolution of Cellular Networks (cont'd)

- 3G Systems:
  - Goal of 3G systems is:-
    - to enable wireless service providers to offer services found on today's wire line networks: broadband Internet access, interactive gaming, and high quality audio and video entertainment.
    - to provide fairly high-speed wireless communications to support multimedia, data, and video in addition to voice.
  - Can operate at 2 megabits per second.
  - The best known example of 3G is the UMTS (Universal Mobile Telecommunications System)/W-CDMA/CDMA2000
  - 3G networks use a connectionless (packet-switched) communications mechanism.
  - The dominant technology in 3G is CDMA

Evolution of Cellular Networks (cont'd)

- 4G Cellular Networks
  - Cellular data rates of 200 Mbps and beyond
  - The high speed could allow users to watch high-resolution movies and television programs on their cellular phones
  - Many new technologies and techniques (multiplexing, smart antennas, digital signal processing) are at the core of 4G networks.
  - IPv6 will be used at the network layer level
  - Challenge: determining the frequency spectrum for 4G-unused bandwidth(e.g.60 GHz band) vs. distance(range is only 100m)

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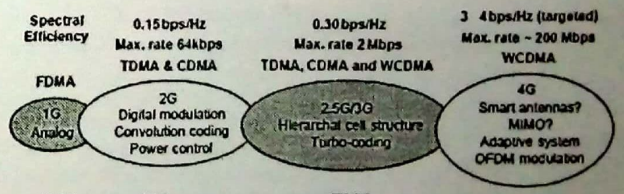

PHS: Personal handy phone system (Japan)
MIMO: Multi-input and multi-output
OFDM: Orthogonal Frequency Division Multiple Access

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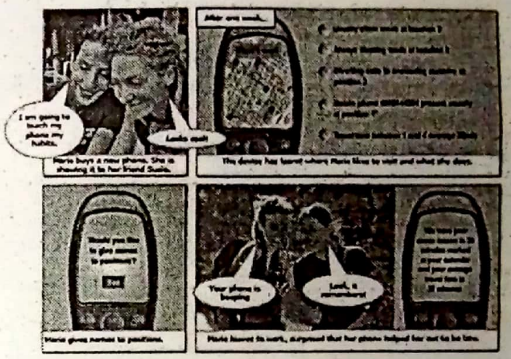
Evolution of Cellular Networks (cont'd)

- 5G Cellular Networks
  - Scheduled to arrive in a 2020 timeframe
  - The idea is to investigate cellular networks that could deliver data rates above 50 Mbps.
  - The general vision of 5G is that a PDA, laptop, and automobile would employ the mix of Bluetooth, IEEE 802.11, and cellular standards from 1G to 3G as needed by the user.
  - Special value added services such as location-based services are automatically activated when needed
  - There is more emphasis on smart antennas, error correction, and improved signal encoding techniques.
  - One of the main emphasis of 5G cellular is collection of information that can be used to make decisions.
  - For example, it could record the path from your home to work. It builds an internal database of what it can do when and where.

Example Application



Wireless Local Area Networks

- Support communication to mobile data users via wireless channel in a small area (around 100 meters).
- Wireless devices that access these LANs are typically stationary or moving at pedestrian speeds.
- The 1G of WLAN products provided data rates of about 1-2 Mbps; Current generation data rates up to 54 Mbps.
- Mobile device in the WLANs connected to wired networks provided through an "access point".
- Operation in the ISM (industrial-scientific-medical) unlicensed frequency band
- The IEEE 802.11 committee is responsible for WLAN standards.

WLAN Con't

- The benefits of wireless LANs are:
  - **Flexibility**: allows the users to roam around a building with their laptops.
  - **Improvements in Productivity**: Wireless LANs can provide LAN users with access to real-time information anywhere in their organization.
  - **Installation Speed and Simplicity**
  - **Reduced Cost**
- Use: mobile Internet, home networking, office networking, temporary networks (installations for internet access in exhibition and conference areas) , coffee shop networks, airports, etc

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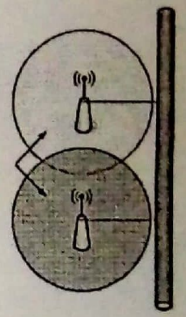
WLAN Con't

- IEEE 802.11 Terminology
  - **I. Access Point (AP)**
    - Provides access to distribution services via the wireless medium
  - **II. Basic Service Area (BSA)**
    - The coverage area of one access point
  - **III. Basic Service Set (BSS)**
    - Group of stations using the same radio frequency
    - A set of mobile stations controlled by one access point

WLAN (cont'd)

IV. ESS

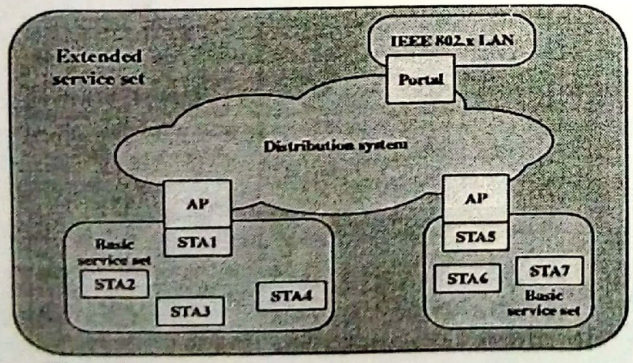
- Set of infrastructure BSS's
  - AP's communicate with each other
  - Forward traffic from one BSS to another
  - Facilitate movement of stations from one BSS to another
- Extends range of mobility beyond reach of a single BSS



V. Distribution system

- The fixed (wired) infrastructure used to connect a set of BSS to form a single network and thereby extends the wireless coverage area.

WLAN (cont'd)



STA = station
AP = access point

Architecture of an infrastructure-based IEEE 802.11

WLAN (cont'd)

- IEEE 802.11 standard belongs to the group of 802.x LAN standards, e.g., 802.3 Ethernet or 802.5 Token Ring
- The standard specifies the physical and medium access layer adapted to the special requirements of wireless LANs
- The standard has been issued in several stages.
- The first part, issued in 1997, is simply called 802.11 and operates at 1 and 2 Mbps
- WLANs include IEEE 802.11a (WiFi 5), IEEE 802.11b (WiFi), IEEE 802.11g and IEEE 802.11n

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WLAN (cont'd)

- 802.11a:
  - operates in the 5 GHz band and can go up to 54 Mbps
  - Transmission range: 100m outdoor, 10m indoor
  - Less prone to interference.
  - More expensive.
- 802.11b:
  - These LANs use the 2.2-to-2.4835 GHz band
  - operates at data rates up to 11 Mbps
  - also known as ***Wi-Fi (abbreviated from wireless fidelity)***
  - provides great vendor interoperability
  - operate in a manner very similar to the wired Ethernet LANs
  - A government license is not required to operate equipment in this frequency range

WLAN (cont'd)

- Prone to interference (it shares airspace with cell phones, Bluetooth, security radios, and other devices).
- Because 802.11b and 802.11a use different radio technologies and portions of the spectrum, they are incompatible with one another.
- 802.11g:
  - 802.11g is an enhancement of 802.11b
  - Dual-mode 2.4 GHz and 5 GHz operability
  - can go up to 54 Mbps
  - Range: Somewhat higher than 802.11a

WLAN (cont'd)

- 802.11a Versus 802.11g
  - operates in different frequency band
  - 802.11a distance range is lower than 802.11g (higher frequencies have shorter ranges)
  - cost of 802.11a could be higher – you need more access points for the same area
- 802.11n:
  - Speed: Up to 700Mbs
  - Range: 50 feet

WLAN standards

Standard	Scope
IEEE 802.11	Medium access control (MAC): One common MAC for WLAN applications
	Physical layer: Infrared at 1 and 2 Mbps
	Physical layer: 2.4-GHz FHSS at 1 and 2 Mbps
	Physical layer: 2.4-GHz DSSS at 1 and 2 Mbps
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11f	Recommended practices for multivendor access point interoperability
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11h	Physical/MAC: Enhance IEEE 802.11a to add indoor and outdoor channel selection and to improve spectrum and transmit power management
IEEE 802.11i	MAC: Enhance security and authentication mechanisms

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IEEE 802.11j	Physical: Enhance IEEE 802.11a to conform to Japanese requirements
IEEE 802.11k	Radio resource measurement enhancements to provide interface to higher layers for radio and network measurements
IEEE 802.11m	Maintenance of IEEE 802.11-1999 standard with technical and editorial corrections
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11p	Physical/MAC: Wireless access in vehicular environments
IEEE 802.11r	Physical/MAC: Fast roaming (fast BSS transition)
IEEE 802.11s	Physical/MAC: ESS mesh networking
IEEE 802.11.2	Recommended practice for the evaluation of 802.11 wireless performance
IEEE 802.11u	Physical/MAC: Interworking with external networks

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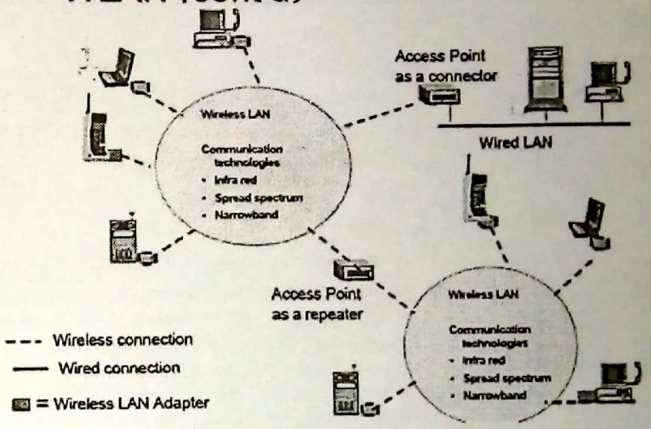
WLAN (cont'd)



▪Wireless LAN Technologies

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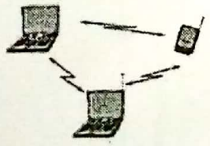
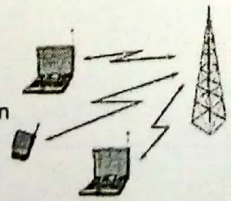
WLAN: main operating modes

- Ad-hoc mode
  - Participants: only clients
  - Communications: peer-to-peer
  - For ad-hoc networks



- Infrastructure mode
  - Participants: AP and clients
  - Communications: only between AP and clients
  - AP: provides also connection between the wireless and wireline networks



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Wireless Personal Area Network

- Networks that connect devices within a small range
  - Typically on the order of 10-100 meters
- Application areas
  - Cable replacement
    - Eliminates need for numerous cable attachments
    - Hook your laptop to your PDA, headphones, mouse, keyboard, printer, camera, etc.
  - Ad hoc networking
    - Device with PAN radio can establish connection with another when in range
- Use band available globally for unlicensed users
- Defined in a global band (2.45 GHz ISM band)

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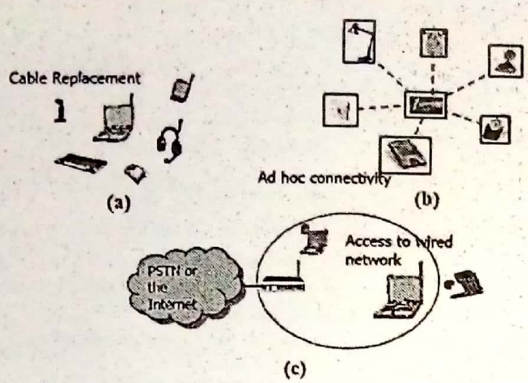
Applications of WPANs



Bluetooth Standard

- Universal short-range wireless capability
  - Bluetooth devices should work anywhere in the world (mostly)
  - Devices within 10 m can share up to 865 kbps of capacity
- Bluetooth ≈ IEEE 802.15.1
- Bluetooth standardization began in 1998
- Sponsors
  - Initial: Ericsson, Nokia, IBM, Toshiba, and Intel
  - Expanded in 1999 to include 3 Com, Lucent, Microsoft, and Motorola. Thousands of companies are now adopters
- Goals of system design
  - Global operation
  - No fixed infrastructure required for network set-up or maintenance
  - Voice and data connections
  - Small, low power radio (1 mW transmit power to get 10 m range)
  - Low cost:

Bluetooth(cont'd)

- Bluetooth enabled electronic devices connect and communicate wirelessly through short-range, ad hoc networks known as **piconets.**
  - Up to 8 devices in one piconet (1 master and 7 slave devices).
  - The reason for the upper limit of eight active devices, is the 3-bit address used in Bluetooth.
- Piconet operation
  - The piconet master is a device in a piconet whose clock and device address are used to define the piconet physical channel characteristics.
  - All other devices in the piconet are called piconet slaves.
  - At any given time, data can be transferred between the master and one slave.
  - The master switches rapidly from slave to slave in a round-robin fashion.
  - Any device may switch the master/slave role at any time.

ZigBee Technology

- ZigBee technology is a low data rate, low power consumption, low cost, wireless networking protocol
- The specification is based on the IEEE 802.15.4 standard
- Is capable of connecting 255 devices per network
- Can be implemented in mesh (peer- to-peer) networks larger than is possible with Bluetooth
- Data rates of up to 250 Kbps at a range of up to 30 m
- Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation

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ZigBee Technology Con't

- Two types of devices: full-function device (FFD) and reduced-function device (RFD)
  - FFD: operating as the PAN coordinator; for network routing and link coordination
  - RFD: Simple send/receive devices
  - An FFD can talk to reduced-function or full-function devices, while an RFD can only talk to an FFD.
- ZigBee supports three types of topologies: star topology, peer-to-peer topology, and cluster tree

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ZigBee Technology (cont'd)

- Star topology
  - communication is established between devices and a single central controller, called the PAN coordinator.
  - Applications: home automation, personal computer (PC) peripherals, toys, and games.
- *Peer-to-peer topology*
  - *peer-to-peer topology, there is also one PAN coordinator.*
  - *In contrast* to star topology, any device can communicate with any other device as long as they are in range of one another.
  - Applications: industrial control and monitoring, wireless sensor networks and asset and inventory tracking

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ZigBee Technology (cont'd)

- Cluster-tree topology
  - Is a special case of a peer-to-peer network in which most devices are FFD and an RFD may connect to a cluster-tree network as a leaf node at the end of a branch.
  - Advantage: increased coverage at the cost of increased message latency.

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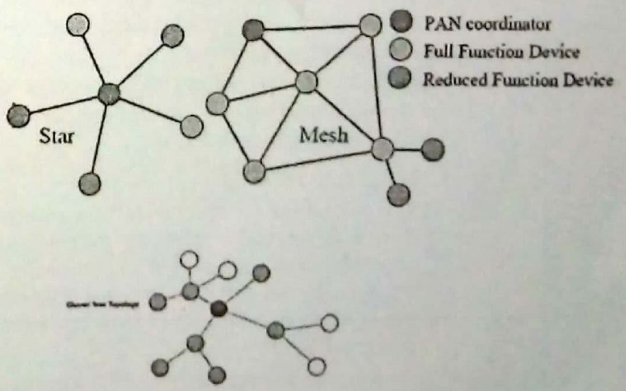
ZigBee Technology (cont'd)



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Wireless Metro Area Networks

- WMAN – Wireless Metropolitan Area Network – IEEE 802.16
- IEEE 802.16
  - Defines the air interface, including the MAC layer and multiple PHY layer options, for fixed Broadband Wireless Access (BWA) systems to be used in WMAN.
  - Often referred to as WiMax (Worldwide Interoperability for Microwave Access)
  - IEEE 802.16 cannot be used in a mobile environment. For this purpose, IEEE 802.16e is being developed.
- WiMAX
  - "a big Wi-Fi"
  - Data rates ~70 Mbps
  - Coverage area ~50 km

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Satellite Network

- Satellite systems are another major component of the wireless communications infrastructure
- Applications:
  - Weather forecasting: Several satellites deliver pictures of the earth
  - Radio and TV broadcast satellites
  - Military satellites
  - Satellites for navigation, GPS
  - Global telephone backbones: being replaced by fiber optical cables crossing the oceans.
  - Connections for remote or developing areas
- Three major classes of satellites, GEO, MEO, and LEO

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Satellite Network(cont'd)

- GEO (Geostationary Orbit)
  - Have a distance of almost 36,000 km to the earth.
  - Objects in Geostationary orbit revolve around the earth at the same speed as the earth rotates. This means GEO satellites remain in the same position relative to the surface of earth.
  - Usage: for almost all TV and radio broadcast satellites, many weather satellites and satellites operating as backbones for the telephone network
  - Advantage
    - complete coverage of almost any spot on earth
    - do not need a handover due to the large footprint
    - Lifetime expectations for GEOs are rather high, at about 15 years
  - Disadvantage
    - The transmit power needed is relatively high (some 10 W), cannot be used for small mobile phones
    - high latency – over 0.25 s
    - Shading of the signals in cities, due to high buildings, limit transmission quality
    - Polar regions are poorly served

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Satellite Network(cont'd)

- **Low earth orbit (LEO)**
  - were mainly used for intelligence
  - using altitudes of 500–1,500 km
  - provide a high quality communication link
  - problem of the LEO concept is the need for many satellites if global coverage is to be reached
  - Advantage
    - Use low power, 1W
    - Delay is about 5–10 ms
    - Can be used for voice communication
    - Smaller footprints of LEOs allow for better frequency reuse

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Satellite Network(cont'd)

- Disadvantage
  - need for many satellites if global coverage is to be reached: 50-200 satellites needed
  - requires additional mechanisms for connection handover between different satellites.
  - Short lifetime of about five to eight years
- Medium earth orbit (MEO)
  - operate at a distance of about 5,000–12,000 km
  - Up to now there have not been many satellites in this class
  - Delay increases to about 70–80 ms

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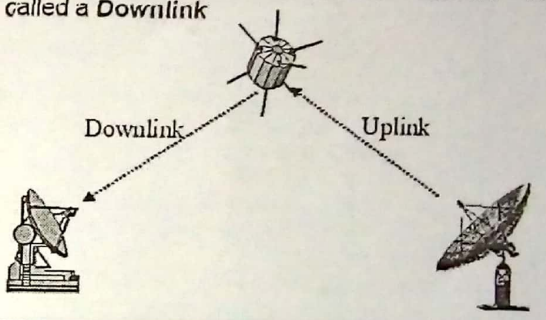
Satellite Network(cont'd)

- One **Earth Station** sends a transmission to the satellite. This is called a **Uplink**.
- The satellite **Transponder** converts the signal and sends it down to the second earth station. This is called a **Downlink**



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Wireless Issues

- **Wireless link implications**
  - *communications channel* is the air
    - poor quality: fading, shadowing, weather, etc.
      - A major technical problem for cellular networks is **fading**, which refers to the time variation of received signal power caused by changes in the transmission medium or path(s).
    - data rate and coverage vary
  - *regulated* by governments
    - frequency allocated, licensing, etc.
  - *limited bandwidth*
    - low bit rate, frequency planning and reuse, interference
  - *power issues*
    - Power levels regulated (safety issue), conserve mobile terminal battery life
  - *security issues*
    - wireless channel is a broadcast medium!

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Summary

- Wireless Wide Area Networks (WWANs)
  - Cellular Networks :
    - GSM, cdmaone (IS-95), UMTS, cdma2000 EVDO
  - Satellite Networks:
    - Iridium, Inmarsat, GPS, etc.
- Wireless Metro Area Networks (WMANs)
  - IEEE 802.16 WiMAX
- Wireless Local Area Networks (WLANs)
  - IEEE 802.11, a, b, g, etc. (infrastructure, ad hoc)
- Wireless Personal Area Networks (WPANs)
  - IEEE 802.15 (Bluetooth), IrDa, Zigbee, sensor, etc

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Summary

Network	Geographic Coverage	Typical Throughput	Standards
WWANs	National, Continent wide, Worldwide	2G: 9.6 – 45 Kbps, 2.5G: 50 -300 Kbps 3G : 50Kbps- 2Mbps 3.5G: .1 – 20 Mbps Satellite – 9.6 – 512Kbps	2G: GSM, cdmaone 2.5G: GPRS, cdma 2000 1X-rt 3G: UMTS, cdma2000 1x-EDVO 3.5G: HSPDA Proprietary
WMANs	Metro, suburb, campus 1-15 km	100 Mbps – 10Gbps	IEEE 802.16
WLANs	In building, campus wide, subdivision wide, Range ~ 100 M per AP	1-100 Mbps	IEEE 802.11a, b, g, etc.
WPANs	5-10 M around device	.1 – 1Mbps	IEEE 802.15 IrDa, BlueTooth, Zigbee

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Reading Assignment

- History of wireless communication

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Computer Science for 4th year (Late)

CHAPTER 2

Multiple Access Techniques for Wireless Communication[1]

The goal in the design of a cellular system is to be able to handle as many calls as possible in a given bandwidth. Multiplexing deals with the division of the resources to create multiple channels. Multiplexing describes how several users can share a medium with minimum or no interference.
One example is highways with several lanes. For wireless communication, multiplexing can be carried out in four dimensions: space, time, frequency, and code.

Introduction:

Frequency division multiple access (FDMA), *time division multiple access* (TDMA), and *code division multiple access* (CDMA) are the three major access techniques used to share the available bandwidth in a wireless communication system. These techniques can be grouped as *narrowband* and *wideband* systems, depending upon how the available bandwidth is allocated to the users. The duplexing technique of a multiple access system is usually described along with the particular multiple access scheme, as shown in the examples that follow.

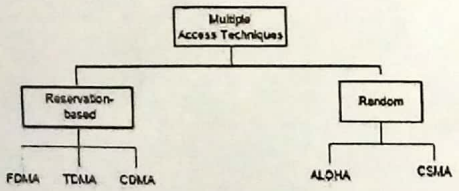
Multiple access techniques can be classified as

1. Reservation-based multiple access-used if data traffic is continuous and a small transmission delay is required.
Examples: voice and video
Types:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

2. Random multiple access-Communication channels is shared by many users and users transmit their data in a random or partially coordinated fashion.
Types:

- ALOHA
- CSMA

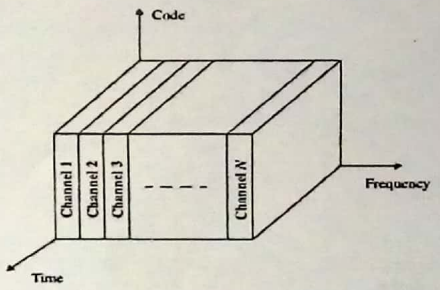


Narrowband Systems - The term *narrowband* is used to relate the bandwidth of a single channel to the expected coherence bandwidth of the channel. In a narrowband multiple access system, the available radio spectrum is divided into a large number of narrowband channels. The channels are usually operated using FDD.

Wideband systems-In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel. In wideband multiple access systems a large number of transmitters are allowed to transmit on the same channel. TDMA allocates time slots to the many transmitters on the same channel and allows only one transmitter to access the channel at any instant of time, whereas spread spectrum CDMA allows all of the transmitters to access the channel at the same time. TDMA and CDMA systems may use either FDD or TDD multiplexing techniques.

Frequency Division Multiple Access (FDMA)

Frequency division multiple access (FDMA) assigns individual channels to individual users. It can be seen from Figure 9.2 that each user is allocated a unique frequency band or channel. These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same channel. In FDO systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel.



FDMA where different channels are assigned different frequency bands.

The features of FDMA are as follows:

- The FDMA channel carries only one phone circuit at a time.
- If an FDMA channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity. It is essentially a wasted resource.
- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.
- The bandwidths of FDMA channels are relatively narrow (30kHz in AMPS) as each channel supports only one circuit per carrier. That is, FDMA is usually implemented in narrowband systems.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.
- FDMA systems have higher cell site system costs as compared to TDMA systems.
- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

The number of channels that can be simultaneously supported in a FDMA system is given by

$$N = \frac{B_t - 2B_{guard}}{B_c}$$

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Where B_t is the total spectrum allocation, B_{guard} is the guard band allocated at the edge of the allocated spectrum band, and B_c is the channel bandwidth.

Problem: If a US AMPS cellular operator is allocated 12.5 MHz for each simplex band, and if B_t is 12.5 MHz, B_{guard} is 10 kHz, and B_c is 30 kHz, find the number of channels available in an FDMA system.

Solution

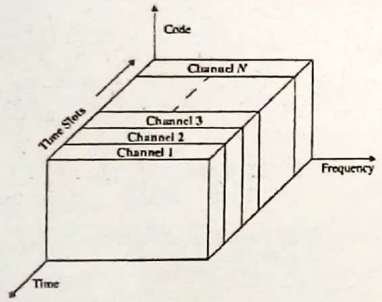
The number of channels available in the FDMA system is given as

$$N = \frac{12.5 \times 10^6 - 2(10 \times 10^3)}{30 \times 10^3} = 416$$

In the US, each cellular carrier is allocated 416 channels.

Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from below Figure that each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a *buffer-and-burst* method, thus the transmission for any user is non-continuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure as shown in Figure 9.4. It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an information message, and tail bits. In TDMA/ TDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels.



TDMA scheme where each channel occupies a cyclically repeating time slot

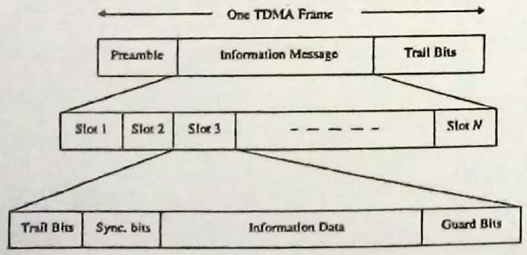


Figure 9.4 TDMA frame structure. The frame is cyclically repeated over time.

In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames.

The features of TDMA include the following:

- TDMA shares a single carrier frequency with several users, where each user makes use of Non-overlapping time slots.
- Data transmission for users of a TDMA system is not continuous, but occurs in bursts.
- Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required
- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized.
- High synchronization overhead is required in TDMA systems because of burst transmissions. TDMA transmissions are slotted, and this requires the receivers to be synchronized for each data burst.
- TDMA has an advantage in that it is possible to allocate different numbers of time slots per frame to different users.

Number of channels in TDMA system - The number of TDMA channel slots that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m(B_{tot} - 2B_{guard})}{B_c}$$

Where m is the maximum number of TDMA users supported on each radio channel.

Problem: Consider Global System for Mobile, which is a TDMA/FDD system that uses 25 MHz for the forward link, which is broken into radio channels of 200 kHz. If 8 speech channels are supported on a single radio channel, and if no guard band is assumed, find the number of simultaneous users that can be accommodated in GSM.

Solution

The number of simultaneous users that can be accommodated in GSM is given as

$$N = \frac{25 \text{ MHz}}{(200 \text{ kHz})/8} = 1000$$

Thus, GSM can accommodate 1000 simultaneous users.

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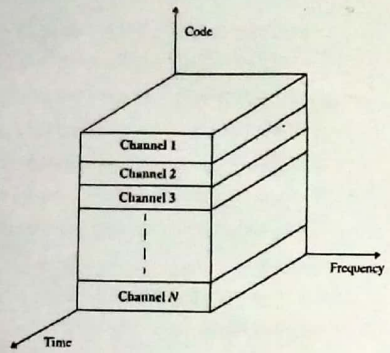
Code Division Multiple Access (CDMA)

In *code division multiple access* (CDMA) systems, the narrowband message signal is multiplied by a very large bandwidth signal called the *spreading signal*. The spreading signal is a pseudo noise code sequence that has a chip rate which is orders of magnitudes greater than the data rate of the message. All users in a CDMA system, as seen from below Figure, use the same carrier frequency and may transmit simultaneously. Each user has its own pseudorandom code word which is approximately orthogonal to all other code words. The receiver performs a time correlation operation to detect only the specific desired code word. All other code words appear as noise due to decorrelation.



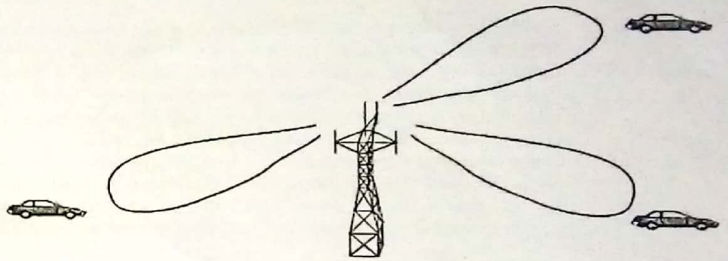
In CDMA, the power of multiple users at a receiver determines the noise floor after de-correlation. If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the *near-far problem* occurs. The near-far problem occurs when many mobile users share the same channel.

The features of CDMA including the following:

- Many users of a CDMA system share the same frequency. Either TDD or FDD may be used.
- Unlike TDMA or FDMA, CDMA has a soft capacity limit. Increasing the number of users in a CDMA system raises the noise floor in a linear manner.
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum.
- Channel data rates are very high in CDMA systems.
- Since CDMA uses co-channel cells, it can use macroscopic spatial diversity to provide soft handoff. Soft handoff is performed by the MSC, which can simultaneously monitor a particular user from two or more base stations.
- Self-jamming is a problem in CDMA system.
- The near-far problem occurs at a CDMA receiver if an undesired user has a high detected power as compared to the desired user.

Space Division Multiple Access (SDMA)

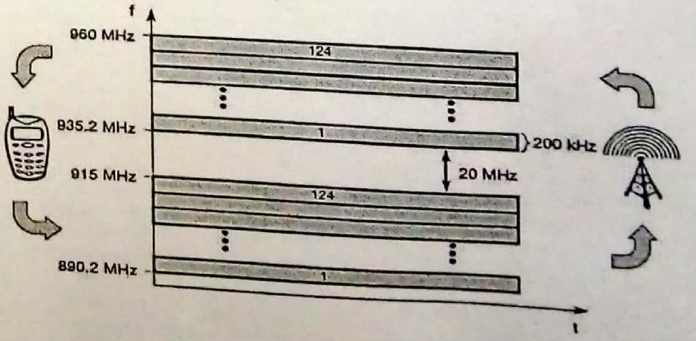
Space division multiple access (SDMA) controls the radiated energy for each user in space. It can be seen from below figure that SDMA serves different users by using spot beam antennas. These different areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system). Sectorized antennas may be thought of as a primitive application of SDMA. In the future, adaptive antennas will likely be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures.



Duplexing

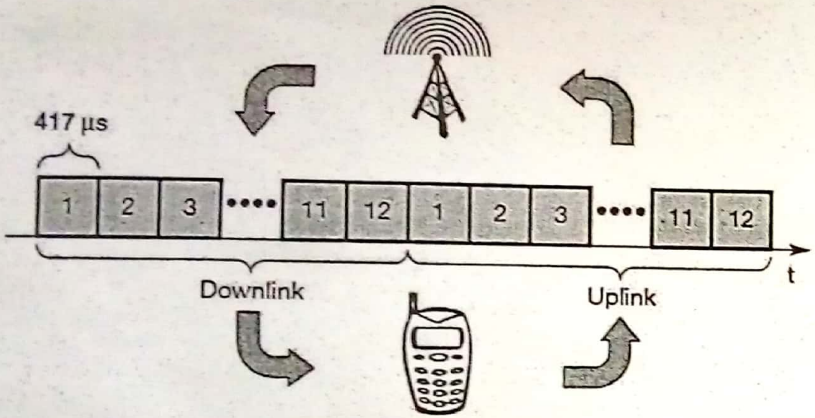
- Simultaneous transmission and reception of up and down-link channels.
- Time and frequency domain techniques:
  - FDD: Frequency division duplex
    - the transmitter and receiver operate simultaneously on different frequencies.
  - TDD: Time division duplex
    - alternates transmission and reception at different time instants on the same frequency band.

FDD/FDMA - General scheme, example GSM



- All uplinks use the band between 890.2 and 915 MHz
- Downlinks use 935.2 to 960 MHz
- If the uplink frequency is fu = 890 MHz + n·0.2 MHz, the downlink frequency is fd = fu + 45 MHz, i.e., fd = 935 MHz + n·0.2 MHz for a certain channel n.
- Each channel has a bandwidth of 200 kHz.

TDD/TDMA - general scheme



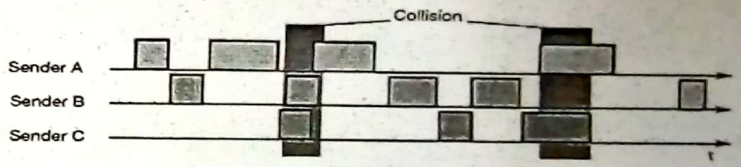
- The base station uses one out of 12 slots for the downlink.
- The mobile station uses one out of 12 different slots for the uplink.
- Up to 12 different mobile stations can use the same frequency.
- Each slot has a duration of 417 μs; access to the medium every 10 ms.

Random Access Methods

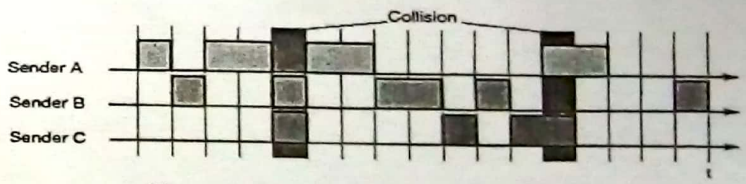
- The reservation-based multiple access technique has a disadvantage:
  - Most data users do not require continuous transmission: data is generated at random time instances, so dedicated channel assignment can be extremely inefficient.
  - Most systems have many more total users (active plus idle users) than can be accommodated simultaneously, so at any given time channels can only be allocated to users that need them.
- The random access methods give freedom for each user to gain access to the network whenever the user has information to send.
- The commonly used random-access protocols are pure ALOHA, slotted-ALOHA, and CSMA/CD.

Pure ALOHA

- In the pure ALOHA scheme, each user transmits information whenever the user has information to send.
- ALOHA neither coordinates medium access nor does it resolve contention on the MAC layer. Instead, each station can access the medium at any time as shown in the next slide.
- The simple Aloha works fine for a light load and does not require any complicated access mechanisms.
- Process
  - A user sends information in packets.
  - After sending a packet, the user waits a length of time equal to the round-trip delay for an acknowledgment (ACK) of the packet from the receiver.
  - If no ACK is received, the packet is assumed to be lost in a collision and it is retransmitted with a randomly selected delay to avoid repeated collisions.



Classical Aloha multiple access



Slotted Aloha multiple access

Slotted-ALOHA

- In slotted ALOHA, time is assumed to be slotted in timeslots of duration τ, and users can only start their packet transmissions at the beginning of the next timeslot after the packet has formed(as shown in the previous slide).
- Thus, there is no partial overlap of transmitted packets, which increases throughput.
- Collisions occur whenever two or more users attempt transmission in the same slot.

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Carrier Sense Multiple Access

- Carriers sense multiple access (CSMA) protocols sense the carrier before accessing the medium.
- Sensing the carrier and accessing the medium only if the carrier is idle decreases the probability of a collision.
- Collisions can be reduced when:
    - Users **sense the channel and delay transmission** if they detect that another user is currently transmitting.
    - A **user waits to transmit a random time period** after sensing a busy channel. This **random backoff** avoids multiple users simultaneously transmitting as soon as the channel is free.

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