Chapter Three

Conducted and Wireless Media

Data Communications and Computer Networks

After reading this chapter, you should be able to:

- Outline the characteristics of twisted pair wire, including the advantages and disadvantages
- Outline the differences among Category 1, 2, 3, 4, 5, 5e, 6, 7 and 8 twisted pair wire
- Explain when shielded twisted pair wire works better than unshielded twisted pair wire
- Outline the characteristics, advantages, and disadvantages of coaxial cable and fiber-optic cable
- Outline the characteristics of terrestrial microwave systems, including the advantages and disadvantages

After reading this chapter, you should be able to (continued):

- Outline the characteristics of satellite microwave systems, including the advantages and disadvantages as well as the differences among low-Earth-orbit, middle-Earth-orbit, geosynchronous orbit, and highly elliptical Earth orbit satellites
- Describe the basics of cellular telephones, including all the current generations of cellular systems
- Outline the characteristics of short-range transmissions, including Bluetooth

After reading this chapter, you should be able to (continued):

- Describe the characteristics, advantages, and disadvantages of Wireless Application Protocol (WAP), broadband wireless systems, and various wireless local area network transmission techniques
- Apply the media selection criteria of cost, speed, right-of-way, expandability and distance, environment, and security to various media in a particular application

Introduction

- The world of computer networks would not exist without a medium to transfer data
- The two major categories of media include:
  - Conducted media (Wired/ Electric)
  - Wireless media (Electromagnetic)

Twisted Pair Wire

- Twisted pair cables are classified into different categories (Cat) based on performance and bandwidth capabilities

water hose as BW

- Primarily used for digital signals (like in Ethernet)

- Twisting and shielding the wires help reduce EMI electric and magnetic interference between the two wires

Ethernet is digital. It transmits data as digital signals over twisted pair cables. Ethernet is a networking technology with standards and protocols, primarily used for wired LAN.

Twisted Pair Wire

Twisted pair is currently Category 1 through Category 8 (1, 2 and 4 are obsolete)

Cat 3 was used for telephone and early networks (10 Mbps).

Cat 5 and 5e are still in use, with **Cat 5e** supporting **1 Gbps**.

Cat 6 and 6a offer better performance and support **10 Gbps** (Cat 6a at longer distances).

Cat 7 and 7a were developed for **shielded** high-speed networking but are not TIA/EIA-recognized.

Cat 8 is the latest, designed for **40 Gbps** short-range data center applications.

TIA/EIA: a technical standard for commercial building cabling for telecommunications products and services.

Twisted Pair Wire (continued)

Figure 3-1
Example of four-pair twisted pair wire

Crosstalk (XT)
Crosstalk is unwanted signal interference between adjacent twisted pairs in a cable. It happens when electric or magnetic signals from one pair "leak" into another, causing data errors.

float around

Why and How to Twist Pairs with Different Angles
Twisting the wires reduces crosstalk by ensuring the interference is equally distributed and canceled out.

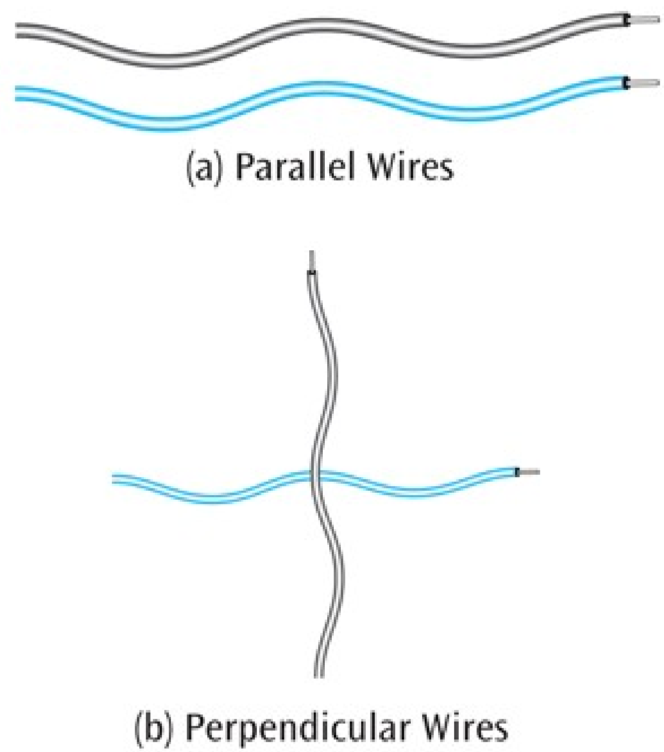
Cat 5e/Cat 6 cables twist lengths, like: Pair 1: **1.5 twists per cm**, Pair 2: **1.8 twists per cm**, Pair 3: **2.0 twists per cm**, Pair 4: **2.2 twists per cm**

Magnetic Interference:
When electric current flows through a wire, it creates a magnetic field. This field can transfer unwanted signals into a nearby wire. (Old tv and speaker)

Electromagnetic Interference:
When two wires are parallel, an electric and magnetic fields form between them, allowing signals to "leak" from one to another. (radio channels static noise)

Twisted Pair Wire (continued)

Figure 3-2
(a) Parallel wires—greater chance of crosstalk
(b) Perpendicular wires—lesser chance of crosstalk
(c) Twisted wires—crosstalk reduced because wires keep crossing each other at nearly perpendicular angles



Twisted Pair Wire (continued)

Figure 3-3
An example of shielded twisted pair

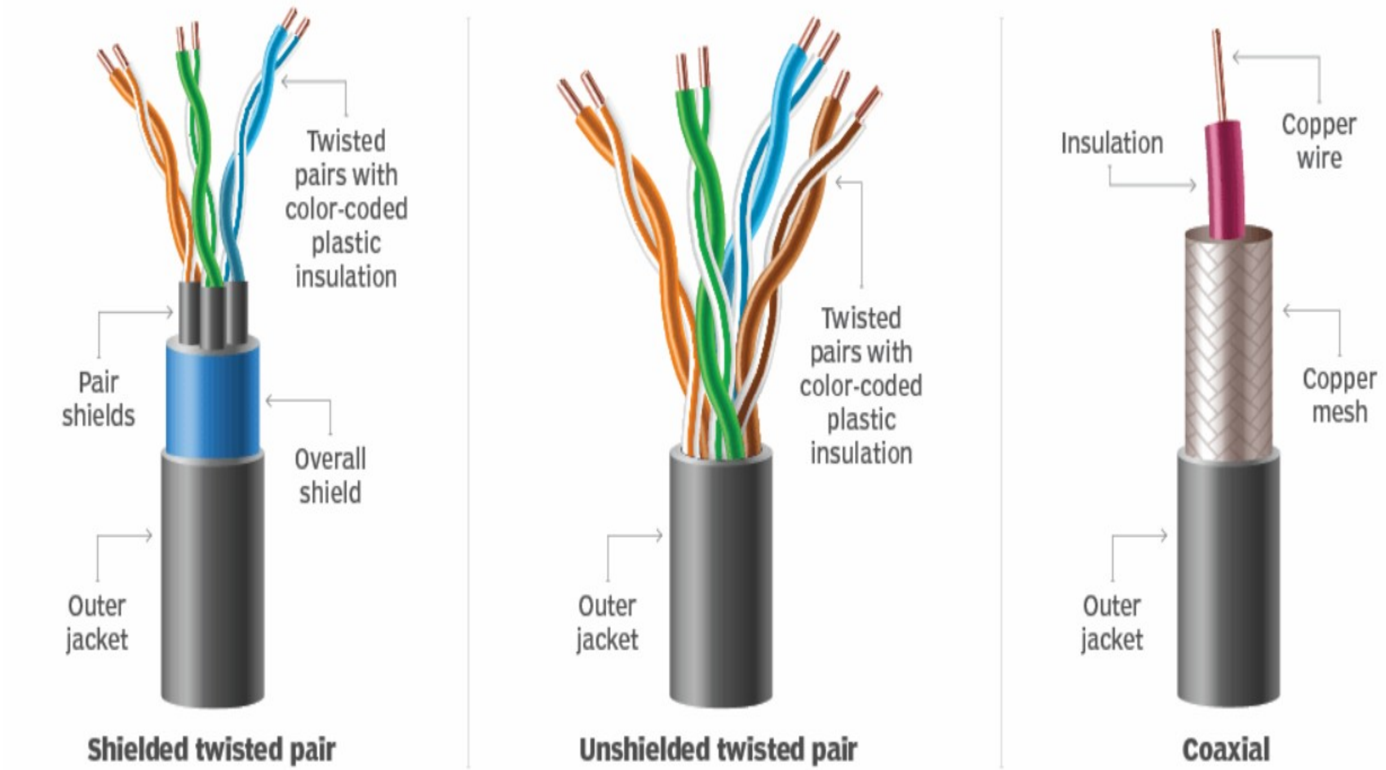


Table 3-1

A summary of the characteristics of twisted pair wires

Category	Data Rate	Transmission range	Advantages	Disadvantages
Cat 5e	Up to 1 Gbps	100 meters	- Cost-effective - Sufficient for most networks - **Moderate noise**	- Limited to 1 Gbps - **Basic security**
Cat 6	Up to 10 Gbps	55 meters (10 Gbps) 100 meters (1 Gbps)	-**Better noise** - **Moderate security** -High speed	- Higher cost - Limited range for 10 Gbps speed
Cat 7	Up to 10 Gbps	100 meters	- **Excellent noise** - **Better security** - Higher speed	- Expensive - **Bulky** due to shielding
Cat 8	Transmits Up to 40 Gbps	30 meters	- **Superior noise** - **High security** - Extreme speed	- Very expensive - **Short range** at high speeds

Twisted Pair Summary

Inexpensive, Easy to install, Carries high data rates, but can suffer from electromagnetic noise and can be easily wire-tapped.

Wiretapping happens by picking up signals from a cable without connecting to it. This can be done by detecting the magnetic or electric fields around the wire, allowing someone to secretly eavesdrop on or record the data being transmitted. It uses external devices to capture magnetic or electric fields around the cable.

Coaxial Cable

•A single copper wire wrapped in plastic filler, surrounded by a braided metal shield, and then covered with a plastic jacket.

•Baseband coaxial technology uses digital signal, where the cable carries only one digital signal using the entire bandwidth. For short distances

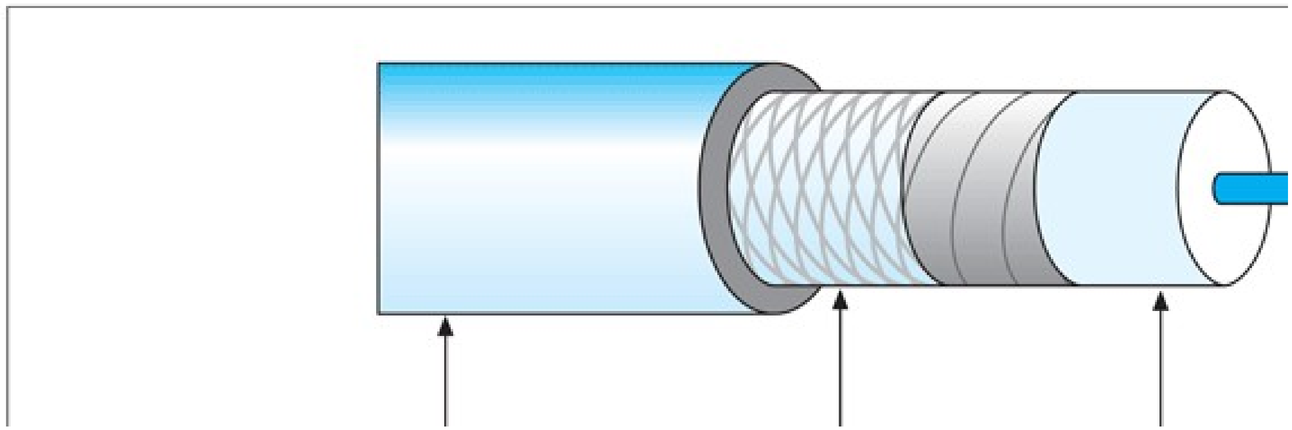
Shared based on time division

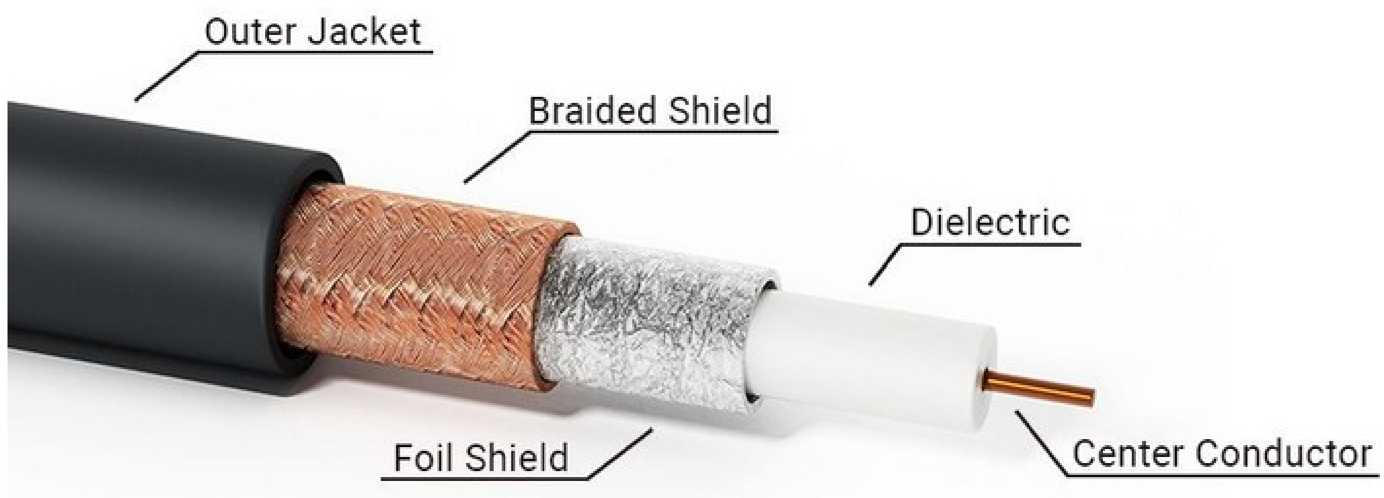
•Broadband coaxial technology transmits analog signals and is capable of supporting multiple analog signals sharing the same bandwidth. For long distances

Single channel: One signal using the entire bandwidth.
Multiple channels: Multiple signals sharing the same bandwidth.

Coaxial Cable (continued)

Figure 3-4
Example of coaxial cable showing metal braid





Coaxial Cable (continued)

Baseband coaxial cables are used for shorter distances and carry a single signal (Ex: Ethernet, CCTV video signals) without modulation.

Single signal: no interference

Broadband coaxial cables are designed for longer distances and can carry multiple signals simultaneously (Ex: TV signals, radio or internet).

Frequency division is the most common method used to transmit analog data signals

Coaxial Cable Summary

- More expensive and harder to install than twisted pair cables, but offers better signal quality and protection against interference.
- A single wire surrounded by a braided metal shield for protection against interference.
- Can carry a wide bandwidth of frequencies, making it ideal for cable TV, internet, and data transmission.

Fiber-Optic Cable

- A thin glass (about the thickness of a human hair) is surrounded by a plastic coating and packaged into an insulated cable.
- A Laser or LED generates pulses of light, which travel down the fiber, these pulses are received by a photo detector.

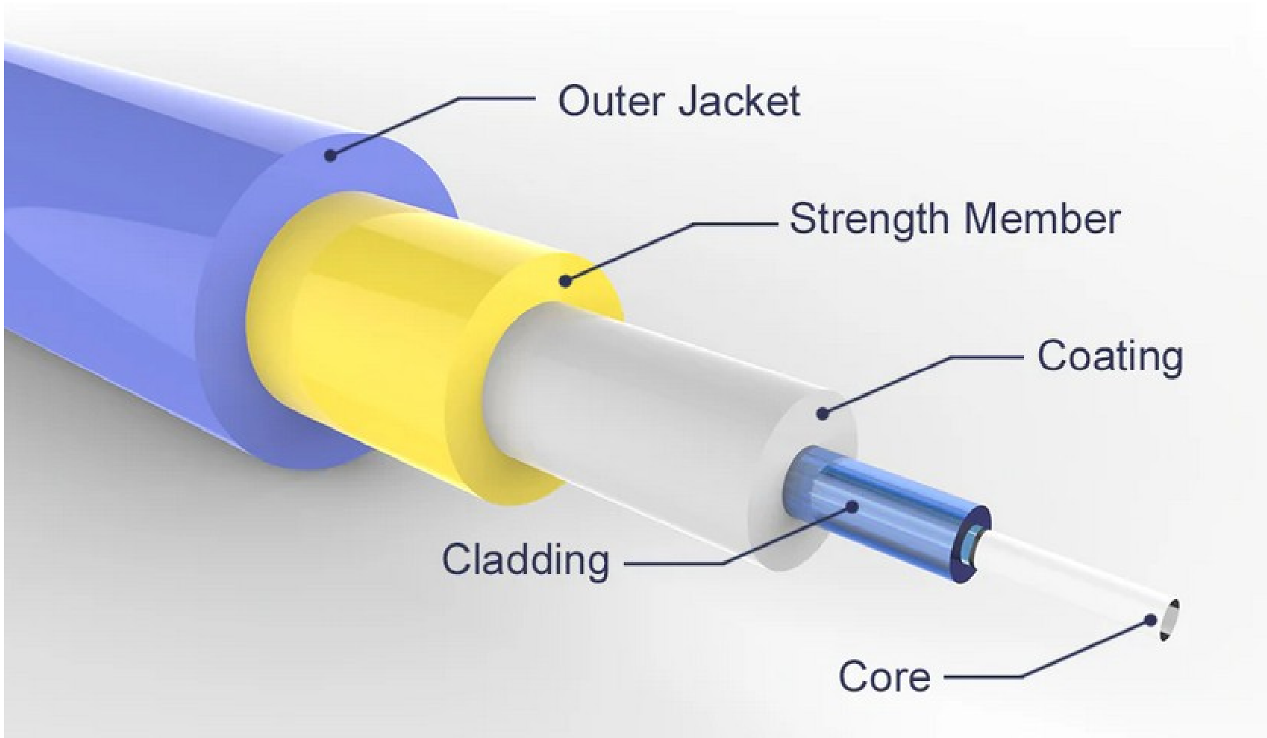
A photo detector is a device that converts light (photons) into an electrical signal. It produces a voltage proportional to the light intensity.

(photons are particles of electromagnetic energy)

Fiber-Optic Cable (continued)

Figure 3-6

a fiber-optic cable in an insulated jacket



Single Mode vs. Multimode Fiber

mode means path

- Single-mode fiber (SMF): Has a small core that allows only one light path, reducing reflection and making it ideal for long-distance transmission (Ex: deep sea internet cables). Laser is used

- Multi-mode fiber (MMF): Has a larger core that allows multiple light paths, making it suitable for short-distance transmission and is cost-effective (Ex: LANs inside buildings). LED is used

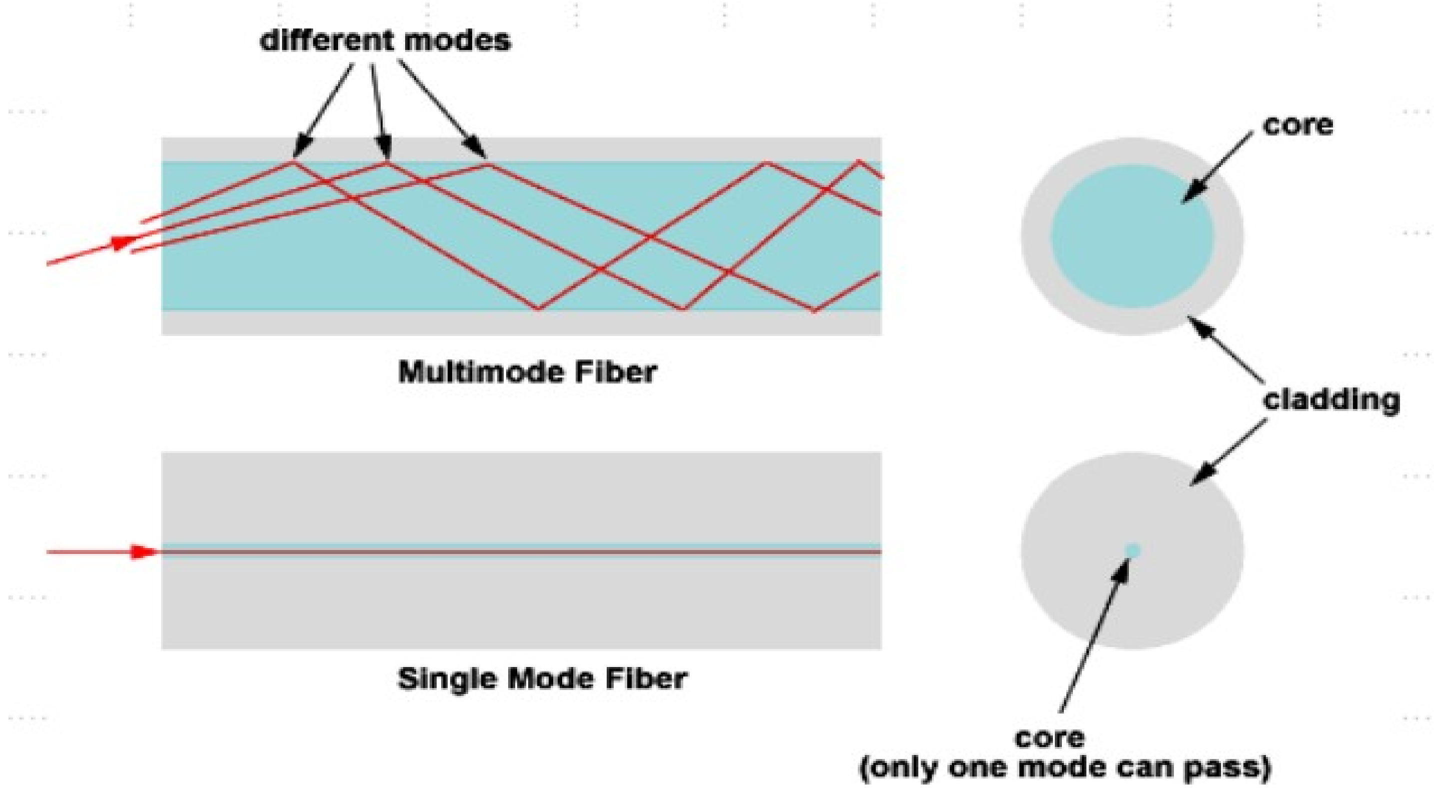
Fiber-Optic Cable (continued)

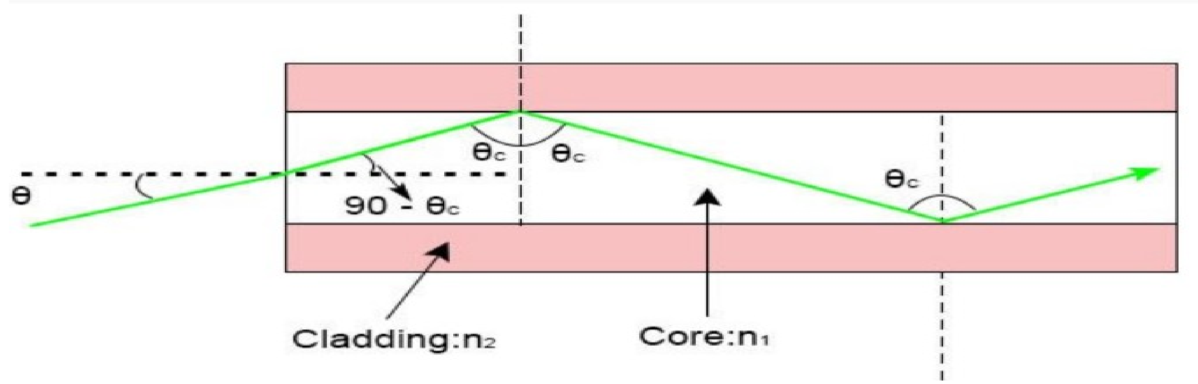
FYI:

Mode is the path that light takes inside the core. this path is determined by the angle the light hits the core's inner wall and changes direction.

The light starts as a single beam, but as it travels through the multimode fiber wide core, it splits and moves freely inside the core (taking different paths and speeds).

This spreading of the light is called dispersion. Dispersion leads to signal distortion and a loss of clarity over longer distances.


different modes
Multimode Fiber
core
cladding
Single Mode Fiber
core
(only one mode can pass)


θ
θc
θc
90 - θc
θc
Cladding:n2
Core:n1

Fiber-Optic Cable (continued)

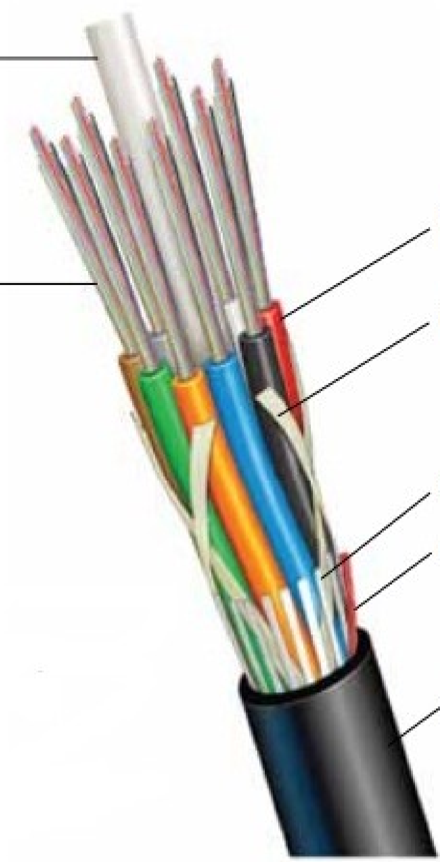
- Fiber-optic cable can support gigabits to terabits per second over thousands of meters. (Gbps and Tb/s)

- Single-mode fiber (8-10/125 microns): Smaller core allows minimal dispersion, enabling faster transmission over long distances. Typically uses a Laser as a light source.

- Multimode fiber (50/125 or 62.5/125 microns): Larger core causes more dispersion, requiring slower transmission speeds over short distances. Uses LEDs as a light source.

Fiber-Optic Cable (continued)

Figure 3-7
A fiber-optic cable with multiple strands of fiber



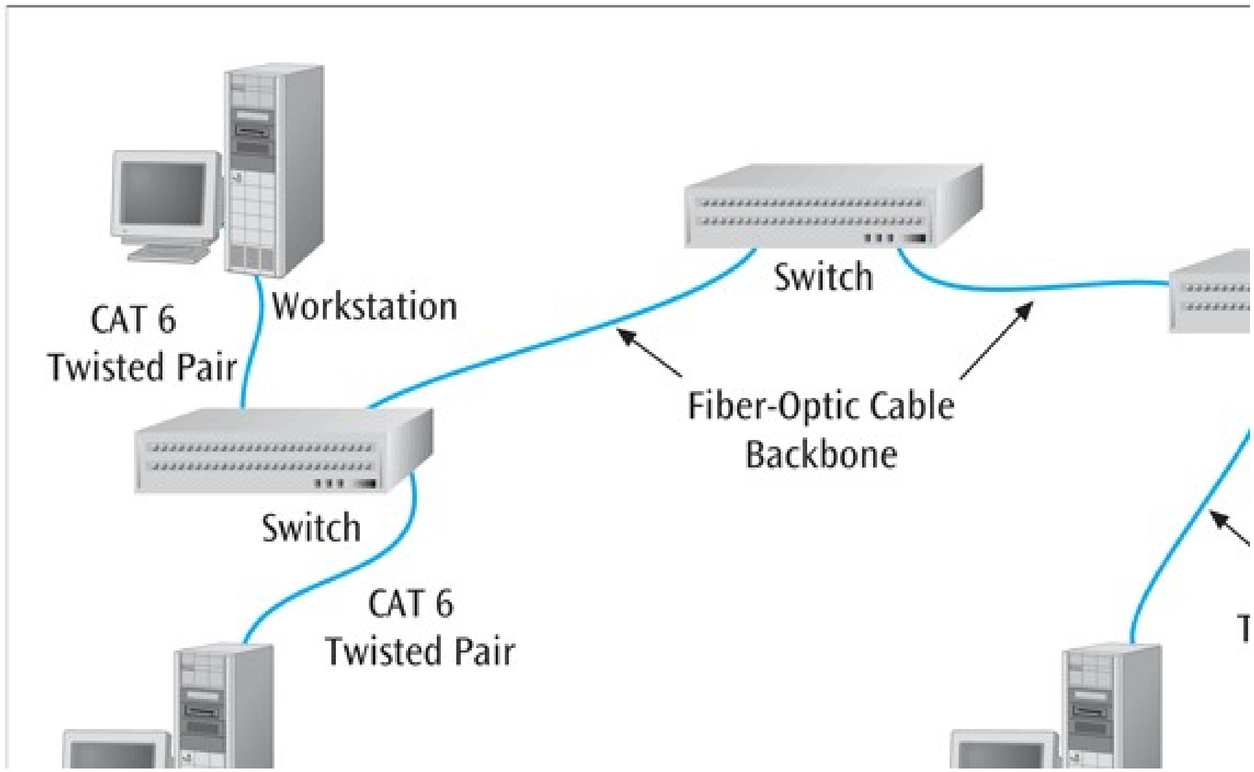
Fiber-Optic Cable (continued)

- Fiber-optic cable is affected by reflection (light bouncing inside the core) and refraction (light leaking outside the core into the cladding). These effects cause signal loss and dispersion, which can impact performance.

- FYI: While fiber is highly resistant to electromagnetic noise, signal quality degrades due to bending or splicing issues.

Fiber-Optic Cable (continued)

Figure 3-8
A fiber-optic backbone with Category 6 twisted pair running to the workstations



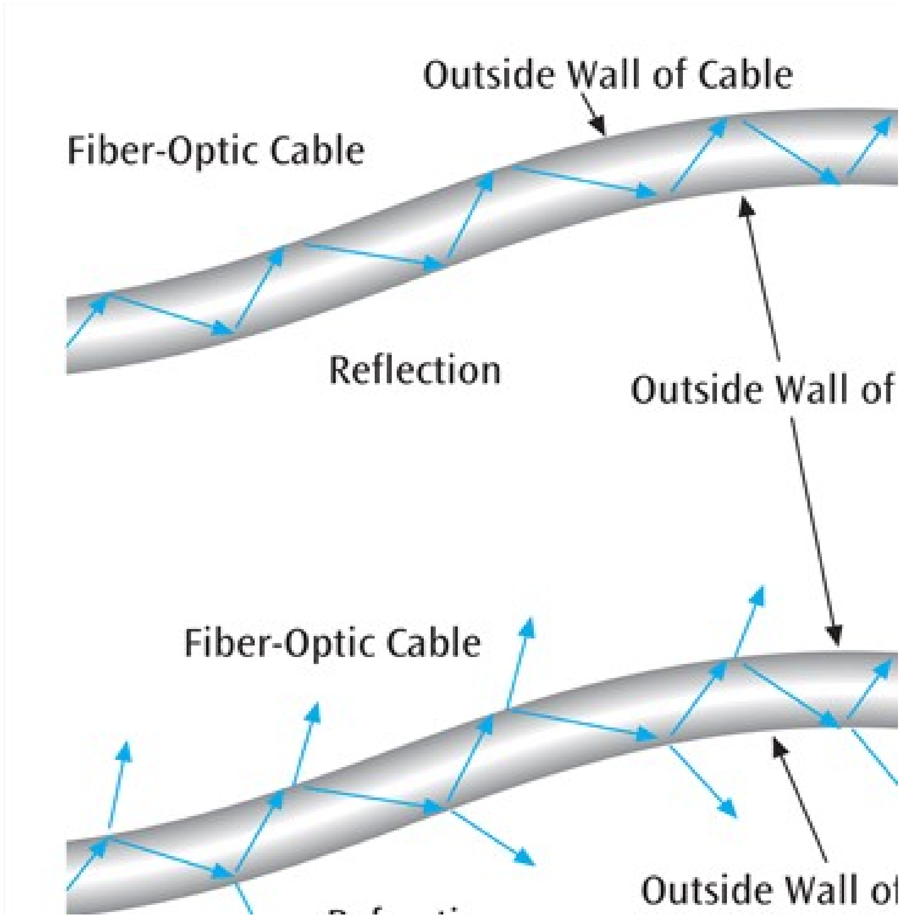
Campuses connecting floors or buildings, factories use it because factories are high noise environment.
Keeps local traffic on UTP while Fiber optics backbone ensures secure link and fast data transmission between segments.

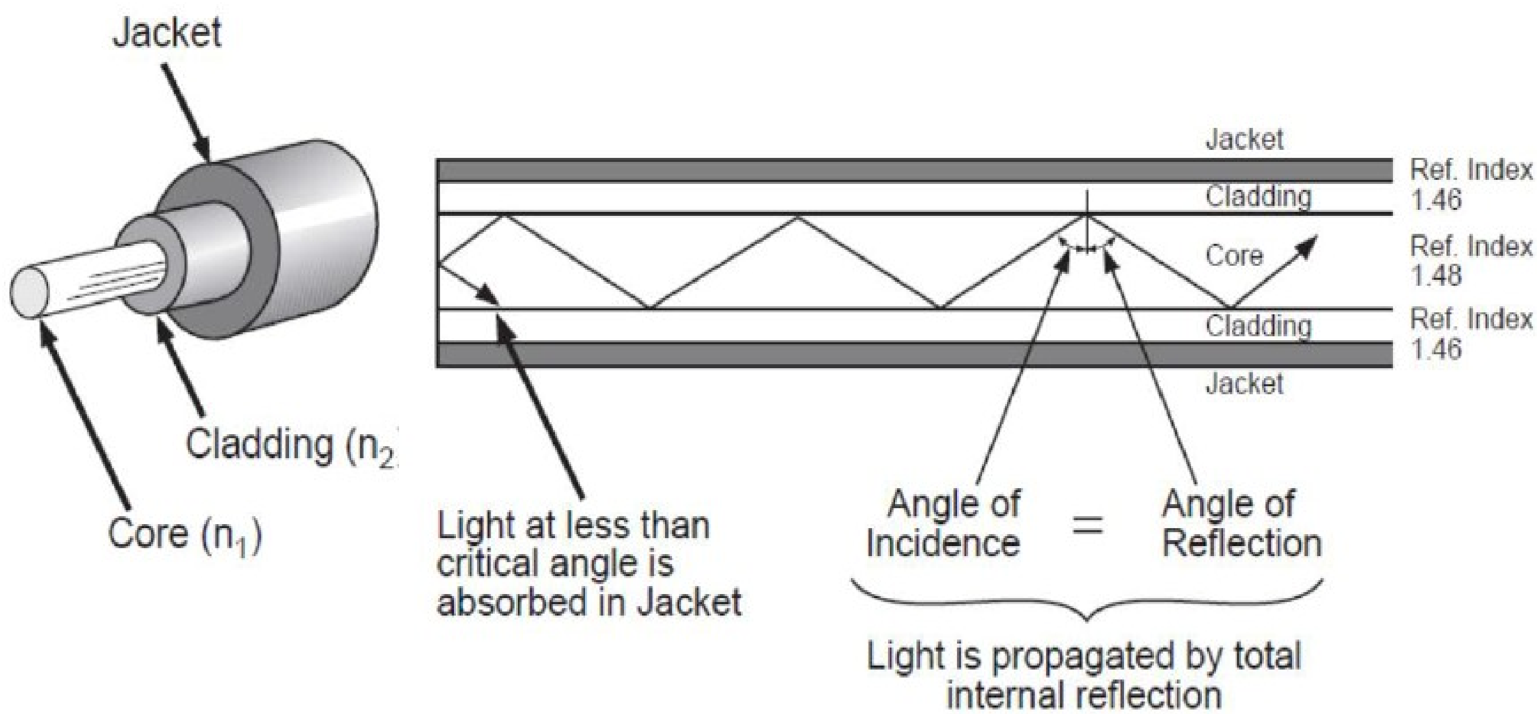
Fiber-Optic Cable (continued)

Fiber-optic backbone: (High speed fiber connection)

- The fiber-optic backbone ensures faster data transmission over long-distances and interference-free communication between network segments.

Fiber-Optic Cable (continued)





In fiber optics, reflection keeps the light bouncing inside the core, staying in the glass. Refraction happens when some light bends at the boundary between the core and the cladding, causing some light to leak into the cladding, which can lead to data loss and signal weakening as some light is absorbed or lost.

Low-quality cables with imperfections can increase these issues.

Conducted Media

Table 3-3 A summary of the characteristics of conducted media

Category	Data Rate	Transmission range	Advantages	Disadvantages
Coaxial Cable	Up to 10 Gbps	Up to 500 meters	Cost-effective, easy to install	electromagnetic interference (EMI)
Multimode Fiber Optic	Up to 100 Gbps	Up to 2 km	High bandwidth, lower signal loss	More expensive, signal loss over long distances
Single-mode Fiber Optic	Up to 100 Gbps and more	Up to 100 km	Long-distance transmission, minimal signal loss	Expensive, requires precise alignment

Wireless Media

Introduction:

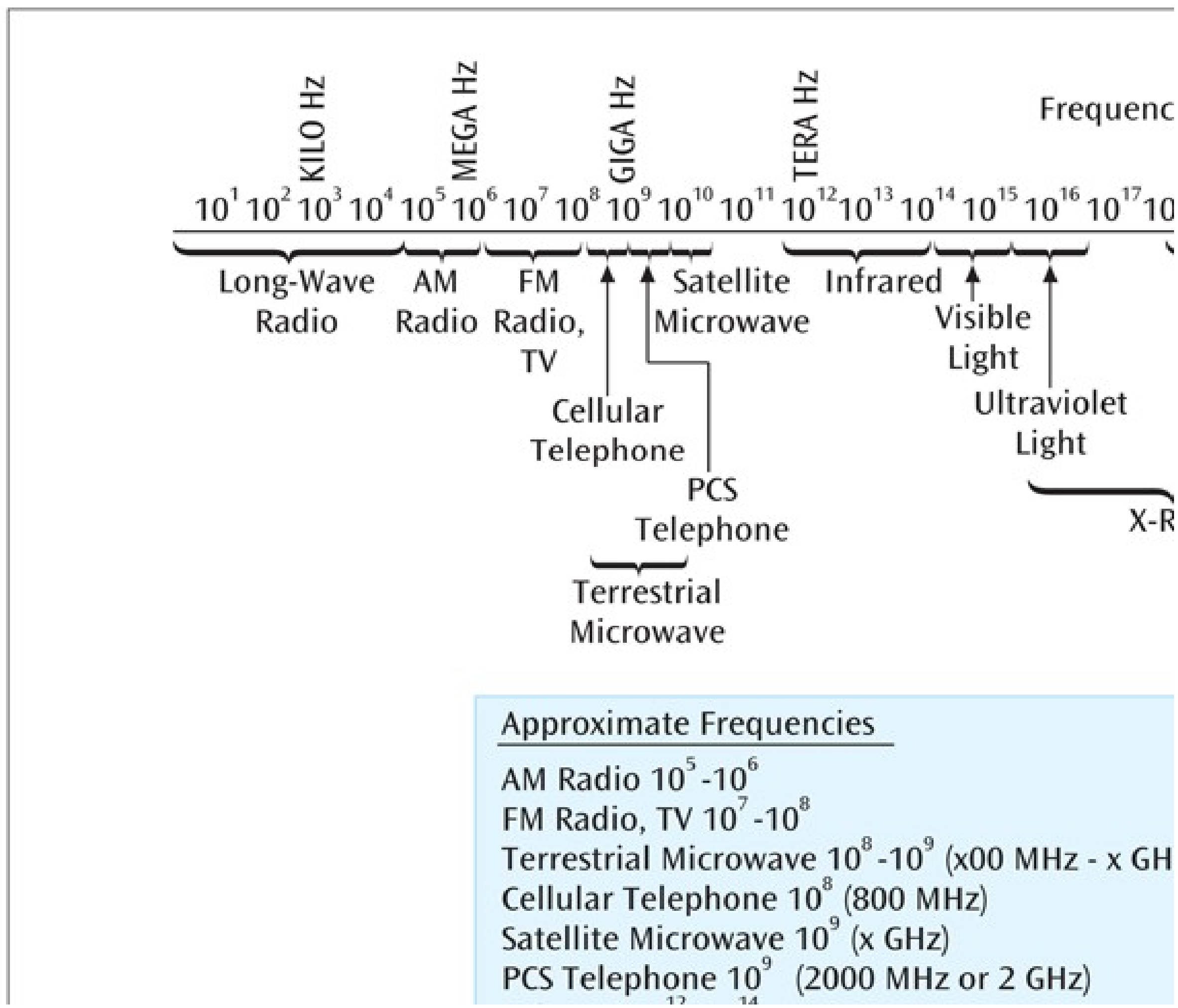
- Radio (antenna), satellite transmissions (microwaves), and infrared light are all different forms of electromagnetic signals that are used to transmit data

- Technically speaking, in wireless transmissions, space is the medium

Notice in the following figure how each form occupies a different set of frequencies.

Wireless Media (continued)

Figure 3-10
Electromagnetic wave frequencies



The most important types of electromagnetic waves:

Wave Type	Frequency Range	Key Applications
Radio Waves (FM)	88 MHz - 108 MHz AM radio: 530 kHz to 1.7 MHz.	Radio broadcasting, FM radio, TV
Microwaves	1 GHz - 100 GHz	Cell phones, Wi-Fi, satellite comm, TV
Visible Light	430 THz - 770 THz	Human vision, lighting, displays
X-rays	30 PHz - 30 EHz	Medical imaging, security scanning

Terrestrial Microwave Transmission

- Land-based, or line-of-sight transmission
- Signals will not pass through solid objects
- Approximately 32-48 km between towers

- Transmits data: data rate typically ranges from 10s Mbps to 100s Mbps why low rate?

Popular with telephone companies and business to business transmissions

Terrestrial Microwave Transmission (continued)

Figure 3-11
A typical microwave tower and antenna

Terrestrial Microwave Transmission (continued)

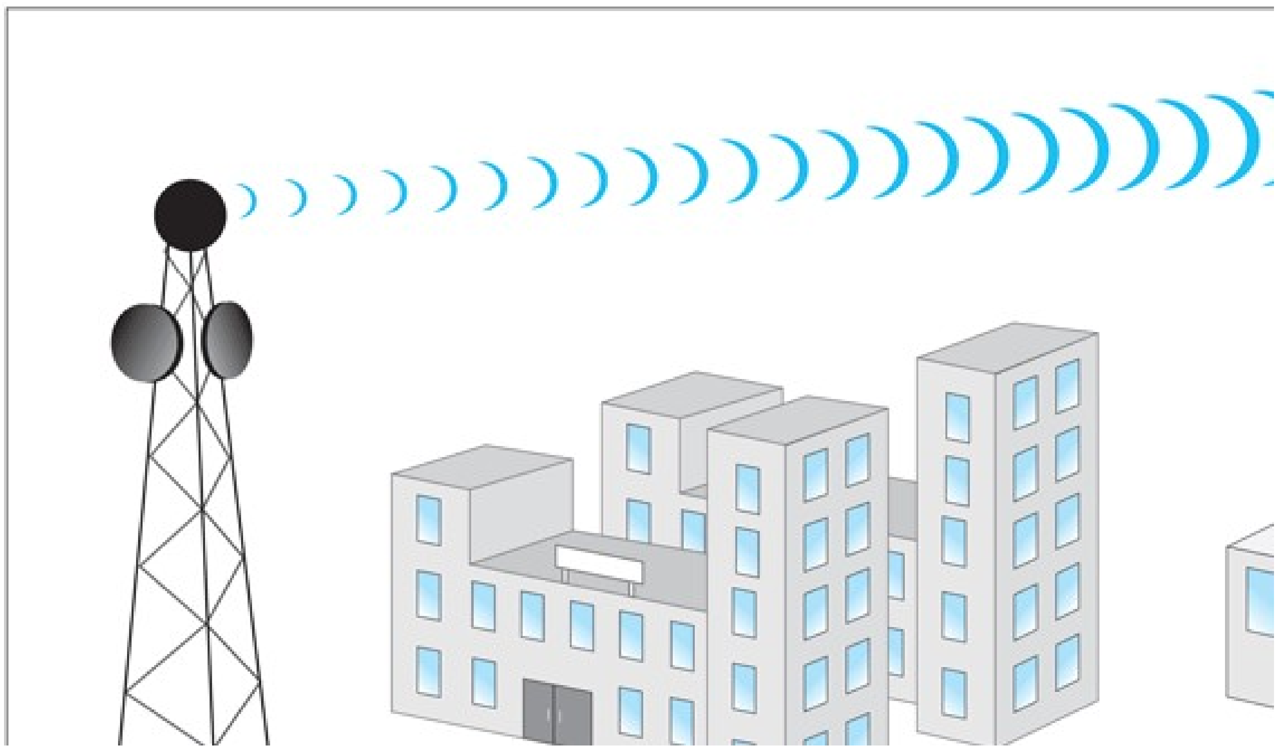
Good to know: *preferred by communication systems*

Found on towers or tall buildings. These transmitters often resemble *drum-like* structures and are used to send and receive microwave signals in a line-of-sight communication system.

Data rate restricted: due to long distances, weather and *spectrum sharing*. Look at this:
[Data rate typically ranges from tens of Mbps to several hundred Mbps.
and The microwave spectrum from 1 GHz to 100 GHz] the entire range
why?
Spectrum is shared by various communication systems lead to congestion and lower data rates even if a large portion of the spectrum is available.

Terrestrial Microwave Transmission (continued)

Figure 3-12
A microwave antenna on top of a free-standing tower transmitting to another antenna on the top of a building



Terrestrial Microwave Transmission

Good to know: why data rate stay low

The entire microwave spectrum is 1 to 100 GHz, shared by many services, terrestrial microwave is one of them. Terrestrial microwave communication typically uses the 1 GHz to 40 GHz range. However, government regulations (spectrum allocation), distance and natural environment and interference from other services limit the bandwidth available for high data rates. As a result, the available bandwidth for terrestrial microwave is much narrower, leading to lower data rates. For terrestrial microwave, the typical bandwidth needed is usually few MHz to few GHz.

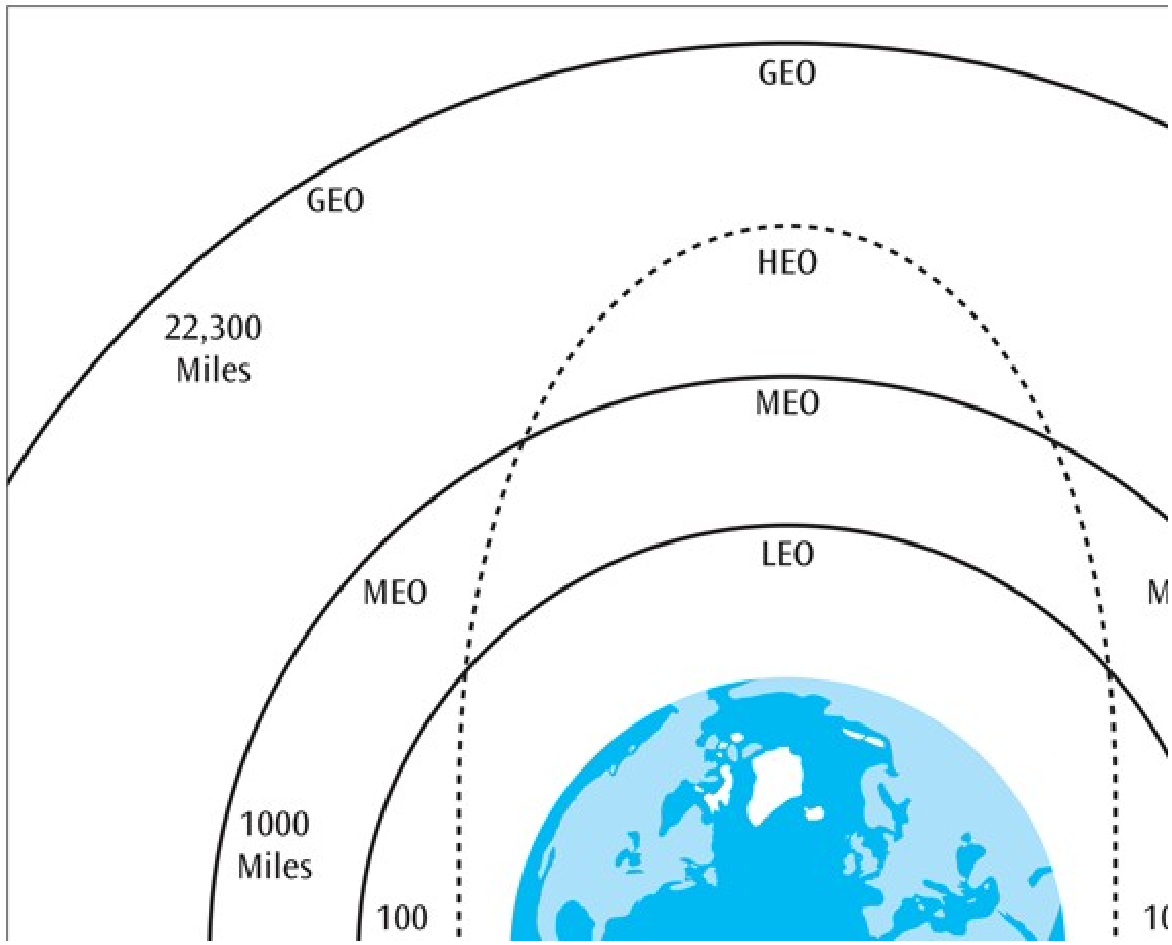
Satellite Microwave Transmission

- Similar to terrestrial microwave except the signal travels from a ground station on earth to a satellite and back to another ground station

- These Satellites are classified based on their Earth Orbit height: LEO (Low), MEO (Medium), HEO (High) and GEO (Geostationary).

Satellite Microwave Transmission (continued)

Figure 3-13
Earth and the four Earth orbits: LEO, MEO, GEO, and HEO



Satellite Microwave Transmission (continued)

- LEO: Used for Smartphone, social apps, mobile data services, video calls.
- MEO: Used for GPS.
- HEO: Used for scientific observation and studying celestial bodies.
- GEO: Used for weather monitoring, television broadcasting, and communication.

Satellite Microwave Transmission (continued)

Satellite microwave configurations:

1- Bulk Carrier Configuration:

This is used for transmitting large amounts of data to one ground station (the company's main office), which receives the data and distributes it to multiple users within the headquarters.

Ex: A large retail company uses this setup to receive daily sales and inventory data from all its stores nationwide. All the data is sent to the company’s headquarters via satellite, where employees in different departments (like finance, logistics, and marketing within the HQ) access and use the data.

Satellite Microwave Transmission (continued)

2- Multiplexed Configuration:

In this setup, the satellite sends different types of data (like phone, video, and internet) to many users (homes or businesses) at once simultaneously, efficiently sharing the bandwidth.

Ex: This satellite configuration is used by satellite TV providers to broadcast hundreds of channels to homes across a country. The same satellite might provide internet and phone services to businesses in the same region.

Public (shared transmission to many users, like satellite TV or internet)

Major headquarters to satellite, satellite to minor HQ, then Minor HQ to users.

Satellite Microwave Transmission (continued)

3- Single-User Earth Station Configuration (VSAT):

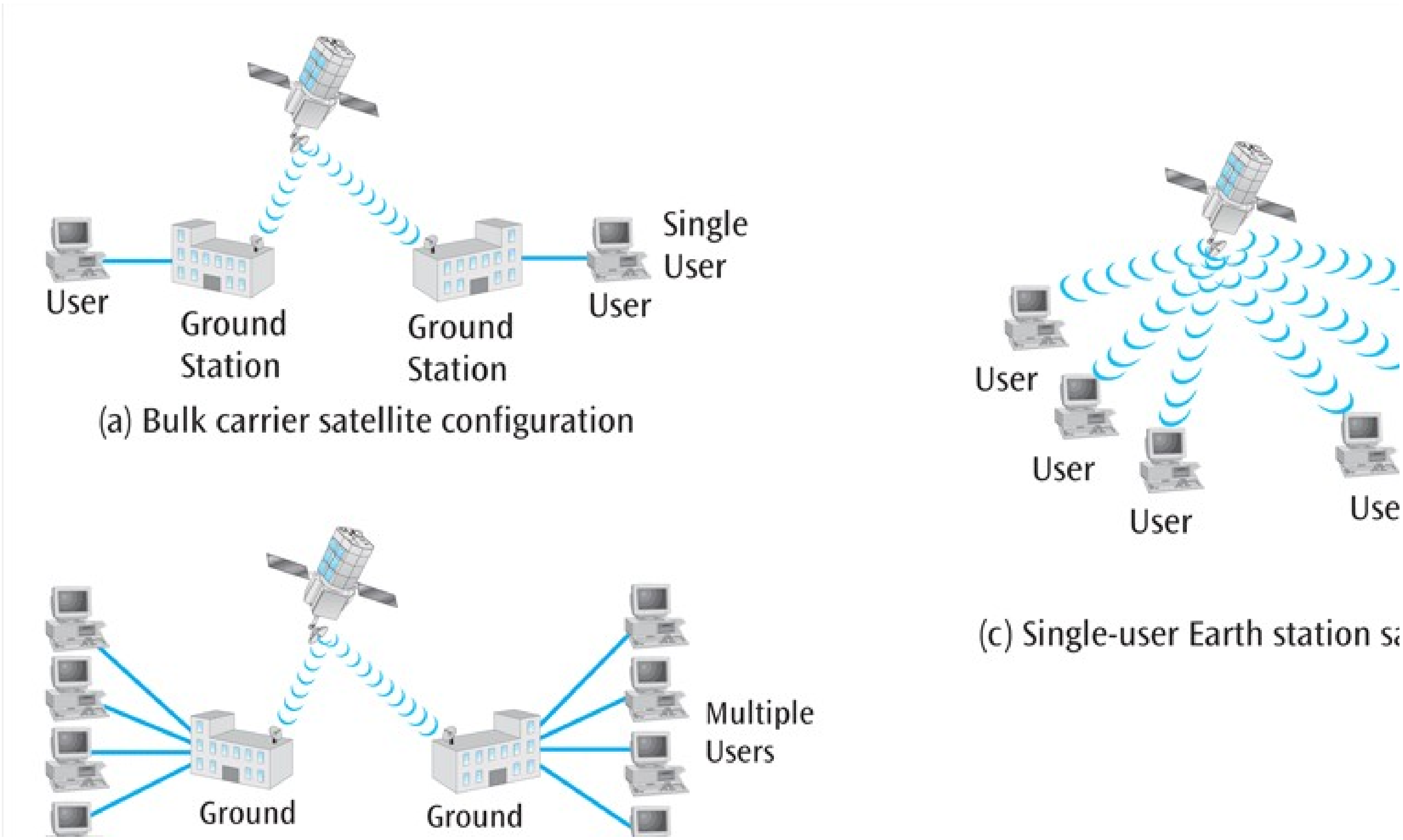
This system is used by one user or location, such as a small business or home, which connects to the satellite via a small dish.

It's typically used for internet access or remote communications, providing data to just that single user or site.

Dedicated connection for a single user or location

VSAT Very Small Aperture Terminal

Satellite Microwave Transmission (continued)



Cellular Telephones

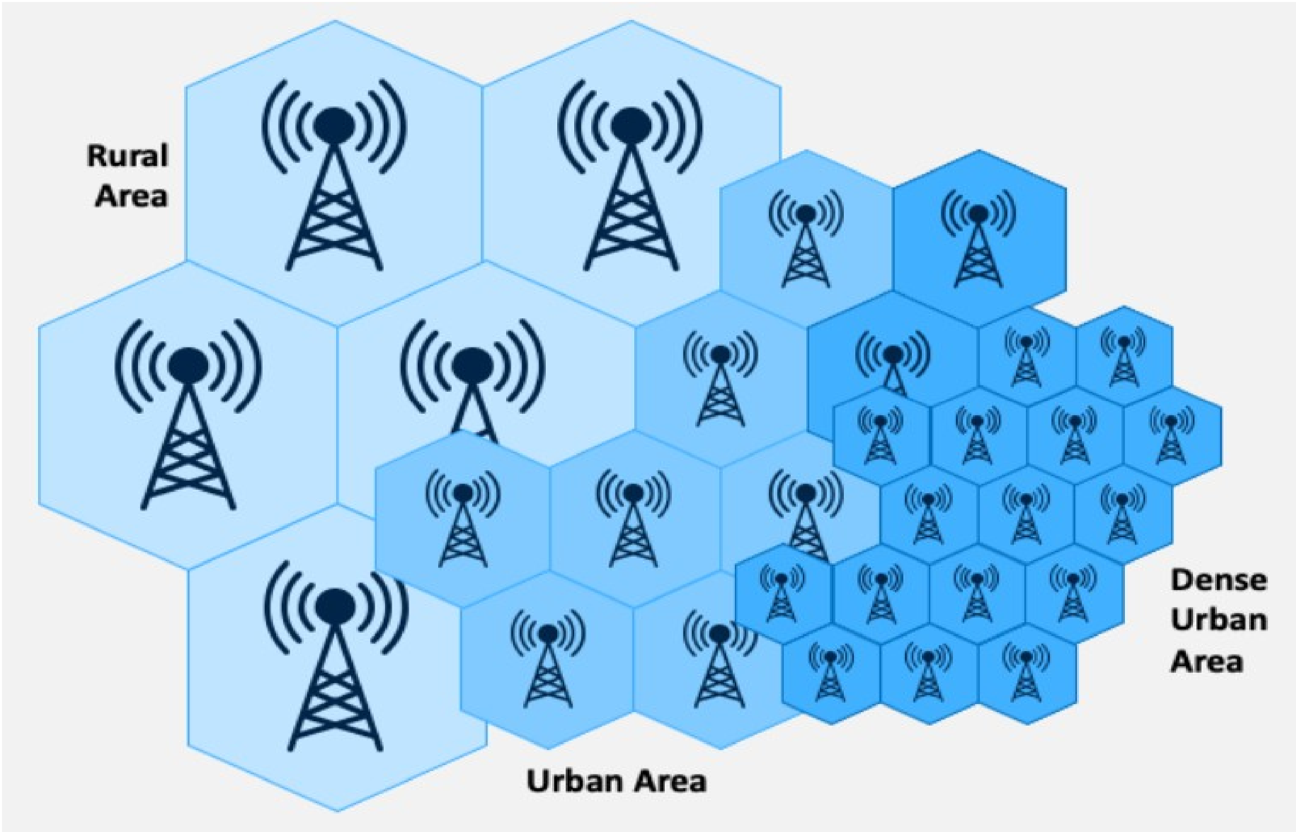
Wireless telephone service

- Supports multiple users by dividing a geographic area into smaller areas called cells.

- A cell is served by a base station (tower), each with its own set of assigned channels (frequency and time).

Cellular Telephones (continued)

Figure 3-16
One cellular telephone market divided into cells



Cellular Telephones (continued)

Figure 3-17
A cellular telephone tower

Cellular Telephones (continued)

- When you place a call on a cell phone, the device communicates with the nearest cell tower, requesting a signaling channel to set up the call. Once authenticated, the system dynamically allocates two separate communication channels: one for transmitting your voice (uplink) and one for receiving the caller's voice (downlink).

requesting frequency

Typically each cell is supported by one tower, but one tower can host multiple cells (sectors / directions, like Matsing)

Cellular Telephones (continued)

- To receive a call, your phone continuously exchanges location updates with the tower, allowing the system to track your position. When a call is incoming, the network identifies your location and routes the call through the appropriate cell tower, connecting it to your phone.

Cellular Telephones (continued)

What is meant by "Exchanges location updates" :

The phone sends signals over the control channel at regular intervals and when it moves to a new cell.

The control channel is like a constant "ping" between the phone and the tower, keeping the connection active and allowing the tower to track the phone's location.

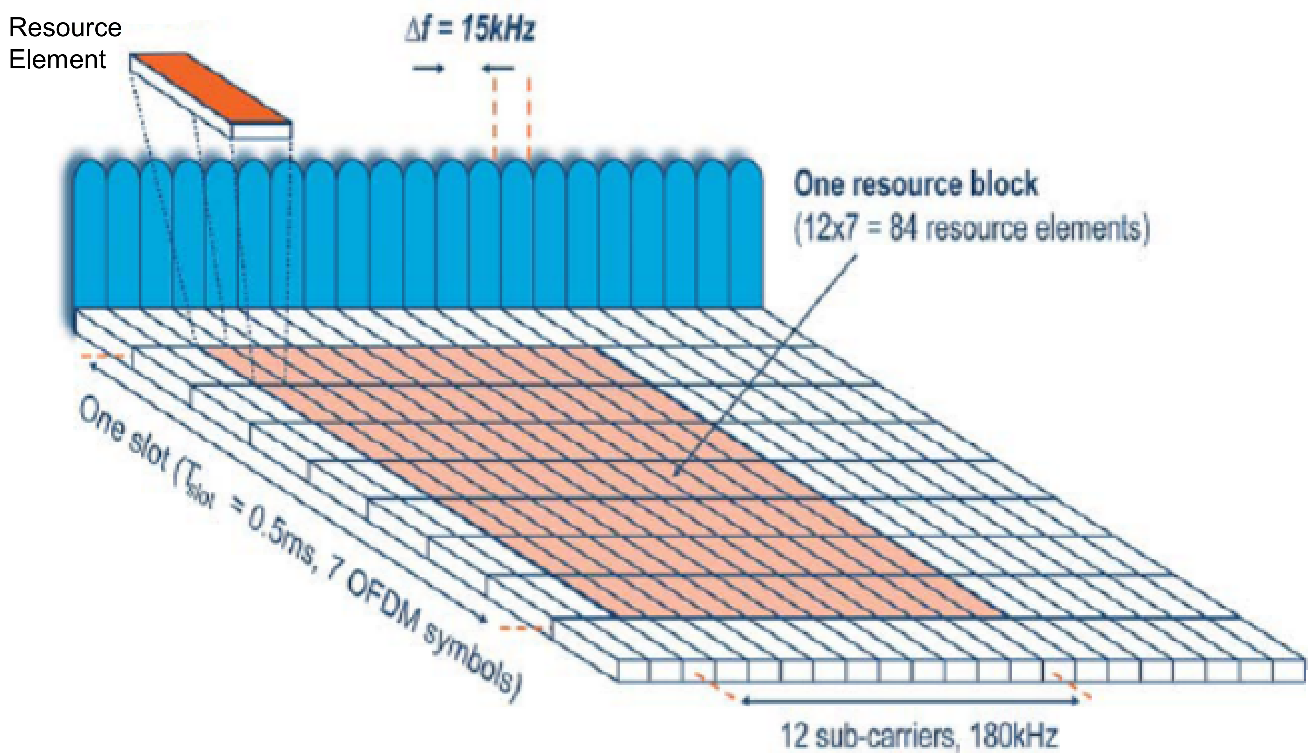
Cellular Telephones (continued)

- 4th Generation
  - LTE (Long Term Evolution) Designed to support IP-based voice, data, and media transmission with speeds ranging from 100 Mbps to 1 Gbps
  - Motivation: to provide higher data rate and greater spectral efficiency.

LTE efficiently transmits data to multiple users simultaneously, using techniques like OFDMA and SC-FDMA to prevent interference.

Cellular Telephones (continued)

LTE Resource Block: is the smallest unit of frequency and time allocated for data transmission. OFDMA uses both frequency subcarriers and time slots to allocate resources to multiple users, improving efficiency and minimizing interference.



Cellular Telephones (continued)

Each resource block contains 84 resource elements

Resource Element = 1 Subcarrier (Frequency) + 1 Symbol (Time domain)

15 KHz ... 0.5 ms/7= 71.4 μs

TTI: Transmission Time Interval = 1ms (2 slots = 168 resource elements)

Ex: If LTE bandwidth is 5MHz ,how many subcarriers is needed?

Hint: Always deduct 10% for guard bands. Now you have 4.5 MHz

LTE sub-carriers = 4.5 MHz/ 15 KHz = 4500 / 15 = 300 sub-carriers

Guard bands are unused frequency to prevent collision and overlapping

Cellular Telephones (continued)

LTE sub-carriers = 4.5 MHz/ 15 KHz = 4500 / 15 = 300 sub-carriers

TTI: LTE Transmission Time Interval = 1ms (2 slots)

In LTE, subcarriers are grouped into Resource Blocks (RBs).
2 RB = (12 subcarriers × 7 symbols/slot) × 2 slots = 168 resource elements

Total RBs in 4.5 MHz = 300/12 = 25 RBs. 12 carriers (fixed), 14 symbols for 1ms

Total REs = 25 RBs × 168 = 4,200 REs/ 1 ms

(Every 1 millisecond (1 TTI), LTE transmits exactly 4,200 Resource Elements (REs) in 4.5 MHz BW)

QPSK Data Rate:
Each RE carries 2 bits (QPSK).
4,200 REs × 2 bits = 8,400 bits/ms = 8.4 Mbps.
How many user? Depends on the carrier, how many RB will be allocated to each user, but its all about how active users are and what services they are accessing, in our case 25 RB might serve 10 users in average but there is no exact answer for this.

Bluetooth

- Bluetooth is a short-range wireless communication technology that allows devices to connect and exchange data over distances of up to 10 meters.
- Bluetooth enables both point-to-point and point-to-multipoint communication, allowing multiple devices to connect at once.
- The signal can pass through obstacles like walls or furniture, but metal objects can interfere with the signal.

Bluetooth

Bluetooth uses very little power to operate, making it highly efficient and ideal for devices like fitness trackers, wireless ear buds, and smart watches that need to run for long hours without frequent charging.

The latest versions of Bluetooth, like Bluetooth 5.0, offer faster speeds (up to 2 Mbps) and can connect over longer distances (up to 240 meters in open space). This makes it much more efficient for smart home devices and the Internet of Things (IoT).

Media Selection Criteria

- Cost
- Speed
- Distance and expandability
- Environment
- Security

Cost

- Different types of costs
  - Initial cost – what does a particular type of medium cost to purchase? To install?
  - Maintenance / support cost
- ROI (return on investment) – if one medium is cheaper to purchase and install but is not cost effective, where are the savings and why not cost effective?

Speed

Two forms of speed:

- **Data transfer speed**: This refers to how quickly the bits in a message are transmitted. It is measured in bits per second (bps). Cat6 10Gbps

- **Propagation speed**: Propagation speed is how fast the first bit of a signal travels from the sender to the receiver. In most everyday activities like browsing or streaming, this delay is so short that we don't notice it. However, for long-distance communications, like satellite links, this propagation delay can add to latency, affecting the speed and responsiveness of the connection.

Distance and Expandability

- Some types of media are easier to expand.

- *Keep in mind*: Physical cables, such as fiber or copper wires, sometimes need permission to be installed on certain land or properties, which can lead to delays or additional costs. And for wireless media, the signal must travel directly through the air without obstacles.

Environment

- Many environments can harm certain media, such as electromagnetic interference (EMI) affecting UTP (Unshielded Twisted Pair) cables, or obstacles like trees, mountains, and bad weather blocking microwave satellite signals.

Security

- To keep data secure during transmission, it's important to use a medium that’s hard to intercept. This can be done by using well-shielded wires to prevent unauthorized access to signals and protect against wiretapping, or by encrypting the data so it remains unreadable even if intercepted.

Summary

- All data communication media can be divided into two basic categories: (1) physical or conducted media, and (2) wireless media, such as satellite systems
- The three types of conducted media are twisted pair, coaxial cable, and fiber-optic cable
- Twisted pair and coaxial cable are both metal wires and are subject to electromagnetic interference
- Fiber-optic cable is a glass wire and is impervious to electromagnetic interference
  - Experiences a lower noise level
  - Has best transmission speeds and long-distance performance of all conducted media

Summary (continued)

- Several basic groups of wireless media exist: terrestrial microwave transmissions, satellite transmissions, cellular telephone systems, Bluetooth.
- Each of the wireless technologies is designed for specific applications
- When trying to select particular medium for an application, it helps to compare the different media using these six criteria: cost, speed, expandability and distance, right-of-way, environment, and security