Topic 8 Notes

8.1 Introduction to satellites

Not so long ago, satellites were exotic, top-secret devices. They were used primarily in a military capacity, for activities such as navigation and espionage. Now they are an essential part of our daily lives. We see and recognize their use in weather reports, television transmission by DIRECTV and the DISH Network, and everyday telephone calls. In many other instances, satellites play a background role that escapes our notice:

i. Some newspapers and magazines are more timely because they transmit their text and images to multiple printing sites via satellite to speed local distribution.
ii. Before sending signals down the wire into our houses, cable television depends on satellites to distribute its transmissions.
iii. The most reliable taxi and limousine drivers are sometimes using the satellite-based Global Positioning System (GPS) to take us to the proper destination.
iv. The goods we buy often reach distributors and retailers more efficiently and safely because trucking firms track the progress of their vehicles with the same GPS. Sometimes firms will even tell their drivers that they are driving too fast.
v. Emergency radio beacons from downed aircraft and distressed ships may reach searchand-rescue teams when satellites relay the signal.

What Is a Satellite?

A satellite is basically any object that revolves around a planet in a circular or elliptical path. The moon is Earth's original, natural satellite, and there are many man-made (**artificial**) satellites, usually closer to Earth.

The path a satellite follows is an **orbit**. In the orbit, the farthest point from Earth is the **apogee**, and the nearest point is the **perigee**. Artificial satellites generally are not mass-produced. Most satellites are **custom built** to perform their intended functions. Exceptions include the GPS satellites (with over 20 copies in orbit) and the Iridium satellites (with over 60 copies in orbit). Approximately 23,000 items of space junk -- objects large enough to track with radar that were inadvertently placed in orbit or have outlived their usefulness -- are floating above Earth. The actual number varies depending on which agency is counting.

Although anything that is in orbit around Earth is technically a satellite, the term "satellite" is typically used to describe a useful object placed in orbit purposely to perform some specific mission or task. We commonly hear about weather satellites, communication satellites and scientific satellites.

The Soviet Sputnik satellite was the first to orbit Earth, launched on Oct. 4, 1957. Because of Soviet government secrecy at the time, no photographs were taken of this famous launch. Sputnik was a 23-inch (58-centimeter), 184-pound (83-kilogram) metal ball. Although it was a remarkable achievement, Sputnik's contents seem meager by today's standards:

i. Thermometer
ii. Battery
iii. Radio transmitter - changed the tone of its beeps to match temperature changes
iv. Nitrogen gas - pressurized the interior of the satellite

On the outside of Sputnik, four **whip antennas** transmitted on short-wave frequencies above and below what is today's Citizens Band (27 MHz). After 92 days, gravity took over and Sputnik burned in Earth's atmosphere. Thirty days after the Sputnik launch, the dog Laika orbited in a half-ton Sputnik satellite with an air supply for the dog. It burned in the atmosphere in April 1958.

8.2 How a Satellite is launched into an Orbit

All satellites today get into orbit by riding on a rocket. Many used to hitch a ride in the cargo bay of the space shuttle. Several countries and businesses have rocket launch capabilities, and satellites as large as several tons make it safely into orbit regularly.

For most satellite launches, the scheduled launch rocket is aimed straight up at first. This gets the rocket through the thickest part of the atmosphere most quickly and best minimizes fuel consumption.

After a rocket launches straight up, the rocket control mechanism uses the **inertial guidance system** to calculate necessary adjustments to the rocket's nozzles to tilt the rocket to the course described in the **flight plan**. In most cases, the flight plan calls for the rocket to head east because Earth rotates to the east, giving the launch vehicle a free boost. The strength of this boost depends on the rotational velocity of Earth at the launch location. The boost is greatest at the equator, where the distance around Earth is greatest and so rotation is fastest.

How big is the boost from an equatorial launch? To make a rough estimate, we can determine Earth's circumference by multiplying its diameter by pi (3.1416). The diameter of Earth is approximately 7,926 miles (12,753 kilometers). Multiplying by pi yields a circumference of something like 24,900 miles (40,065 kilometers). To travel around that circumference in 24 hours, a point on Earth's surface has to move at 1,038 mph (1,669 kph). A launch from Cape Canaveral, Florida, doesn't get as big a boost from Earth's rotational speed. The Kennedy Space Center's Launch Complex 39-A, one of its launch facilities, is located at 28 degrees 36 minutes 29.7014 seconds north latitude. The Earth's rotational speed there is about 894 mph (1,440 kph).

The difference in Earth's surface speed between the equator and Kennedy Space Center, then, is about 144 mph (229 kph). (Note: The Earth is actually **oblate** -- fatter around the middle -- not a perfect sphere. For that reason, our estimate of Earth's circumference is a little small.) Considering that rockets can go thousands of miles per hour, you may wonder why a difference of only 144 mph would even matter. The answer is that rockets, together with their fuel and their payloads, are very heavy. For example, the Feb. 11, 2000, lift-off of the space shuttle Endeavour with the Shuttle Radar Topography Mission required launching a total weight of 4,520,415 pounds (2,050,447 kilograms). It takes a huge amount of energy to accelerate such a mass to 144 mph, and therefore a significant amount of fuel. Launching from the equator makes a real difference.

Once the rocket reaches extremely thin air, at about 120 miles (193 kilometers) up, the rocket's navigational system fires small rockets, just enough to turn the launch vehicle into a **horizontal** position. The satellite is then released. At that point, rockets are fired again to ensure some separation between the launch vehicle and the satellite itself.

8.2.1 Satellite Launch Window

A launch window is a particular period of time in which it will be easier to place the satellite in the orbit necessary to perform its intended function. With the space shuttle, an extremely important factor in choosing the launch window was the need to bring down the astronauts safely if something went wrong. The astronauts had to be able to reach a safe landing area with rescue personnel standing by. For other types of flights, including interplanetary exploration, the launch window must permit the flight to take the most efficient course to its very distant destination. If weather is bad or a malfunction occurs during a launch window, the flight must be postponed until the next launch window appropriate for the flight. If a satellite were launched at the wrong time of the day in perfect weather, the satellite could end up in an orbit that would not pass over any of its intended users. Timing is everything!

8.3 Inside a Typical Satellite

Satellites come in all shapes and sizes and play a variety of roles. For example:

i. **Weather satellites** help meteorologists predict the weather or see what's happening at the moment. Typical weather satellites include the TIROS, COSMOS and GOES satellites. The satellites generally contain cameras that can return photos of Earth's weather, either from fixed geostationary positions or from polar orbits.

ii. **Communications satellites** allow telephone and data conversations to be relayed through the satellite. Typical communications satellites include Telstar and Intelsat. The most important feature of a communications satellite is the **transponder** -- a radio that receives a conversation at one frequency and then amplifies it and retransmits it back to Earth on another frequency. A satellite normally contains hundreds or thousands of transponders. Communications satellites are usually geosynchronous.

iii. **Broadcast satellites** broadcast television signals from one point to another (similar to communications satellites).

iv. **Scientific satellites** perform a variety of scientific missions. The Hubble Space Telescope is the most famous scientific satellite, but there are many others looking at everything from sun spots to gamma rays.

v. **Navigational satellites** help ships and planes navigate. The most famous are the GPS NAVSTAR satellites.

vi. **Rescue satellites** respond to radio distress signals (read this page for details).

vii. **Earth observation satellites** observe the planet for changes in everything from temperature to forestation to ice-sheet coverage. The most famous are the LANDSAT series.

viii. **Military satellites** are up there, but much of the actual application information remains secret. Intelligence-gathering possibilities using high-tech electronic and sophisticated photographic-equipment reconnaissance are endless. Applications may include relaying encrypted communication, nuclear monitoring, observing enemy movements, early warning of missile launches, eavesdropping on terrestrial radio links, radar imaging, photography (using what are essentially large telescopes that take pictures of militarily interesting areas)

Despite the significant differences between all of these satellites, they have several things in common. For example:

i. All of them have a metal or composite frame and body, usually known as the **bus**. The bus holds everything together in space and provides enough strength to survive the launch.

ii. All of them have a source of **power** (usually solar cells) and batteries for storage. Arrays of solar cells provide power to charge rechargeable batteries. Newer designs include the use of fuel cells. Power on most satellites is precious and very limited. Nuclear power has been used on space probes to other planets (read this page for details). Power systems are constantly monitored, and data on power and all other onboard systems is sent to Earth stations in the form of telemetry signals.

iii. All of them have an **onboard computer** to control and monitor the different systems.

iv. All of them have a **radio** system and antenna. At the very least, most satellites have a radio transmitter/receiver so that the ground-control crew can request status information from the satellite and monitor its health. Many satellites can be controlled in various ways from the ground to do anything from change the orbit to reprogram the computer system.
v. All of them have an **attitude control system**. The ACS keeps the satellite pointed in the right direction.
vi. The Hubble Space Telescope has a very elaborate control system so that the telescope can point at the same position in space for hours or days at a time (despite the fact that the telescope travels at 17,000 mph/27,359 kph!). The system contains gyroscopes, accelerometers, a reaction wheel stabilization system, thrusters and a set of sensors that watch guide stars to determine position.

8.4 Types of Satellite Orbits

There are three basic kinds of orbits, depending on the satellite's position relative to Earth's surface:

i. **Geostationary** orbits (also called **geosynchronous** or **synchronous**) are orbits in which the satellite is always positioned over the same spot on Earth. Many geostationary satellites are above a band along the equator, with an altitude of about 22,223 miles, or about a tenth of the distance to the Moon. The "satellite parking strip" area over the equator is becoming congested with several hundred television, weather and communication satellites! This congestion means each satellite must be precisely positioned to prevent its signals from interfering with an adjacent satellite's signals. Television, communications and weather satellites all use geostationary orbits. Geostationary orbits are why a DSS satellite TV dish is typically bolted in a fixed position.
ii. In a **polar** orbit, the satellite generally flies at a low altitude and passes over the planet's poles on each revolution. The polar orbit remains fixed in space as Earth rotates inside the orbit. As a result, much of Earth passes under a satellite in a polar orbit. Because polar orbits achieve excellent coverage of the planet, they are often used for satellites that do mapping and photography.

8.5 Satellite Altitudes

Looking up from Earth, satellites are orbiting overhead in various bands of altitude. It's interesting to think of satellites in terms of how near or far they are from us. Proceeding roughly from the nearest to the farthest, here are the types of satellites whizzing around Earth:

Observation satellites, typically orbiting at altitudes from 300 to 600 miles (480 to 970 kilometers), are used for tasks like photography. Observation satellites such as the Landsat 7 perform tasks such as:

i. Mapping
ii. Ice and sand movement
iii. Locating environmental situations (such as disappearing rainforests)
iv. Locating mineral deposits
v. Finding crop problems

Science satellites are sometimes in altitudes of 3,000 to 6,000 miles (4,800 to 9,700 kilometers). They send their research data to Earth via radio telemetry signals. Scientific satellite applications include:

i. Researching plants and animals
ii. Earth science, such as monitoring volcanoes
iii. Tracking wildlife
iv. Astronomy, using the Infrared Astronomy Satellite
v. Physics, by NASA's future study of microgravity and the current Ulysses Mission studying solar physics

For **navigation**, the U.S. Department of Defense built the **Global Positioning System**, or GPS. The GPS uses satellites at altitudes of 6,000 to 12,000 miles to determine the exact location of the receiver. The GPS receiver may be located:

i. In a ship at sea
ii. In another spacecraft
iii. In an airplane
iv. In an automobile
v. In your pocket

Weather forecasts visually bombard us each day with images from weather satellites, typically 22,223 miles over the equator. You can directly receive many of the actual satellite images using radio receivers and special personal-computer software. Many countries use weather satellites for their weather forecasting and storm observations.

Data, television, image and some telephone transmissions are routinely received and rebroadcast by **communications** satellites. Typical satellite telephone links have 550 to 650 milliseconds of round-trip delay that contribute to consumer dissatisfaction with this type of long-distance carrier. It takes the voice communications that long to travel all the way up to the satellite and back to Earth. The round-trip delay forces many to use telephone conversations via satellite only when no other links exist. Currently, voice over the Internet is experiencing a similar delay problem, but in this case due to digital compression and bandwidth limitations rather than distance.

Communications satellites are essentially radio relay stations in space. Satellite dishes get smaller as satellites get more powerful transmitters with focused radio "footprints" and gain-type antennas. Subcarriers on these same satellites carry:

i. Press agency news feeds
ii. Stock market, business and other financial information
iii. International radio broadcasters moving from short-wave to (or supplementing their short-wave broadcasts with) satellite feeds using microwave uplink feeds
iv. Global television, such as CNN and the BBC
v. Digital radio for CD-quality audio

8.6 Satellite Internet

How do you access the Internet other than dial-up if you live too far from a phone company office for DSL and there is no cable TV on your street? Satellite Internet access may be worth considering. It's ideal for rural Internet users who want broadband access. Satellite Internet does not use telephone lines or cable systems, but instead uses a satellite dish for two-way (upload and download) data communications. Upload speed is about one-tenth of the 500 kbps download speed. Cable and DSL have higher download speeds, but satellite systems are about 10 times faster than a normal modem.

Firms that offer or plan to offer two-way satellite Internet include StarBand, Pegasus Express, Teledesic and Tachyon. Tachyon service is available today in the United States, Western Europe and Mexico. Pegasus Express is the two-way version of DirecPC.

Two-way satellite Internet consists of:

i. Approximately a two-foot by three-foot dish
ii. Two modems (uplink and downlink)
iii. Coaxial cables between dish and modem

The key installation planning requirement is a clear view to the south, since the orbiting satellites are over the equator area. And, like satellite TV, trees and heavy rains can affect reception of the Internet signals.

Two-way satellite Internet uses Internet Protocol (IP) multicasting technology, which means up to 5,000 channels of communication can simultaneously be served by a single satellite. IP multicasting sends data from one point to many points (at the same time) by sending data in compressed format. Compression reduces the size of the data and the bandwidth. Usual dial-up land-based terrestrial systems have bandwidth limitations that prevent multicasting of this magnitude.

Some satellite-Internet service still requires you to have a dial-up or cable modem connection for the data you send to the Internet. The satellite data downlink is just like the usual terrestrial link, except the satellite transmits the data to your computer via the same dish that would allow you to receive a Pay-Per-View television program.

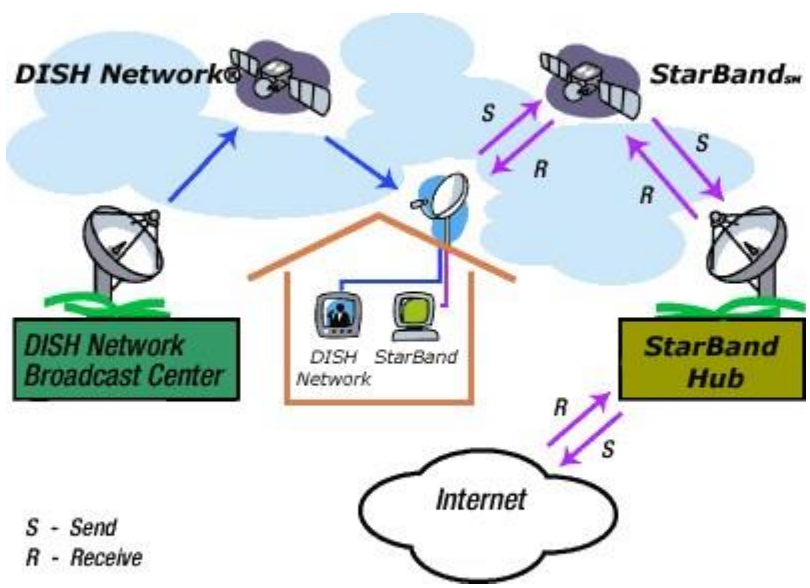

Fig 8.1: Satellite communication

8.7 Global Positioning System (GPS)

The **Global Positioning System** (GPS) is actually a **constellation** of 27 Earth-orbiting satellites (24 in operation and three extras in case one fails). The U.S. military developed and implemented this satellite network as a military navigation system, but soon opened it up to everybody else.

Each of these 3,000- to 4,000-pound solar-powered satellites circles the globe at about 12,000 miles (19,300 km), making two complete rotations every day. The orbits are arranged so that at any time, anywhere on Earth, there are at least four satellites "visible" in the sky.

A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location. This operation is based on a simple mathematical principle called **trilateration**.

8.7.1 GPS Calculations

A GPS receiver calculates the distance to GPS satellites by timing a signal's journey from satellite to receiver. As it turns out, this is a fairly elaborate process.

At a particular time (let's say midnight), the satellite begins transmitting a long, digital pattern called a **pseudo-random code**. The receiver begins running the same digital pattern also exactly at midnight. When the satellite's signal reaches the receiver, its transmission of the pattern will lag a bit behind the receiver's playing of the pattern.

The length of the delay is equal to the signal's travel time. The receiver multiplies this time by the speed of light to determine how far the signal traveled. Assuming the signal traveled in a straight line, this is the distance from receiver to satellite.

In order to make this measurement, the receiver and satellite both need clocks that can be synchronized down to the nanosecond. To make a satellite positioning system using only synchronized clocks, you would need to have atomic clocks not only on all the satellites, but also in the receiver itself.

The Global Positioning System has a clever, effective solution to this problem. Every satellite contains an expensive atomic clock, but the receiver itself uses an ordinary quartz clock, which it constantly resets. In a nutshell, the receiver looks at incoming signals from four or more satellites and gauges its own inaccuracy. In other words, there is only one value for the "current time" that the receiver can use. The correct time value will cause all of the signals that the receiver is receiving to align at a single point in space. That time value is the time value held by the atomic clocks in all of the satellites. So the receiver sets its clock to that time value, and it then has the same time value that all the atomic clocks in all of the satellites have. The GPS receiver gets atomic clock accuracy "for free."

Since the receiver makes all its distance measurements using its own built-in clock, the distances will all be **proportionally incorrect**. The receiver can easily calculate the necessary adjustment that will cause the four spheres to intersect at one point. Based on this, it resets its clock to be in sync with the satellite's atomic clock. The receiver does this constantly whenever it's on, which means it is nearly as accurate as the expensive atomic clocks in the satellites.

In order for the distance information to be of any use, the receiver also has to know where the satellites actually are. This isn't particularly difficult because the satellites travel in very high and predictable orbits. The GPS receiver simply stores an **almanac** that tells it where every satellite should be at any given time. Things like the pull of the moon and the sun do change the satellites' orbits very slightly, but the Department of Defense constantly monitors their exact positions and transmits any adjustments to all GPS receivers as part of the satellites' signals.

8.7.2 Differential GPS

A GPS receiver calculates its position on earth based on the information it receives from four located satellites. This system works pretty well, but inaccuracies do pop up. For one thing, this method assumes the radio signals will make their way through the atmosphere at a consistent speed (the speed of light). In fact, the Earth's atmosphere slows the electromagnetic energy down somewhat, particularly as it goes through the ionosphere and troposphere. The delay varies depending on where you are on Earth, which means it's difficult to accurately factor this into the distance calculations. Problems can also occur when radio signals bounce off large objects, such as skyscrapers, giving a receiver the impression that a satellite is farther away than it actually is. On top of all that, satellites sometimes just send out bad almanac data, misreporting their own position.

Differential GPS (DGPS) helps correct these errors. The basic idea is to gauge GPS inaccuracy at a stationary receiver station with a known location. Since the DGPS hardware at the station already knows its own position, it can easily calculate its receiver's inaccuracy. The station then broadcasts a radio signal to all DGPS-equipped receivers in the area, providing signal correction information for that area. In general, access to this correction information makes DGPS receivers much more accurate than ordinary receivers.

The most essential function of a GPS receiver is to pick up the transmissions of at least four satellites and combine the information in those transmissions with information in an electronic almanac, all in order to figure out the receiver's position on Earth.

Once the receiver makes this calculation, it can tell you the latitude, longitude and altitude (or some similar measurement) of its current position. To make the navigation more user-friendly, most receivers plug this raw data into map files stored in memory.

You can use maps stored in the receiver's memory, connect the receiver to a computer that can hold more detailed maps in its memory, or simply buy a detailed map of your area and find your way using the receiver's latitude and longitude readouts. Some receivers let you download detailed maps into memory or supply detailed maps with plug-in map cartridges.

A standard GPS receiver will not only place you on a map at any particular location, but will also trace your path across a map as you move. If you leave your receiver on, it can stay in constant communication with GPS satellites to see how your location is changing. With this information and its built-in clock, the receiver can give you several pieces of valuable information:

i. How far you've traveled (odometer)
ii. How long you've been traveling
iii. Your current speed (speedometer)
iv. Your average speed
v. A "bread crumb" trail showing you exactly where you have traveled on the map
vi. The estimated time of arrival at your destination if you maintain your current speed

Revision questions

1. What is a satellite system?
2. What are the functions of a satellite system?
3. Which components are integrated in a satellite system?
4. How is a satellite launched?
5. How does a GPS system operate?