INTRODUCTION TO SATELLITE COMMUNICATIONS TECHNOLOGY FOR NREN

THOM STONE, CSC, APRIL 2004

1. INTRODUCTION

NREN requirements for development of seamless nomadic networks necessitates that NREN staff have a working knowledge of basic satellite technology. This paper addresses the components required for a satellite-based communications system, applications, technology trends, orbits, and spectrum, and hopefully will afford the reader an end-to-end picture of this important technology.

Satellites are objects in orbits about the Earth. An orbit is a trajectory able to maintain gravitational equilibrium to circle the Earth without power assist. Physical laws that were conceptualized by Newton and Kepler govern orbital mechanics.

The first satellite was the Moon, of course, but the idea of communications satellites came from Sir Arthur C. Clark in 1945. The Soviets launched the first manmade satellite, *Sputnik 1*, in 1957. The first communications satellite (a simple reflector) was the U.S. *Echo 1* in 1960. The first "geosynchronous" (explained later) satellite, *Syncom*, went up in 1962. There are now over 5000 operational satellites in orbit, 232 of which are large commercial (mostly communications) satellites.

Satellites have become essential for modern life. Among the important applications of satellite technology are video, voice, IP data, radio, Earth and space observation, global resource monitoring, military, positioning (GPS), micro-gravity science and many others. From direct-to-home TV to the Hubble telescope, satellites are one of the defining technologies of the modern age. Video is the most successful commercial application for satellites, and direct-to-home distribution is the most promising application for the technology at this time. "Spot" images of places on Earth, GPS, and Internet access—both for providers and direct-to-home or office—have been most successful, while cell phone systems based on fleets of low flying satellites have been a flop. Mobile phone-like connections for marine and mobile services have been with us for some time, however.

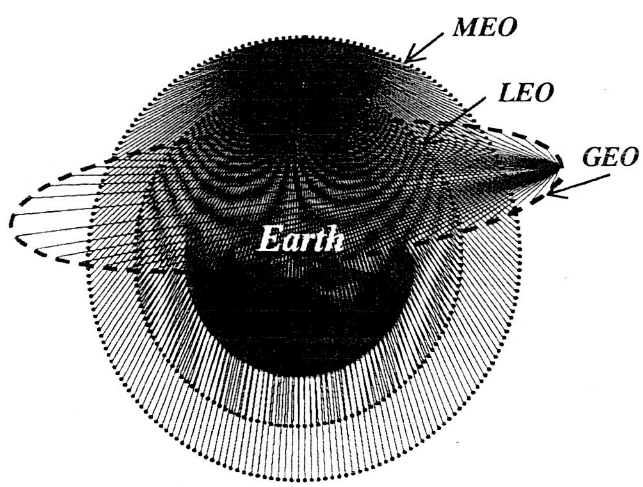
Satellite services have some big advantages, such as being available almost everywhere on Earth without wires, being mobile, being the perfect broadcast medium, and being protocol agnostic. The downside to satellite technology is that satellites have either a limited visibility over a spot on Earth, or a long round-trip time, and they broadcast data that can be received by anyone under them. Satellite transmissions are also affected by both terrestrial and space weather. They are subject to a higher error rate than fiber, and they are complex from both a physical and regulatory point of view.

Satellites are launched from Earth by the shuttle, from high-flying airplanes, or from ground-based rockets. Once launched, payloads must reach proper elevation and escape velocity to be boosted into orbit. In order to maintain proper orbit, satellites are controlled from a ground station on Earth that sends commands and receives status and telemetry from the satellite.

2. ORBITS

Satellites are classified by the distance of their orbits above the Earth. Low Earth Orbiting (LEO) satellites are located at an altitude of from 100 to 1200 miles, and Medium Earth Orbits (MEO) are located at an altitude of from 4,000-12,000 miles. Geo-stationary orbits are located exactly 23.4 miles high. There are two Van Allen radiation belts around the Earth. These areas of intense radiation are to be avoided in deploying satellites. The two zones separate LEO and MEO orbits.

LEO and MEO (sub-geosynchronous) orbiting satellites are visible for only a period of time from the point of view of an observer on Earth. Satellites in these orbits can communicate with the Earth by "pass off" to a fleet of like satellites providing full Earth coverage. They can also pass off to a geosynchronous relay satellite, or they can dump data to the ground as they pass over a ground station. Most of these "near Earth" satellites are in orbits that go over or near the poles; some go over the same place on Earth at least several times a day. The coordination and placement of Earth stations to "operate" and take data from these satellites is a major consideration in the life cycle of a satellite. The advantage of sub-geo satellites over those in geosynchronous orbit is that lower orbits are less expensive to launch, it takes less power to send and receive data, and the round trip time from Earth is faster.



THEO (Twelve Hour Eccentric Orbits, or Molniya orbits) are not quite polar orbits that stay in a hemisphere for half of a day. This approach allows for two MEO satellites to cover an area of the Earth, thus giving continuous service as a geosynchonous satellite would. This was developed and used extensively in Russia.

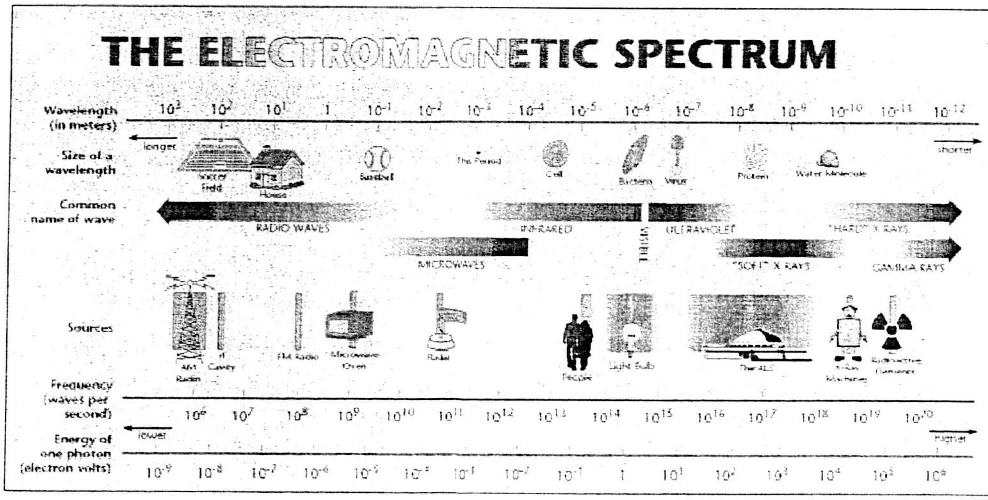
Geosynchronous orbits are the most desirable and the most expensive to obtain. "Geosynch" satellites appear stationary to observers on the Earth. The orbit is always at the equator at a height of 23,400 miles; the satellite thus travels in the same direction and speed as the rotation of the Earth. These satellites, because they provide continuous coverage, are the workhorses of the commercial satellite industry. Geosynch satellites must be spaced at least 1/2 a degree apart to prevent signal interference. "Slots" are closely regulated by the International Telecommunications Union (T.C.U.). They are highly sought after and expensive to acquire, and since geosynch orbits are also expensive to launch and maintain, most satellites in this orbit are big and complex.

Geosynchronous orbits require at least a quarter second round-trip time because of the 23,400-mile distance above the Earth plus the distance to the equator from the ground station. More power is also needed because of the distance (although a larger antenna on some satellites mitigates some of this). Since geosynch satellites are always in approximately the same place with regard to the Earth, it is possible to precisely map a "footprint" so that users can calibrate ground station equipment to minimize power and bandwidth.

Geosynch satellites are kept tightly in their orbits by expending fuel. Older satellites are often let to drift north and south while keeping in their east-west slots. Satellites allowed to drift are said to be inclined orbits. This might require some tracking by ground equipment, but when the drift is large enough, it allows the satellites to be seen in the polar regions.

3. SPECTRUM

Satellites use the microwave band for communications (some older ones used the radio frequencies UHF, VHF). For a description of the electromagnetic spectrum check *http://imagine.gsfc.nasa.gov/docs/science/know_11/emspectrum.html.*



We modify sound waves to make speech. Dynamics such as loudness and tone are changed to convey meaning. Telecommunication modifies electromechanical signals such as microwaves to carry information in the same ways.

Microwave bandwidth is regulated by the FCC in the U.S. and by the ITU internationally. Obtaining parts of the regulated bandwidth is expensive. Satellite operators must apply years in advance to get spectrum for launch support, tracking, telemetery and operations, and for data transfer.

Parts of the microwave spectrum are designated and used as follows (for a detailed description see: http://www.NTIA.doc.gov/osmhome/nebbie.html):

- VHF/UHF 0.1-0.3 GHz - MilSat- amateur radio, "little" LEO
- L Band -1-2 GHz - Mobile Sat/marine, "big" LEO
- S Band 2-4 GHz - Satellite command/control
- C Band 4-8 GHz - Data, voice, video distribution
  * X Band 8-12 GHz - Military-EOS
- Ku 12-18 GHz - Direct TV, Data, Voice, SNG, IP services
- K 18-27 GHz -N/A (22.3-H_2O absorption)
- Ka 27-40 GHz - The next wave
  * V 40-75 GHz - Released in the future (60 GHz -O_2 absorption)

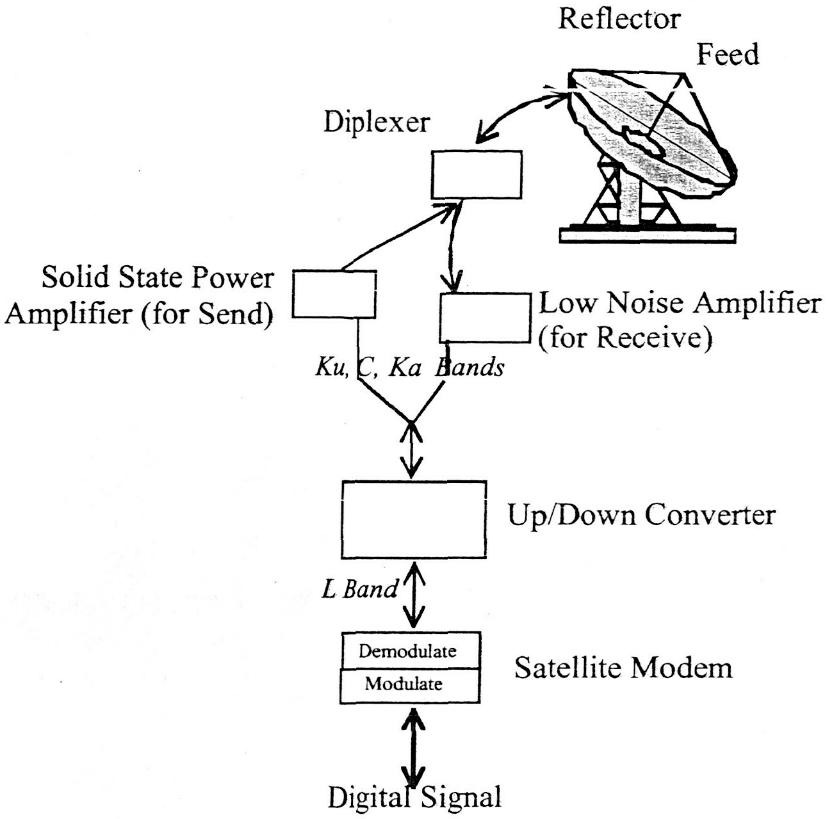
Uplink (from the Earth to the satellite) uses the upper part of a frequency range while downlink uses the lower frequencies. This is because a satellite is less capable of dealing with the overtones derived from transmission.

The higher the frequency the more bandwidth it takes to send a bit. That is because there is greater attenuation of the signal by the atmosphere as we get closer to the frequencies that are absorbed by water and free Oxygen. Also, the higher the frequency the smaller is the antenna needed for the same bandwidth, as antenna size is related to the size of the waveforms. The exception to this is L-Band where the signal is omni-directional. K-Band is not used for satellite transmission as these frequencies are absorbed completely by water vapor. Traditional C-Band, the first spectrum opened to satellites for communications, requires a BUD (big ugly dish) at least 3 meters in diameter for even a small bandwidth V-Sat, and up to 20 meters for a proper Earth station. Ku and Ka use small dishes that can be portable.

4. EARTH STATIONS

Teleports, gateways, and "flyaways" are names for the terrestrial interface where the signal from satellites meets the ground and where data is uplinked to the satellite. The traditional architecture for satellite systems is to have a central complex with an antenna or antennas controlling transmission to and from satellites. Smaller antennas communicate to other ground stations or terrestrial networks via the central teleport. Teleports act as a gateway between terrestrial networks such as the PSTN, the Internet or cable TV infrastructure, and the satellite.

Aside from the interface equipment to connect to ground networks, the Earth station will have an assortment of hardware to receive and send the microwave signals to and from the satellite:



1. *A reflector and feed*: This is the "dish" that is the most visible component of the system. The dish focuses the signal on the feed which sends it on. The size and shape of the dish are a function of the frequencies used and the strength of the signal. The larger the dish, the smaller the area of the sky it can see. This seems counter-intuitive but it is true.
2. *Outdoor equipment:* This equipment isolates the signals to those we are interested in and amplifies the signals (both send and receive). The equipment to change the frequency range to those the satellite expects (up and down converters) from L-Band can be either indoor or outdoor.
3. *Cable:* Cable connects the antenna to the inside equipment.
4. *A satellite modem* that operates in L-Band (this could be separate modulators and demodulators): These modems do more than the common terrestrial versions in doing

A/D and D/A conversion. They also define the signal method, do error correction using redundancy coding, do time and frequency multiplexing, and perform link monitoring. Satellite links are often asymmetric, having the ability to receive more data than they can send.

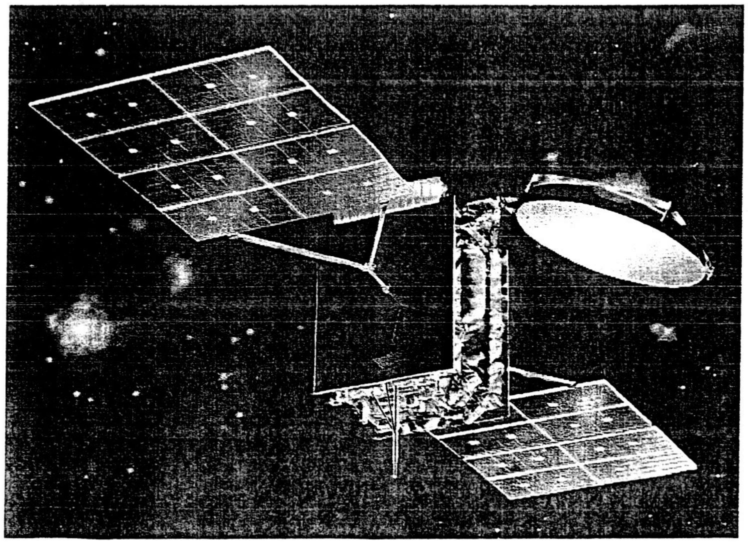
5. *Tracking gears:* Gears move the antenna, if needed.
6. *A microwave transparent building* (radome): A radome is required if the reflector, feed and outdoor equipment requires covering from wind and snow.
7. *The terrestrial interconnect*: This could be a router, or a video codex or a multiplexer to combine several input streams.

In order for an Earth station to become operational it must go through a series of tests and adjustments. The tests are designed to test whether proper frequencies and time slots (for TDM access) are used. Measurements are made and documented to insure that the power levels are correct. The power is measured in terms of Effective Isotropic Radiated Power (EIRP). The units are decibels (dBW). Too much power can cause the signal to be distorted and could disrupt other communications. Under-powered transmission can be error prone.

The noise level in both directions is measured. This is G/T (the ratio of the gain from the antenna and outdoor equipment to the signal noise). The higher the ratio the better. The definitive test is of course the actual error statistics measured by sending test data in both directions.

5. COMMUNICATIONS ONBOARD A SATELLITE

Earth orbiting satellites are a wonder of modern technology. Everything must withstand the rigors of space in addition to the strain of the launch. In space there are extreme cold and heat, radiation and micrometeorites, and storms on the Sun. Orbits must be obtained and maintained and critical systems must be monitored. There are as many "floor plans" to satellites as there are applications for the technology.



The main systems on a satellite are power, propulsion, guidance, sometimes science instruments, and of course communications and tracking.

The minimum communications capability for any satellite, no matter its purpose, is a low-speed link capable of send and receive for commanding, tracking and telemetry.

6. COMMUNICATIONS SATELLITES

Communications satellites divide bandwidth between “transponders.” A transponder is the hardware needed to take signals in on one set of frequencies and re-send to the ground on other frequencies (like a bent pipe). Usually a transponder is capable of sending and receiving about 45 Mb/sec. These are analog signal processors, so the modulation technique will determine the bandwidth a user can actually expect.

1. C-band transponders are usually 36 MHz wide
2. Ku-band transponders are usually 54 MHz wide
3. Ka-band transponders are usually 100 MHz wide

The total capacity of a “Comsat” is between 1/2 and 2 Gb/sec, much less than a pair of fiber strands. Frequency reuse is obtained by use of beams. They separate the direction of the transmissions and reception by pointing the antenna at the ground in different directions. Thus a satellite can send the same frequencies on a beam to Chicago and also on a beam to New York. Additional bandwidth is obtained by use of polarization that doubles usable bandwidth.

Solar weather can very adversely affect communications satellites, sometimes to the extent that a flare will actually render a communications satellite inoperable.

Geosynchronous communications satellites have a predictable power signature for areas covered by their transponders. This footprint makes it possible to know the required dish size and power requirements before an Earth station is assembled at a site. Errors can be minimized and higher bandwidth obtained by using a bigger dish, more power, or better coding.

7. DIRECTIONS IN THE SATELLITE INDUSTRY

The great down-turn that has hit the technology and communications industry in general has not spared the satellite industry. Some nations, such as Japan, have drastically cut back their space research and development. Even the International Space Station may never reach its lofty goals. Both commercial and government (except military) launch schedules have been cut back making it unlikely that all of the players who build and launch satellites will last the next few years.

Even amid this “consolidation, competition, retrenchment and turbulence” there are positive trends that will survive this turndown and thrive in the early 21st century. Some of the trends include the following:

1. Spurred by the military, there will be more big “birds” with more bandwidth and new spectrum.

2. New coding technologies now perfected will double bandwidth of even existing satellites. Launch costs will decline substantially.
3. The new paradigm is universal, bi-directional access, including television, Internet and new media over the next-generation satellite systems.
4. There will be more IP in space. Multicast will become accepted after adoption on satellite-based ISP backbones.
5. IP services will be integrated with TV broadcast, first using DVB-S (digital video broadcasting-satellite) technology and then straight IP.
6. Novel applications (like the roll out of satellite car radio) will be developed.
7. Earth science applications will require more spectrum and direct access for users internationally. "On demand" will be the next wave. As global warming and other environmental issues come to the forefront, Earth Observing satellites will become more prominent.

Satellites have been with us nearly half a century and have evolved considerably. The next 50 years will bring more technological changes that will affect our lifestyles.