Satellites

Satellites circle the Earth on 3 possible orbits:

GEO: a geostationary orbit of 36,000 km above the surface.

MEO: a belt of orbits ranging from 8000 km to 20000 km.

LEO: a belt of orbits of less than 1500 km above the Earth surface.

Communication with satellites requires line–of–sight contact because there is nothing that would reflect the signal. There are two basic approaches to using satellites in communications: active (there is a transmitter) and passive (only a mirror).

The lower orbits are not randomly chosen because of the Van Allen radiation belts (see image). These belts have a complicated shape and vary in intensity.

GEO satellites

They circle the Earth at an altitude of about 36,000 km (35,786 km to be exact). If it orbits around the equator, it gives the impression of “not moving” because it always sits above the same place on Earth, a fact widely used in applications.

Three GEO satellites are sufficient to cover the whole Earth. since they are stationary, it is easy to build satellite networks using these satellites.

However, the distance to the Earth is a major problem: light travels 36,000 km in 120–140 ms, yielding a propagation delay (between transmission and reception) of of $\sim$260 ms in temperate areas. This delay exceeds acceptable bounds for voice communication.

Nonetheless, **GEO** satellites are used for TV, lousy voice and for data (delays matter little in these applications).

MEO

Satellites in these orbits circle the Earth in 8 to 12 hours. The higher the satellite, the fewer of them needed to cover the globe, but the longer the propagation delay.

GPS

GPS (Global Positioning system) is the most famous MEO system.

GPS consists of 31 (varying number) satellites orbiting at an altitude of 20,200 km (some say 18,000 km) in 6 planes. They circle the Earth in 12 hours (appearing over the same spot twice a day).

Each satellite continuously transmits a 1500 bit frame containing:

1. The current satellite time.
2. Satellite health.
3. Satellite's own position.
4. $\frac{1}{25}$ of an **almanac** containing information about all the other satellites.

The frames are transmitted using **CDMA** at a rate of 50 b/s.

Triangulation

The Earth–based receiver sees at least 4 GPS satellites at any given time (unless there are problems). With an accurate clock, the receiver can compute the distance from each satellite (knowing the speed of light).

The position of each satellite being known and the distance computed, it is easy to find the location of the receiver with 4 satellites within line of sight (in 3–D space), provided all the information is perfect.

Not all information is perfect; in particular, the receiver's clock is unlikely to be sufficiently accurate. Also, the speed of light is almost constant but not quite so.

The clock inaccuracy dt is not a problem because the error is the same for all measurements:

$$D_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} + c \times dt$$

If we have 4 such equations and 4 unknowns (x,y,z,dt), all 4 can be determined.

The variability of the speed of light is a minor nuisance. with more than 4 satellites visible the error caused by it becomes insignificant for current GPS uses.

LEO networks

Several satellites circle Earth on a non–stationary orbit in the 800–1,500km range. Propagation delays are of the order of 2–20 ms (not all receivers are directly below the satellite). This delay magnitude is acceptable for two–way voice communication.

The main drawback: a ground location is within the **footprint** of a LEO satellite for about 15 minutes. When is leaves the footprint, the call has to be handed to another satellite (**handoff**).

LEO satellite systems are used mainly for bi–directional communication, with voice being of particular relevance.

Both passive and active satellites are used in **LEO** systems. The systems differ also in the type of orbits: Iridium uses polar orbits (86.4°) while Globalstar uses 52° orbits.

Iridium

A project started by Motorola; it changed hands a few times. Currently owned by **Iridium Satellite LLC**, it is reasonably profitable (jesters claim that it is courtesy of Iraq and Afghanistan)

Approach: active satellites, which requires frequent handoffs, hence expensive: $1 per minute on land (anywhere, but 2400 b/s), $1.50/KB file transfer. ($11/minute from a ship using the Inmarsat network). Iridium has 66 satellites on six 780 km orbits. The network covers the whole Earth (unlike Globalstar) but some remote areas have very low QoS (the technology used by Iridium requires 72 satellites to cover all the surface with good QoS).

Iridium had 359,000 subscribers worldwide in June 2009 (05/2006: 130,000+30,000 US DoD).

Globalstar

Approach: passive satellites (mirrors), no handoffs.

Globalstar supposedly has 40 (2009) (48 n 2008) satellites on a 1414 km orbit (some of them appear to be broken, new ones were to be launched in 2009, but were not). Coverage

Pricing depends on the region; in Canada it is $35 per month (unlimited calls). Pricing

Globalstar satellites do not communicate with each other—they only communicate with stationary ground stations (and with mobile users). They merely mirror whatever their antenna picks in the **S** frequency band.

Quality of Service

An independent consultant measured the proportion of attempted calls that went through when a satellite is 15° above the horizon.

The experiments were conducted in Northern California and in Central Texas.

	Iridium	Globalstar
CA	98.1%	36.2%
TX	94,7%	31.8%

Equipment

- Satellite phones
- Qualcomm handset.