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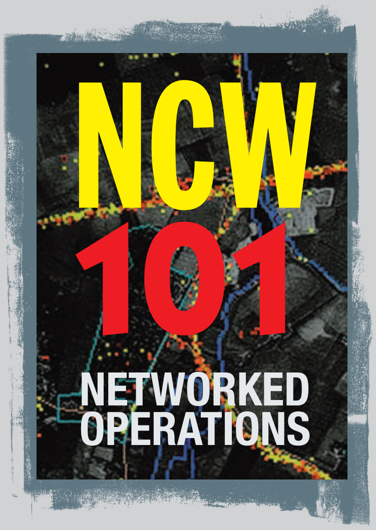


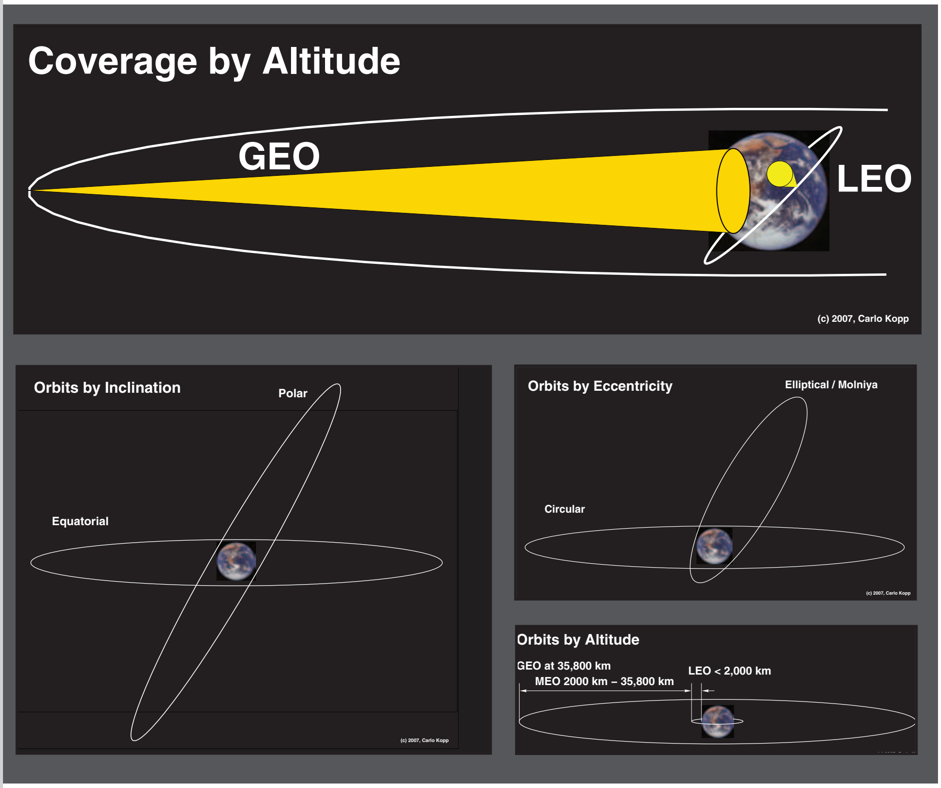
Satellite communications in NCW

NCW 101 Part 10

Dr Carlo Kopp

Satellite communications (Satcom) form a vital part of the global communications infrastructure, and play a pivotal role in the global networking of military systems. What is less obvious is that Satcom covers a diversity of possible schemes, with widely varying characteristics.

The basic idea of Satcom is simple: place a radiofrequency communications relay package into a satellite and lift it up into orbit. Systems within line of sight of the satellite can then communicate, but the simplicity ends there.



Orbital Geometries and Coverage

In principle, there are an infinite number of possible orbits a satellite can be launched into. In practice, specific orbital geometries have an enormous impact in terms of coverage, duration of coverage, and the radio frequency characteristics of what links the Satellite Vehicle (SV) can support.

Broadly, satellite orbits can be divided by geometry into elliptical and circular, the latter being elliptical orbits with both foci at the centre of the earth. Satellite orbits can be divided by inclination into equatorial orbits in the plane of the equator, and polar orbits where the satellite crossed the poles periodically in an inclined orbit. Finally, orbits can be divided by altitude, into Low Earth Orbit (LEO at 200 km to 2,000 km altitude), Medium Earth Orbit (MEO at 2,000 up to 35,800 km altitude), and Geostationary Earth Orbit (GEO at exactly 35,800 km altitude).

The GEO orbit is a special case, as at this altitude the angular velocity of the SV is identical to that of the earth at the equator, and an SV in an equatorial GEO orbit appears suspended without relative motion above the equator. Orbits at lower altitudes than the GEO orbit have higher angular velocities and shorter orbital periods, increasingly so with decreasing altitude. At any given altitude, if the SV is accelerated its orbit will descend, and vice versa.

What altitude a communications SV is orbited at depends critically on the application it is to be used for. The equatorial GEO orbit is used mostly for: commercial traffic; communications and, more recently, communications into underdeveloped areas; and broadcast television services.

A key factor with all satellite communications is the issue of pathlength or Friis loss, also known as inverse square law loss. In any radiofrequency or optical communications link through free space, the power, which can be received, declines with the inverse square of the distance to the transmitter, regardless of the size of the antennas used. How much data can be pumped through a digital link, for a given transmitter power rating, receiver sensitivity rating, and antenna performance, is limited by the inverse square law. In practical terms, this results in vastly bigger antennas used for links to SVs in equatorial GEO compared to satellites in LEO.

The problem that satellite system architects have confronted since the 1950s is that only the GEO provides uninterrupted line of sight to a single SV. All lower orbits will see the SV appear from under the horizon, fly overhead (not necessarily through the zenith) and then disappear below the horizon again, with the duration of visibility increasingly shorter the lower the altitude.

The attractiveness of LEO is not only in the economy of radio bandwidth per dollar invested in link equipment, but also in the much lower cost to lift the SV up from the earth's gravity well. Per kilogram of payload, orbital altitude produces an enormous increase in booster cost with increasing altitude. The downside is that a large constellation is required to provide continuous service to any given point on the surface of the earth, thus pushing providers into the business of global communications, rather than local or regional service.

To date, the only genuinely technically successful LEO satellite communications system has been Motorola's Iridium, which has no less than 66 SV in 780 km altitude orbits, with an orbital period of around 100 minutes. The economics of maintaining this size of constellation were prohibitive and the service never paid for itself, going into bankruptcy in 1999. Other LEO schemes such as Teledesic (initially to have 840 SVs, later 288) never got off the ground, Orbcomm (30 SVs) went bankrupt in 2000, while Globalstar (40 SVs) went bankrupt in 2002. While Iridium remains operational and actively used by the US DoD, it is a shadow of what the marketers had hoped for in 1995.

MEO has not been more successful for commercial operators, with ICO Global Communications going bankrupt during 1999, with 10 of its planned 12

SVs now in storage. GEO's success has, on the other hand, been unchallenged, but has other problems such as orbital congestion in areas of orbit above heavily populated regions.

A key issue for all orbital altitudes is that of radio propagation latency, or the time it takes for radio link signals (or laser if applicable) to travel from a ground station up to the satellite and back. Radio signals travel at the constant speed of light of 3 x 10^8 m/s, thus making the latency for a GEO link of the order of 0.2 seconds – irrelevant for TV broadcast but an impediment for voice and some digital communications protocols.

There is a fourth category of orbit, which has been technically successful. It is the Highly Elliptical Orbit (HEO) or Molniya orbit, named after the Soviet Molniya communications SVs. Molniya orbits see the SV travelling at high speed during the low orbit portion of the ellipse, and very slow speed during the high orbit portion of the ellipse, with a very slow 'dwell' at the apogee or peak of the high orbit portion. The Soviets devised the Molniya with an apogee above the North Polar Region, to provide Satcom services to northern Siberia, which is so far north that, an equatorial GEO satellite is below a useful radio horizon. The classified US Satellite Data Relay system uses Molniya category elliptical orbits. A capability that has emerged in more recent satellite constellations, is the provision of crosslinks between SVs, which permit traffic to be routed between satellites, thus avoiding latency and signal degradation otherwise arising through multiple hops through ground station uplinks and downlinks.

Radio spectrum is another key factor in satellite systems, and how it interacts with propagation impairments such as bad weather.

Antenna size always favour shorter radio wavelengths, as these permit a narrower beam per given antenna dimensions, and thus more bandwidth to a cheaper ground station. Unfortunately, the ability of the signal to punch through cloud, rain and fog degrades rapidly with shortening radio wavelength above 10 GHz. As a result there has been considerable crowding of the radio spectrum between 1 GHz and 10 GHz where weather penetration is best, and increasing crowding in the 10 GHz to 22 GHz bands. While airborne Satcom systems can be less impaired, as an aircraft flying at 36 kft is usually above most of the weather, this is an unavoidable issue for land and maritime ground terminals.

The size and cost of an SV depends largely on its payload, which must be customised to the type of end user equipment it is to support, the band it operates in, and its orbital behaviour.

Most satellites used for Satcom applications are what engineers term 'bent pipe' repeaters. A bent pipe repeater uses an antenna to receive a radio signal from the ground, it then retransmits this signal, at an offset frequency, back to the ground, without demodulation, retiming, buffering, or any other processing. As a result, bent pipe designs can be highly sensitive to signal quality on the uplink channel.

More recent systems, especially some of the military designs, are more sophisticated and may demodulate and retime incoming digital signals.

Most SVs are powered by solar panels, often deployed as 'wings' for SVs with large power demands. Nuclear thermo-electric generators have been used for deep space SVs, but in practice are seldom used for communications applications.

Military Communications Satellite Systems

Military communications traffic is today carried both by dedicated military satellite constellations, but also through commercial satellites, as the aggregate capacity of all in-service military systems at this time falls well short of demand.

While there has been much enthusiasm for the use of commercial services, it is worth observing that these have always been used in conflicts where the opponent has been technologically underdeveloped if not inept. Unlike military Satcom, which often uses jam resistant modulations and protocols for data transfer, commercial links are usually built only to handle nature's impediments to transmission, not the carefully crafted jamming waveforms created by human opponents. Therefore, conflicts involving technologically competent opponents will seriously limit what opportunities exist for use of commercial services, as these will be jammed, and jammed effectively more than often.

All satellites have a control uplink for ground operators to command the vehicle and its communicaitons payload. It is not commonly appreciated that even in very stable orbits perturbations and drift can and do occur, requiring more than often ground commanded corrections to the SV orbit and attitude. Moreover, most repeater payloads are configurable, and often downlink antennas can be adjusted to optimise ground spot coverage. If the command uplink to the satellite is either jammed or penetrated, the SV can be rendered unusable via its own control system.

Jamming of the communication channel uplinks through the SV is also a potentially profitable play for an attacker. To achieve good effect, the attacker has to situate a ground station within the antenna footprint of the SV uplink, and then transmit enough power in the jamming signal to overwhelm the power received from a legitimate ground station. Unless the modulation and protocols carrying data over the channel are built for high jam resistance, odds are the attack will succeed.

An attacker has choices other than jamming. Electromagnetic pulse bombs, especially nuclear ones, can be used to burn out the electronics in an SV. Anti-Satellite weapons (ASAT), such as the recent Chinese launched weapon on a rocket booster, can be used to destroy the SV by impact or by shrapnel/spall and blast effects.

In assessing military satellite architectures, the US system is the largest and most complex, and the most likely to be used by the ADF in a deployed contingency, globally.

The US divides its system into three broad categories: the 'Narrowband' systems comprising the Mobile User Objective System (MUOS), the UHF Follow On (UFO) system and the proposed UHF Follow-On/Enhanced (UFO/E) gap filler; the 'Protected' systems comprising Milstar I and II, the Advanced EHF and Advanced Polar systems; and finally the 'Wideband' systems comprising the Defence Satellite Communication System III (DSCS III), the Global Broadcast System (GBS), the Wideband Gap filler Satellite and the Advanced Wideband System (AWS).

The UFO and UFO/E systems are replacements for the earlier UHF band FLTSATCOM and AFSATCOM systems, and currently comprise a 9 SV constellation, each SV providing 38 UHF band channels each providing 5 or 25 kHz capacity. The UFO systems are being replaced by the Advanced Narrowband System, which includes the MUOS, as UFO is heavily overburdened with users. The MUOS system will provide additional capabilities, likely including multiple spot beams.

The Milstar (Military Strategic and Tactical Relay) I and II system is a constellation of five SVs in GEO, all providing 192 data channels at 75 bps to 2,400 bps, the three Milstar II SVs also providing 32 channels with 4.8 kbps to 1.544 bps capabilities. Milstar provides jam resistant encrypted voice, data, teletype or facsimile communications for all four US services, with SVs incorporating onboard data switching and millimetric wave band SV crosslinks.

Milstar was to be replaced with the Advanced Extremely High Frequency System (AEHF), supplemented by the two SVs of the Advanced Polar System (APS) in Molniya orbits, which are to provide ten times the capacity of the Milstar system.

The X-band DSCS II and Ka-band GBS systems provide wideband capabilities out to tens of Megabits/s and are being replaced the WGS SVs during the transition to the AWS constellation.

A detailed discussion of the characteristics and user applications of the respective US systems far exceeds the scope of an introductory primer.

Australia's capabilities are trivial in comparison, involving the Joint Project 2008 Phase 3D Optus and Defence C1 payload on a Loral FS1300 SV, with 4 X-band 50 Watt transponders, 4 Ka-band 130 Watt transponders, and 6 UHF band transponders, supplementing the commercial payload of 24 Ku-band transponders. The footprint is constrained to Australia and the near region, the satellite owned by Singapore.

In a networked warfighting environment, Satcom provides a valuable ability to connect to platforms and other user terminals, which are out of reach of the terrestrial infrastructure. The drawback inherent in all Satcom systems is the extremely high cost of the capability, per Megabits/s capacity, and the latency period. Therefore in the longer term we can expect to see increasing use of alternatives, such as UAV 'pseudolite' communications relay payloads in applications where the global connectivity of a Satcom constellation is not required operationally.

Other technologies which will see increasing use will be phased array antennas for X, Ka, K, Ku-band terminals, especially those carried by military platforms.

The UFO constellation replaces the UHF band FLTSATCOM and AFSATCOM systems.

The Milstar I/II constellation is the workhorse of the US Satcom architecture.