O3b 2.4m antennas operating in California. Photo courtesy Hung Tran, O3b Networks

Challenging, innovative and fascinating

The satellite communications industry is challenging, innovative and fascinating. It has evolved from a handful of satellites flying in the early 1960s to hundreds flying today. As more satellites launch, communications capabilities grow broader, while the enabling technologies become more complex. As anyone working in SATCOM knows, no two days are ever alike – and none are ever boring. Tracking the ever-growing number of satellites in orbit presents its own challenges, however, with technological advancements, today there are a host of options available. Dave Provencher, Vice President at AvL Technologies, provides a detailed explanation of the nuances of satellite tracking technologies.

Most of the satellites flying above Earth today are in geostationary (GEO) orbit, some are in medium Earth orbit (MEO), and even more – including the International Space Station (ISS) – are in low Earth orbit (LEO). From Earth, GEO satellites appear stationary in the sky as they follow Earth's rotation in the plane of the equator. GEO satellites have the advantage of being fairly simple to communicate with using 'fixed' ground antennas. But this popular group of satellites is also further away – a staggering 22,236 miles from the Earth's surface – so communications are more susceptible to latency issues and interference.

MEO satellites are closer at 1,243 to 22,236 miles, but don't maintain a stationary position relative to Earth, requiring very dynamic ground communications antennas. MEO satellites can also be positioned in an equatorial orbit. This approach (versus a non-equatorial orbit) reduces the complexity of the ground station antenna dynamics, but MEOs are typically visible for tens of minutes during each orbital circuit, rising in the west and descending in the east as viewed from the Earth. This requires very active and sophisticated ground equipment to constantly acquire at the

Dave Provencher, Vice President at AvL Technologies

point of ascension, track across the visible arc, and quickly re-trace to the point of ascension – over and over. Continuous communications with other ground stations requires multiple, evenly-spaced satellites in the same orbit and complex ground station equipment that must acquire and track these constantly moving targets.

LEO satellites are closer still at 99 to 1,243 miles above Earth. LEO satellites are typically visible for minutes per orbit, so a LEO constellation requires many satellites to maintain constant communications in a given area.

Satellite orbit challenges

GEO satellites only appear to be stationary as viewed from Earth. To begin with, the Earth's rotation is imperfect: The north-south axis of rotation actually wobbles over time. GEO satellite orbits are also affected by gravitational attraction from the sun and moon, as well as solar wind (charged particles emitted by the sun). To minimise these effects, modern GEO satellites are equipped with efficient on-board thrusters and sufficient thruster propellant to maintain the desired orbit stability over the design life of the satellite, typically 15 years. These thrusters can be commanded from satellite control facilities on Earth (via an on-board command communication antenna) to produce very precise orbital adjustments that compensate for unwanted satellite motion, a technique known as station-keeping. When the propellant is consumed their orbits degrade, resulting in drift motion in the shape of an analemma, which is similar to a flattened 'figure 8.' The shape of the analemma is determined by the parameters of each satellite's orbit and can be teardrop-shaped or elliptical, and the shape can appear differently from different locations on Earth. As such, antennas on Earth communicating to drifting, degraded GEO satellites must be able to track these satellites as they travel through the analemma pattern.

MEO and LEO satellites are also susceptible to atmospheric drag, gravitational pull and other external forces, so their orbits can shift over time just as GEO satellite orbits do.

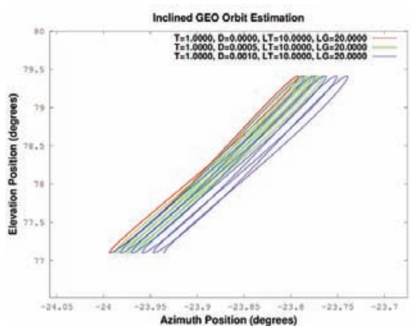

Figure 1: Drifting Inclined Orbits with Analemma Shape

Simple Step Tracking for moving GEO satellites

There are many ways to track a satellite in motion, and one of the simplest is Step Tracking. Step Tracking is often used for tracking GEO satellites, including those with degraded orbits traveling in an analemma shape above the equator. Parabolic antennas must physically move to properly track the moving satellite, and Step Tracking instructs the antenna to move the reflector – one step at a time in a hill-climb direction – toward the peak energy coming from the satellite. Step Tracking uses simple algorithms and averages, and uses 'seek and correct' scanning to take steps along the analemma path. This method works well when the antenna remains on the peak signal coming from the satellite, but it can have issues discerning side lobes.

TLE Tracking for GEO, MEO or LEO satellites

Two-line element or two-line ephemeris (TLE) tracking is an ideal tracking method when memory is constrained. TLE was developed in the 1960s as a standardised data format for defining details about the satellite and a list of orbital properties at a given point in time. TLE uses two lines of ASCII text formatted into 80 columns, and must be paired with an appropriate algorithm containing Standard General Perturbation models, such as SGP, SGP4 or SGP8. These perturbation models serve as a propagator, or math engine, which translates the orbit of a satellite in terms of pointing angles. The beauty of TLE tracking is in its simplicity: An antenna control system for an Earth station reads the TLE through the SGP propagator to determine a satellite's location and pointing angles at any point in time – but it does not require additional memory to 'remember' the satellite's location.

Parabolic Step Tracking for GEO, MEO or LEO satellites

Parabolic Step Tracking is a further refined peaking method, ideal for tracking satellites that have been in orbit for some time and have sub-optimal orbits due to gravitational pull and other external forces. This method starts with TLE tracking angles and adds offsets, which are intentional shifts along the satellite's expected path. A satellite initially may be acquired by raster scanning over the propagated TLE angles, locating the peak of receive energy.

A finer acquisition is then performed by spiral scanning at the satellite's discovered location, and final peaking is performed whereby tracking offsets are determined with periodic re-peaking along the parabola of the primary lobe of the antenna's signal. Re-peaking determines the positional offset angle against TLE propagated angles then follows the corrected path, which is often parallel to the TLE trajectory.

This system is complex due to the combining of Parabolic Step Tracking with TLE and SGP propagation, along with layers of course and fine scanning data, and failures are still possible. A typical failure occurs when an antenna is not able to locate a satellite's location during a periodic re-peaking cycle. To avoid this type of failure, Earth station antennas are often programmed with instruction for frequent re-peaking; they follow open loop TLE data to find the

satellite and re-peak on the signal, and the signal loss is often unnoticed.

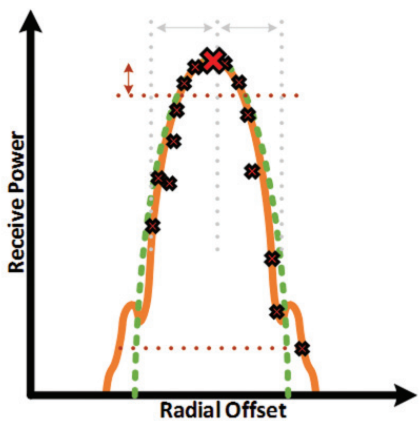

Figure 2: Parabolic Step Track Method

Intelligent Tracking for GEO satellites with highly inclined orbits

Satellites in GEO orbit are aligned with Earth's equatorial plane. Satellites with inclined orbits are misaligned with the Earth's equatorial plane at an angle that's on the order of one degree, and an orbit is considered highly inclined if the angular variance from the equatorial plane is on the order of 10 degrees. Intelligent Tracking is designed for use with satellites flying in both standard GEO orbits and highly-inclined orbits. Intelligent Tracking does not use TLE data, but it does require a discerning signal source, such as from a beacon or DVB receiver, as well as an accurate heading, which can be sourced through differential GPS or a reference point.

With an estimate of the target satellite's inclination, Intelligent Tracking will generate raster scans in geodetic (satellite latitude, longitude and altitude) coordinates, covering all probable locations for the satellite given its constraints. The geodetic raster scan is converted into antenna pointing look angles, and is used to determine an initial position for the target. Once the satellite is coarsely acquired, a spiral scan is initiated to provide a more refined satellite position. The antenna will then begin periodic Step Tracking utilising the previously described parabolic beam fitting method. Each detected peak energy location is translated to geodetic coordinates, and recorded to facilitate generating a mathematical model. This process continues until the model of the orbit approaches a level of mathematical certainty, and the antenna begins following the model with far less frequent Step Track peaking operations.

If an antenna using Intelligent Tracking is powered off then moved, the antenna control system will engage GPS to determine the new location and pair it with the stored geodetic data, and the antenna will begin communicating with and tracking the satellite immediately utilizing the previously generated model.

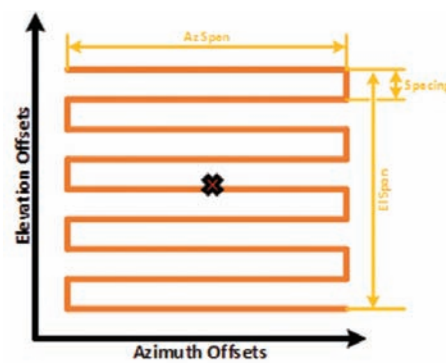

Figure 3: Vertically Aligned Raster Scan

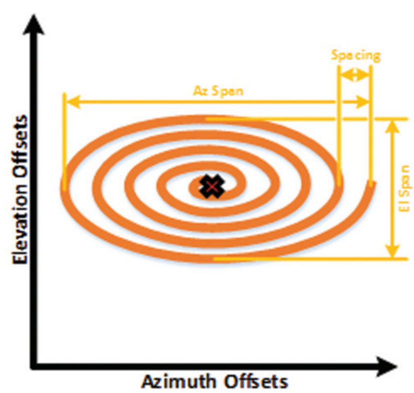

Figure 4: Horizontally Aligned Spiral Scan

Autotracking

There are many forms of satellite Autotracking, which are fairly simple but effective, and one common Autotracking method employs an antenna control system to receive data on several (typically four) simultaneous signals from the satellite being received at different physical locations on the antenna. The antenna uses a beacon receiver or other signal receiver for the simultaneous signals, then processes this data to determine angle errors. The angle errors could include differences in the axis of the satellite and the pointing angle of the antenna, and the antenna control system drives the antenna to correct its position accordingly. Additional issues impacting antenna positioning and signal accuracy may include structural changes to the antenna or temperature changes and atmospheric distortion, and the signal data is calculated into angle changes to compensate for these issues and the antenna is repositioned for peak signal alignment.

Autotracking requires significant and quick mathematical calculation capabilities, and is often used with LEO gateways as it's ideal for tracking satellites with narrow beams and high-frequency signals, and primarily by antennas with large reflectors. Autotracking often only works with satellites emitting stable energy as modulating energy will cause the receiver to misinterpret signal data from the satellite.

Conical Scanning for GEO, MEO or LEO satellites

Conical scanning is a highly accurate satellite tracking method that's only used with cassegrain antennas with the feed mounted on the surface of the centre of the antenna's reflector. Conical scanning is a way to electronically monitor a satellite's movement with the antenna's subreflector continuously scanning the satellite's receive signal in a cone-shaped circular motion. During scanning, the antenna actively tracks and records the satellite's movement and the antenna is physically moved (pulled) in the direction of the satellite's peak signal. Conical Scanning is ideal for tracking satellites with narrow beams and for satellites moving quickly, and it can be used for tracking any satellite emitting stable energy in GEO, MEO or LEO orbits.

MEO Tracking for the O3b constellation

O3b Networks has a constellation of 12 MEO satellites in operation, with plans to launch an additional eight within the next three years. These satellites are orbiting Earth at a distance of 5,010 miles and offer unprecedented capability. The Ka-band communications satellites have steerable beams with extremely high throughput and low latency – 'Fibre speed with satellite reach' – enabling many new

communications applications for military, marine and other uses.

AvL Technologies was engaged to design and build a family of transportable terminal antenna systems for O3b Networks in sizes ranging from 85cm to 2.4m, with all being transportable in durable transit cases and to be set up and on-the-air within two hours. The systems operate with a pair of tandem-operation antennas with one antenna actively communicating with a satellite while the other is on standby awaiting handoff from the first.

Essential to being on-the-air in a minimal amount of time is AvL's AAQ antenna control system. An O3b-proprietary module was added to the AAQ that employs data from the antennas' GPS sensors, inclinometers, pitch and roll sensors, O3b's satellite schedule, and O3b TLE data. This data is used to calculate both the antennas' pedestal angles and the world angle for the expected position of the satellite, and sample positions are recorded into memory. The AAQ then creates a new coordinate transform (a translation from true world angles to motor-directed angles), and the first antenna goes live on the air for transmit and receive, while the second antenna continues learning. When the first antenna reaches the far horizon, the antennas' roles switch. After several satellite passes, the antennas discontinue shadow learning to reduce their duty cycles, and revert to less frequent scanning. The antennas use periodic re-peaking during the learning process, and once the shadow learning is complete, the system will perform a learning operation for one satellite pass, once a day, to keep the model up to date.

Conclusion

Though the first satellites were flying around Earth in the early 1960s, the laws of physics that govern how to communicate with a satellite thousands of miles above remain the same. However, modern satellites offer more power and signal variations, and current antenna control systems offer infinite advances in efficient signal processing and mathematical models to manage amounts of data that were unthinkable 50 years ago. Thanks to the engineers among us, we now have limitless satellite communications capabilities – and many innovative ways to track and engage these mobile (yet seemingly motionless) satellites.

Photo courtesy of Shutterstock