Introduction to satellite constellations
orbital types, uses and related facts

Dr Lloyd Wood
space team, Cisco Systems
http://www.cisco.com/go/space

Guest lecture, ISU summer session
July 2006
All orbits are ellipses

- **Kepler’s first law**
  Earth mass $M$ at focus of an ellipse. Circular orbit is just a ‘special case’ of the ellipse, where the two focii are positioned together to form one.

- **Kepler’s second law**
  equal areas covered in equal times.
Most useful for communications –
geostationary Earth orbit (GEO)

- Altitude (35786km) chosen so that satellite moves at same angular velocity as Earth’s rotation, so appears still. (period: 1 *sidereal day*.)
- Three satellites spaced equally around the Equator cover most of Earth – but not the poles. (Arthur C. Clarke, 1945)
- Inmarsat’s I-4 **BGAN** is nearest match to this. (2 of 3 satellites launched.)
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Satellite antennas tailor footprints

- Satellites don’t always support perfectly spherical coverage areas.
- Shaped spotbeams let you concentrate coverage and power where you want it.
- Movable antennas let you provide more support (traffic) to a region on demand.
Actual geostationary orbit use (2001)

Solar panels aren't wings...

The GEO Belt

Note gap over the Pacific – too large to span (unlike Atlantic); small populations.
Inclined geosynchronous orbit

- Geostationary satellite reaches end of its planned life – stationkeeping fuel has run out, satellite moves in the sky south/north of the Equator. Can be used give a few hours’ connectivity cheaply each day for polar research stations.
- Forms a figure-of-eight groundtrack throughout the day. Investigated for use for mid-latitude Japan to give high-bandwidth comms with smaller footprints.
Useful highly elliptical orbits (HEO)

- Molnya (0.5sd ~12hr) and Tundra (~24hr 1sd orbits) – cover high latitudes at apogee.
- Invented by Soviet military; then Russian satellite television in 1960s. 63.4° inclination.

Yellow circular GEO orbit shown for scale
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- *Sirius Radio* adopts this model over the continental US. (*XM Radio* has two GEO satellites, *Sirius* plans new GEO sat for diversity.)
Optimal elliptical constellation

- Four satellites provide visibility to the entire Earth (Draim, 1987).
- Earth always inside a tetrahedron.
- Assumes Earth is flat – satellites often very low above horizon, easily obscured. **Not built.**
- Huge 2\( sd \) \(~48\)-hr orbits with repeating groundtracks.
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Ellipso – John E. Draim again

- Use of elliptical apogee to provide service at the northern high polar regions.
- Circular MEO orbit covers equatorial areas.
- Coverage of south poor: ‘my business plan can do without the people on Easter Island.’ – David Castiel, Wired 1.05
- Business plan to sell voice telephony. Oops. Not built. Merged into ICO.
Shadowing and urban canyons

- No. of satellites you can see above horizon is diversity.

*Galileo* – lots of satellites in view.
Shadowing and urban canyons

• No. of satellites you can see above horizon is diversity.
• But buildings/trees block your view of the horizon, limiting the number of satellites you can see.
• Skyscrapers and urban canyons mean no view of the sky (why Sirius Radio and XM Radio build city repeaters).

Galileo – lots of satellites in view. …if you’re not standing in a city street.
Navigation constellations

- *Galileo* and *GPS* (and *Glonass*) need to have high satellite diversity.

- You really need to see at least four satellites for a quick and accurate positioning fix (including height).
It’s all about system capacity

• Multiple spotbeams let you reuse precious frequencies multiple times, increasing use.
• Reuse of frequencies by different spotbeams over multiple satellites increases overall system capacity.
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7-colour frequency reuse
ICO satellite footprint approximation
Walker star constellations

- Walker star geometry, based on Adams/Rider ‘streets of coverage’. Best diversity at poles, worst at Equator.
- Has orbital seam where ascending and descending planes pass each other and must overlap.
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A star is a rosette cut in half

Topologically speaking, a rosette is a torus mapped onto a sphere; a Walker star is half a torus stitched onto a sphere. A star has one surface of satellites over the Earth, a rosette, two.
The incredible shrinking *Teledesic*

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- Until 1997: planned 288 satellites. Still biggest!
- Also most intersatellite links; redundant mesh even crossing the seam.
- Until 2002, down to thirty MEO satellites…
- Then bought *ICO Global* (which planned ten MEO sats for telephony; **only one in orbit.**)
Continuous coverage only needed for continuous communication

- *Orbcomm* is a ‘little LEO’ constellation for simple messaging. Satellites are just simple VHF repeaters. Message delivered to ground station when satellite is in view.

- Store and forward – but here it’s at the sender, not on the satellite.

LEO remote sensing satellites

- LEO sun-synchronous orbits (inclination varies with altitude) are very useful; satellite ascends over the Equator at the same time every day everywhere on Earth. Makes it easier to calibrate, correct and compare your images. E.g. Landsat, growing commercial imaging market.

- Also GEO imaging satellites for wide-area weather patterns, e.g. Meteosat.

- Triana – Al Gore proposed imaging from Earth-Sun Lagrange L1 point. He didn’t win there, either.
Disaster Monitoring Constellation

- Single plane of four sun-synchronous imaging satellites, ascending at 10:15am over Equator. Fifth satellite at 10:30am.
- Gives overlapping daily coverage of any point on the Earth’s surface.
- Coverage map shows 600km pushbroom imaging swath – large area by LEO imaging standards.
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Other sensing satellites

- Radar imaging satellites don’t have the daytime restrictions of imaging satellites – but night is still a strain on batteries.
- So these can be sun-synchronous at dawn and dusk – riding the day/night terminator, solar cells always in sunlight.
Quick overview of Earth orbits

- **Polar view** compares altitudes as if all orbits lie on Equator.
- **Van Allen belts** and radiation environment simplified – solar wind pushes them out of circular.

Orbital altitudes for satellite constellations
- peak radiation bands of the Van Allen belts (high-energy protons)
- orbits are not shown at actual inclination, this is a guide to altitude only
How to describe an orbit?

• Two-line element (TLE) format designed by NORAD, introduced November 1972.

```plaintext
NORAD# Int. Desig. epoch of TLE  1st/2nd mean motion deriv. drag orbital model to use
1 NNNNNC NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN  NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNNN
```

NORAD# orbital elements (inc, RAAN, e, arg. p., mean an.) mean motion revs. info

Sample FORTRAN code can be found.

**INTELSAT 506**

1 14077U 83047A 97126.05123843 -.00000246 00000-0 10000-3 0 721
2 14077 5.1140 60.2055 0003526 327.1604 183.6670 1.00269306 18589

126th day

year of epoch.

year of launch, before ID in year.

TWO-DIGIT. **NOT** Y2K COMPLIANT!

But claimed good until... 2056.
Summary

This talk has outlined:

• Overview of satellite orbits and coverage.
• Their advantages and uses.
• A number of unsuccessful business plans that were unable to make advantage of the advantages.
Questions?

Thankyou

Lloyd Wood
http://www.ee.surrey.ac.uk/L.Wood/

oh, just google…
Exercises with SaVi