IWSSC 2008 Tutorial
Satellite Networks I: constellations
orbital types, uses and advantages

Lloyd Wood, Cisco Systems
Who am I? What’s my perspective?

• Did masters project on satellite constellations with intersatellite links, at ENST Toulouse.
• Did PhD on same at University of Surrey.
• Went to program router code for Cisco Systems.
• Later moved into their new space team.
• Tested Cisco mobile Internet router in space on UK-DMC satellite, working with Surrey Satellite Technology Ltd and NASA Glenn.
  – My team was first to test IPv6 in space…
  – and first to use the ‘bundle protocol’ in space.
• I’m networking-oriented. Not a channel guy!
Lloyd's satellite constellations

Introduction | Background | Overview | General | References | Media | Comments?

Cisco router tested onboard disaster monitoring constellation satellite
Savi shows live Orbcomm coverage

One of the best sources of information about satellite networking... The mecca of satellite constellation information. more useful than most of the professional sites. You want to know about LEOs, you've got it.

- Upside, 1996.

One reason my PhD took so long...
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 foci are positioned together to form one.

- **Kepler’s second law**
  equal areas covered in equal times.

- **Kepler’s third law**
  Circular orbits ($T^2 \propto r^3$) are the most useful for us.
How to describe an orbit?

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

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

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Sample FORTRAN code can be found.
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 can see most of the Earth – but not the poles. (Arthur C. Clarke, 1945)
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• Inmarsat’s I-4 BGAN is nearest match to this. Third sat launched 18 Aug 2008.
Intersatellite links are an old idea…
commonly written as ISLs

…but interconnecting geostationary satellites is still cutting-edge stuff.
Fig 3 from Extra-Terrestrial Relays, Arthur C. Clarke, Wireless World, 1945.
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.
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.
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 (0.5\( sd\) ~12hr) and Tundra (~24hr 1\( sd\) orbits) – cover high latitudes at apogee.

- Invented by Soviet military; then Russian satellite television in 1960s. 63.4\(^\circ\) inclination.

Yellow circular GEO orbit shown for scale
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- *Sirius Radio* adopted this model over the continental US, before merging with *XM Radio*, which had two geostationary satellites.
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 $2sd \sim 48$-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).
Communication 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
Spotbeams!

huge fold-out
9m deployable reflector

transmitters/receivers

Inmarsat-4 satellite
Broadband Global Area Network (BGAN)
first launched November 2005

QinetiQ
Thuraya
Satphone service
launched October 2000
12m reflector
Uplink and downlink choices

traditional ‘bent-pipe’ switching on ground can lead to ‘double hops’

Can make a choice – where to go down? Another spotbeam? Intersatellite link?

could come down using entirely different frequency and waveform

can lead to ‘double hops’

newer ‘onboard processing’ gaining some acceptance with different tradeoffs.

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Globalstar vs Iridium

bent-pipe
CDMA recombination. Uses diversity, but must complete link in nearby ground station

onboard processing
 Doesn’t use CDMA or diversity. But doesn’t need a nearby ground station; less ground infrastructure.

across intersatellite links to satellite that sees ground station
Globalstar coverage

where its satellites can connect you to a local ground station

notice Cuba – interdicted.
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.
- Circular orbits are most useful throughout the orbital period – signal strength remains consistent.
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- Best diversity at mid-latitudes.
- Usually no coverage at poles; not global.
- Only operating LEO example: Globalstar (Voice telephony. Also went through US bankruptcy protection after Iridium did, 2002-2004.)
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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.
## Globalstar Inc. vs Iridium Satellite

Compare Q2 2008 results for three months ending 30 June.

<table>
<thead>
<tr>
<th></th>
<th>Globalstar Inc.</th>
<th>Iridium Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>subscribers</td>
<td>316,000</td>
<td>280,000</td>
</tr>
<tr>
<td>revenue</td>
<td>$16.7 million</td>
<td>$82 million</td>
</tr>
<tr>
<td>EBITDA</td>
<td>($2 million) <em>loss</em></td>
<td>$26 million</td>
</tr>
<tr>
<td>new satellites</td>
<td>currently being integrated and tested by Thales Alenia Space.</td>
<td>Iridium NEXT downselected to: Thales Alenia Space, Lockheed Martin.</td>
</tr>
</tbody>
</table>

Both are planning replacement constellations as existing satellites near end of life.

>20% of Iridium Satellite’s profits is from polar regions. Globalstar Inc. spent $1.1 million buying Brazilian gateway operator.
The incredible shrinking *Teledesic*

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- 1994: 840 satellites – announced the largest network system ever.
- 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; no ISLs and only one in orbit.)
**New kid on the block: Google.**

Needs satellite imagery for Google Maps and Google Earth. Gets ~4m resolution imagery from GeoEye-1 (launched 6 Sep 2008). <0.5m imagery is restricted.

Funding **O3b Networks**, along with HSBC, others. O3b aims to backhaul African cellular networks via MEO ring of satellites covering 45°-45° latitude.
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.

Some views of intersatellite links

- **Iridium** has 10Mbps Ka-band radio crosslinks.
- **ESA** plans backhauling LEO remote sensing satellites. Demonstrated with SILEX laser long-distance crosslink and Artemis Ka-band.
- **Clustering and slot clouds** short-distance wireless connecting stationkeeping satellites.
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* and the 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.
Disaster Monitoring Constellation

• Single plane of four active 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 by LEO imaging standards. More to be launched
Disaster Monitoring Constellation

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- Gives overlapping daily coverage of any point on the Earth’s surface.
- Communications access a little larger – passes over ground stations <14 min.
- *RapidEye* (5 sats launched 29 August 2008) similar.
Sample Disaster Monitoring Constellation (DMC) image

The Cape of Good Hope and False Bay. False colours – red is vegetation. Taken by UK-DMC satellite on the morning of Wednesday, 27 August 2008. First sensor imagery delivered by bundles from space.
Other sensing satellites

- Radar imaging satellites are active, not passive sensors.
- They 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.
Sensing benefits from ISLs

• backhauling through GEO to give longer periods of connectivity to download data, e.g. half an hour instead of ten minutes.

• Synchronising payloads on different sensor satellites, so that measurements taken at the same time can be combined.
  – 3D stereoscopic imaging
  – Wide-aperture phased-array sensing
  – combined hyperspectral imaging,
    • e.g. combining the capabilities of the climate-sensing ‘A-train’.
  – scientific measurements otherwise not possible,
    • e.g. GRACE gravity measurement (launched March 2002).
Summary

This talk has outlined:

• An overview of satellite orbits and coverage.
• A number of satellite constellation designs
• Their varied advantages, uses, and tradeoffs.
• Intersatellite links and design choices.
• Business plans using constellations – the successful and unsuccessful ones.
• A boom-and-bust cyclical industry.
Questions?

Thankyou

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

oh, just google…