Department of Engineering & Design

Professor Chris Chatwin

MSc
Satellite & Space Systems - Introduction & Overview

25th April 2017
Advanced Space Systems - Topics

- Space vehicle Power Systems
- Rocketry and propulsion systems
- Orbital Mechanics
- Applications
- Security
Space Applications

Applications

• Communications
• Meteorological
• Remote Sensing
• Navigation
• Scientific
• Defence
• Security

Fregat-MT upper stage (left) releasing a dispenser holding the first two Galileo satellites
Global Positioning System

- 24 spacecraft in 12 hour circular orbits, with 3 on-orbit spares. Six circular orbital planes, R=26,560km
- All users with clear view of sky see the minimum of 4, but usually see 6-8
- Augmentation generally not only improves accuracy but integrity, availability and continuity of GPS signals and GNSS signals generally.
EADS Astrium Ka-SAT, 6.1 Tonnes at launch, 15 year lifetime, 11 kW

KA-SAT will provide ubiquitous complete coverage of Europe and the Mediterranean Basin through its 82 spot beams in Ka-band
Global Positioning System

24 spacecraft in 12 hour circular orbits, with 3 on-orbit spares. Six circular orbital planes, \( R = 26,560 \text{ km} \)

GPS User: Horseback Biologist in Amazon
Virtual Private Networks over Satellite
Untethered Trailer Tracking Wireless Terrestrial Communications
Galileo should be operation by 2017, it will be inter-operable with GPS and GLONASS

30 satellites in Medium Earth Orbit (MEO) at an altitude of 23,222 km

Ten satellites will occupy each of three orbital planes inclined at an angle of 56° to the equator.

The inclination of the orbits was chosen to ensure good coverage of polar latitudes, which are poorly served by the US GPS system.
Space Surveillance Network

Worldwide Network of 20 Optical and Radar (Mechanical & Phased Array) Sensor Sites
Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) - Diego Garcia / Maui / Socorro

- Primary Mission: Space Surveillance
- Supports Air Force Space Command (AFSPC) as a dedicated Deep Space (DS) sensor
- GEODSS brings together the telescope, low-light-level cameras, and computers
Inside Diego Garcia GEODSS Station

22,000 objects being tracked - 1,100 active
Boeing is working on the Space-Based Surveillance System (SBSS) satellite program.
Space Based Space Surveillance (SBSS) - Operates in conjunction with the Space Surveillance Network (SSN)

USN Universal Space Network; RTS Remote Tracking Station; VAFB Vandenberg Air Force Base; JSpOC Joint Space Operations Centre; OCN Operational Control Node; SOC Satellite Operations Center
Space Based Space Surveillance, LEO

SBSS Delivers:
- 2-axis gimbaled sensor
- Large aperture
- 630-km, ~sun-sync
- 24-hr/day duty cycle

Better Timeliness
Better Sensitivity
Increased Capacity
Increased Orbit Accuracy
SBSS is free of terrestrial limitations – 24/7 on orbit data collection

Detection of faint objects including space debris
Space Based Infrared Systems (SBIRS) contributes to the Department of Defense mission to deter war and protect the security of the U.S. by providing timely and accurate missile warning/defense information. The SBIRS systems are critical for protection against global and theater ballistic missile attacks against the U.S., its deployed forces and its allies.
Defense Meteorological Satellite Program (DMSP) satellites "see" such environmental features as clouds, bodies of water, snow, fire, and pollution in the visual and infrared spectra. Scanning radiometers record information which can help determine cloud type and height, land and surface water temperatures, water currents, ocean surface features, ice, and snow. Communicated to ground-based terminals, the data is processed, interpreted by meteorologists, and ultimately used in planning and conducting U.S. military operations worldwide.
The NASA A-Train

CALIPSO and CloudSat fly in formation with other Earth Observing Satellites
The Wideband Global SATCOM satellite is the successor to the Defence Satellite Communications System-III. One WGS satellite has about 12 times the bandwidth of a DSCS-III satellite.
Space Surveillance

- Conduct space surveillance from space
- Surveillance of entire geosynchronous belt
- Assured access to objects of military interest

NAVSPACE Fence

- Provides up to date satellite orbital elements to Fleet and Fleet Marine forces
- Supports US Space Command as part of nation’s worldwide Space Surveillance Network
Ubiquitous Sonar Surveillance Systems
Satellite Image of Military Vehicles
What resolution is needed

MST’s sonar systems are able to accurately identify small submerged objects such as discarded evidence or corpses, making it ideal for law enforcement investigations.
Sonar Systems

MST’s sonar detection systems can accurately image small underwater threats such as mines.

Thales CAPTAS - Combined Active / Passive Towed Array Sonar - is a family of low frequency variable depth ASW sonars for surface ships.
UHF and VHF radio relay links, a C-band line-of-sight data link which has a range of 150nm and UHF and Ku-band satellite data links.

The vehicle carries electro-optical and infrared cameras and a synthetic aperture radar.

The two-colour DLTV television is equipped with a variable zoom and 955mm Spotter. The high resolution FLIR has six fields of view, 19mm to 560mm.
Global Hawk High-Altitude, Long-Endurance, Unmanned Reconnaissance Aircraft, USA

Performance:
- Maximum Endurance: 42 hours
- Loiter Velocity = 343kt
- Maximum Altitude: 65,000ft

Communications:
- Satellite Comms Datalink: 1.5Mbps, 8.67Mbps, 20Mbps, 30Mbps, 40Mbps, 47.9Mbps
- Line of Sight (LOS) Datalink: 137Mbps

Synthetic Aperture Radar (SAR): 1m/0.3m resolution (WAS / Spot)
Moving Target Indicator: 4kt minimum detectable velocity
Electro-Optical: NIIRS 5.5 / 6.5 (WAS/Spot)
Infrared: NIIRS 5.0 / 6.0 (WAS/Spot)
Management and Protection
- OTN fault isolation
- Protection switching
- Easy-to-use network management software

High Capacity
- Up to 80 channels
- Up to 10 Gb/s
- 40 Gb/s migration
- Muxponding/Aggregation

Transparent
- Ethernet, GbE, 10 GbE
- SONET/SDH
- Legacy - PDH
- ESCON, FICON, Fibre Channel
- Video

Cell Backhaul
- CWDM

Wavelength Services
- CWDM
- Access CWDM

Core Transport
- Metro DWDM, ROADM, OADM

Voice/Data/Video
- CWDM
- WDM
Diagram of Total Information Awareness system, taken from official (decommissioned) Information Awareness Office website

Total Information Awareness of transnational threats requires keeping track of individuals and understanding how they fit into models.
Police in the Liverpool region made Britain's first ever arrest using a camera mounted on a remote control eye-in-the-sky mini-helicopter.
EADS Astrium Ka-SAT, 6.1 Tonnes at launch, 15 year lifetime, 11 kW

The British military's Skynet 5 satellite system is based on this. The spacecraft is part of a £3.6bn system that will deliver secure, high-bandwidth communications for UK and allied forces.

Eutelsat’s Ka-SAT is one of the world’s most powerful satellites, with a total capacity of more than 70 Gbps, 35 times the throughput of traditional Ku-band satellites.

KA-SAT will provide ubiquitous complete coverage of Europe and the Mediterranean Basin through its 82 spot beams in Ka-band
ViaSat-1, which will be positioned at 115.1 degrees West longitude, is expected to provide more than 100 gigabits per second throughput in the Ka band, mostly for use in the West Coast of the U.S. and east of the Texas panhandle. The satellite has 72 spot beams, with 63 in the U.S. and nine over Canada.
Space Router – A Software Defined Architecture

Any-Frequency Transponders

- X
- C
- Ku
- Ka

Modem Interface Chassis (MIC)
- Modem (TDMA)
- Modem (SCPC)

Route Processing Engine (RPE)
- Services
- Control Plane (Dynamic Routing)

Software Defined Architecture

Future-Proofing Satellites with Upgradeability in Space Cisco IOS Software and Modem Waveforms
Traditional Satellite Networking (Left) vs.
IP-Based Satellite Networking (Right)
The Space-Ground Architecture Enabled by Cisco IRIS
The Intelsat Satellite Network 2008
Very Small Aperture Terminal (VSAT)
Satellite Communication Systems Integrate into the Global Fibre Backbone
DWDM Optical Fibre Communications
- Capacity: 7.1 terabytes per second Dec 2007

Fundamental element of Panopticon

The internet's undersea world

The vast majority of the world's communications pass around the Earth on cables that stretch across the oceans. This map shows the locations of all the cables and the countries they connect. It's a bit like the electrical wiring in your house, but on a global scale.

Internet access affected by the Alexandria accident

The map shows the impact of the Alexandria accident, which caused widespread outages around the world.
Arctic Fibre is deploying state of the art technology utilizing 100 gigabit wavelengths to construct a system with a capacity of 24 terabits/s.

The construction of the system is beginning in May 2014 and is scheduled to be in service in January 2016.
More than adequate terabyte capacity at the shores of Africa

- **WEST COAST:** OVER 15TBPS AND 55 TBPS BY 2Q OF 2015
- **EAST COAST:** 10.160TBPS AND 15.460 TBPS BY 4Q OF 2014
- **MEDITERRANEAN:** 10.56TBPS

✓ WEST COAST: OVER 15TBPS AND 55 TBPS BY 2Q OF 2015  
✓ EAST COAST: 10.160TBPS AND 15.460 TBPS BY 4Q OF 2014  
✓ MEDITERRANEAN : 10.56TBPS
Nigerian Satellite Communication System

• NIGCOMSAT-1 was launched 13th May, 2007 GMT Nigerian time and was de-orbited on 10th November, 2008 due to in-orbit subsystem anomaly – After launch satellite internet prices almost halved, then increased by 50% when it was de-orbited.

• Nigcomsat-1R was launched on 20th December 2011.(GMT) Nigerian time but early hours of 21st December, 2011 Chinese Local Time. Internet connection charges decreased considerably.
Nigcomsat-1R Satellite up to 5 Gbps
Nigcomsat-1R Satellite – 9kW quad band

- C-Band Transponder – 4 active transponders - 36MHz
- Ku-Band Transponder – 14 active transponders – 31.5MHz
- Ka-Band Transponder and – 8 active transponders – 120MHz
- L-Band (Navigation) Transponder – 2 active transponders
- Seven (7) Service Antennas
- NigComSat-1R with service life of more than 15 years has a designed life of 22.5 years with more than 0.70 reliability value at the end of its service life.
Nigcomsat-1R Footprints and Coverage

ECOWAS C-BAND COVERAGE

ECOWAS I KU-BAND COVERAGE

ECOWAS II KU-BAND COVERAGE

ASIA KU-BAND COVERAGE

KA-BAND COVERAGE OVER NIGERIA

KA-BAND COVERAGE OVER SOUTH AFRICA

KA-BAND COVERAGE OVER EUROPE

GLOBAL NAVIGATIONAL COVERAGE IN L-BAND
GCHQ's headquarters are in Cheltenham, Gloucestershire. There are two much smaller sites in Cornwall and Yorkshire but most of the 5500 staff work at the impressive state of the art building at Benhall in Cheltenham.
Trans-Atlantic Fibre Optic Cables
The 9,300 square metre data centre near Frankfurt – requires a reliable power supply

- European data centres consumed 56TWh of electricity in 2007 and in the UK they are responsible for almost three per cent of electricity use.
International Space Station

- **Orbit height:** 431 km
- **Speed on orbit:** 7.66 km/s
- **Max speed:** 27,600 km/h
- **Launch date:** November 20, 1998
- **Cost:** 150 billion USD
- **Solar panel array:** 4,000 m²
International Space Station
Mars Landing:

Aspects to consider:

Little atmosphere- can use parachute to reduce speed but need retrorocket and/or, as on Pathfinder, used bouncing ball cushions to withstand landing shock (originally used by Russians on moon landings).

Landing zone inclination-craters, rocks, etc.
Low solar constant $\rightarrow$ Power requirements
Low temperatures
Dust storm effects on sensitive optics.
Rovers, power requirements, autonomous movement, telemetry back, etc.
Exploration considered by long distance rover, Balloon, aircraft, etc.
Earth-Mars planet alignments favour launches every 2+ years. Use Phobos and Deimos as staging posts/stations for exploration of Mars? Life on Mars? Most likely place to look in solar system.

NASA Sample return mission 2011. Return: dock with mars orbiter [difficult!]

Avoid contamination of samples > Earth Orbiter? quarantine?

Closest planet and most likely destination for manned missions beyond moon →

new US initiative & ESA Aurora project → probably international (US lead) ~2025

Far future: generate return fuel at Mars from Mars materials (CO & O₂ ?).
Mars Express
Mars Express

High Resolution Stereo Camera (HRSC)

The HRSC is imaging the entire planet in full colour, 3D and with a resolution of about 10 metres. Selected areas will be imaged at 2-metre resolution.
Mars North Pole 12kM dia Water Ice Lake
Mars Express view of Olympus Mons
Nasa's experiment to find water on the Moon was a major success

The space agency smashed a rocket and a probe into a large crater at the lunar south pole, hoping to kick up ice. Scientists who have studied the data now say instruments trained on the impact plume saw copious quantities of water-ice and water vapour.

A camera on the probe shows the ejecta plume about 20 seconds after impact.
Titan, (size>Mercury,<Mars) is the only body in the solar system, other than Earth, that may have oceans and rainfall on its surface, but oceans & rain of ethane- methane rather than water.

Present environment \(-180^\circ C\) degrees, so cold that water ice would be as hard as granite – might be similar to that on Earth billions of years ago, before life began pumping oxygen into the atmosphere. *Titan’s atmosphere, 4 bar, mainly N\(_2\) + trace methane and ethane* -> thick, orange, hydrocarbon haze (impenetrable to cameras) (similar to terrestrial smog methane dissociated by sunlight) . 16day orbit, possible rotation rate16d (-> same side to Saturn).

NASA/ESA Cassini Mission launched Oct 97 with ESA Hygens probe to enter Titan atmosphere in, battery power 600W-
Mission aims for Titan:

1. determine density, pressure, temperature, etc. of atmosphere as a function of height;
2. measure constituents of atmosphere
3. investigate the atmosphere's chemistry /photochemistry, organic molecules & smog
4. meteorology: cloud physics, lightning discharges, and general circulation;
5. examine the physical state, topography, and composition of the surface.
ESA Huygens probe

ESA Huygens is 1.3 m diameter descent module with a spherical nose and a conical aft section. A thermal protection aeroshell surrounds the descent module, slowing it from 6 Km/s at arrival to 400 m/s in about two minutes and protecting it from the heat of entry. A parachute then deployed and the aeroshell jettisoned. The probe floats down through the atmosphere.

Instrumentation for the probe includes: an aerosol collector and pyrolyzer, a descent imager and spectral radiometer, a Doppler wind experiment, a gas Chromatograph/mass spectrometer, an atmospheric structure instrument, and a surface science package.
NASA Cassini to Saturn & ESA Huygens probe to Titan
Cassini-Huygens Spacecraft

Structures and Materials
Science Data Networks

- TDRSS
- Space Station
- Planetary Missions
- Shuttle Payloads
- Deep Space Network
- White Sands Complex
- Other Science Missions

**MISSION OPERATIONS**
- Mission Planning & Scheduling
- Monitor & Control
- Mission Management

**SCIENCE OPERATIONS**
- Science Data Processing
- Experiment Planning & Scheduling
- Interactive Instrument/Experiment Operations

**RESEARCH OPERATIONS**
- Worldwide Access to Data & Information Services
- Locate, Browse, Retrieve Data
- Explore, Analyze, Visualize
- Modeling, Data Assimilation
- Automated Analysis, Feature Extraction, Classification

**PRODUCTION DATA PROCESSING**

**DATA ARCHIVING & DISTRIBUTION**
Comets

- Left over from early solar system

Giotto probe to Comet Halley (above) & Rosetta Comet mission, 2004 (right), including lander on comet nucleus.
Mars Science Laboratory Mission - NASA launched 26th Nov 2011 – heading for the inside of the Gale Crater - Curiosity
Mars Rover & Curiosity

- https://www.youtube.com/watch?v=XRCIzZHpfFtY
- Curiosity
- https://www.youtube.com/watch?v=FZYnIsLNz3c
NASA’s Curiosity Rover in Profile
NASA’s Curiosity Rover on Mars

Hubble Space Telescope
Galaxy GN-108036, dating back to 750 million years after the Big Bang that created our universe.