ITU/ITSO Workshop on Satellite Communications, AFRALTI, Nairobi Kenya, 8-12, August, 2016

Basics of Satellite Communications

Presenter: E. Kasule Musisi
ITSO Consultant
Email: kasule@datafundi.com
Cell: +256 772 783 784
Topics Outline

• Birth of Satellite Communications
• Communication Links
• The Space Segment
• Satellite Design
• The Ground Segment
• Teleports
• Satellite Orbits
• Building and Launching Satellites
• Satellite Regulation
• Earth Station Registration
• Satellite Regulatory Organisations
• Satellite Operators
• Satellite Services
• Technology Trends
What is a satellite?
- In the context of spaceflight, a satellite is an object which has been placed into orbit by human endeavor.

Why is the above definition not quite accurate?
- Because we also have natural satellites such as the Moon. To be more exact, the above definition is for artificial satellites.
A communications satellite acts as a repeater.
Frequently Asked Questions (FAQs)

1. Who invented satellites?
   - Arthur C. Clarke, who went on to be a well-read author of science fiction novels

2. When were satellites invented?
   - The first satellites were experimented with in the late 1950’s and early 1960’s. Intelsat’s first satellite, which was called ‘Early Bird’, was launched on 6 April 1965. First satellite was launched in 1957 by Russia. It was Sputnik 1.

3. How big is a satellite?
   - Based on the Intelsat 9 series, before liftoff it’s, about 4,500 kilograms! Without fuel, it’s about 2,000 kilograms! The body is 5.6 meters, and the solar panels are 31 meters wide – more than a 10-story building!

4. How many years can a satellite last?
   - It varies by satellite type. The type of satellites that Intelsat owns can last over 20 years, but typically their work life is approximately 15 years
5. How do you fix satellites if they get broken?
   - The satellites send back ‘health check’ information to ground engineers all the time. Pre-developed commands are sent to the satellite to perform certain functions, such as firing a booster or changing the angle of a solar panel, so that it can repair itself.

6. How does a satellite get its power?
   - Mostly solar power collected by the solar arrays/panels. There are also batteries on the satellites for the times when the satellite passes through the Earth's shadow. This is called eclipse.

7. How much power does it take to transmit a signal?
   - The power used to send a communications signal to the Earth from a satellite is about the same as a typical 60W light bulb, just like you have at home.

8. What kinds of people work in the satellite industry?
   - All kinds! Engineers, rocket scientists, sales people, writers, accountants and lawyers
Birth of satellite communications 5/8

Communications satellites may be used for many applications:
- relaying telephone calls
- providing communications to remote areas of the Earth,
- TV direct to user broadcasting
- providing communications to ships, aircraft and other mobile vehicles
- etc.
Benefits of Satellites

- Adaptable to customer requirements
- Mobility
- Cost advantage
- Not affected by geographical obstructions
- Quick implementation
- Alternate routing (backup) or redundancy
- Cost is independent of distance
- Cost effective for short term requirements
Satellites are complementary to cable for the following reasons:

- Submarine cables (and landline fibre) are subject to cuts
- Interim solutions for cellular backhaul and internet trunking
- Satellite systems utilizing MEO (Medium Earth orbit) have both high capacity and high quality.
Types of satellites

• Communications satellites

• Weather satellites
  - provide meteorologists with scientific data to predict weather conditions and are equipped with advanced instruments

• Earth observation satellites

• Navigation satellites
  - using GPS technology, these satellites are able to provide a person’s exact location on Earth to within a few meters

• Broadcast satellites
  - broadcast television and radio signals from one point to another (similar to communications satellites).

• Scientific satellites
  - perform a variety of scientific missions e.g. The Hubble Space Telescope

• Military satellites
Uplink - The transmission of signals to the satellite
Downlink - The transmission of information from the satellite. Many Earth Stations can be covered by one satellite footprint.
NOTE:

- Satellites receive at a different frequency than they transmit at
- Different wavelengths give different radiation patterns on the antennae
- This causes slightly different footprints for uplink and downlink
- For marketing reasons the patterns may be different
A satellite “footprint”

C-band East Hemi Beam Peak up to 44.3 dBW
## Satellite frequency bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency Range</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-band</td>
<td>1.5 – 1.7 GHz</td>
<td>Mobile Satellite Services (MSS)</td>
</tr>
<tr>
<td>S-band</td>
<td>2.0 – 2.7 GHz</td>
<td>MSS, Digital Audio Radio Services (DARS)</td>
</tr>
<tr>
<td>C-band</td>
<td>3.4 – 7.1 GHz</td>
<td>Fixed Satellite Services (FSS)</td>
</tr>
<tr>
<td>X-Band</td>
<td>7.25 – 8.4 GHz</td>
<td>Military/Satellite Imagery</td>
</tr>
<tr>
<td>Ku-band</td>
<td>10.7 – 14.5 GHz</td>
<td>FSS, Broadcast Satellite Services (BSS)</td>
</tr>
<tr>
<td>Ka-band</td>
<td>17.7 – 21.2 GHz and 27.5 – 31 GHz</td>
<td>FSS Broadband and inter-satellite links</td>
</tr>
</tbody>
</table>

Source: Satellite Industry Association (USA), 2012
The Satellite Communication System

- space segment
- ground segment
- transmission medium (99% “free space”)
A telecommunications satellite comprises of:

- A **platform (or bus)**: propulsion system, fuel tanks, batteries, solar panels, attitude and orbit control functions, etc. It is usually standardized by the manufacturer.

- A **payload**: the equipment used to provide the service for which the satellite has been launched. Its is customized for a given mission.
The Space Segment 2/4

Block Diagram of a Communications Satellite
The Transponder

This is the equipment which provides the connecting link between the satellite’s transmit and receive antennas. It forms one of the main sections of the payload, the other being the antenna subsystems.

Satellite Transponder Capacity

Typically satellites have between 24 and 72 transponders. A transponder bandwidth is typically 36 MHz, 54 MHz or 72 MHz.
The Space Segment 4/4

A closer look at the Transponder

- Input frequency
- Low noise amplifier
- Mixer
- Power amplifier
- Output frequency
- Frequency coverage limited to bandwidth required to be received
- Local oscillator

20
Key aspects of Satellite Design

• Electrical Power
• Station Keeping
• Attitude Control
• Orbital Control
• Thermal Control
Satellite Design 2/2

Orbital Control

- Necessary keep the satellite stationary with respect to all the earth station antennas that are pointed at it.

- Each satellite carries a thrust subsystem to give it an occasional nudge to keep it “on station.”
Topic Outline

- Ground Earth Station (GES) components
- Factors governing antenna sizes
- The differences between a major earth station and a VSAT
- Permissions required to install and operate a VSAT / Earth station
GES Components- simplified list

1. **Reflector**
   - Physical reflecting piece – focuses signal into the LNB assembly and / or focuses the transmission signal towards the satellite

2. **Feed horn**
   - Device to accept the focussed RF signals into the LNB or conversely to output the RF signal to the satellite

3. **Power amplifier**
   - Device that accepts a signal from the modem and boosts it to a suitable level for onward transmission to the satellite

4. **LNA, B or C - Low Noise Amplifier**
   - Receives the signal from the satellite,
GES Components- simplified list (Cont’d)

5. **Modem**
   - Converts a data signal to one suitable for transmission to the satellite

6. **Up Converter**
   - Converts the modulated signals from RF to RF frequency

7. **Down Converter**
   - Converts the modulated signals from RF to RF frequency

8. **Mounting**
   - Some form of mounting to hold the antenna assembly vertical and pointed correctly under most normal condition
The Ground Segment

Indoor
- Router
- Power Amplifier
- UPS
- Power

Outdoor
- Feed Horn
- Reflector
- Rigid Mounting

GES Components - generic simplified diagram
The Ground Segment 5/6

Uplink Block Diagram

Downlink Block Diagram
The Ground Segment

Feed horn assembly

RF Power amplifier (SSPA)

Receive cable
From LNB modem

Transmit cable
From indoor modem

VSAT components
Factors Governing GES Reflector Sizes

**Technical Factors**
- Large earth stations have smaller beam width therefore point more accurately
- Large antennas results in less RF signal wastage
- Large antennas have less co-satellite interference
- Link Budget requirement

**Cost Factors**
- A Larger antenna may be less than the cost of a lease with a smaller antenna

**Regulatory Factors**
- Planning permission the Government or Local Authority may limit the minimum or maximum antenna size (e.g. for EM safety or aesthetics)
**VSAT - Very Small Aperture Terminal:**
- A VSAT is typically a small earth station 0.7M to 3.7M
- Usually operates a single service or application

**Major Earth Station**
- Typically a Major Earth station is sized from 3.7M to 16M+
  - weighing 20 T or more costing $1M+
- Basically same components in each station
- Supports multiple services
- All components redundant
- Can transmit and receive in multiple polarisations
- Usually configured with large RF power amplifiers
- Always connected to suitable Power supplies
- Usually connected to multiple terrestrial paths
Major Earth Station and VSAT $^{2/3}$

Picture of a VSAT

Reflector

Ground Mount with weights
Major Earth Station and VSAT

Large earth station antennas
What is a Teleport

- Multiple large earth stations
- Well specified antennas
- Good power systems
- Ample Rack space for ancillary equipment
- 24X7 staff on-site to maintain systems
- Quality support and technical staff to assist with design, install and operation
- Good terrestrial connectivity
- Preferably to more than a single fibre supplier
A typical Teleport
Permissions required to install & operate a VSAT / Earth station

Just because it can work does not necessarily mean you may go out install and operate!

- Planning permission
  - Local Authority building departments
  - Zoning issues
- Landlord’s permission
  - Will the landlord permit your activity?
- Regulatory authority
  - Does the law allow you to build and operate?
## Satellite Orbits 2/6

<table>
<thead>
<tr>
<th>Type</th>
<th>LEO</th>
<th>MEO</th>
<th>GEO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Low Earth Orbit</td>
<td>Medium Earth Orbit</td>
<td>Geostationary Earth Orbit</td>
</tr>
<tr>
<td></td>
<td>Equatorial or polar orbit</td>
<td>Equatorial or Polar orbit</td>
<td>Equatorial orbit</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>100-500 miles</td>
<td>6000-12000 miles</td>
<td>22,282 miles</td>
</tr>
<tr>
<td><strong>Signal Visibility / orbit</strong></td>
<td>15 min</td>
<td>2-4 hrs</td>
<td>24 hrs</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>Lower launch costs</td>
<td>Moderate launch cost</td>
<td>Covers as much as 42.2% of the earth's surface Ease of tracking No problems due to doppler</td>
</tr>
<tr>
<td></td>
<td>Short round trip signal delay</td>
<td>Small round trip delays</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small path loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Tracking antenna required</td>
<td>Tracking antenna required</td>
<td>Large round trip delays</td>
</tr>
<tr>
<td></td>
<td>Short life, 5-8 years</td>
<td>Larger delays</td>
<td>Weaker signals on Earth</td>
</tr>
<tr>
<td></td>
<td>Encounters radiation belts</td>
<td>Greater path loss than LEO's</td>
<td></td>
</tr>
</tbody>
</table>
Satellite Orbits 3/6
Inclined Orbits: Implications for earth station tracking:

Stations must have tracking systems so that their pointing is adjusted to aim at the satellite all during the day.
Orbital Slot Registration

- The ITU Member States have established a legal regime, which is codified through the ITU Constitution and Convention, including the Radio Regulations.
- All countries, including lesser developed countries, have an equal right to orbital slots.
- At conferences in 1985 and 1988, the ITU did give all countries the rights to an orbital slot directly over their territory.
Building and launching a telecommunications satellite

GEO Satellite Launch

Multiple “burns” to achieve GEO orbit
Building and launching a telecommunications satellite

Generic Transfer Orbit Profile

PKM  Perigee kick motor
GTO  Geosynchronous transfer orbit
LAM  Liquid apogee motor
LEO  Low earth orbit

Launch injection into LEO
LAM perigee augmentation burns
Post-PKM burn
GTO
LAM apogee burns
Final geosynchronous orbit
Building and launching a telecommunications satellite

- It takes about 3 years to get a GEO telecom satellite built and launched.
- Satellite payloads are customized for a given mission.
- Satellites are heavily tested on the ground in facilities that reproduce the space environment:
  - Mechanical, Thermal, Noise and RF tests
- **Typical cost of a satellite is $150-$250 million**
  - Some satellites can cost as much as $500 million.
  - Not including launch services ($55-$100 million) and insurance
As most satellite operators are for profit businesses, this investment must be recovered from sale of services over the satellite’s lifetime.

The services may be sold directly to communication service providers or through satellite service providers.
Levels of satellite regulation

1. Global: The Radio Regulations of the ITU done by the WRCs + (Rules of Procedure done by the RRB)

2. Regional: Regional (continental) agreements, guidelines and/or regulations, e.g. EU Decision No 626/2008/EC on the selection and authorisation of systems providing mobile satellite services (MSS).

3. Sub-regional: Sub-regional agreements, guidelines and/or regulations e.g. the 2015 SADC decision on Sharing of the Ka band (26.5 – 40GHz). Fixed service and Satellite service.

4. National: National regulations

5. (State/County: Limited scope regulations e.g. earth station licensing)
A licence is required by the national telecommunications authority of a country where any earth station as a part of a network, be it the hub, a control station or a VSAT, is planned to be installed and operated.
In the past, national telecommunication authorities have required licensing of individual VSAT terminals in addition to requiring a network operator’s license. Then, the US Federal Communication Commission (FCC) implemented with success a *blanket licensing* approach for VSATs operated within the US.
Blanket licensing has since gained interest among national telecommunications authorities all over the world, as a result of equipment manufacturers complying with the recommendations issued by international standardization bodies, such as the International Telecommunication Union (ITU) and the European Telecommunications Standards Institute (ETSI).
A licence usually entails the payment of a licence fee, which is most often in two parts: a one-time fee for the licensing work and an annual charge per station.
The licensing procedure is simpler when the network is national, as only one telecom authority is involved.
For transborder networks, licences must be obtained from the national authorities of the different countries where the relevant earth stations are planned to be installed and operated, and rules often differ from one country to another.
Orbital positions and radio interferences

Control of Interference

**Allocation**
Frequency separation of stations of different services

**Regulatory Protection**
e.g. No. 22.2: Non-GSO to protect GSO (FSS and BSS)

**Power Limits**
PFD to protect TERR services / EIRP to protect SPACE services / EPFD to protect GSO from Non-GSO

**Coordination**
between Administrations to ensure interference-free operations conditions
ITSO
The International Telecommunications Satellite Organization is an intergovernmental organization charged with overseeing the public service obligations of Intelsat.

GVF
Global VSAT Forum is an association of key companies involved in the business of delivering advanced digital fixed satellite systems and services.
ITSO

- ITSO is the continuation of INTELSAT, the intergovernmental organization established by treaty in 1973.
- On July 18, 2001, the satellite fleet, customer contracts and other operational assets of the Organization were transferred to Intelsat Ltd, a new private company now registered in Luxembourg and various amendments to the ITSO Agreement took effect.
- Under the ITSO Agreement, as amended, ITSO’s primary role was that of supervising and monitoring Intelsat’s provision of public telecommunications satellite services as specified in the Public Services Agreement (PSA) entered into between ITSO and Intelsat.
- In addition, the Director General, on behalf of the Organization, must consider all issues related to the Common Heritage. ITSO currently has 149 Member States.”
Some International/Regional Satellite Operators

- Iridium
- Eutelsat
- 3B Networks
- Arabsat
- Intelsat
- Inmarsat
- OneWeb
- Avanti
- Thuraya
- Yahsat
- Viasat
ITU Satellite radiocommunications services classifications

1. Aeronautical mobile-satellite (OR) service
2. Aeronautical mobile-satellite (R) service
3. Aeronautical mobile-satellite service
4. Aeronautical radionavigation-satellite service
5. Amateur-satellite service
6. Broadcasting-satellite service
7. Earth exploration-satellite service
8. Fixed-satellite service
9. Inter-satellite service
10. Land mobile-satellite service
ITU Satellite radiocommunications services classifications

11. Maritime mobile-satellite service
12. Maritime radionavigation-satellite service
13. Meteorological-satellite service
14. Mobile-satellite service
15. Radiodetermination-satellite service
16. Radiolocation-satellite service
17. Radionavigation-satellite service
18. Space operation service
19. Space research service
20. Standard freq. and time signal-satellite service
Industry Satellite Services Products

**Voice/Video/Data Communications**
- Rural Telephony
- News Gathering/Distribution
- Internet Trunking
- Corporate VSAT Networks
- Tele-Medicine
- Distance-Learning
- Mobile Telephony
- Videoconferencing
- Business Television
- Broadcast and Cable Relay
- VOIP & Multi-media over IP

**Direct-To-Consumer**
- Broadband IP
- DTH/DBS Television
- Digital Audio Radio
- Interactive Entertainment & Games
- Video & Data to handhelds
Industry Satellite Services Products

GPS/Navigation
- Position Location
- Timing
- Search and Rescue
- Mapping
- Fleet Management
- Security & Database Access
- Emergency Services

Remote Sensing
- Pipeline Monitoring
- Infrastructure Planning
- Forest Fire Prevention
- Urban Planning
- Flood and Storm watches
- Air Pollution Management
- Geo-spatial Services
Technology trends 1/11

- Satellite capacity continues to grow despite fibre deployment
- Potential shortage of capacity in some areas for certain types of capacity due to heavy cutbacks in launches
- Bandwidth is ever increasing on a per link basis
Addressing the bottom line through the use of the latest technologies

- DVB-S2 and DVB-S2x
- Adaptive Coding and Modulation
- Carrier Cancellation Technology (CCT) or “C’nC”
- Lower Roll off factors
- Multi-demodulator Hub Cards
DVB-S2 & Extensions: A new standard enables true convergence

- Excellent spectral efficiency:
  - Up to 40% bandwidth saving compared to DVB-S
  - Up to 2dB better than Turbo Codes
  - HDTV enabler

- Unlike DVB-S, DVB-S2 is optimised for MPEG and IP

- Allows for DTH and DTT distribution in single carrier
Adaptive Coding & Modulation

- Higher throughput for the same amount of resources
- When rain fade issues arise, the modulation can adjust so as to ensure the remote stays in the network
- Allows lower per Mbps price points to be achieved, leading to more competitive prices in the market

Maximum achievable data throughput by utilizing the most efficient coding and modulation scheme at any moment in time, depending on location within the satellite contour, antenna size and atmospheric conditions.
Carrier Cancellation Technology

Typical 8PSK Link

Bandwidth increases, Power decreases

Apply DoubleTalk Carrier-in-Carrier - Composite Carrier uses Less Bandwidth & Less Power Compared to Original
Roll Off

- Allocated BW directly proportional to Symbol rate × Roll off
- Typical roll off - 35%
- Most recent roll off available 5%
- Drives efficiency
Multi-Demodulator Cards: Multiple inbound carriers in one return card

- Reduces cost of equipment - fewer cards and less chassis space
- Potential to pay as you grow with existing hardware (only software required)
- Ease of manageability
- Far more common today across various platforms
Combination of Features: Equipment Vendors are integrating options to their products

- DVB-S2 with ACM
  - Satellite equipment vendors (eg. HNS, iDirect, Shiron)
- Carrier in Carrier
  - Comtech EFData CDM-625/CDM-625A
  - Viasat/iDirect PCMA
- DVB-S2, Carrier in Carrier with ACM
  - Comtech EFData CDM-750
- Hub demodulator card
  - iDirect, Comtech, etc
Technology trends 9/11

User demands

- Smaller terminals
- High throughput
- Enhanced capability
- Constellations
- Lower costs - $1000 now and lower!
  - Easier access to space segment
  - Easier licensing regimes
  - Open standards
Open Standards?

- Industry Players (Satellite Operators, Network Operators, Equipment manufacturers and End-Users) agree that Open Standards are good for everyone.
- But which one is the best one or is it a multitude of answers and solutions?
Technology trends

- Global usage and coordination
- Ka / Ku/ C Band
- Interference issues
- Global /Regional frequency coordination