1. Overview of Satellite Systems

What is Satellite Communication...

- A communication satellite is basically an electronic communication package placed in orbit whose prime objective is to initiate or assist another through space.
- Satellite communication is one of the most impressive spin-offs from the space programs and has made a major contribution to the pattern of international communication.
- The information transferred most often correspondences to voice (telephone), video (Television) and digital data.

Contents

- What is satellite communication
- The origin of satellite
- Basic satellite System
- System design Considerations
- Advantages of Satellite / Applications
- Limitation of Satellites
- Frequency Allocation

Cont...

- Communication satellite are off-course only one means of telecommunication transmission. The traditional means include copper wire and microwave point-to-point links. Newer techniques involves use of optics either point-to-point infrared or fiber optics. Point-to-point radio system such as short wave radio may also be used.
The origin of satellite

- The concept of using objects in space to reflect signals for communication was proved by the Naval Research Lab in Washington D.C. in 1940 when it used the Moon to establish a very low data rate link between Washington and Hawaii.
- Russian started the Space age by successfully launching SPUTNIK, the first artificial spacecraft to orbit the earth, which transmitted telemetry information for 21 days in Oct. 1957.
- The American followed by launching an experimental satellite EXPLORER in 1958.
- In 1960 two satellites were deployed “Echo” & “Courier”.
- In 1963 first GEO “Syncom”.
- The first commercial GEO (Intelsat & Molnya) in 1965 provides video (Television) and voice (Telephone) for their audience.

Elements of Satellite Communications

- The basic elements of a communication satellite service are divided into:
  - Space Segment
  - Ground Segment
- The space segment consists of the spacecraft & launch mechanism and ground segment comprises the earth station and network control center of the entire satellite system.

Applications

- Communication (trunking call)
- Teleconference
- Telemedicine
- TV Broadcasting
- Data communication
- Telemetry (TEC, remote sensing etc)
- Weather telecast
- Navigation
- GPS
- Security/Calamity monitoring
- Standard Time
- Military

Propagation Delay

<table>
<thead>
<tr>
<th>Single Hop</th>
<th>Double Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>270 ms</td>
<td>540 ms</td>
</tr>
</tbody>
</table>

Satellite Communications System

Concept

Transponder

Earth station (site A)

Earth station (site B)
Early Satellites

Satellite Launching Date     Country/Organization
INTELSAT 4 1971 INTELSAT/COMSAT
ANIK 1 1972 Canada/Telesat
WESTAR 1974 USA/Western Union

Satellite Services

- The ITU has grouped the satellite services into three main groups:
- Fixed Satellite Services (FSS)
- Broadcast Satellite Services (BSS)
- Mobile Satellite Services (MSS)

Satellite Services

Satellite Services

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- Mobile Satellite Services (MSS)

Asiasat 2

Space Segment

- Space segment consist of a satellite in suitable orbit.
- Space segment classified on the basis of orbit:
  - LEO
  - MEO
  - HEO
  - GEO & GSO

Space Segment

Ground Segment

- The ground segment of each service has distinct characteristics.
- Services like:
  - FSS
  - BSS
  - MSS
    - Maritime, Aeronautical & Land base
  - DBS
  - Etc.
Advantages of Satellite

- Wide band capability
- Wide area coverage readily possible
- Distance-insensitive costs
- Counter inflationary cost history
- All user have same access possibilities
- Point to point, point to multipoint (broadcast) and multipoint to point (data collection) are all possible
- Inherently suited for mobile application.
- Compatible with all new technologies
- Service directly to the users

Limitation of Satellites

- High initial investment
- New investment require in Ground Segment
- Short life time (7-10 years)
- Spectrum crowding
- Regulatory aspects
- Launch vehicle reliability

Frequency Allocations

- Frequency bands for satellite services are shared with terrestrial services.
- Satellite signal strength is constrained to avoid interference by it to others.
- Thus a large antenna and sensitive receiver are needed at the earth station.
- Frequency sharing techniques are an important study area.
- Many satellites have to share a limited frequency band (and limited orbital arc) thus coordination in frequency and orbital location is important.
- Frequency allocation are done by international agreements.

Frequency Allocation and Regulatory Aspects

- Domestic
  - U.S. Federal Communication Commission (FCC)
  - National Telecommunication and Information Administration (NTIA) in Pakiace, PTA (Pakistan Telecommunication Authority)

- International
  - International Telecommunication Union (ITU)
  - Formed in 1932 from the International Telegraph Union
  - Consists of over 150 members nations
  - World Administrative Radio Conference (WARC)
    - International Radio Consultative Committee (CCIR) consists of 13 study groups.

ITU Regions

ITU divides the surface area of the earth into three regions for the purpose of frequency allocation

- Region 1: Pacific Ocean Region
  - North and South America
  - Greenland

- Region 2: Atlantic Ocean Region
  - Europe
  - Africa
  - Middle East
  - Central Asia

- Region 3: Indian Ocean Region
  - Pakistan-India Sub-continent , South East Asia & Australia
Frequency Allocations to Satellite Services

Examples of Satellite Radio Services:
- Fixed Satellite Service (FSS)
- Mobile Satellite Service (MSS)
- Broadcast Satellite Service (BSS)
- Radio-Navigation Satellite Service (RNSS)
- Radio-location Satellite Service (RSS)
- Space Operation Service (SOS)
- Earth observation Satellite Service (ESS)

In total more than 18 radio services

The International Telecommunications Union

Region 1: 19.7 - 20.1 GHz
- FIXED-SATELLITE (space-to-earth)
- MOBILE-SATELLITE (space-to-earth)
- S5.524

Region 2: 19.7 - 20.1 GHz
- FIXED-SATELLITE (space-to-earth)
- MOBILE-SATELLITE (space-to-earth)
- S5.524, S5.525, S5.526

Region 3: 19.7 - 20.1 GHz
- FIXED-SATELLITE (space-to-earth)
- MOBILE-SATELLITE (space-to-earth)
- S5.527, S5.528, S5.529

The International Telecommunications Union

A license is required by every operator in order to operate a satellite system nationally; a license may only be acquired if:
- the operator can show that he has a contract with the system owner to be his service provider
- the frequencies for the system have been cleared / coordinated / notified
- the system is fully registered with the ITU
- the operator has workers registered as operators

A license will be cancelled if:
- there are no more registered operators to work the system
- the service provider has breached ‘data protection laws’

2. Orbit and Launching Methods

Before the lecture
- Try to find out more by reading:
  - http://ctd.grc.nasa.gov/rlleonard/regcontent.html
  - http://www.aticourses.com/iridium.htm
  - http://www.milesat.com/Article9.html
Orbits

- Circular orbits are simplest
- Inclined orbits are useful for coverage of equatorial regions
- Elliptical orbits can be used to give quasi stationary behaviour viewed from earth
  - using 3 or 4 satellites
- Orbit changes can be used to extend the life of satellites

Satellites

Several types
- LEOs - Low Earth Orbit
- MEOs - Medium Earth Orbit
- HEOs - Highly Elliptical Orbit
- GSO - Geostationary Earth Orbit

LEO

- Low Earth Orbit
- 200-3,000 km
- High orbit speed
- Many satellites
- Predominately mobile
- Iridium, Globalstar
  - (space shuttle orbit)

MEO

- Medium Earth Orbit
- 6,000 – 12,000 km
- New generation
- About 12 satellites
- Voice and mobile
  - ICO (Odyssey), Orbcomm, Ellipso

Sub-Satellite Track of a HEO

The 24 h HEO of Sirius
The 24 h HEO of Sirius

HEOs: Molnya and Tundra

<table>
<thead>
<tr>
<th></th>
<th>Molnya</th>
<th>Tundra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>12 h</td>
<td>24 h</td>
</tr>
<tr>
<td>Apogee</td>
<td>39,500 km</td>
<td>46,300 km</td>
</tr>
<tr>
<td>Perigee</td>
<td>10,000 km</td>
<td>25,300 km</td>
</tr>
<tr>
<td>Inclination</td>
<td>63.4°</td>
<td>63.4°</td>
</tr>
</tbody>
</table>

Satellite Orbits and Periods

<table>
<thead>
<tr>
<th>Height of Orbit (km)</th>
<th>Period (h)</th>
<th>Cell Diameter (km)</th>
<th>Visible Part of Earth (%)</th>
<th>4 of Satellites</th>
<th>Duration of Overflight (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1.5</td>
<td>3,154</td>
<td>1.5</td>
<td>56</td>
<td>7</td>
</tr>
<tr>
<td>760</td>
<td>1.6</td>
<td>5,720</td>
<td>5.0</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>1000</td>
<td>1.8</td>
<td>6,719</td>
<td>6.8</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>1,314</td>
<td>1.9</td>
<td>7,806</td>
<td>9.1</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>10,000</td>
<td>5.6</td>
<td>14,935</td>
<td>38.6</td>
<td>4</td>
<td>130</td>
</tr>
<tr>
<td>20,000</td>
<td>11.6</td>
<td>16,912</td>
<td>36.9</td>
<td>9</td>
<td>500</td>
</tr>
<tr>
<td>35,786</td>
<td>24.0</td>
<td>18,100</td>
<td>42.6</td>
<td>3</td>
<td>24 h/d</td>
</tr>
</tbody>
</table>

GEOs

- Originally proposed by Arthur C. Clarke
- Circular orbits above the equator
- Angular separation about 2 degrees - allows 180 satellites
- Orbital height above the earth about 23,000 miles/35,786.16km
- Round trip time to satellite about 0.24 seconds

GEOs (2)

- GEO satellites require more power for communications
- The signal to noise ratio for GEOs is worse because of the distances involved
- A few GEOs can cover most of the surface of the earth
- Note that polar regions cannot be “seen” by GEOs

GEOs (3)

- Since they appear stationary, GEOs do not require tracking
- GEOs are good for broadcasting to wide areas
- Currently 329 GEO are in orbit
  (ref: web site provided by Johnston)
The original vision
- 1945 Arthur C Clark envisaged "extraterrestrial relays"
- 3 satellites
- Period: 23 h 56 min 4.091 s
- Height: 36,000 km above equator
- Speed of flight: 3.074 km/s

and then..
- 1957 Sputnik
- A rush of experimental satellites in many orbits
- Intelsat 1965 – 1st commercial GEO service
- Over 800 objects registered so far

GEO - geostationary earth orbit
- Characterised by:
  - Delay (echo) ~0.5 sec return
  - High power
  - 5-7 years life
  - Global and spot beams
  - C and K band (4-6 GHz and 12-14 GHz)
  - 2-3° spacing
- Currently more than 200 GEO satellites in operation

The view from 36,000 km

Earth coverage with 2 spacecraft

Coverage of the inhabited world except for Polynesia

Some GEO’s above us
- Optus * 3
- AsiaSat * 3
- PAS * 2
- Intelsat * 7
- Inmarsat * 2
- Palapa * 2
- And others

Some Service Providers:
- Netspeed
- Austar
- Optus
- Telstra
- iHug
- Newspace
- Megasat
- NTL
- Heartland
- Ariadne
Satellite Footprints

Satellite beams their signals in a straight path to the earth. The satellite focus these microwaves signals onto the specified portions of the earth's surface to most effectively use the limited power of their transponders. These focused signals create unique beam patterns called “footprints.”

Types of footprints:
- Global beam footprint
- Hemispheric Beam Footprint
- Zone Beam Footprint
Key Input Data...

Bands:
- C-Band
- Ku-Band

Beams:
- Global
- Hemi
- Zone
- Spot

Characteristics of a Geostationary Satellite

- **Eccentricity (e)**: 0
- **Inclination of the orbital plane (i)**: 0º
- **Period (T)**: 23h 56m 4s
- **Semi-major axis (a)**: 42164 km
- **Satellite altitude (R)**: 35786 km
- **Satellite velocity (Vs)**: 3075 m/s

\[ F = GMm/r^2 \]
\[ T = \frac{2\pi}{\sqrt{\mu}} \]
\[ a = \frac{GM}{\mu} \]
\[ e = \frac{c}{a} \]
\[ V = \sqrt{\frac{\mu}{a}} \]

Elevation, distance to the satellite:

\[ K_{geos} = \text{M} \times G \times \frac{1}{r^2} \]
\[ K_{cent} = \text{M} \times G \times \frac{1}{r^2} \]
\[ \Delta \text{lon} = \text{Longitude Satellite} - \text{Longitude} \]
\[ \Delta \text{lat} = \text{Latitude Satellite} - \text{Latitude} \]

Distance:
\[ d = R_o \sqrt{6.611^2 - 2 \times 6.611 \times \cos \alpha + 1} \]

Elevation:
\[ \epsilon = \sin^{-1} \left( \frac{6.611^2 R_o^2 - R_o^2 - d^2}{2 R_o d} \right) \]

Test:
- \( \alpha = 81.3^\circ \) \( d = 41680 \) km and \( \epsilon = 0^\circ \)
- \( \alpha = 0^\circ \) \( d = 35786 \) km and \( \epsilon = 90^\circ \)

The GEO

Elevation, distance to the satellite:

The GEO

The inclination (1)

The GEO

The inclination (2)
Transfer Orbits

Eklipse

SONNE

Akquirierung

Transfer Orbit

GEO

Drift Orbit

Abtrennung

langsame

Bedrallung

1. Apogäum

2. Zündungsende

3. Zündungsende

1. Zündungsende

2. Zündungsbeginn

3. Zündungsbeginn

Sonnenorientierung

3-Achsen Stabilisierung

Restpaneelentfaltung

Entdrallung

Erdorientierung

Akquirierung

C-Band satellites in GEO

Legend:
- am Orbit
- im Bau
- ITU Appl.

Legende
- im Orbit
- im Bau
- ITU Appl.

C and Ku-Band satellites in America

Early experiments

- US Navy bounced messages off the moon
- ECHO 1 “balloon” satellite - passive
- ECHO 2 - 2nd passive satellite
- All subsequent satellites used active communications

C and Ku-Band satellites in America

ECHO 1

Photo from NASA
Early satellites
- Relay
  - 4000 miles orbit
- Telstar
  - Allowed live transmission across the Atlantic
- Syncom 2
  - First Geosynchronous satellite

TELSTAR

SYNCOM 2

Major problems for satellites
- Positioning in orbit
- Stability
- Power
- Communications
- Harsh environment

Comparison chart

<table>
<thead>
<tr>
<th>Features</th>
<th>GEO (km)</th>
<th>MEO (km)</th>
<th>LEO (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (km)</td>
<td>36,000</td>
<td>6,000-12,000</td>
<td>200-3000</td>
</tr>
<tr>
<td>Time per Orbit (hrs)</td>
<td>24</td>
<td>5-12</td>
<td>1.5</td>
</tr>
<tr>
<td>Speed (km/hr)</td>
<td>11,000</td>
<td>19,000</td>
<td>27,000</td>
</tr>
<tr>
<td>Time delay (ms)</td>
<td>250</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Time in site of Gateway</td>
<td>Always</td>
<td>1-4 hrs</td>
<td>15 mins</td>
</tr>
<tr>
<td>Satellites for Global Coverage</td>
<td>3</td>
<td>10-12</td>
<td>50-70</td>
</tr>
</tbody>
</table>
Mega LEOs, MEOs, HEOs, and GEOs

1. TELEDESIC of Microsoft with 288 LEOs at Ka-Band
2. V-Band Supplement of TELEDESIC/microsoft with 72 LEOs at Q-Band
3. GS-40 of Globalstar LP with 60 LEOs at Q-Band
4. M-Star of Motorola with 72 LEOs at Q-Band
5. LEO ONE of LEO ONE Corp. with 48 LEOs at Q-Band
6. ORBLINK of Orbital LLC with 7 MEOs in Q-Band
7. SkyBridge of ALCATEL with 64 LEOs and 9 GEOs in Ku-Band
8. WEST of MATRA with 10 MEOs and 12 GEOs in Ka-Band
9. GESS of TRW with 15 MEOs and 4 GEOs in Q-Band
10. CELESTRI by Motorola MTT with 53 LEOs and 10 GEOs in Ka-Band
11. SpaceWay of Hughes Communications with 20 GEOs and 16 GEOs in Ka-Band
12. StarLynx of Hughes Communications with 20 MEOs and 4 GEOs in Q-Band
13. DSCC Telecom LLC PenTriad in HEO in Ku-, Ka-, V- and W-Band

back to GEOs

- given current-generation LEO's and MEO's are predominately used for mobile voice and low-speed data services (MPSS)
- good voice coverage for remote regions
- adjunct to GSM mobile networks — Globalstar

the future

- continual development in VSAT (GEO) technology
  - bandwidth gains
  - multiple services = choice
- Broadband LEOs
  - Teledesic
    - fixed and transportable terminals
      - 64 - 288 and above (Gb)
    - 288 satellites
    - 2005 launch?
  - SkyBridge
    - 80 satellites
    - 2004

what is SkyBridge?

SkyBridge is an Alcatel controlled company planning to establish a constellation of 80 satellites to provide broadband data communications direct to business & residential premises.

- Satellites are Low Earth Orbit (LEO) at an altitude of 1500 km
- offers “last mile” broadband access from 2004
- no long-haul trunking capability - connects users to terrestrial gateway
- System cost is approx US$4.8bn

broadband LEO — low latency

Launching

Step 1: satellite is released into the Low Earth Orbit by launch vehicle

Step 2: The Payload Assist Module (PAM) rocket fires to place the satellite into the geostationary transfer orbit (GTO)
Launching (Continued)

Step 3: Several days after the satellite gets into the GTO the Apogee Kick Motor (AKM) fires to put the satellite into a nearly circular orbit.

Launching (Continued)

Step 4: Orbital Adjustment by firing the AKM to achieve a circular geosynchronous orbit.

Launch Vehicles

| Launch Vehicle | Atlas II | Delta II | Ariane 4 | Proton | Long
|----------------|----------|----------|----------|--------|--------|
| Country        | USA      | USA      | Europe   | Russia | Japan
| Gross Weight   | 460 t    | 680 t    | 202 t    | 260 t  | 200 t
| Boost to GTO   | 3,000 kg | 1,819 kg | 2,200 kg | 2,000 kg | 650 kg |

Summary of Launchers

Proton Launch Vehicle

- Stage 1: 6x YF-150
- Stage 2: 6x YF-150
- Stage 3: 6x YF-150
- Upper: 6x YF-150
- Lower: 6x YF-150
Sea Launch

At the Equator

11 day travel, 3 days on site, 9 days back
1. and 2. stage fueled on launch site; 3. stage and satellite fueled in Long Beach

Sea Launch

Lift Off:
Up to 6 t
3000 m deep water
Commander is 5 km away for launch

The Launch Service Alliance

ArianeSpace, Boeing Launch Services, and Mitsubishi Heavy Industries
mutual backup to mitigate schedule risks, range issues, etc.

Summary of Launchers

International Launch Services, ILS
Lockheed Martin, USA
Khrunichev, BUSP, Energia, RUS
Atlas IAR, Proton-M
Baikonur Launch Site

Types of Launches

The Evolution:

Ground Launch since the 60ies
Rail Launch since the 70ies
Air Launch since the 80ies

Sea Launch since the 90ies
A communication satellite consists of the following subsystems:

- **Antenna**: For receiving and transmitting signals.
- **Transponder**: It contains the electronics for receiving the signals, amplifying them, changing their frequency and retransmitting them.
- **Power Generation and Conditioning Subsystem**: For creating power and converting the generated power into a usable form to operate the satellite.
- **Command and Telemetry Subsystem**: For making the adjustments to the satellite's orbital position and altitude.
- **Transponder**: It contains the electronics for receiving the signals, amplifying them, changing their frequency and retransmitting them.
- **Antenna**: For receiving and transmitting signals.

**Latency**

Latency is the time between initiating a way and receiving a response. It is often measured in milliseconds (ms) and can vary widely depending on the network and the amount of data being transmitted.

**Multicast**

Multicast is a communication technique used to send a single message to multiple recipients at the same time. Unlike broadcast, where every node in the network receives the same data, multicast allows for more efficient data delivery to a specific group of nodes.

**Broadcast**

Broadcasting is a one-to-many simultaneous communication model. It is commonly used in scenarios where a single message needs to be distributed to a large number of recipients efficiently.

**Orbits**

- **LEO (Low Earth Orbit)**: Orbits at altitudes between 200 and 3,000 km. LEO satellites are known for low latency due to their proximity to Earth.
- **MEO (Medium Earth Orbit)**: Orbits at altitudes between 6,600 and 12,000 km. MEO satellites offer a balance between latency and coverage.
- **GEO (Geostationary Earth Orbit)**: Orbits at an altitude of 36,000 km. GEO satellites remain in a fixed position relative to Earth, providing continuous coverage.

**VSAT**

Very small aperture terminal (VSAT) refers to a small, portable satellite dish that allows for direct communication with a satellite, bypassing traditional terrestrial infrastructure.

**Fixed Services**

These services include Direct Broadcast (DBS), DTH (Direct To Home), and DAB (Digital Audio Broadcast). They are typically associated with larger, permanent installations.

**DAB**

Digital Audio Broadcast is a satellite-based service that transmits high-quality audio to a wide audience. It is often used in areas where traditional radio reception is poor.

**VSAT**

Very Small Aperture Terminal is a type of satellite dish that allows for high-speed connectivity through a single satellite. It is widely used in remote areas and for business applications requiring secure, reliable communication.

**Common Abbreviations**

- **GEO**: Geostationary Earth Orbit
- **LEO**: Low Earth Orbit
- **MEO**: Medium Earth Orbit
- **Iridium**: Inclined Geo-Synchronous Orbit
- **LEO**: Low Earth Orbit
- **GEO**: Geostationary Earth Orbit
- **MEO**: Medium Earth Orbit
- **HEO**: Highly Inclined Elliptical Orbit
- **DTH**: Direct To Home
- **DBS**: Direct Broadcast Satellite
- **DAB**: Digital Audio Broadcast
- **HAP**: High Altitude Platform
- **VSAT**: Very Small Aperture Terminal
- **Mega**: Mega-bit/s services
- **DTH**: Direct To Home
- **VSAT**: Very Small Aperture Terminal

**Internet Protocol (IP)**

Internet Protocol is the standard for how data is transferred over networks. It is the foundation of the modern internet, enabling the seamless exchange of information across the globe.