First SatNEx Summer School 2005
Pisa, Italy, 22nd - 26 August

OVERVIEW of SATELLITE SYSTEMS ARCHITECTURES

Prof. Michel BOUSQUET
michel.bousquet@supaero.fr

CONTENT OF PRESENTATION

- SATELLITE APPLICATIONS and PROS &CONs
- SATELLITE SYSTEM ARCHITECTURES
- TYPES OF ORBITS
- COMMUNICATION SATELLITES
- COMMUNICATION PAYLOAD ARCHITECTURE
- EARTH STATION ARCHITECTURE & MULTIPLE ACCESS ISSUES
- COMMUNICATION LINK ISSUES
- PERSPECTIVES

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APPLICATIONS

- **Voice**
  - Telephony Trunking
  - Personal Telephony
  - Remote Pay Phones
- **Messaging**
  - Pager, Meter Reading
- **Data**
  - Software Distribution
  - Databases, etc
  - E-mail
  - Very Small ApertureTerminal (VSAT)Networks
- **Broadcast**
  - Digital Audio Radio,
  - Television Distribution
  - Direct Broadcast Television
- **Multimedia**
  - Telemedicine, Tele-Education…
  - Teleconferencing, Telecommuting,
  - Video On Demand,
  - Home Shopping
  - Satellite News Gathering
- **Internet**

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RADIOFREQUENCY BANDS

❒ **MAIN FREQUENCY BANDS (UPLINK/DOWNLINK)** allocated by International Telecommunication Union(ITU) for satellite communications are :

- Communications with MOBILES :
  - 1.6/1.5 GHz (L-band)
  - 2/2.2 GHz (S-band)
- Communications with FIXED EARTH STATIONS :
  - 6/4 GHz (C-band)
  - 8/7 GHz (X-band, military use only)
  - 14/12 GHz (Ku-band)
  - 30/20 GHz (Ka-band)

❒ **Use of DISTINCT BANDS for uplink and downlink avoids satellite output/input INTERFERENCE.**

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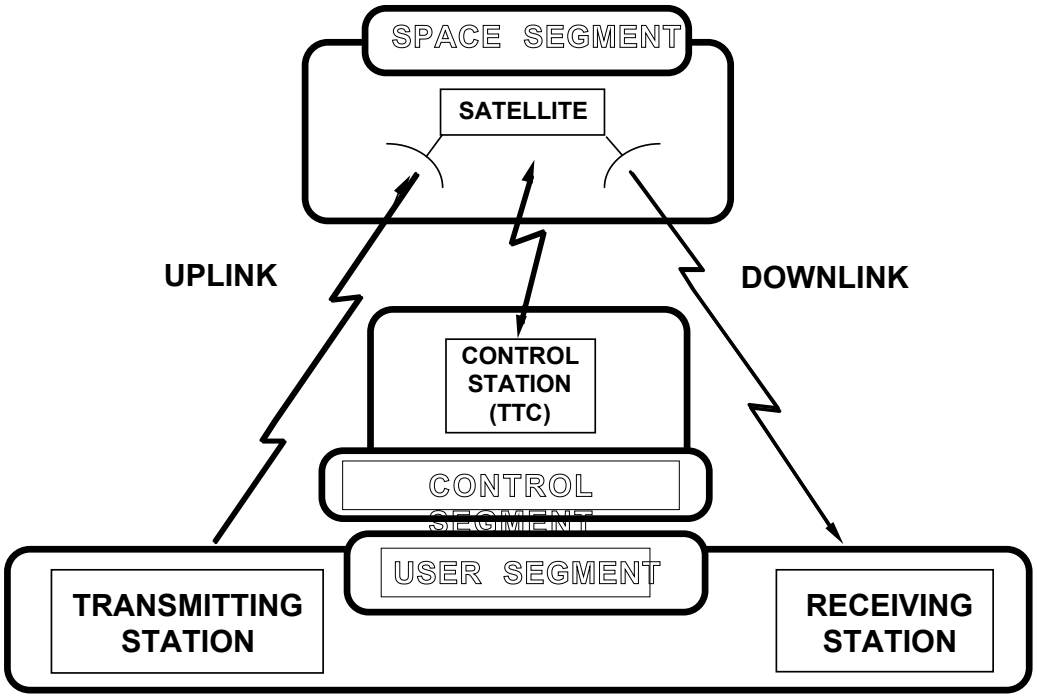
SATELLITE COMMUNICATIONS SYSTEM ARCHITECTURE



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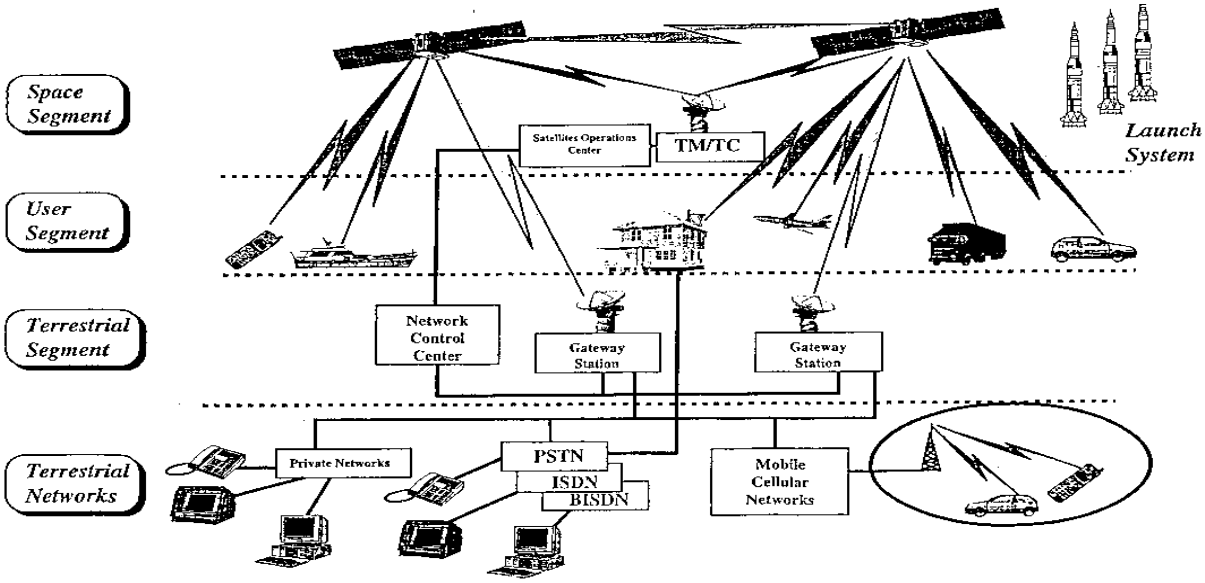
MOBILE SATELLITE SYSTEM ARCHITECTURE



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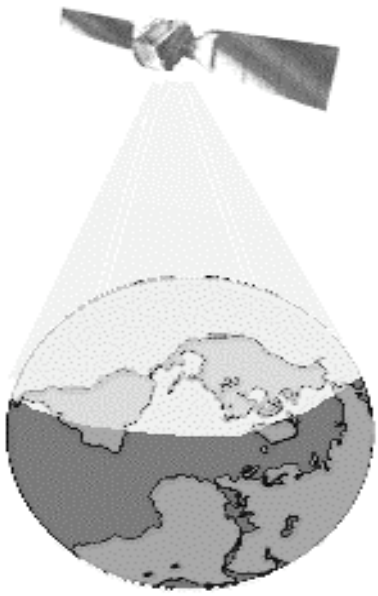
SATELLITE COMMUNICATIONS PROS & CONS

- **ADVANTAGES**
  - **Natural broadcast ability**
  - **Wireless nature useful for mobile applications**
  - **Quick installation**
  - **Bypass rugged terrain**
- **DISADVANTAGES**
  - **Delay (GEO, Propagation time to GEO altitude is around 1/8 second)**
  - **Limited Bandwidth**
  - **Path losses and Noise (error rate)**
  - **Interference**



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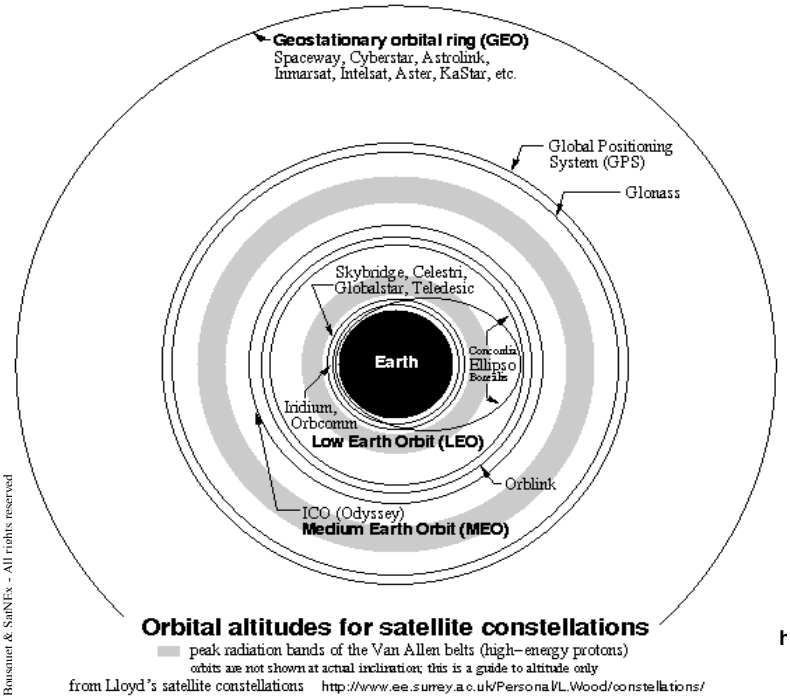
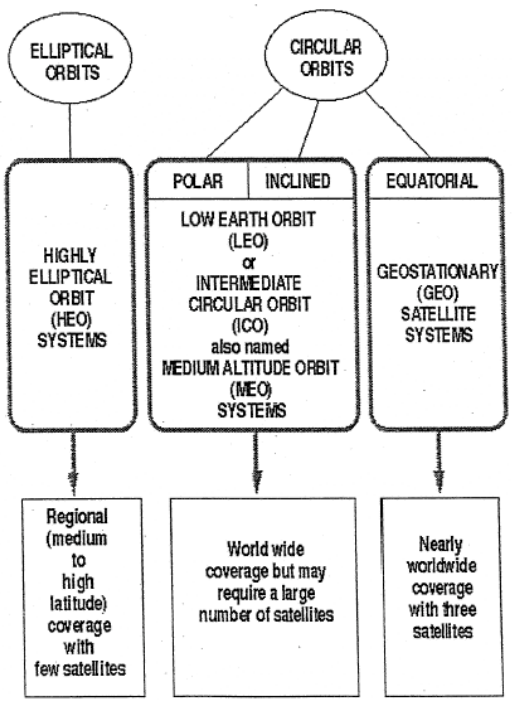
TYPES OF ORBITS





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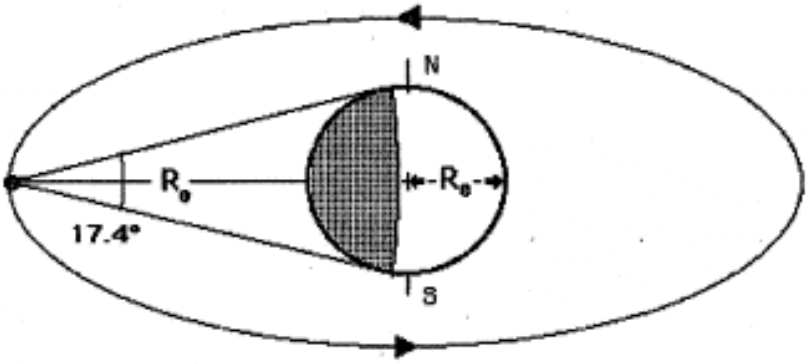
GEOSTATIONARY SATELLITE ORBIT



➢ The satellite orbits in the equatorial plane on a circular orbit at an angular velocity equal to that of the Earth.

➢ Re = Earth radius = 6 378 km Ro = satellite altitude = 35 786 km

➢ The Earth is viewed from the satellite with an angle equal to 17.4°

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GEOSTATIONARY SATELLITE ORBIT

❒ **ADVANTAGES :**

➢ The satellite appears to be fixed at a specific point in the sky when viewed from the Earth.

➢ Very small Doppler shift, satellite permanently in view, no tracking required for small earth station antennas.

➢ 42.4% of the earth's surface is in view from the satellite.

➢ Distant earth stations scattered over large areas may be interconnected

❒ **DRAWBACKS :**

➢ Polar regions (latitudes larger than 81.3°) are not covered.

➢Large propagation delay, about 0.25 s

➢ High power loss (_ 200 dB) on thepath

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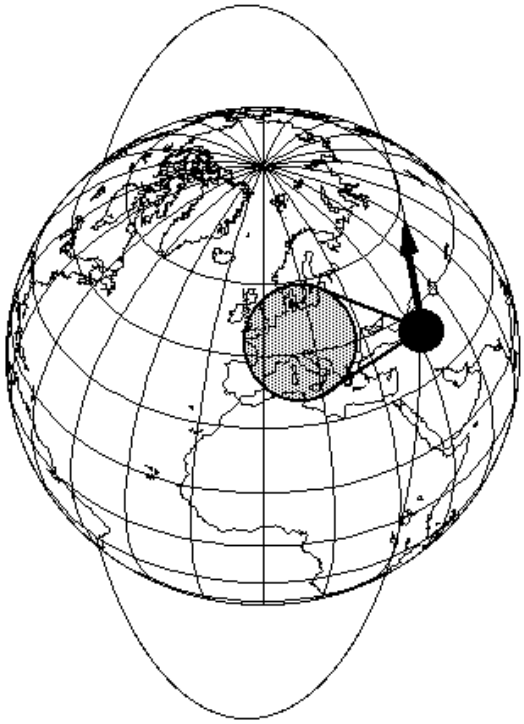
POLAR ORBIT



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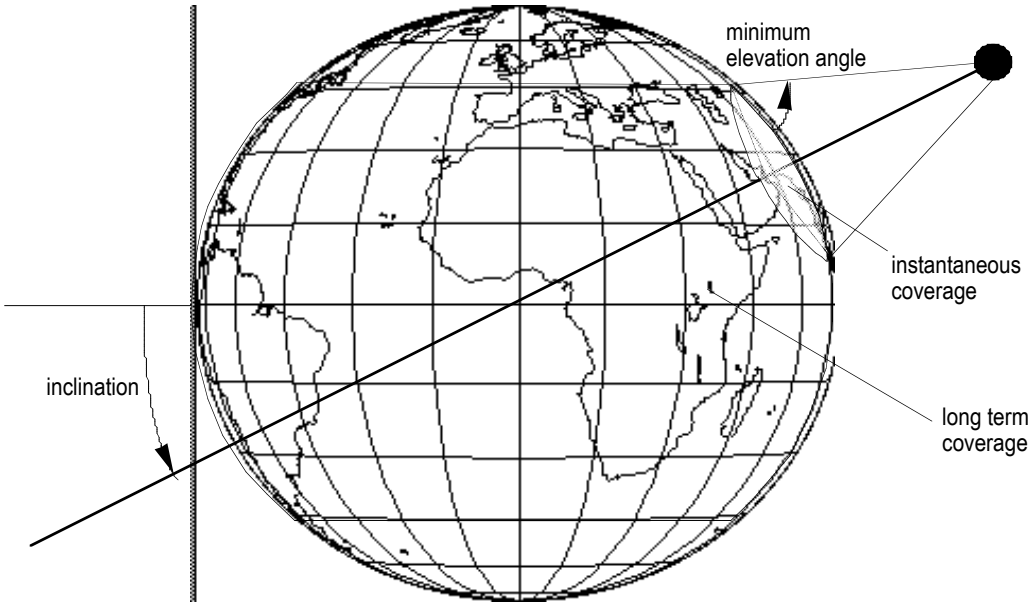
INCLINED ORBIT



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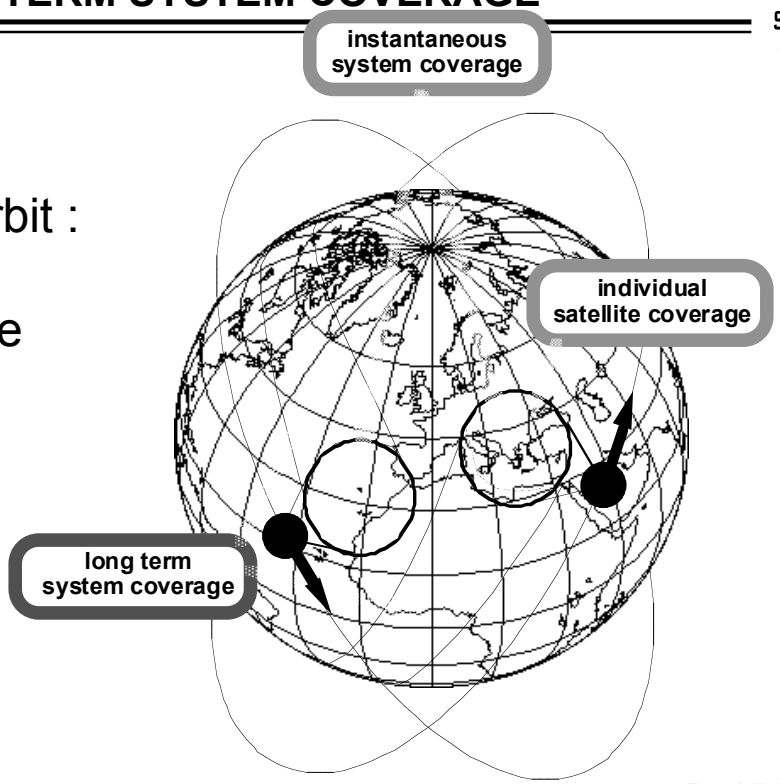
INSTANTANEOUS/LONG-TERM SYSTEM COVERAGE

Polar or inclined orbit :
long-term
system coverage



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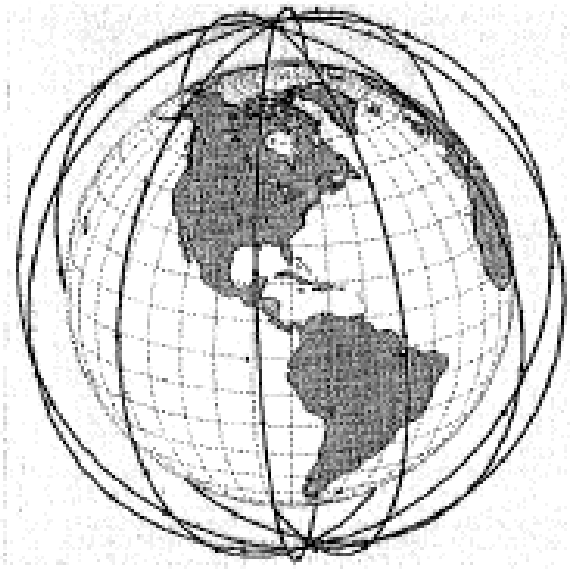
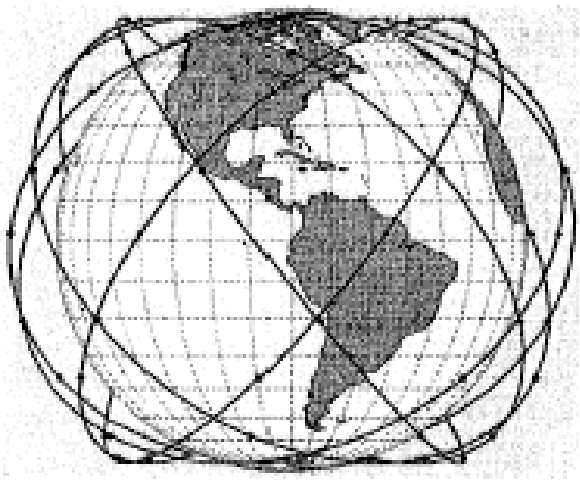
POLAR vs INCLINED ORBIT CONSTELLATIONS

Walker Star (Polar)
Iridium
Teledesic



Walker Delta (Inclined)
Globalstar
ICO



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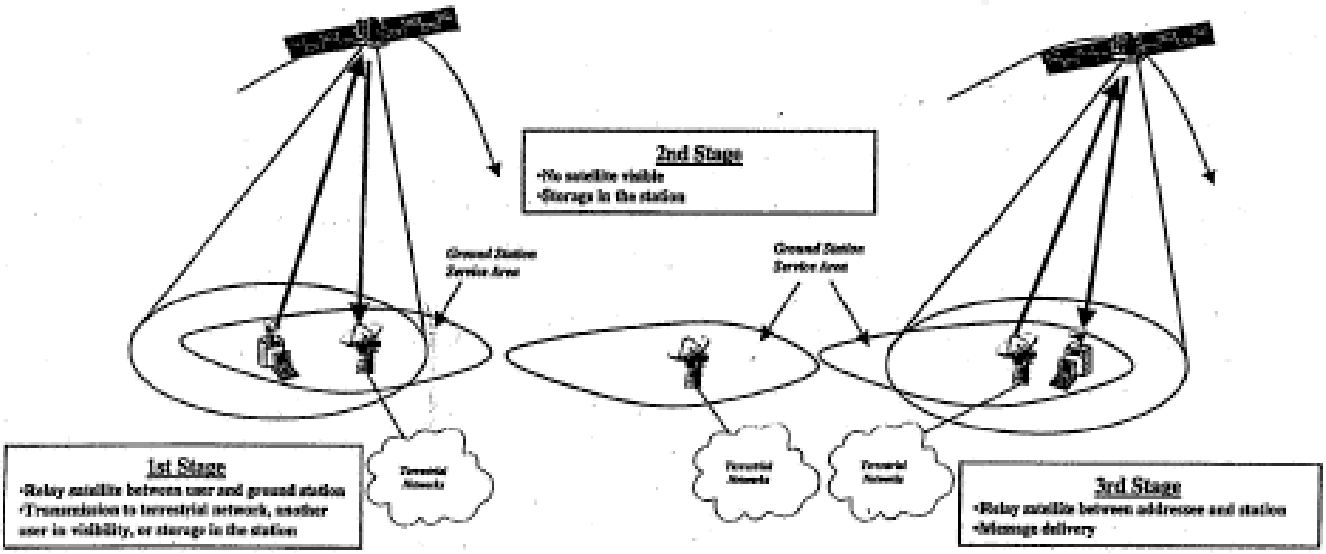
NON REAL TIME ARCHITECTURES: GROUND STORAGE



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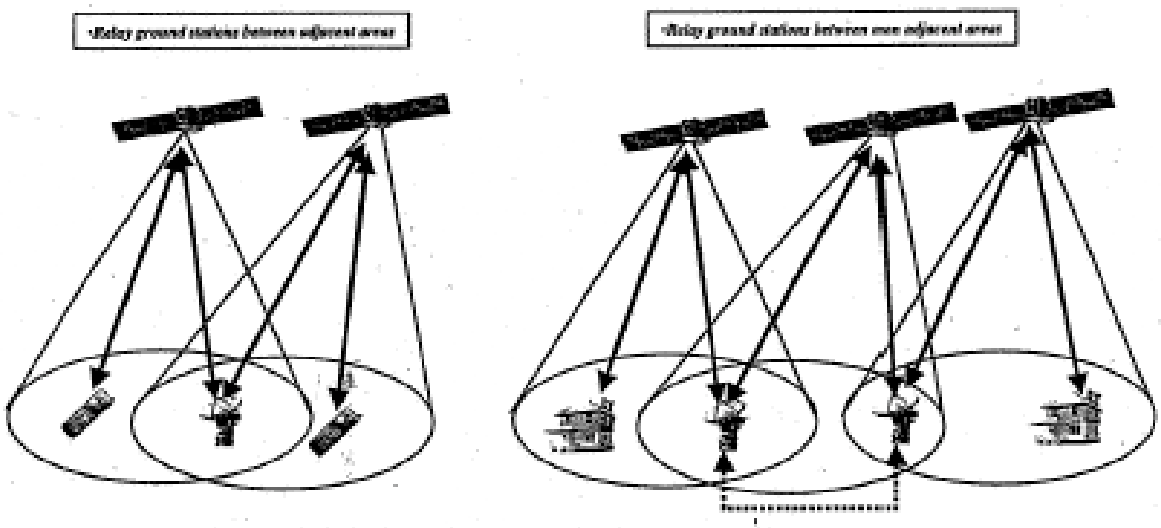
REAL TIME ARCHITECTURES USING RELAY GROUND STATIONS



- Bent pipe payload is enough
- Local , regional or global coverage (LEO,MEO,HEO, GEO)
- Number of hops limited by applications time delay
- Typical applications: globalstar, ICO, ellipso, skybridge,...

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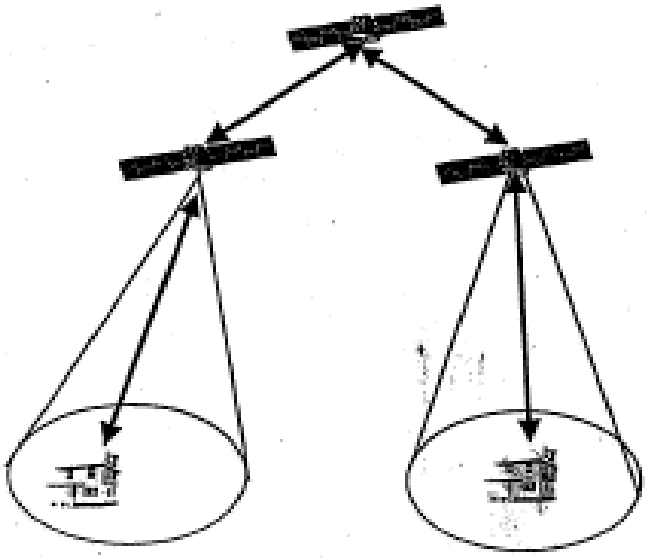
REAL TIME ARCHITECTURE USING INTERSATELLITE LINKS



- More complex payload
- Multi- regional or global coverage (LEO,MEO,HEO, GEO)
- Number of hops limited by applications time delay
- Typical applications: *iridium, teledesic, celestri,astrolink,...*

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COMMUNICATION SATELLITE ARCHITECTURE

COMMUNICATIONS PAYLOAD

ANTENNAS
REPEATER

BUS

STRUCTURE
ELECTRICAL POWER SUBSYSTEM
SATELLITE ATTITUDE CONTROL SUBSYSTEM
PROPULSION SUBSYSTEM
THERMAL CONTROL SUBSYSTEM
TELEMETRY, TRACKING AND COMMAND (TTC)

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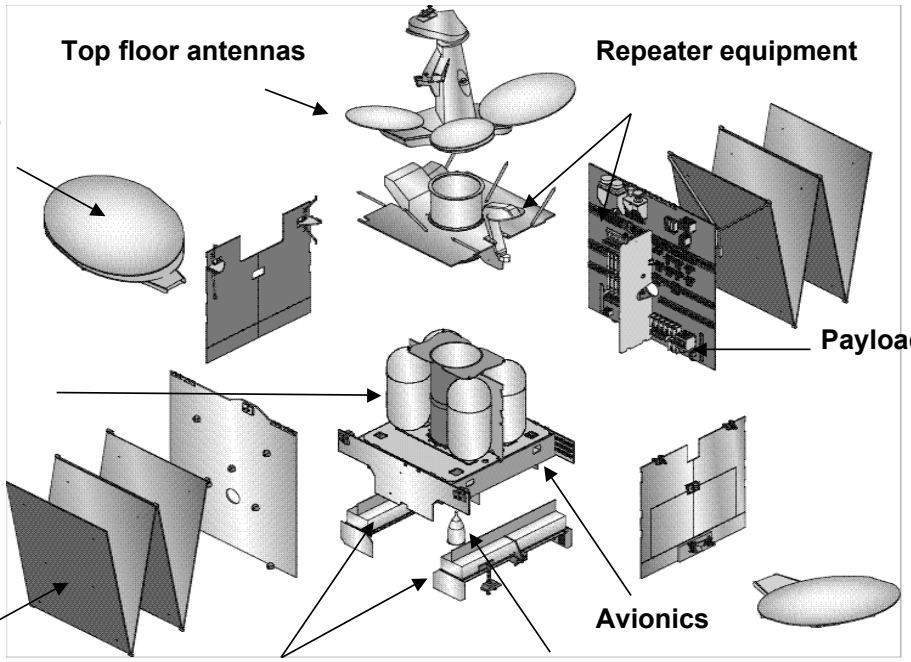
SPACECRAFT SIMPLIFIED LAYOUT



Communications Module

Service Module

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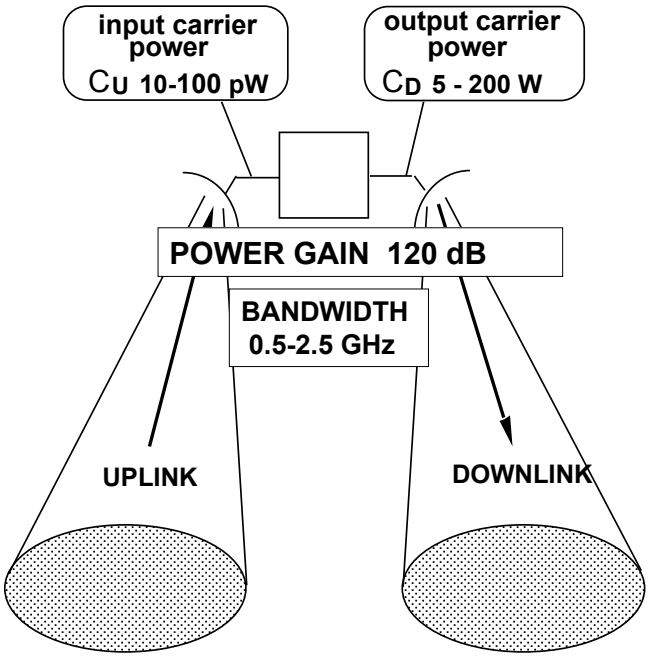
PAYLOAD FUNCTIONS



- COLLECT microwave carriers from given zone on earth
- AMPLIFY radiofrequency carriers
- CONVERT carrier frequency from uplink to downlink frequency
- TRANSMIT microwave carriers to given zone on earth.

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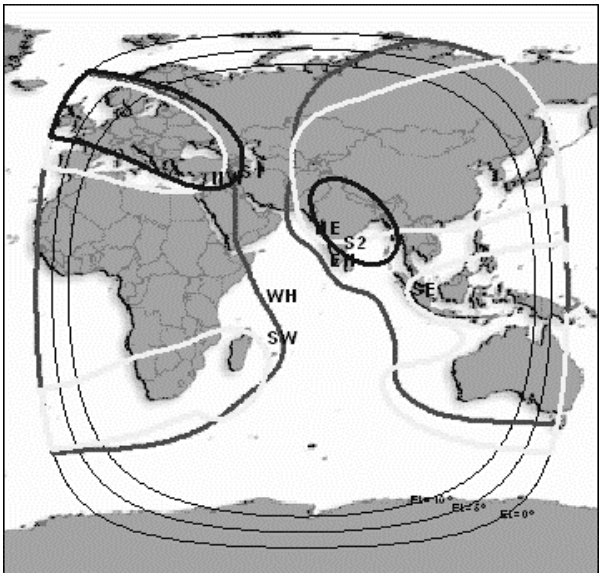
TYPES OF ANTENNA COVERAGE



- GLOBAL coverage antenna
- ZONE coverage antenna
- SPOT BEAM coverage antenna

  e.g. INTELSAT coverage of Indian Ocean Region (IOR)

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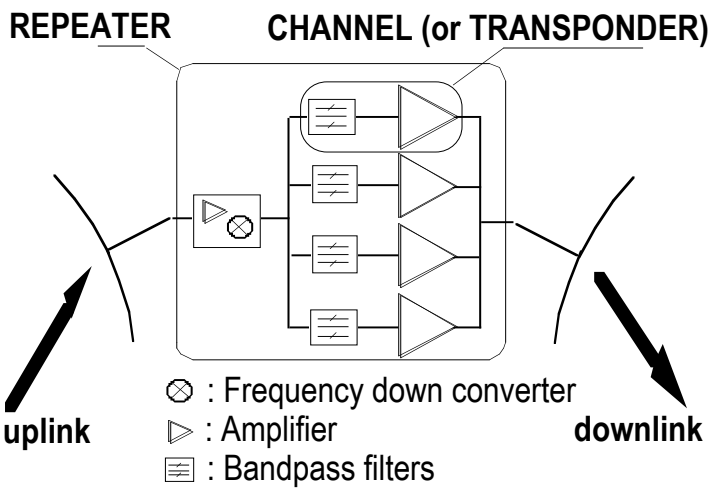
REPEATER AND CHANNELS (OR TRANSPONDERS)



- ➢ Total allocated bandwidth is too large for a single amplifer to deliver sufficient power density (W/Hz).
- ➢ On the other hand, no carrier occupies such a large bandwidth on its own.
- ➢ Hence the total REPEATER bandwidth is split into subbands (a few tens of MHz each).
- ➢ Each subband corresponds to a given so-called CHANNEL or TRANSPONDER

EXAMPLE : A satellite equipped with sixteen 50W- transponders, each with 70 MHz bandwidth, benefits from a total radiofrequency power of 800 W and a total bandwidth of 1.12 GHz.

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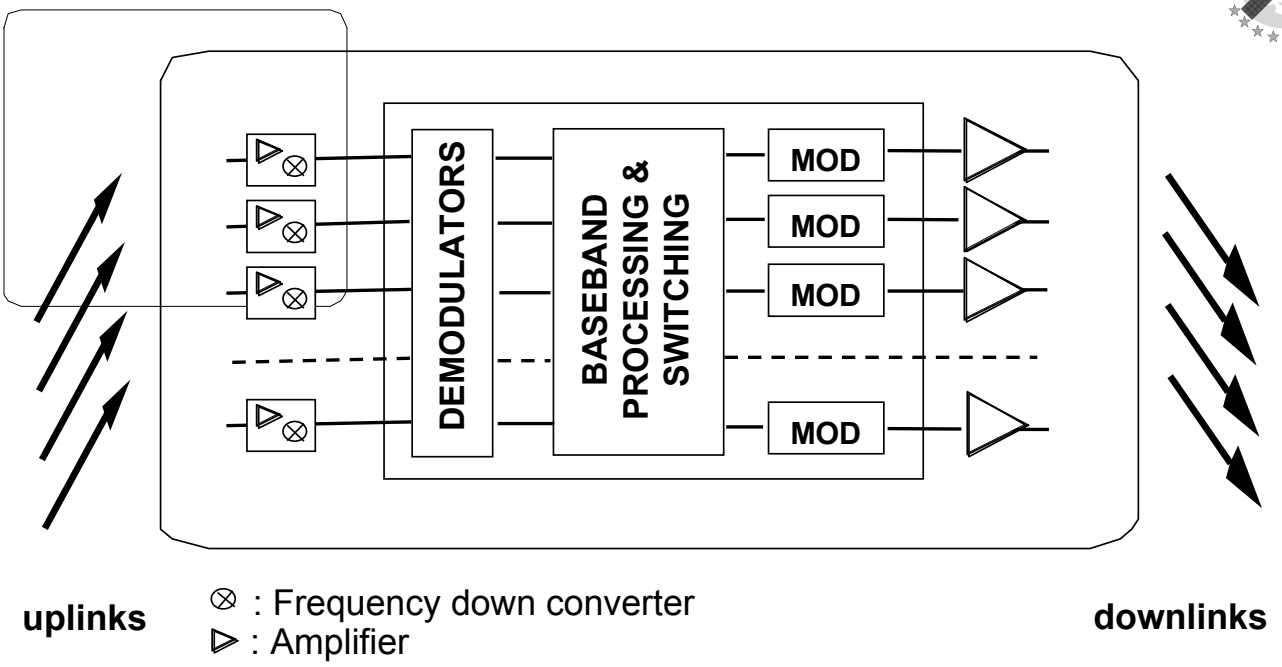
REGENERATIVE/ON-BOARD PROCESSING PAYLOAD



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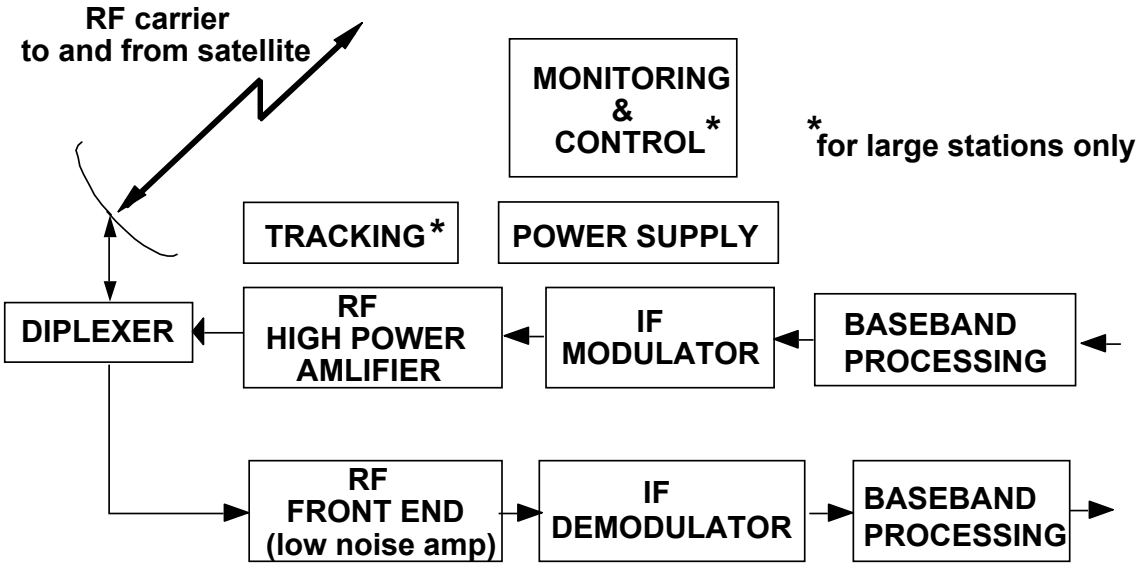
EARTH STATION ARCHITECTURE



RF : Radio Frequency I F : Intermediate Frequency

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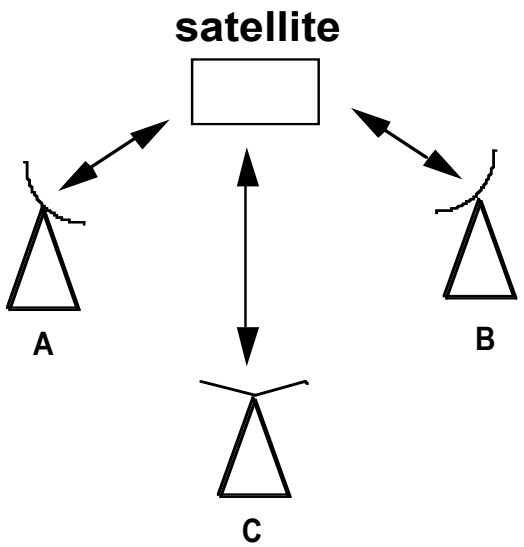
EARTH STATION ACCESS TO SATELLITE



- **COMMUNICATIONS SATELLITE SYSTEMS involve many transmitting and receiving earth stations accessing simultaneously a UNIQUE SATELLITE.**
- **This poses the problem of MULTIPLE ACCESS.**

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MULTIPLE ACCESS

- **Three main ways to allow several stations to share the communication system resource**
  - **FDMA** – Frequency Division Multiple Access
    - Each station gets their own frequency channel
    - Simple, but intermodulation due to non linearities
  - **TDMA** – Time Division Multiple Access
    - Each user gets a turn in time to use the resource
    - No intermodulation, but needs synchronization procedures
  - **CDMA** – Code Division Multiple Access (spread spectrum technique)
    - Each user gets a code to extract their data
    - Encoded, jam resistant, potential for greater capacity

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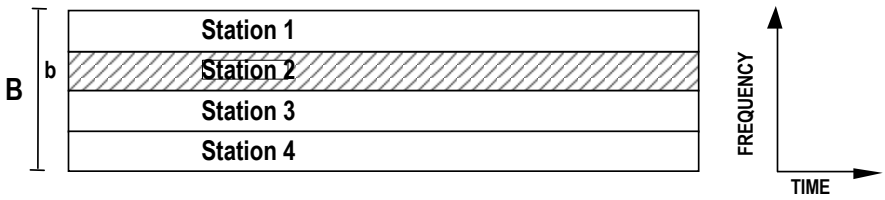
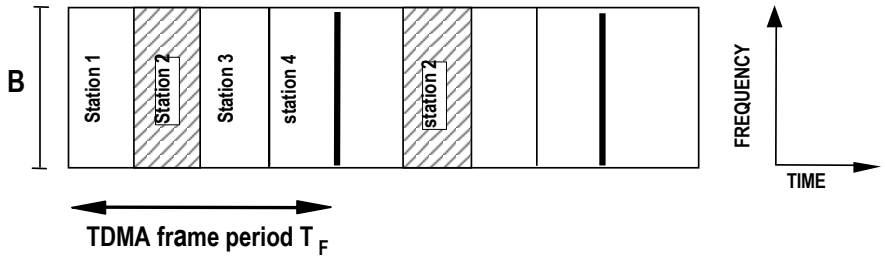
MULTIPLE ACCESS

FREQUENCY DIVISION MULTIPLE ACCESS (FDMA) :



TIME DIVISION MULTIPLE ACCESS (TDMA) :



CODE DIVISION MULTIPLE ACCESS (CDMA) :

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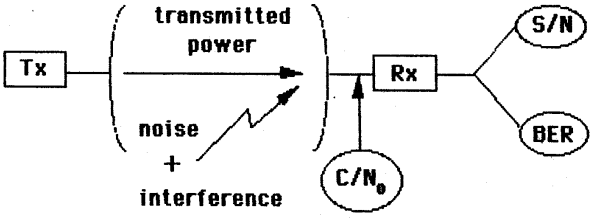
LINK PERFORMANCE EVALUATION



- **RF LINK PERFORMANCE**
  - Characterized by C/N_0 ratio at receiver (Rx) input, where :
    - C : power of received carrier (W)
    - N_0 : Power Spectral Density of noise (W/Hz

EIRP (W) Rx Figure of merit (K^{-1})

$$C/N_0 = (P_T G_T)(1/L)(G/T)(1/k)$$

Path Loss

- **USER LINK PERFORMANCE**
  - Link performance expresses in terms of Bit Error Probability (or BER)
  - BER is related to $(C/N_0)_T$ depending on Bit Rate & Coding and Modulation format

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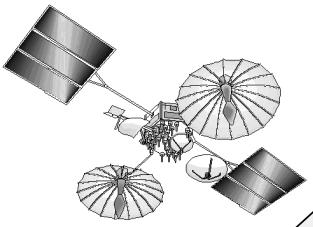
SIMPLIFIED LINK BUDGET

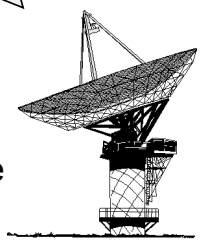


Transmitter power Pt = 10 dBW
Antenna Gain Gt = 45 dB
EIRP = Pt Gt = 55 dBW

[C/No] = EIRP – Lfs + Gr/T + 1/k
dbHz

dBx = 10 $\log_{10}$ (x)

Free space loss
Lfs = 200 dB



Received carrier power
C = EIRP – Lfs + Gr
= -115 dBW = 3.16 pW

Antenna Gain Gr = 30 dB
System Noise Temperature
T = 200 K = 23 dBK

Noise power density No = kT
= - 223:6 + 23 = - 200.6 dBHz

C/No = 85.6 dBHz = 3.63 10^8 Hz

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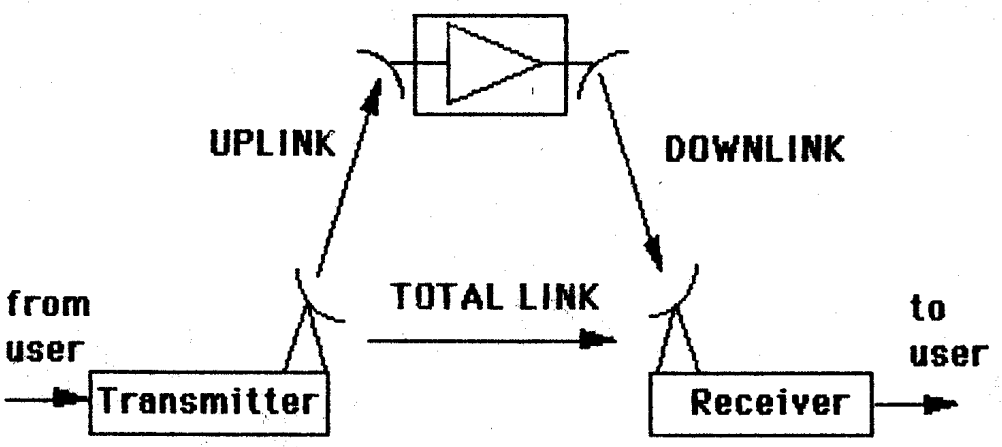
OVERALL LINK ARCHITECTURE



- **TOTAL (OR OVERALL) RF LINK PERFORMANCE DEPENDS ON :**
  - **RF uplink performance**
  - **RF downlink performance**

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OVERALL LINK BUDGET with INTERMOD & INTERFERENCE

- **INTERMODULATION ISSUES**
  - Non-linear amplifiers (earth station and mainly satellite)
  - Multicarrier operation results in intermodulation products
  - Intermodulation noise corrupts useful modulated carriers

- **SOURCES OF INTERFERENCE**
  - Within the considered satellite system (frequency reuse, filter masks..)
  - Between different Satellite systems operating in the same frequency band
  - Satellite systems ↔ terrestrial microwave systems

$$(C/N_0)_T^{-1} = (C/N_0)_U^{-1} + (C/N_0)_D^{-1} + (C/N_0)_{IM}^{-1} + (C/N_0)_I^{-1}$$

where:

$(C/N_0)_I$ represents the Carrier power-to-Intermodulation noise power density Ratio
$(C/N_0)_I$ represents the Carrier power-to-Interference noise power density Ratio
(includes uplink and downlink contributions)

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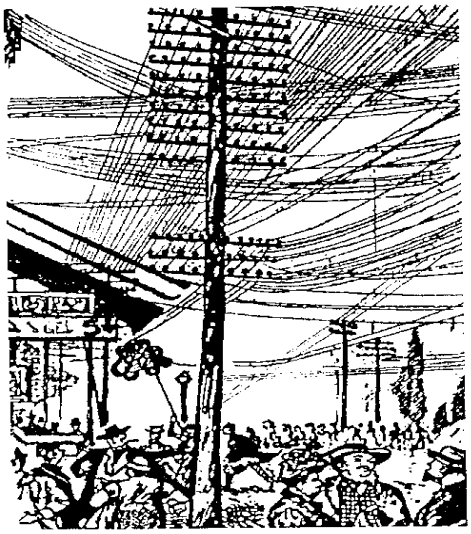
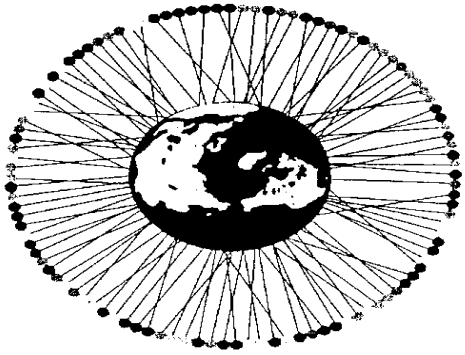
AVAILIBILITY OF SPECTRUM AND ORBITAL SPACE

The old problem





The new problem

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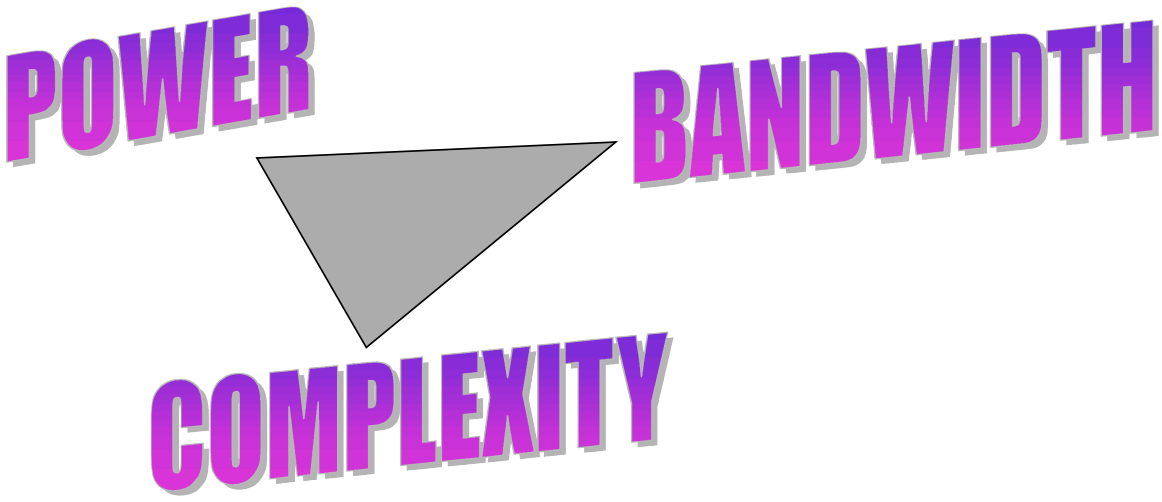
DESIGN TRADE-OFFS

- **DESIGNER HAS TO TRADE ONE OF THESE THREE AGAINST THE OTHER TWO**



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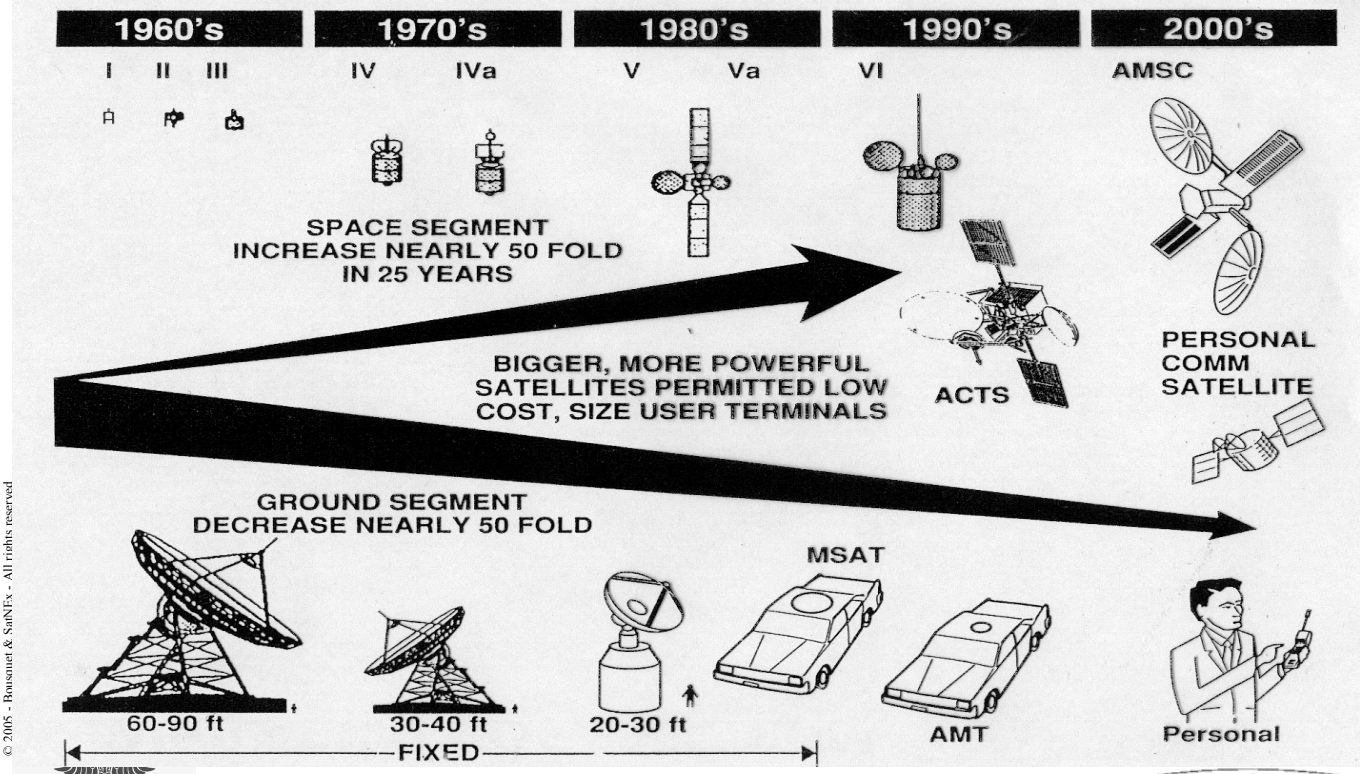
SATELLITE SYSTEMS EVOLUTION (1)



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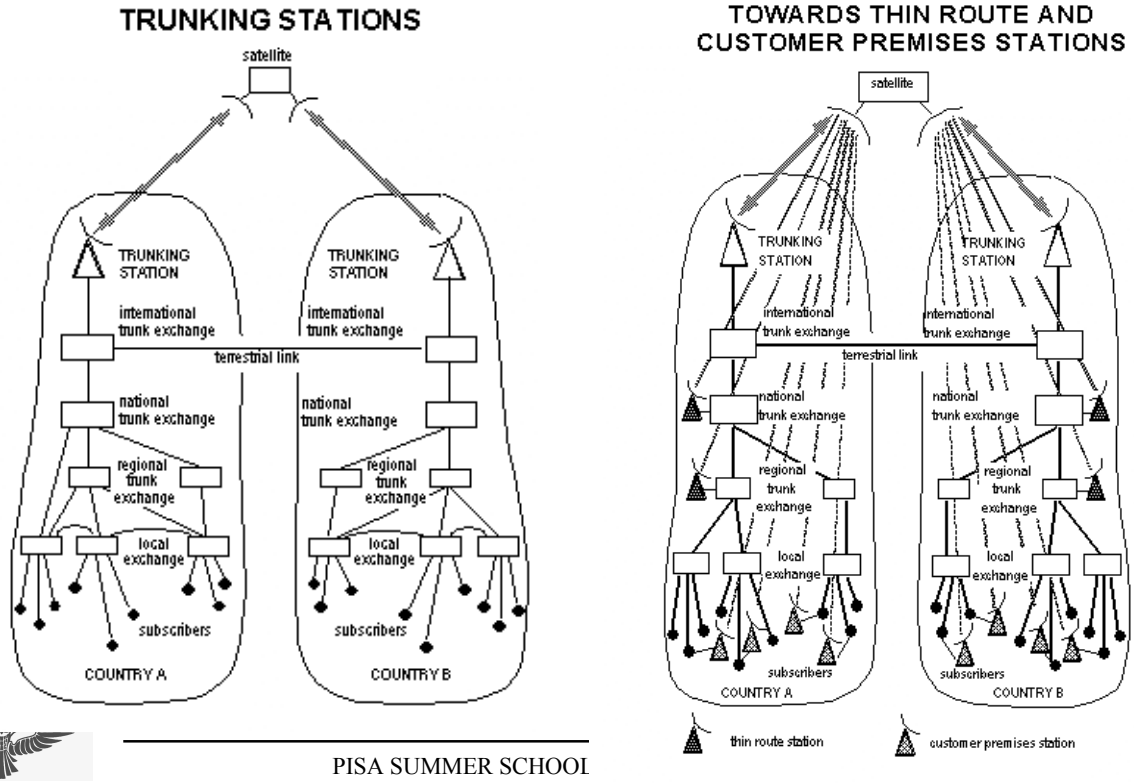
SYSTEM ARCHITECTURE EVOLUTION



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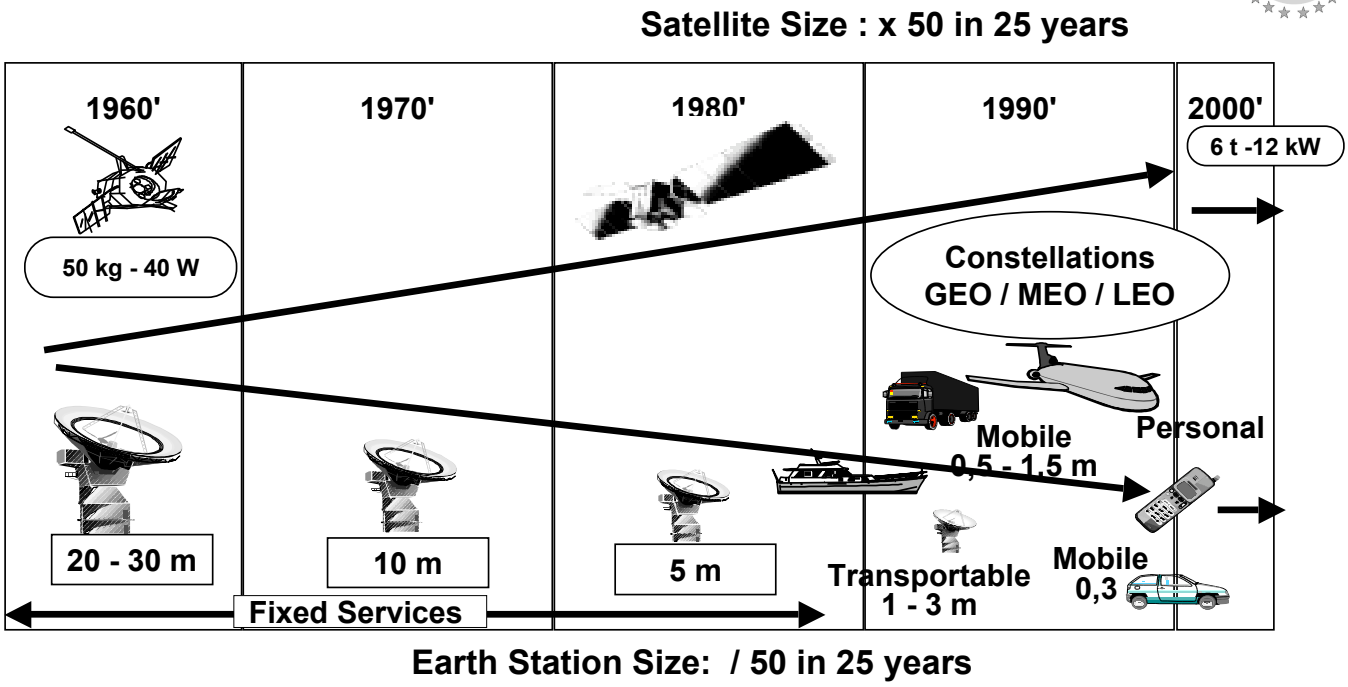
SYSTEMS and SERVICES EVOLUTION (2)



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INMARSAT 4

Mission

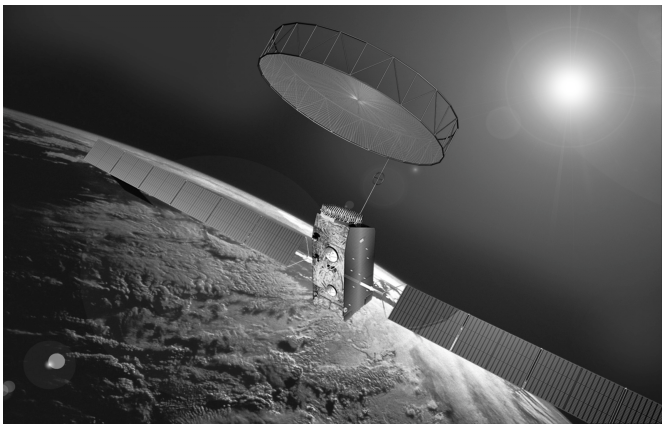
- 3rd generation mobile communications via satellite : hand held telephony, data and Internet access to laptop and palm computers up to 432 Kbps
- enhanced Inmarsat 3 communication and navigation services over Americas, Europe, Africa and Asia

Characteristics

- 630 channels of 200 kHz in L-band
- 200 spot beams
- Processed payload
- Payload power 9 kW
- Lifetime > 10 years,
- Mass at launch : 5.5 tons
- Prime Contractor: Astrium
- E3000 platform

Launch

- 1st satellite launched early 2005 + 1
- 1 spare, might be launched later



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Service Trends

- **Seeking new and user-friendly services**
- **Representing good value for money**
- **Integrating today & tomorrow´s multimedia services**
  - Industry convergence: Telecom, TV, Broadcasting, Computer
- **Improving reliability and safety**
  - Road, Sea, and Air Transportation

SATELLITE AT THE CONVERGENCE OF TELECOMMUNICATION, BROADCASTING, AND INFORMATION TECHNOLOGY

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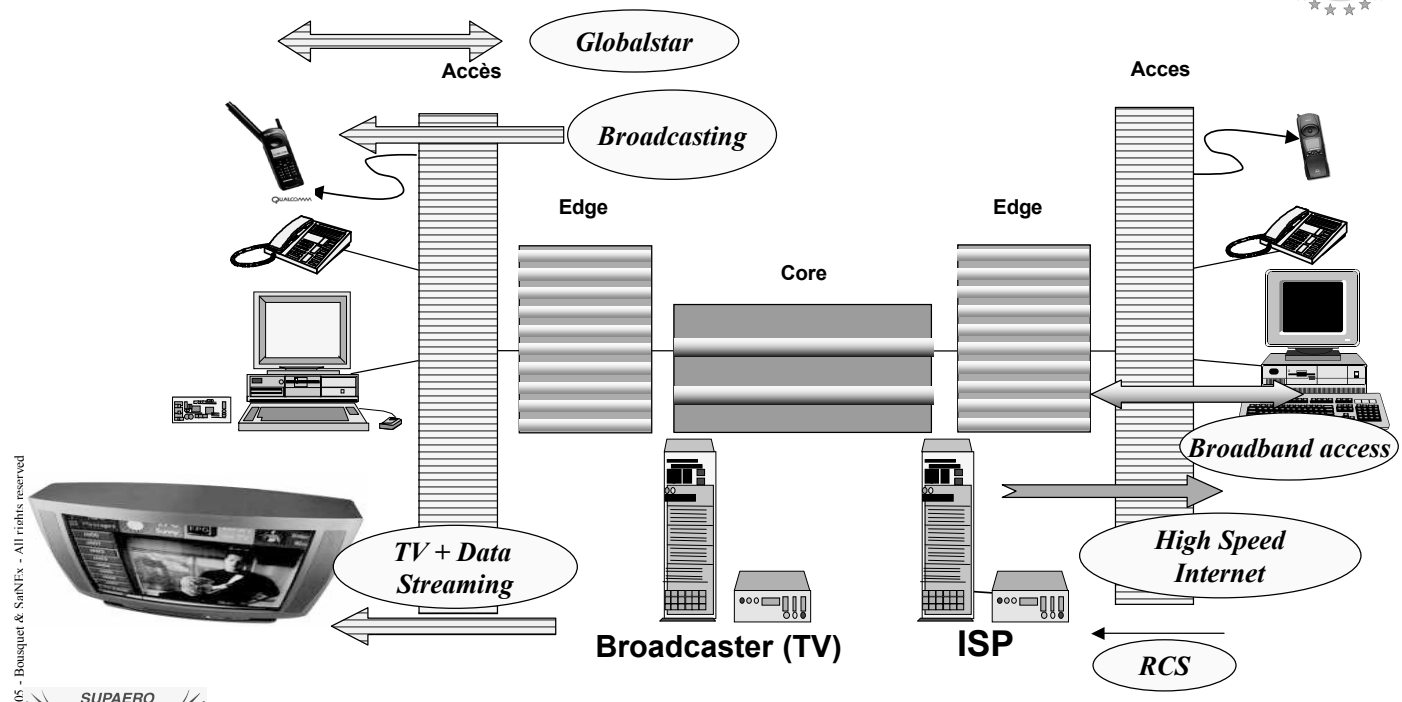
ACCESS SERVICES – « LAST MILE »



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Technical Trends

- ➢ **Signal recording and transmission techniques going from ANALOG to DIGITAL**
- ➢ **Digital COMPRESSED information along with High Speed INTERACTIVITY**
- ➢ **GEO systems complemented with Non-GEO constellations**
- ➢ **More powerful satellites, bigger antennas in GEO**
- ➢ **Higher frequencies (Ka-band –30/20 GHz, optical comms…)**
- ➢ **On-board processing and switching, intersatellite links…**

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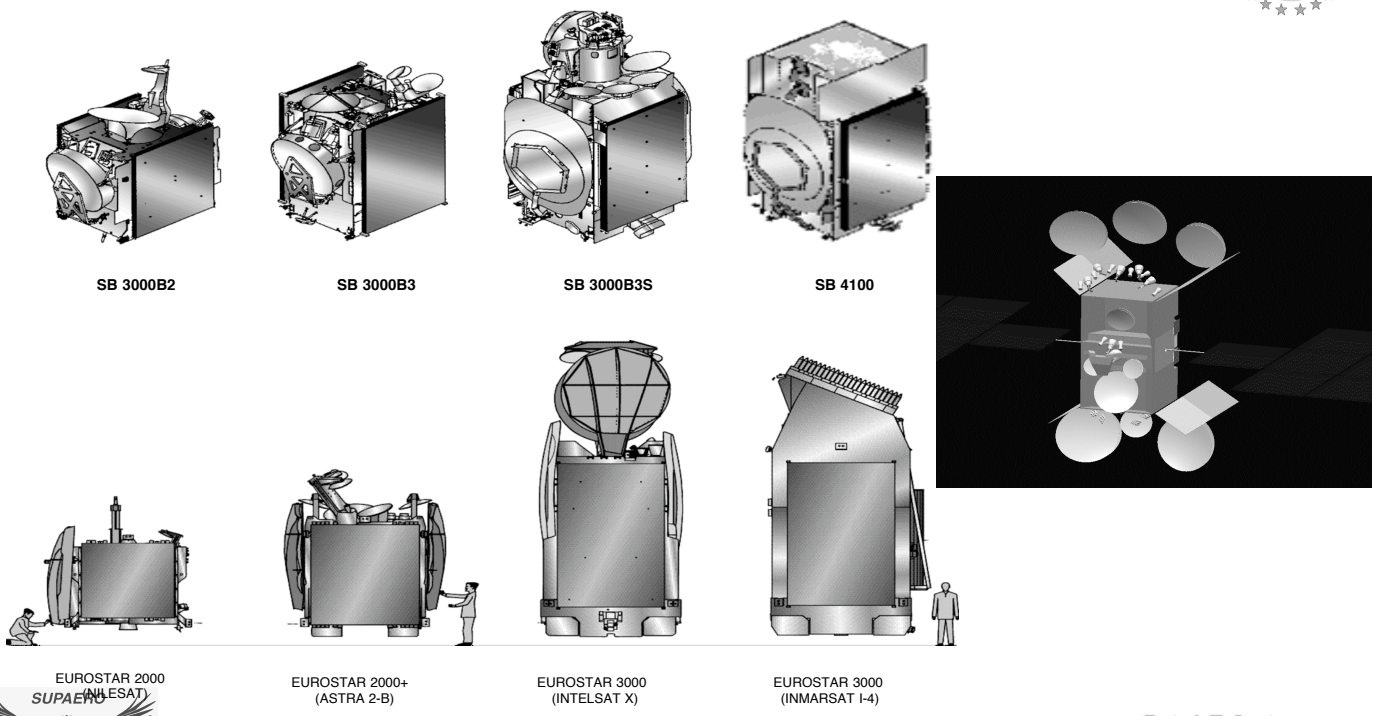

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HISTORY TIMELINE

Clarke's orbit	**1945**	
Spoutnik	**1957**	
Score	**1958**	**Eisenhower Xmas greetings**
Echo	**1960**	**reflective balloon**
Courrier	**1960**	**Store-and forward**
Syncom	**1963**	**1st GEO satellite**
INTELSAT I	**1965**	**1st Commercial GEO**
MOLNYA	**1965**	**1st Soviet ComSat HEO**
Anik	**1972**	
DirectTV	**1994**	
Iridium	**1998**	**First Mobile constellation**
Wordstar	**1999**	**1st Digital audio Broadcast**
Thuraray	**2000**	**1st Mobile GEO**
??	**200?**	**1st Multimedia Ka-band**

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Co-operative Research Laboratory

Prof Michel BOUSQUET
Director Aerospace Communications Programmes
SUPAERO
BP 54025 - 10 avenue Edouard Belin
F-31055 TOULOUSE Cedex 4
Tel: +33 562 17 8086 - Fax: +33 562 17 8345
michel.bousquet@supaero.fr
michel.bousquet@tesa.prd.fr
http://www.supaero.fr

TéSA
14-16 Port Saint Etienne
31000 TOULOUSE
http://www.tesa.prd.fr

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EVOLUTION OF SATELLITE COMMUNICATIONS

Service Trends

- **Seeking new and user-friendly services**
- **Representing good value for money**
- **Integrating today & tomorrow´s multimedia services**
  - Industry convergence: Telecom, TV, Broadcasting, Computer
- **Improving reliability and safety**
  - Road, Sea, and Air Transportation

SATELLITE AT THE CONVERGENCE OF TELECOMMUNICATION, BROADCASTING, AND INFORMATION TECHNOLOGY

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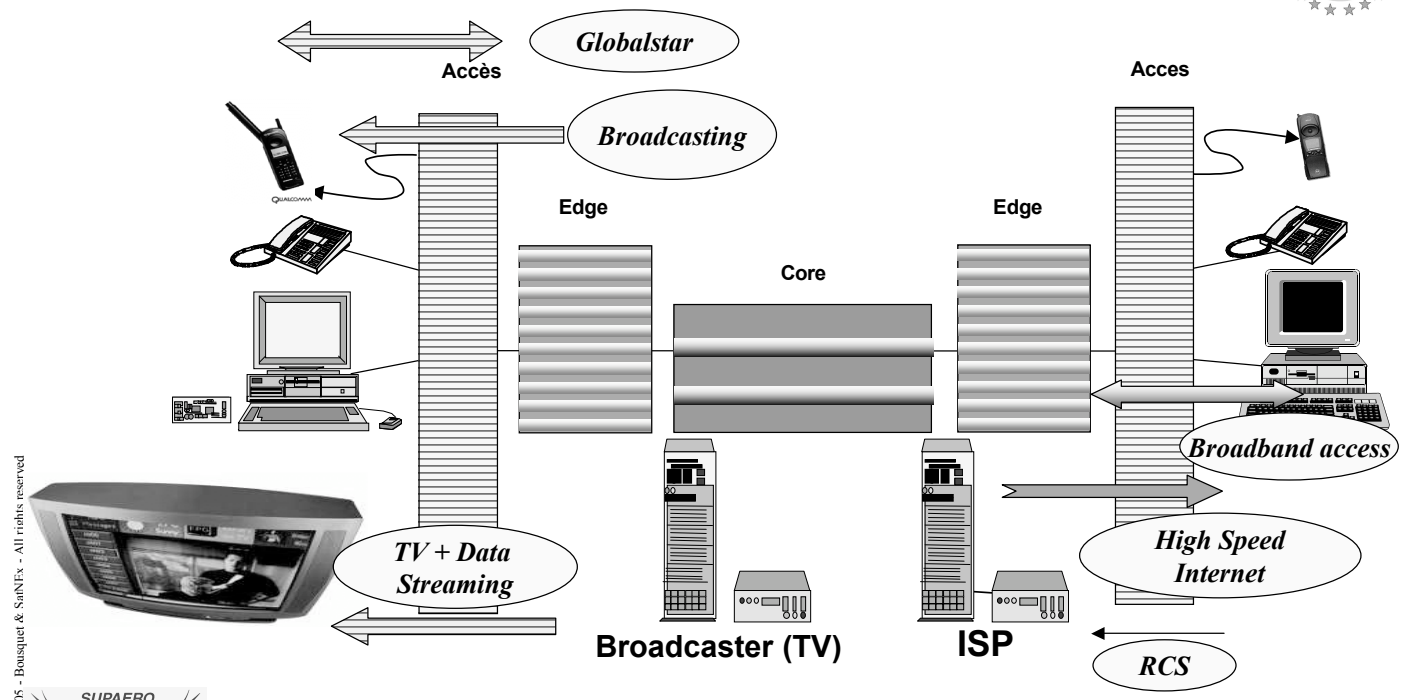
ACCESS SERVICES – « LAST MILE »



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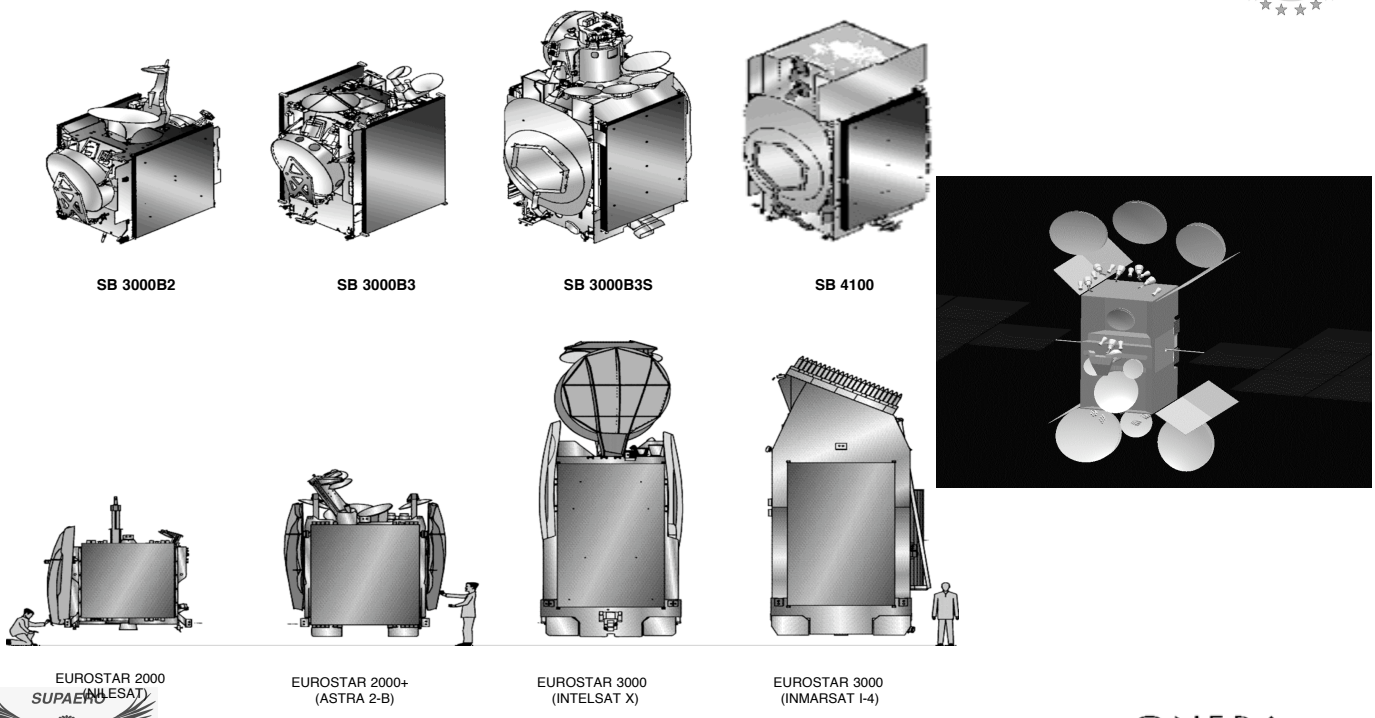

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SUPAERO
BP 54025 - 10 avenue Edouard Belin
F-31055 TOULOUSE Cedex 4
Tel: +33 562 17 8086 - Fax: +33 562 17 8345
michel.bousquet@supaero.fr
michel.bousquet@tesa.prd.fr
http://www.supaero.fr

TéSA
14-16 Port Saint Etienne
31000 TOULOUSE
http://www.tesa.prd.fr

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