EENG 470
Satellite Communications

Lecture # 1
Introduction to Satellite Communications

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Course Contents

1. Introduction

1.1 What do satellites do? (Types of satellites, The satellite market)

1.2 Different orbits for different missions.

1.3 Advantages and disadvantages of satellite communications.

1.4 Frequency Allocations for satellite services Satellite frequencies (L, S, C, X, ku, ka, examples)

2. Orbit control and Launching Methods

2.1 Launch Vehicles and services (How are satellites placed into orbit)

2.2 Keppler law, coverage area, Doppler effect

2.3 Tracking, telemetry and Command

2.4 Attitude control subsystem

2.5 Launching orbits (polar, inclined, equatorial, LEO, MEO, GEO)

2.6 Power, Thermal Control

3. Microwave Link Budget

3.1 Link budget (system noise, uplink, downlink, effects of Rain)

3.2 Cross link

3.3 Interference

Course Contents

4. Space Segment (BUS Configuration and subsystems)

4.1 Transponder model, Payload, Bus, TT&C

4.2 Satellite Transponder

4.3 Station keeping and TT&C subsystem

4.4 Space segment processing (frequency translation)

5.Earth station Segment

5.1 Earth station configuration

5.2 Tracking Telemetry & Command (TT&C) ground facility

5.3 FECC, Direct broadcasting satellites

5.4 Home TV systems, LNB

6. Satellite Antennas

6.1 Corrugated Horn antenna, Double reflector antennas.

6.2 Multifeed Offset Fed Parabolic Reflector.

6.3 Shaped reflector for (multibeam radiation).

6.4 Phased arrays.

6.5 Earth footprints and power levels (EIRP).

Course Contents

7. Digital communication techniques

7.1 Modulation Techniques.

7.2 FDMA (Power requirement of the transponder)

7.3 TDMA (Network synchronization, closed loop timing)

7.4 CDMA (DS, FH)

7.5 Error Correcting Codes

8. Applications and Seminars / Projects

Course grades

Lab + HWs	20%
Test1	20%
Projects	20%
Final test	40%

Course References

Textbook:

1. Satellite Communications, By Timothy Pratt, Charles Bostian, and Jeremy Allnutt, John Wiley, 2003

References:

1. Dennis Roddy, "**Satellite Communications**", 3rd edition, McGraw-Hill, 2001.
2. G. Maral & M. Bousquet, ***Satellite Communication Systems***, John Wiley and Sons, Inc., 1999.
3. 2. J.J Spilker, "**Digital communications by satellites**", prentice hall, 1977.
4. 3. Bruce R. Elbert, "**Introduction to Satellite communications**", 2nd Edition, Artech House, 1999.

Project / Seminars: communication applications

1. Satellite Internet Based.
2. Direct Broadcasting satellite services
3. Satellite mobile services
4. VSATs (very Small aperture satellites)
5. Remote sensing satellites +SAR
6. ‘GPS’ Global positioning Satellite system
7. GMDSS, search and rescue(SAR), NOAA
8. Small Satellites
9. Digital communications for satellites
10. International Space Station (ISS)

Required:

1. Written report with references.
2. Each subject should consider a specified sat as an example (30%)
3. Power point presentation (30%)
4. Every student will be given a time to present his report to the class in 45 min and 15 mins for discussion.

4. The seminars will start from the 8^{th} week.

Course Description:

This course covers the most relevant aspects of satellite communications, with emphasis on the most recent applications and developments.

The course begins with a review on the background and basic concepts of satellite communications. Next it covers the orbital aspects, with emphasis on the geostationary orbit. Satellite subsystems, launching methods, and on-board processing are also discussed.

The design of a digital satellite link is discussed in detail, including link budgets, modulation, error control coding, baseband signaling theory, and multiple access methods. Frequency assignments and propagation aspects that affect the satellite link are then discussed.

Antennas and earth station technology are presented, including the design of very small aperture terminals (VSATs). The course then covers non-geosynchronous orbits and their applications. Specific applications of satellites are also explored, including the global positioning system (GPS), satellites for mobile communication, and satellites for internet

Topics to be Covered:

- Introduction and Background
- Orbital Aspects and Launching
- Spacecraft Subsystems
- Link Budgets
- Modulation, Multiple Access & On-Board Processing , Error Correcting Codes
- Antennas and Frequency & Propagation Aspects
- Applications (GPS, Mobile, Internet, etc.)


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598826544


СОЮЗ

satellite

Satellite dish with antenna

sattelite

satellite

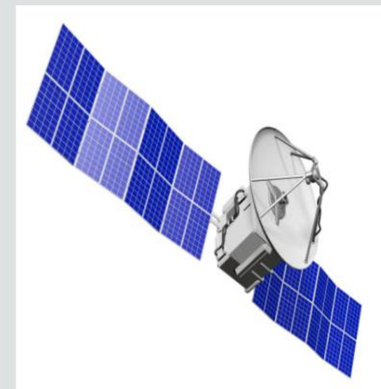
Orbiting satellite isolated on white

Satellite dish with solar panel isolated...

Modern World Global Navigation Satelite. 3d R...

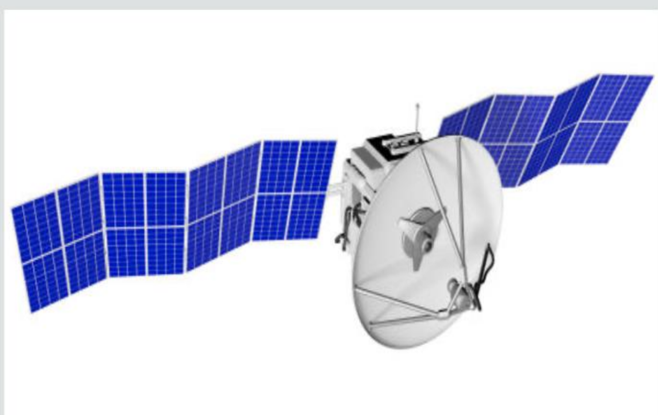
Satellite

Communication Space Satellite Isola...



orbital satellite industrial illustration - spacesh...

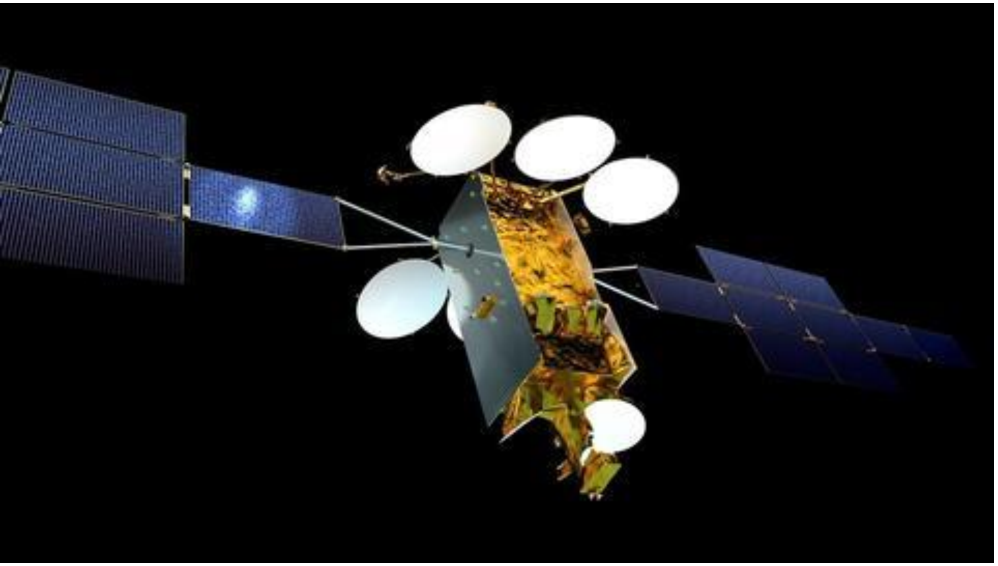
Telecommunication Satellite



space satellite industrial illustration - spaceship with big...

satellite on grey background

Satellite Deploys Solar Panels



Eurostar NEO

XMM-Newton was the most powerful X-ray telescope ever placed in orbit and set the record as the biggest scientific satellite built in Europe. It had a launch mass of 3,800 kg., with an overall length of 10 metres.

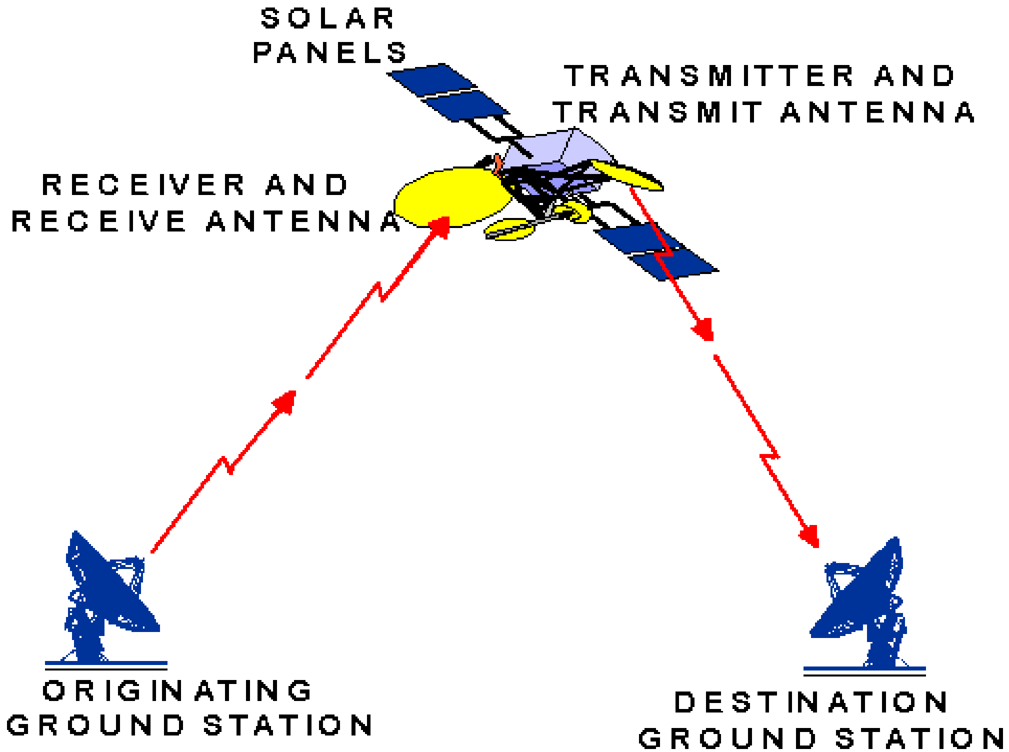
Galileo satellites in orbit around the Earth.

Eutelsat Hotbird 13F telecommunications satellite in the mechanical test facility

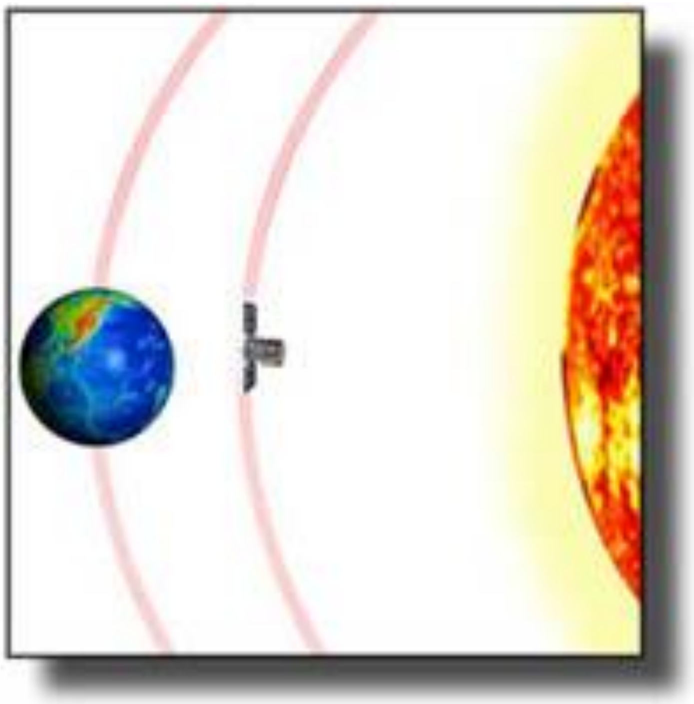
Introduction

Types of satellite services

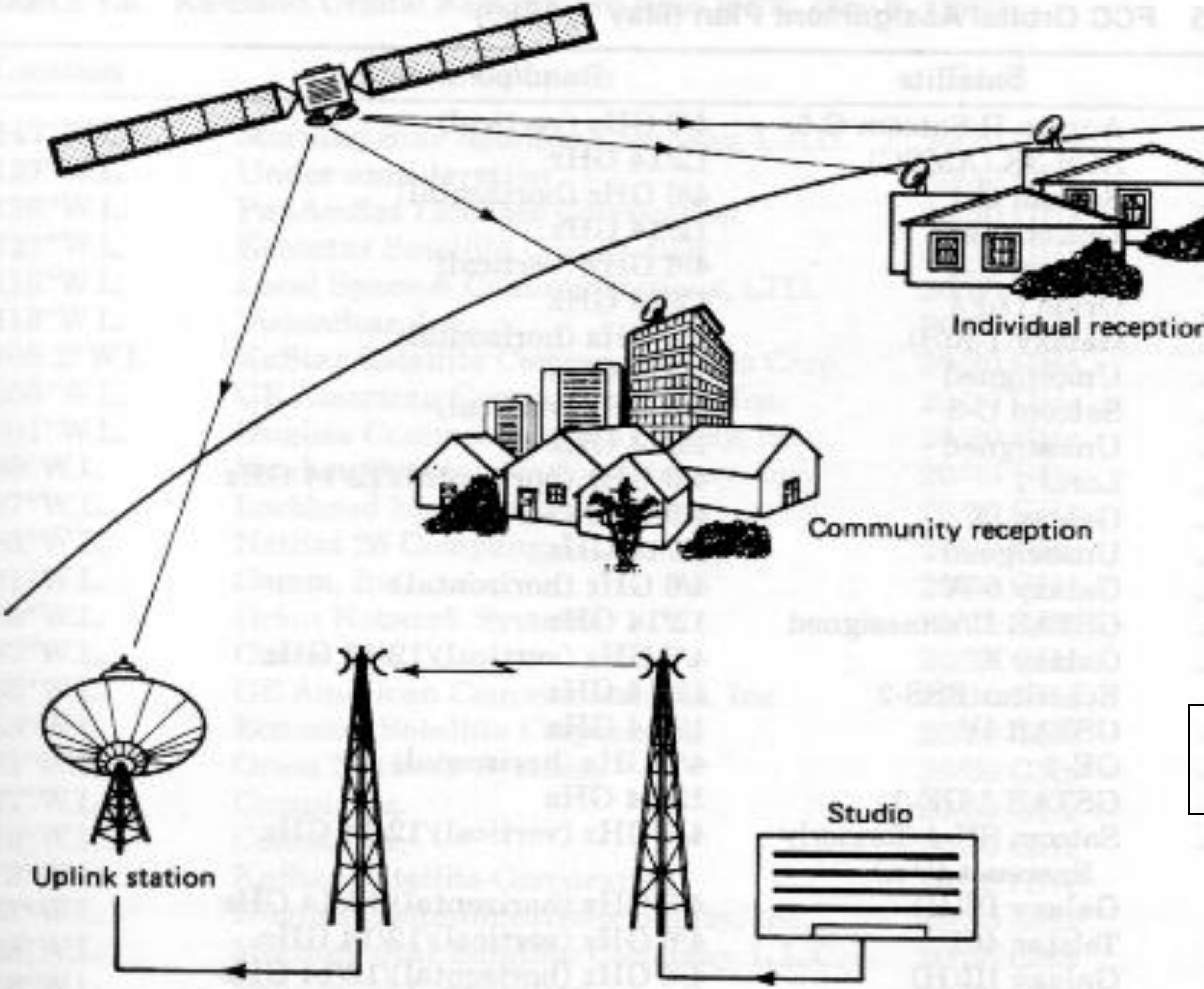
1. **Fixed satellite service (FSS)**
   - Links for existing telephone networks
   - Transmitting TV signals to cable companies.
2. **Broadcasting Satellite Service (BSS)**
   - Direct to home (DTH) =Direct broadcasting satellites (DBS)
3. **Mobile satellite service (MSS)**
   - Land mobile , maritime mobile and aeronautical mobile
4. **Navigation satellite service (GPS)**
   - Global positioning system (S&R)
5. **Meteorgolical satellite service (Weather Forecast)**
6. **Deep Space Satellites**



(FSS) Radio Relay station in space



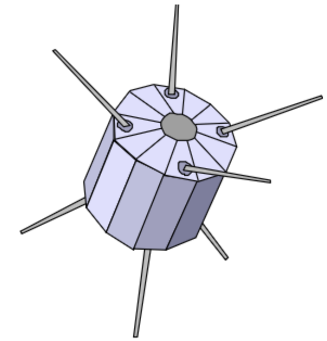
Deep Space Satellites



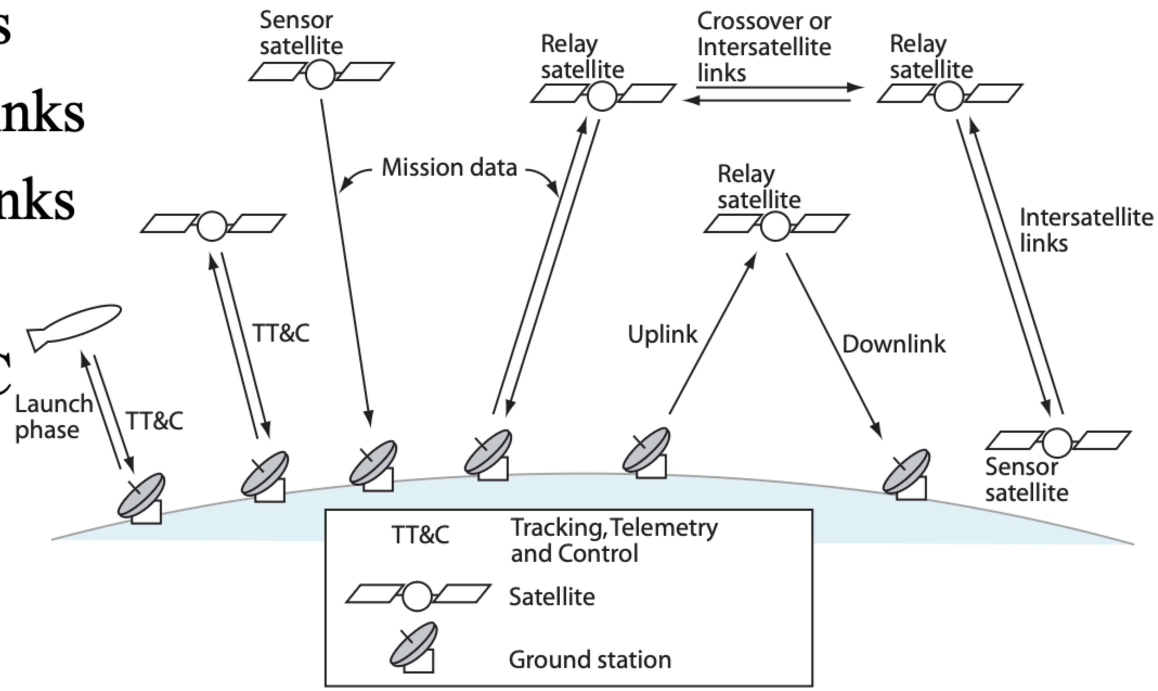
BSS

Figure 1.5 Components of a direct broadcasting satellite system. (*From Government of Canada, 1983, with permission.*)

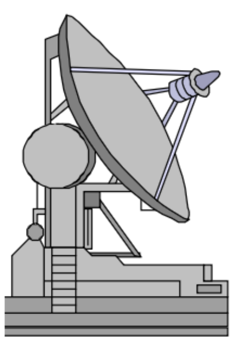
Definition



- Uplinks
- Downlinks
- Crosslinks
- Relays
- TT & C



The communications architecture consists of satellites and ground stations interconnected with communications links. (Adapted from SMAD.)



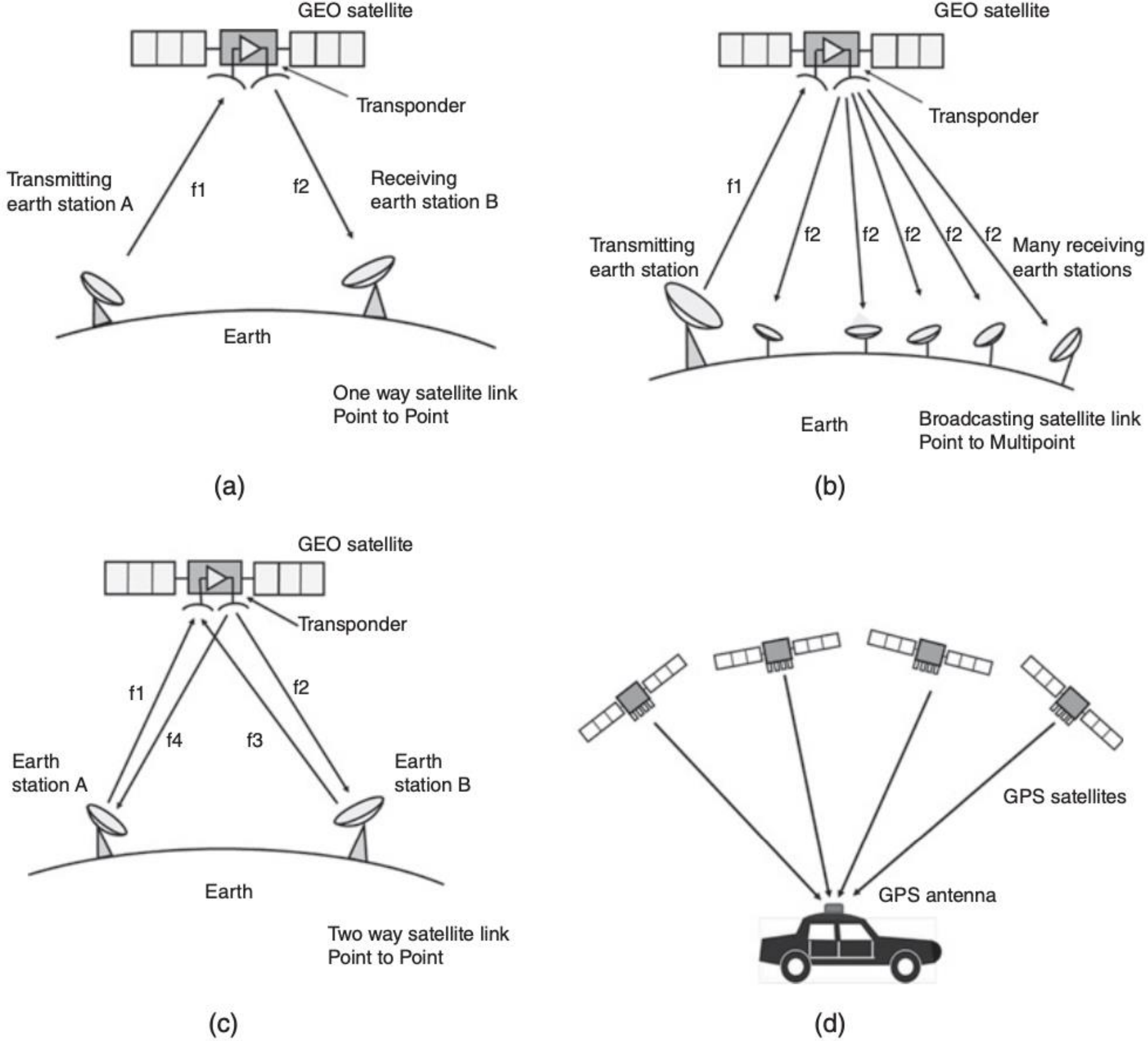


Figure 1.3 Illustration of different application of satellites. (a) One way satellite link from earth station A to earth station B. Uplink frequency is $f1$, downlink frequency is $f2$. (b) Point to multipoint link (broadcasting) from a single uplink transmitting station to many receiving stations. Uplink frequency is $f1$ and all downlinks are at the same frequency $f2$. (c) Two way connection between earth station A and earth station B. Station A transmits at frequency $f1$ and receives at frequency $f4$. Station B transmits at frequency $f3$ and receives at frequency $f2$. (d) Illustration of four GPS satellites broadcasting to an automobile. The GPS receiver uses an omnidirectional antenna.

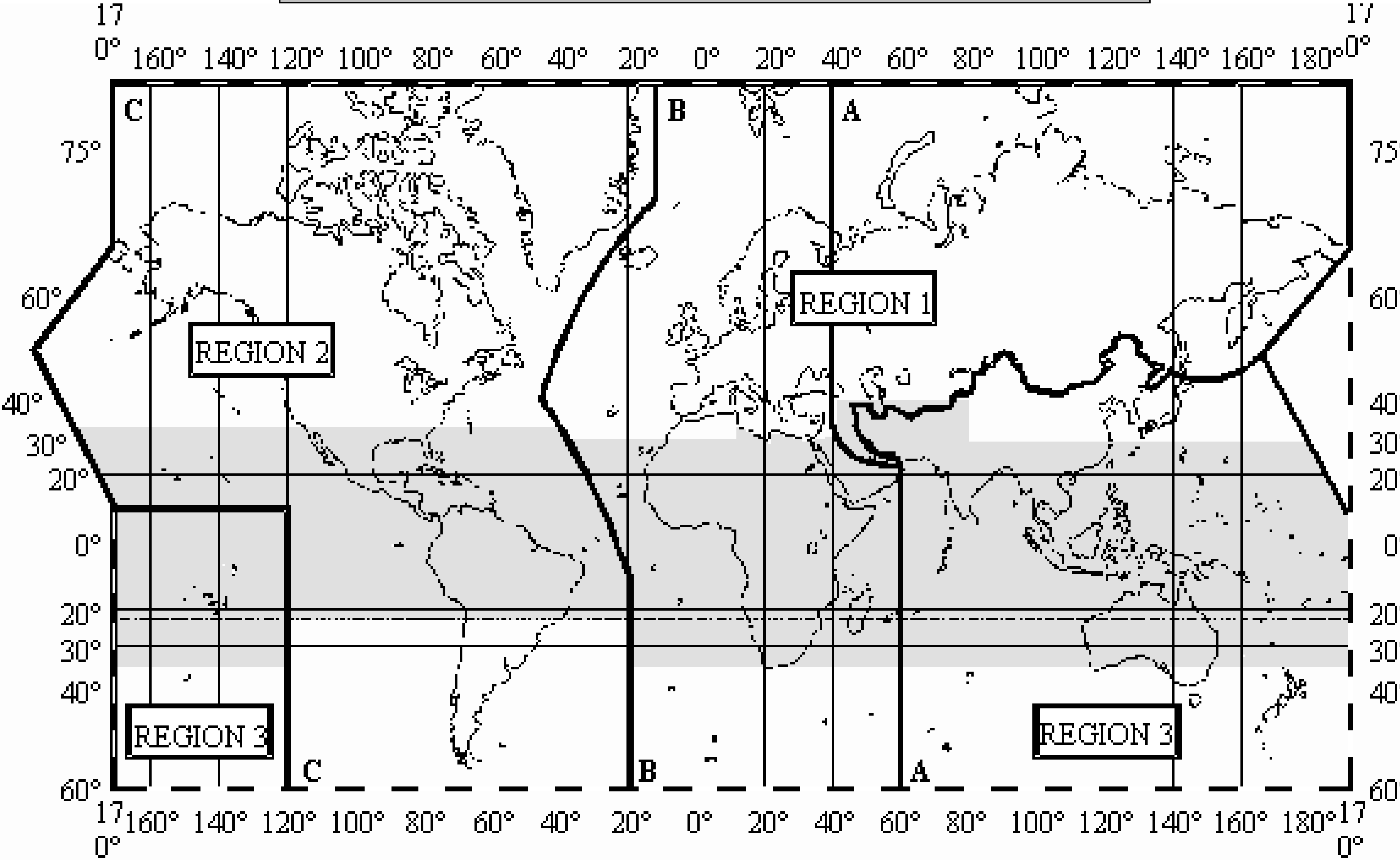
Advantages of satellite communications

1. Mobile/Wireless Communication, independent of location
2. Wide area coverage:country,continent, or globe
3. Wide bandwidth available throughout
4. Independence from terrestrial infrastructure
5. Rapid installation of ground network
6. Low cost per added site
7. Uniform service characteristics
8. Total service from a single provider
9. Small Fading margin (3dB)

Disadvantages of satellite communications

1. High cost for satellite
2. Short life time maximum of 15 years
3. Redundancy in component!

ITU Spectrum allocation and regions



The shaded part represents the Tropical Zones as defined in Nos **S5.16** to **S5.20** and **S5.21.**

Radio Frequency Spectrum
Commonly Used Bands

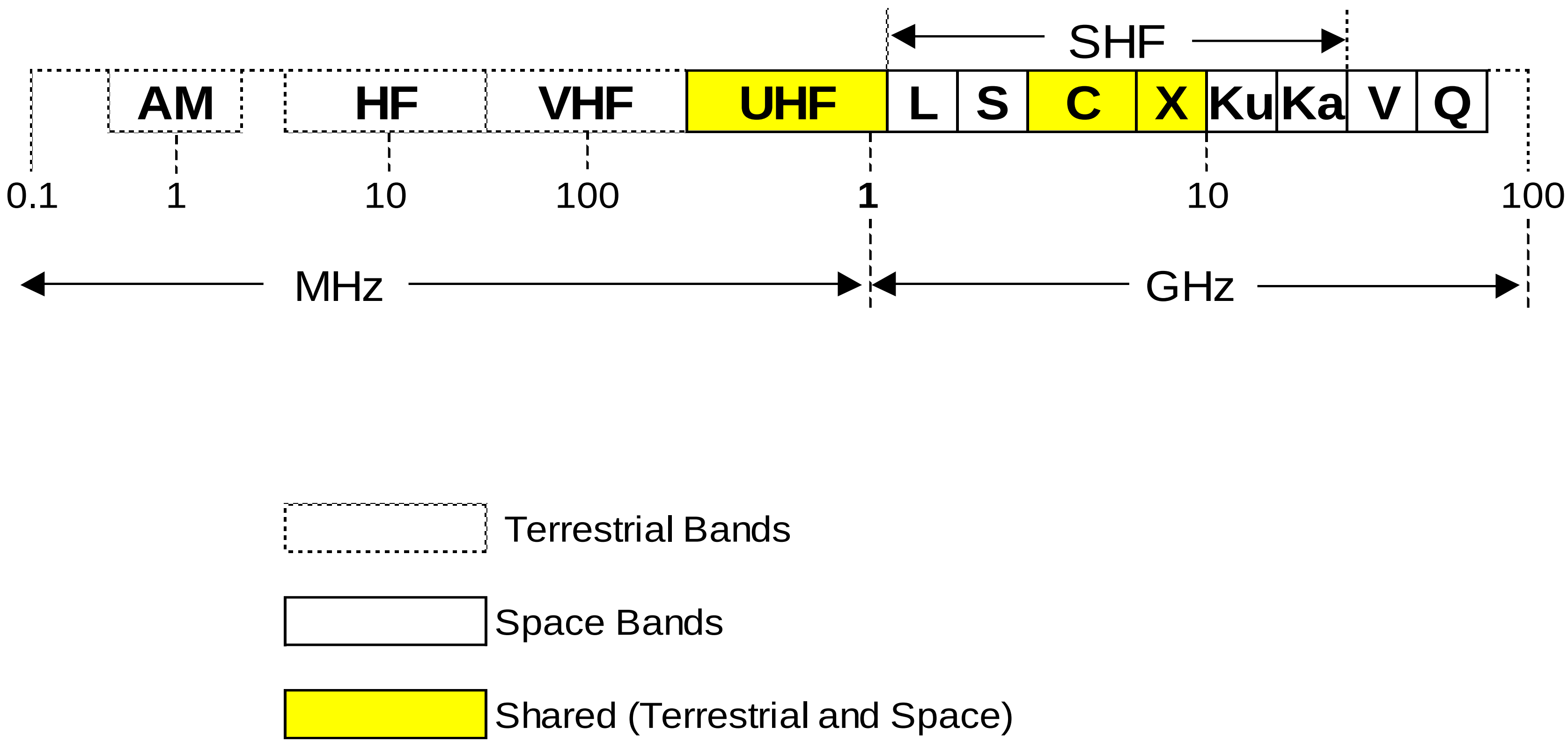


TABLE 1.1 **Frequency Band Designations**

Frequency range, GHz	Band designati
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	μm

Service	Bands Up/Down	Earth-to-Space (GHz)	Bandwidth (MHz)	Space-to-Earth (GHz)	Bandwidth (MHz)
Fixed	C/S	5.725–7.075	1,350	3.400–4.200	800
				4.500–4.800	300
	Ku/Ku	12.750–13.250	500	10.700–11.700	1,000
		14.000–14.500	500		
Fixed	Ka/K	27.500–30.000	2,500	17.700–20.200	2,500
Maritime,	L/L	1.6265–1.6455	19	1.530–1.544	14
Aeronautical,		1.6465–1.660	13.5	1.545–1.559	14
Mobile[a]		1.6455–1.6465	1	1.544–1.545	1
Broadcast[a]	/S			2.500–2.690	190
Fixed and Broadcast[b]	/Ku			11.700–12.700	1,000

Ku band: DBS and FSS

C band: FSS (no DBS are allowed)

VHF band : certain MSS and data transfer from weather satellites.

L band: MSS and navigation sat. systems.

Uplink freq. > downlink freq.(Ex. FSS:C=6/4 GHz) (DBS:ku14/12GHz)

Table 1.1 IEEE standard definitions for radio frequency bands [IEEE Std 521-2002]

Letter band	Frequency range
HF	3–30 MHz
VHF	30–300 MHz
UHF	300 MHz–1 GHz
L	1–2 GHz
S	2–4 GHz
C	4–8 GHz
X	8–12 GHz
Ku	12–18 GHz
K	18–27 GHz
Ka	27–40 GHz
V	40–75 GHz
W	75–110 GHz
mm wave	110–300 GHz

TABLE 1.2 ITU Frequency Band Designations

Band number	Symbols	Frequency range (lower limit exclusive, upper limit inclusive)	Corresponding metric subdivision	Metric abbreviations for the bands
4	VLF	3–30 kHz	Myriametric waves	B.Mam
5	LF	30–300 kHz	Kilometric waves	B.km
6	MF	300–3000 kHz	Hectometric waves	B.hm
7	HF	3–30 MHz	Decametric waves	B.dam
8	VHF	30–300 MHz	Metric waves	B.m
9	UHF	300–3000 MHz	Decimetric waves	B.dm
10	SHF	3–30 GHz	Centimetric waves	B.cm
11	EHF	30–300 GHz	Millimetric waves	B.mm
12		300–3000 GHz	Decimillimetric waves	

SOURCE: ITU Geneva.

Background:

- Satellite communications originated from Arthur C. Clarke's 1945 article proposing the use of satellites for long-distance radio communication.

- Clarke envisioned geostationary satellites in equatorial orbit, predicting their development for direct broadcast television and data communications.

- In October 1945, Clarke published in the British magazine Wireless World a technical paper entitled “Extra-terrestrial Relays — Can Rocket Stations Give World-wide Radio Coverage?”

Development and Expansion:

- In 1957, the launch of the Russian satellite **Sputnik** and subsequent GEO satellites validated Clarke's ideas.

- In 1965, the first geostationary communications satellite, Early Bird, provided transatlantic telephone service.

- The late 1960s saw the development of launch vehicles for telecommunication satellites, marking the start of global expansion.

- By 2016, there were 1459 active satellites, with over 500 GEO communication satellites globally.

- Applications included television, telephony, data transmission, internet access, and navigation. DBS-TV and video distribution dominated satellite usage, contributing to over half the revenue.

Revenues and Industry Landscape:

- Revenue from satellite communication systems grew at an average of 5% annually, reaching US$260B in 2016. Global revenue from all satellite activities in 2016 was US$260B, with DBS-TV and GNSS contributing significantly.
- GEO satellites faced competition from optical fibers for point-to-point communications but excelled in broadcasting.

Impact on Telecommunications:

- The capacity of optical fibers and satellites, along with the shift from analog to digital, reduced the cost of long-distance telephone calls.
- Telecommunications and computers achieved a cost reduction of nearly 2000 times between 1960 and 2010.
- GEO satellites were complemented by LEO satellites for applications like satellite telephone, data services, and earth imaging.

Future Challenges and Developments:

- The dominance of GEO satellites for internet access faced challenges from proposed LEO satellites, aiming to provide worldwide internet access after 2020.

GPS and similar systems revolutionized navigation, becoming consumer products integrated into cellular phones and cars.

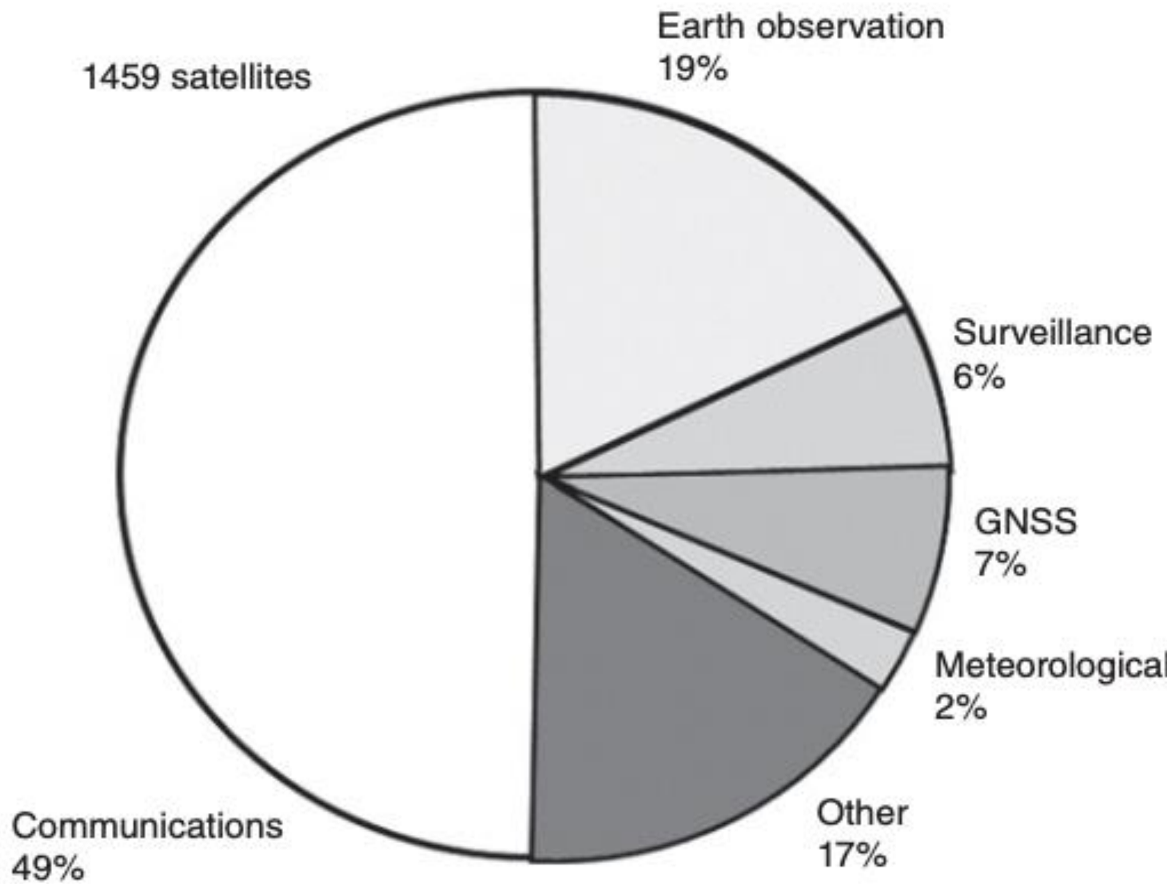


Figure 1.1 Distribution of satellites in orbit in 2016 by application. More than 500 satellites were in geostationary orbit. Communications includes DBS-TV, civil, and military links. Earth observation by small satellites increased quickly between 2014 and 2017 with the introduction of cubesats. Source: Adapted from data in (SIA 2017).

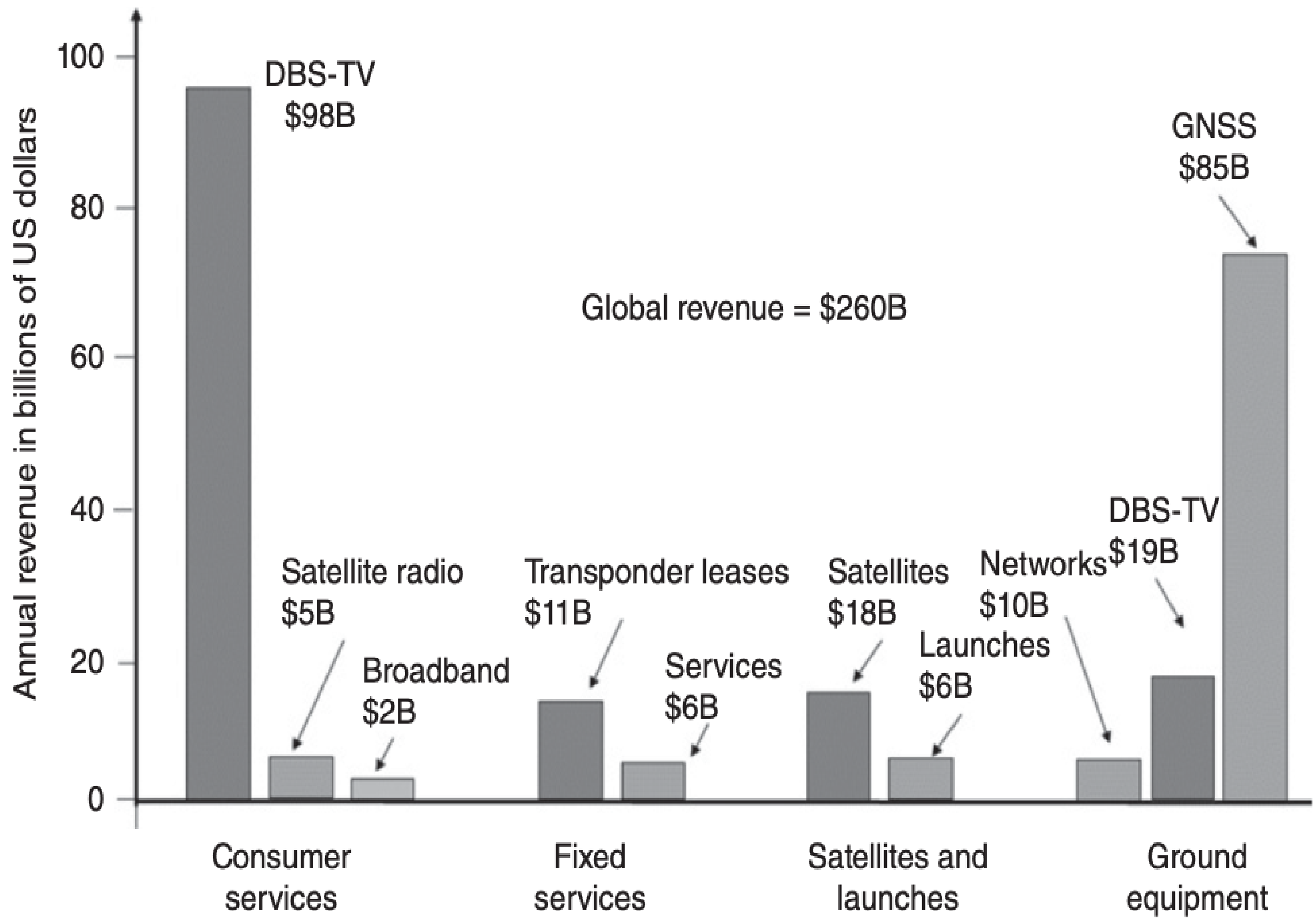


Figure 1.2 Distribution of global revenue earned from all satellite activity in 2016. Direct broadcast satellite television (DBS-TV) and Global Navigation Satellite Systems (GNSS) dominate with US$183B in revenue out of a total of US$261B. Source: Adapted from data in (SIA 2017).

- **Detailed Timeline of Satellite Communications:**

1957: USSR launches Sputnik I, the first artificial satellite, sparking the space race.

1958: (January): United States successfully launches Explorer I, initiating its satellite program. (December): Project Score transmits President Eisenhower's Christmas message from space, demonstrating early communication capabilities.

1962-1963: (July 1962): Telstar I, a collaboration between the U.S., France, and the UK, launches, enabling the first live transatlantic television broadcasts. (May 1963): Telstar II is launched, expanding the capabilities of satellite communication.

1964: (July): Representatives from 12 countries sign the initial agreement for the International Telecommunications Satellite Organization (Intelsat), a pivotal moment for global collaboration in satellite communications.

1965: (April): INTELSAT I (Early Bird) is launched, marking the beginning of commercial satellite communications between Europe and the United States.

1974: (May): Canada launches ANIK 1A, becoming the first nation to establish a national telecommunication system using GEO satellites.

2001: Intelsat is sold for US$3.1 billion to private equity firms, signaling a shift toward privatization. Société Européenne de Satellites (SES) introduces two-way multimedia and internet access service in western and central Europe at Ka-band.

2011: ViaSat launches ViaSat I, a revolutionary Ka-band satellite with 140 Gbps digital data capacity, transforming internet access capabilities.

2016:

- United Launch Alliance achieves 164 consecutive satellite launches without a single failure, establishing increased reliability.
- Demand for Direct Broadcast Satellite TV plateaus as internet-based subscription services gain traction.

2020:

- ADS-B becomes mandatory for all aircraft under air traffic control, facilitating a transition to a GPS-based system.
- Iridium satellites equipped with GPS and ADS-B transponders contribute to global location tracking for commercial aircraft.

Present:

- Ongoing advancements include the evolution of satellite communication frequencies (Ku-band, Ka-band) to meet the demands of digital traffic.
- GNSS systems like GPS, Galileo, and Beidou redefine navigation, with ADS-B playing a critical role in air traffic control.

Satellite communication remains an integral part of global telecommunications and navigation systems, emphasizing high-capacity satellites and enhanced internet access capabilities.

Satellite Variety:

- Satellites come in various sizes, from small cubesats used in education to large GEO satellites serving a significant portion of the Earth.

- Cubesats, especially popular in schools and universities, have led to cost-effective satellite development and the creation of LEO satellite constellations for global internet access.

GEO Satellites:

- Large GEO satellites, traditionally crucial for commercial satellite communications, have evolved to weigh up to 6 tons, generate 16 kW of power, and carry multiple transponders.

- Electrical propulsion systems are used to reach GEO orbit, reducing the need for fuel.
  Multiple beam antennas enable efficient radio frequency reuse and transmission of DBS-TV signals.

TV Program Distribution:

- Television program distribution and DBS-TV contribute significantly to satellite industry revenues.

- DBS-TV dominates the satellite communication industry until 2020, with millions of customers worldwide.

Communication Revenue and Capacity:

- High-capacity GEO satellites rely on high-power terrestrial transmitters and earth station antennas, which directly affect communication capacity and revenue.

- Fixed directional antennas offer lower delivery costs compared to low-gain antennas.

LEO Satellites:

LEO satellites are utilized for earth observation, including agricultural surveys, weather monitoring, and military surveillance for high-resolution imaging.

Proposals for LEO satellite constellations aim to provide global internet access.

Frequency Spectrum:

Satellite communication started in C-band, then moved to Ku-band, and now includes Ka-band and higher frequencies for expanding services.

There is an ongoing demand for more spectrum to support DBS-TV and high-speed data services.

World Radio Conferences and Frequency Bands:

Successive World Radio Conferences have allocated frequency bands for commercial satellite services, including L, S, C, Ku, K, Ka, V, and W bands.

Satellite Integration:

Despite the growth of fiber optic links, the demand for satellite systems continues to rise.

Satellites are integrated into complex communication architectures, such as VSAT/WLL in developing countries and GEO/LMDS for urban fringes in developed nations.

In summary, the satellite communication landscape involves a diverse range of satellites, with GEO satellites and TV distribution playing key roles. The industry continues to evolve with the introduction of cubesats, LEO constellations, and the exploration of higher frequency bands.

Overview of satellite communications (highlighting key concepts, challenges, and applications).

Purpose of Satellite Communication:

- Satellite communication systems exist due to the Earth's spherical shape.
- Radio waves used for wideband communications travel in straight lines, requiring repeaters to convey signals over long distances.
- Satellites serve as repeaters, linking places on Earth that are thousands of miles apart.

Geostationary Earth Orbit (GEO) Satellites:

- In 2023, the majority of communication satellites were in geostationary earth orbit at an altitude of 35,786 km over the equator. (GEO satellites use transponders as repeaters).

Signal Weakness and Cost Considerations:

- Signals to and from satellites are weak due to the long path length.
- The cost of launching geostationary satellites places restrictions on their size and weight.
- Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites are less costly to launch but require constellations for continuous coverage.

Satellite Communication Configurations:

- One-way links between two Earth stations via a single transponder on a GEO satellite.
- Point-to-multipoint links for broadcasting to many receiving Earth stations.
- Two-way links through a single transponder using frequency division multiplexing or time division multiplexing.
- Position location systems like GPS utilizing constellations of satellites.

Antenna Evolution and Frequency Bands:

•Early satellite systems required large receiving antennas, but as satellites became more powerful, smaller antennas became feasible.

•Satellite systems operate in the microwave and millimeter-wave frequency bands (1-50 GHz).

Transition to Digital Communication:

•Analog signals, especially using frequency modulation (FM), were prevalent in the early years but are now obsolete for commercial use.

•Almost all communication signals are now digital, including telephony, data, broadcasting, and navigation.

Broadcasting as a Profitable Application:

•Broadcasting, especially via GEO satellites, has been the most profitable application of satellite communications.

•Broadcasting to entire continents, such as North America and Europe, is common.

Future Challenges and Opportunities:

• Proposals for LEO satellite systems for internet access are increasing.

• Worldwide constellations of LEO satellites providing internet access may change the landscape of satellite communications.

• Challenges include serving a large user base at competitive data rates and prices.