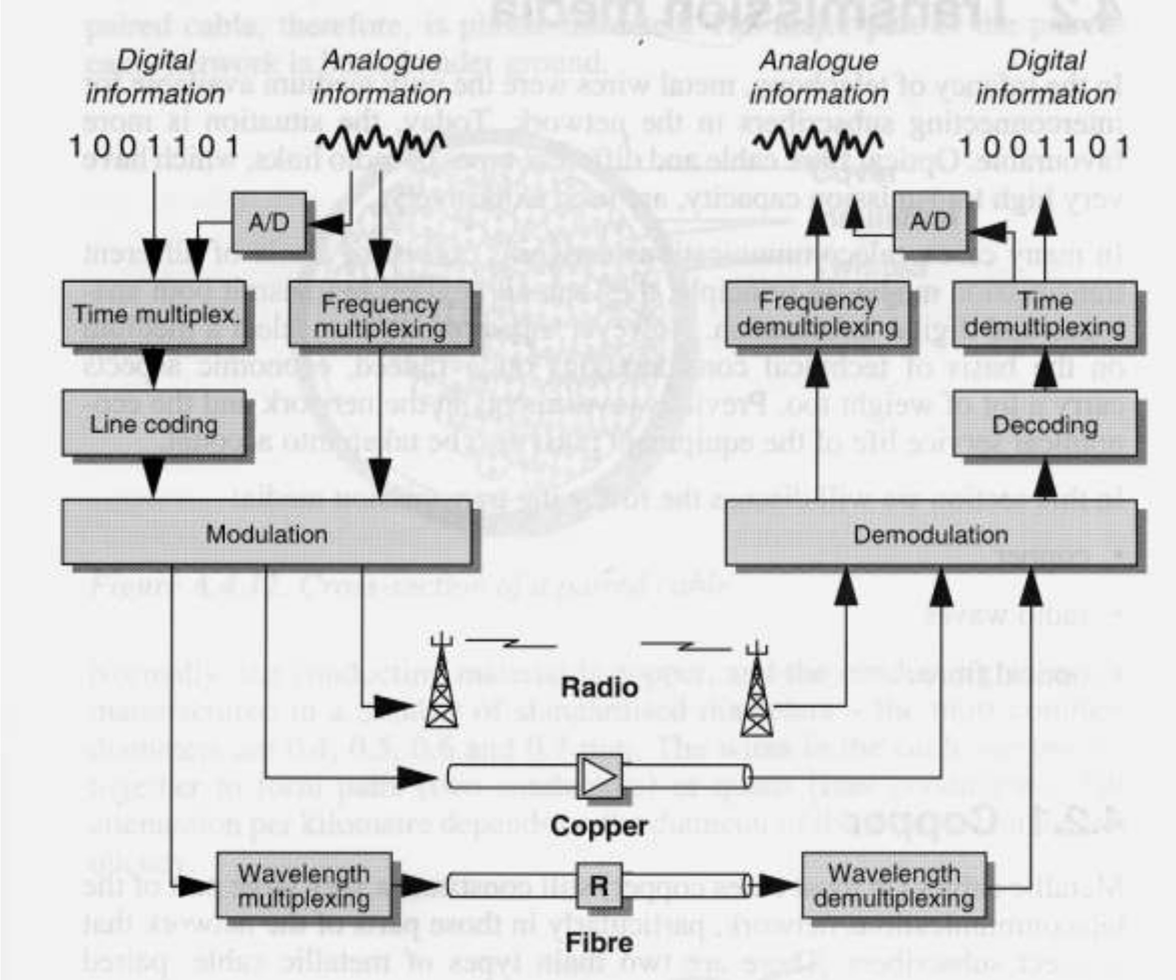
Infocommunication systems
Infokommunikációs rendszerek
Lecture 3. előadás
Radio transmission
Rádiós átvitel

Takács György

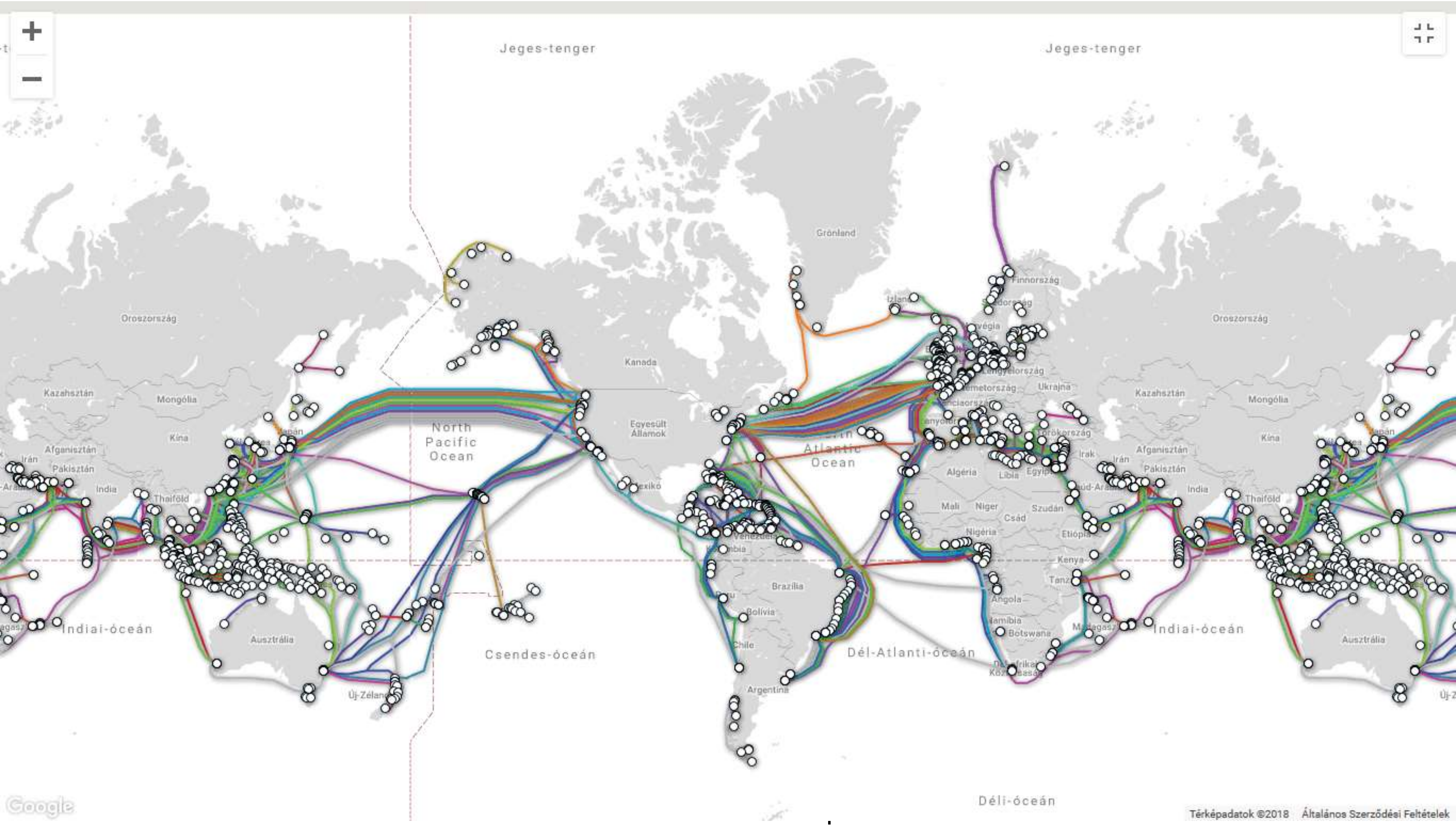
Melyik átviteli közeg jobb?



Cable or radio?

- As of 2018 there are over 1.2 million kilometers of submarine cables in service globally.
- Some cables are quite short, like the 131 kilometer CeltixConnect cable between Ireland the United Kingdom. In contrast, others are incredibly long, such as the 20,000 kilometer Asia America Gateway cable.
- The new MAREA cable is capable of carrying 160 Tbps (terabits per second, equal to 1 million megabits per second).
- Satellites do a wonderful job of reaching areas that aren’t yet wired with fiber. They are also useful for distributing content from one source to multiple locations.
- Cables can carry far more data at far less cost than satellites.
- When using your mobile phone, the signal is only carried wirelessly from your phone to the nearest cell tower. From there, the data will be carried over terrestrial and subsea fiber-optic cables.
- The majority of damage to submarine cables comes from human activity, primarily fishing and anchoring, not sharks.

Submarine Cable Map



Radio transmission media

- Frequency bands and wave propagation modes
- Terrestrial radio connection
- Satellite communication
- In door radio connection

Media characteristics

- Transmission parameters (path loss, delay, fading, radio interferences)
- Reliability and availability - equipment and propagation parameters (lightning, snow, rain, fog, smoke)
- Openness – interferences - privacy

Is radio communication a technical issue (1)?

- Radio communications use open and common media. Using a radio frequency means consuming. So management of radio frequency is inevitable.
- Using a radio frequency means a kind of environment pollution! Frequency police?
- Radio frequencies are limited resources. The „good” frequencies are already consumed. Frequency fees! NMHH.
- Propagation of radio waves do not consider political borders! Frequency management is a typical international process. (CCIR, ITU-R)

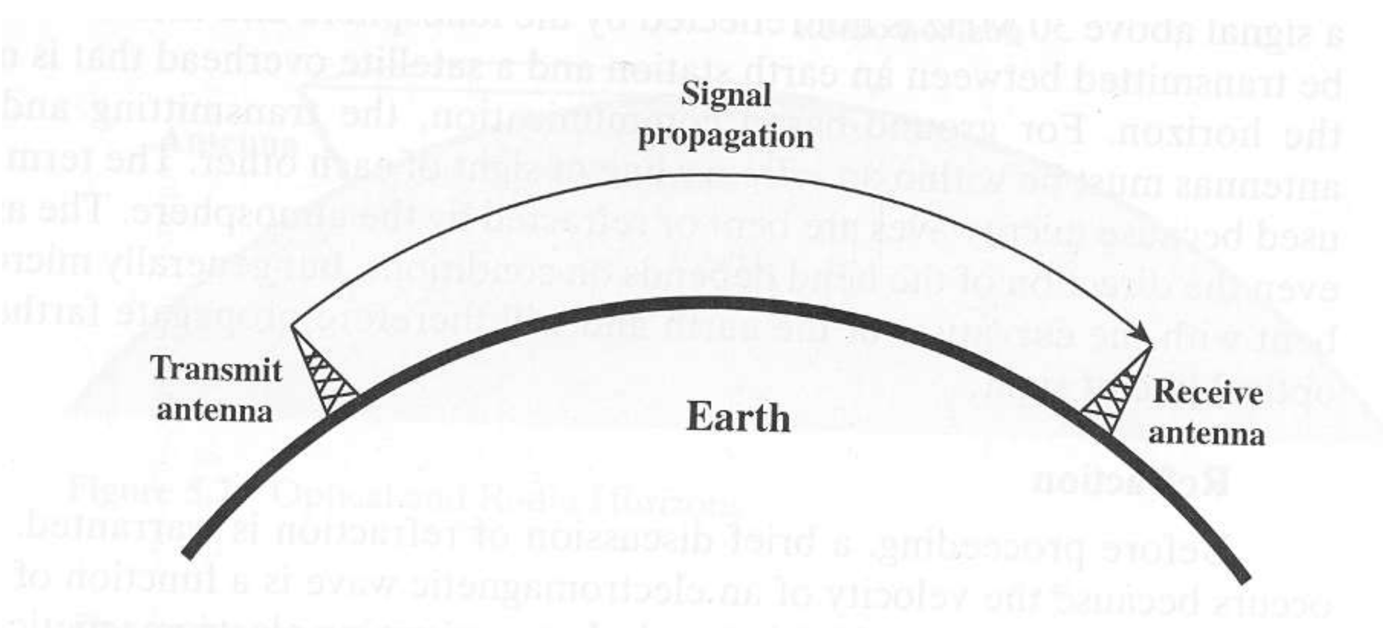
Is radio communication a technical issue (2)?

- Radio frequencies have considerable physiological effect!
- Antennas are considered as special constructions. Local municipalities regulate construction rules and issue building licences.
- Satellite positions are limited resources too. The „good” positions are consumed.
- Differential equations of electromagnetic wave propagation are quite simple – in the case of plane wave and free space. Solutions in real geographic situations (among hills, valleys, buildings or especially inside buildings) are extremely difficult.

Frequency bands and wave propagation modes

- LF (30-300kHz)
- MF (300-3000kHz)
- HF (3-30 MHz)
- VHF (30-300 MHz)
- UHF (300-3000MHz)
- SHF (centimetric waves, 3-30GHz)
- EHF (millimetric waves, 30-300GHz)

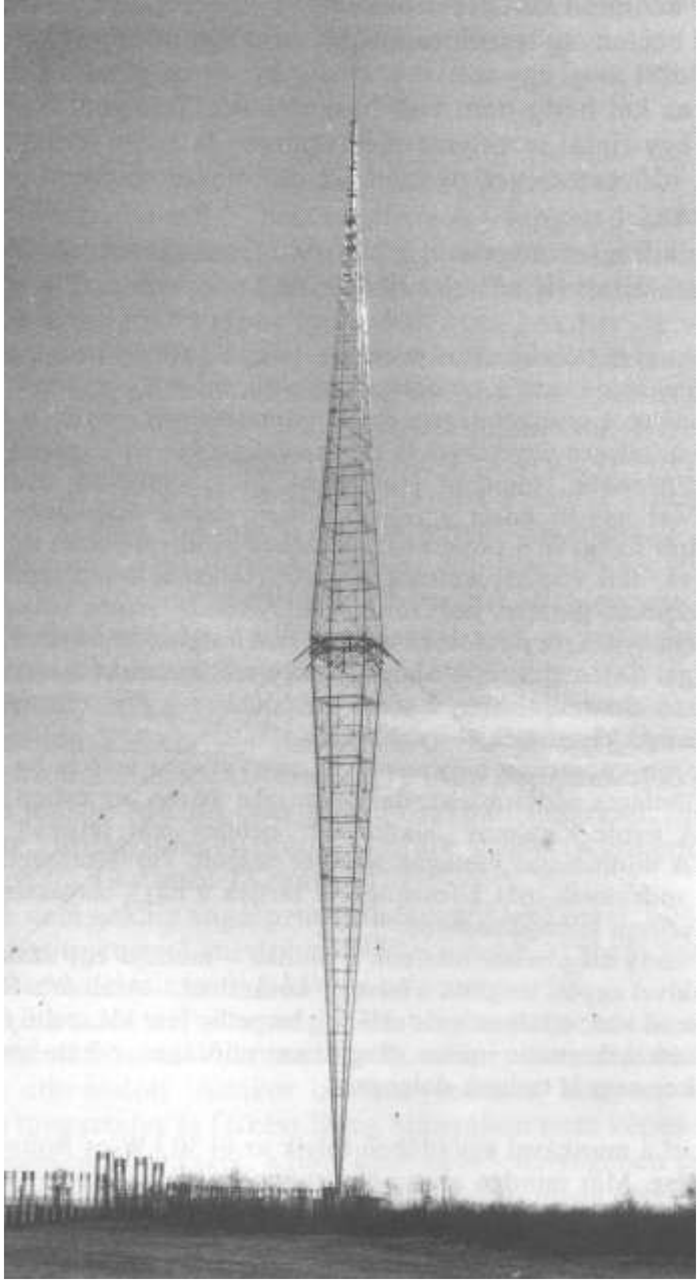
Propagation modes and antennas



(a) Ground wave propagation (below 2 MHz)

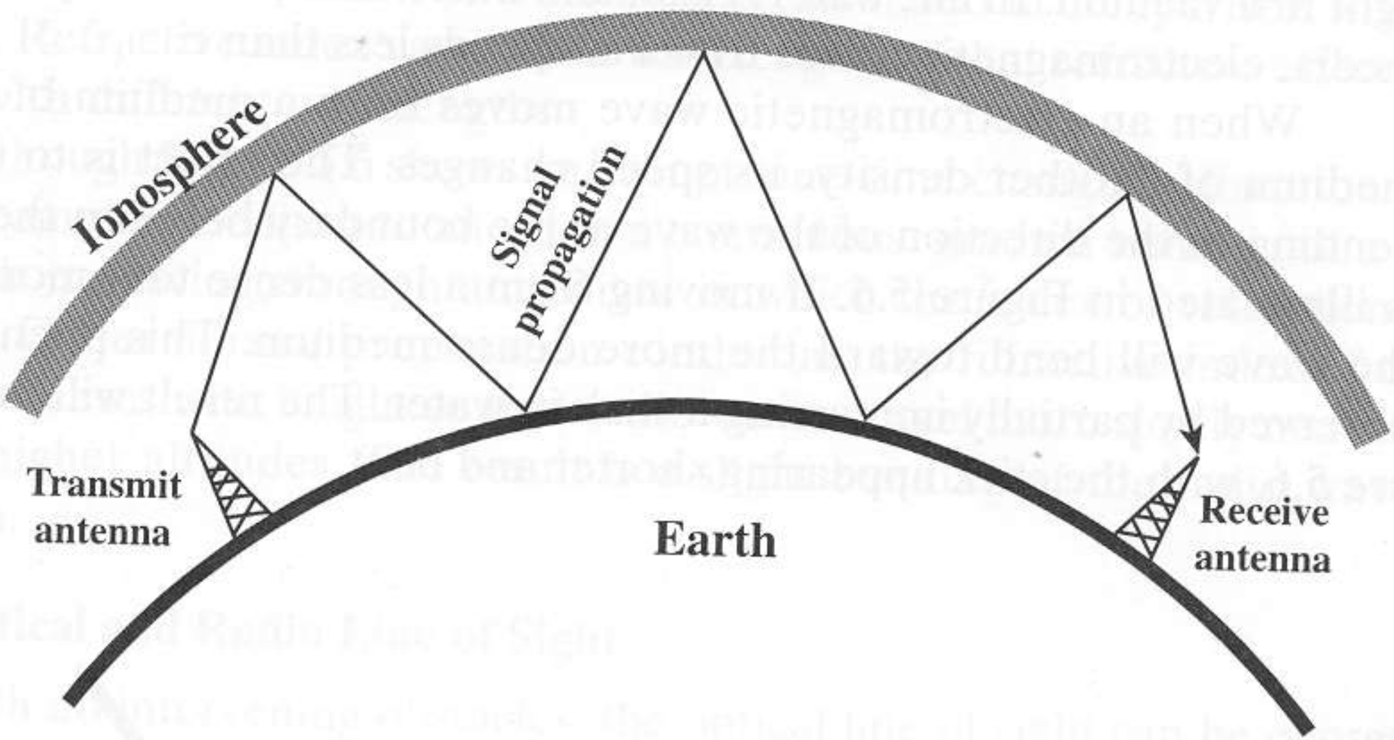
LF
MF

Figure 1.6.11. Propagation of surface waves

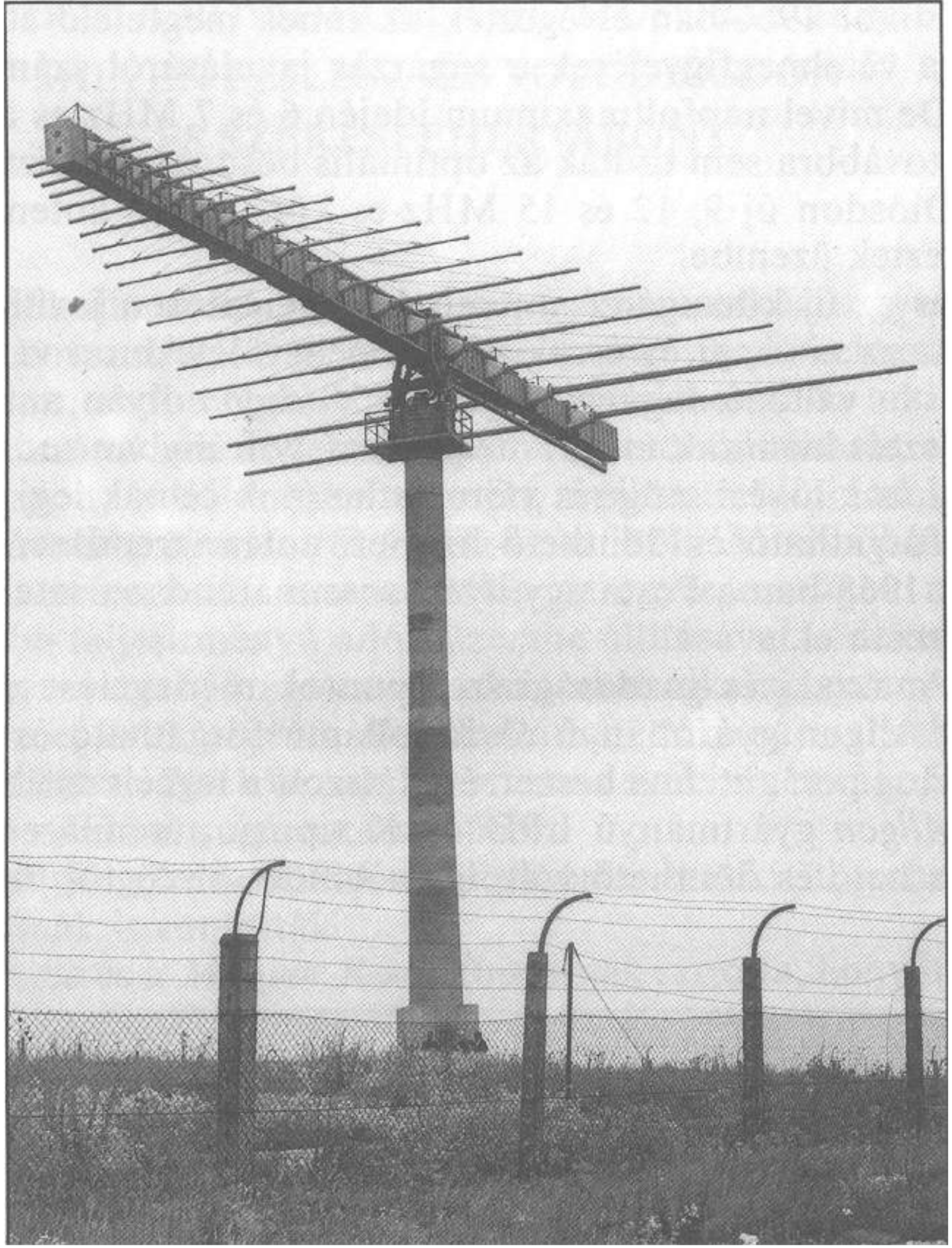


Propagation modes and antennas

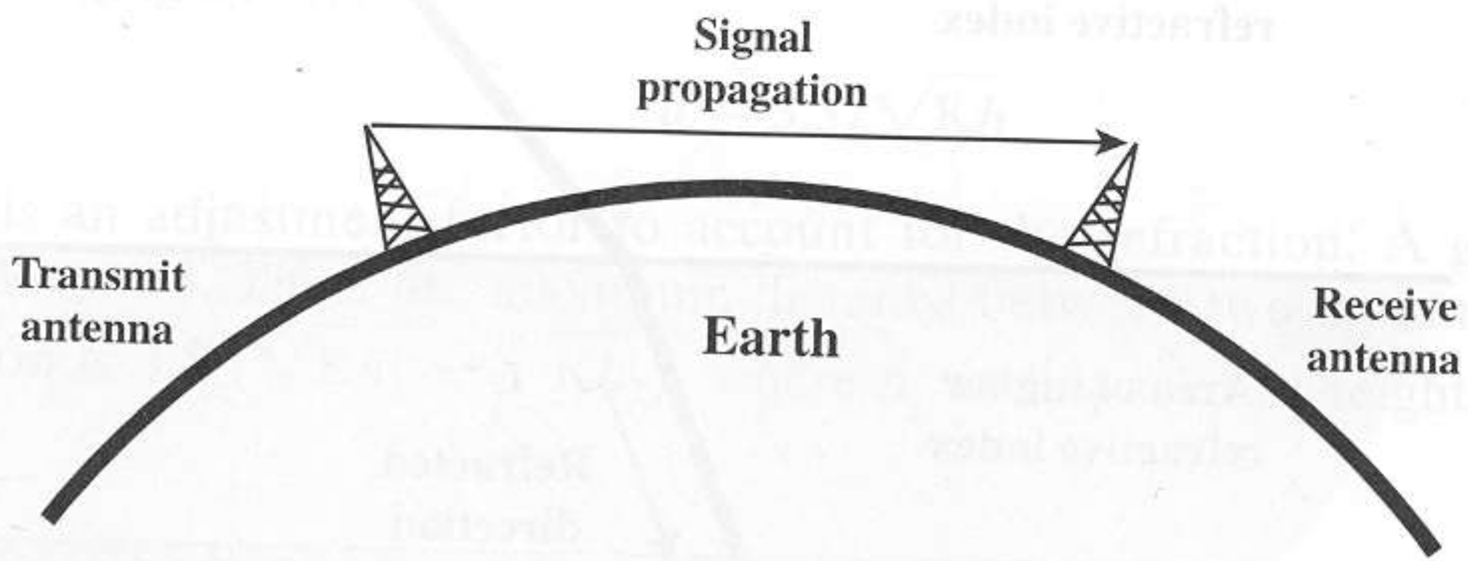
HF



(b) Sky wave propagation (2 to 30 MHz)



Propagation modes and antennas

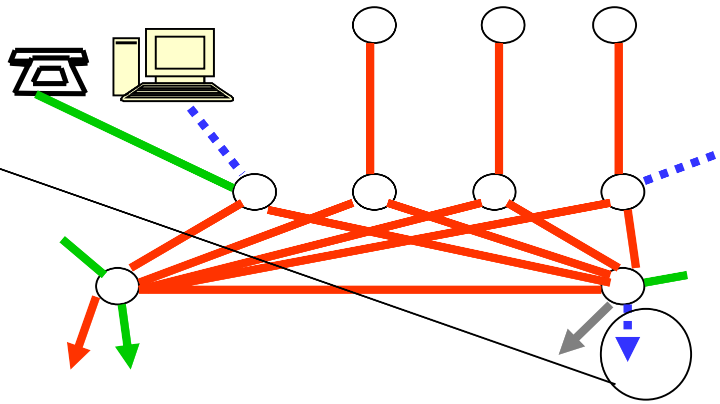


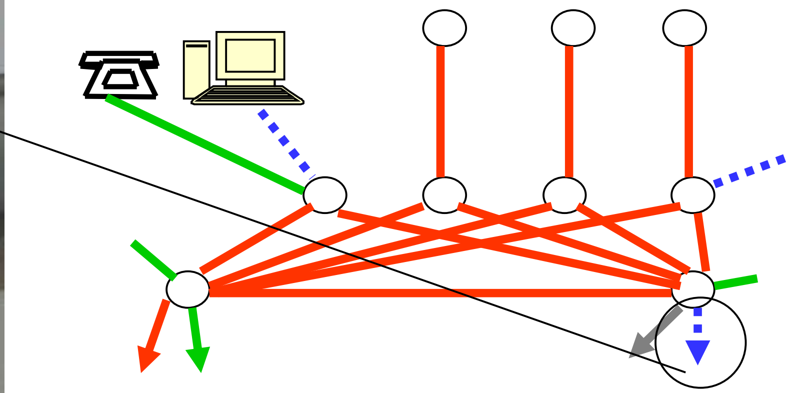
(c) Line-of-sight (LOS) propagation (above 30 MHz)

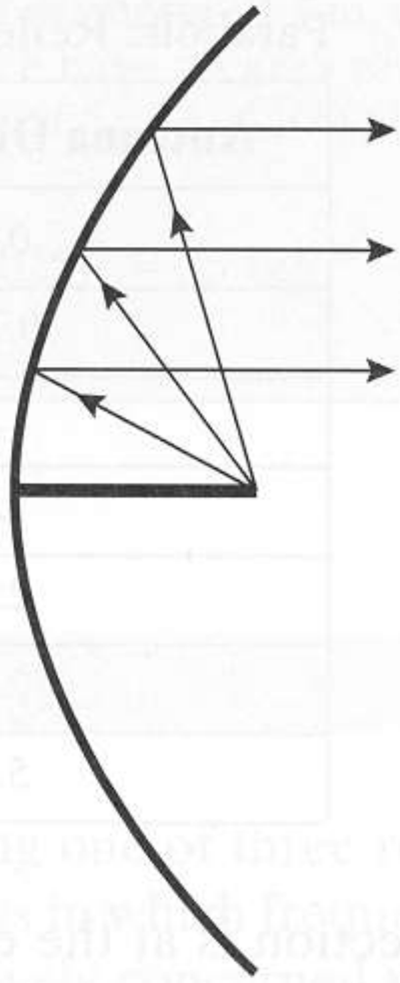
Figure 5.5 Wireless Propagation Modes

UHF
VHF
SHF
EHF

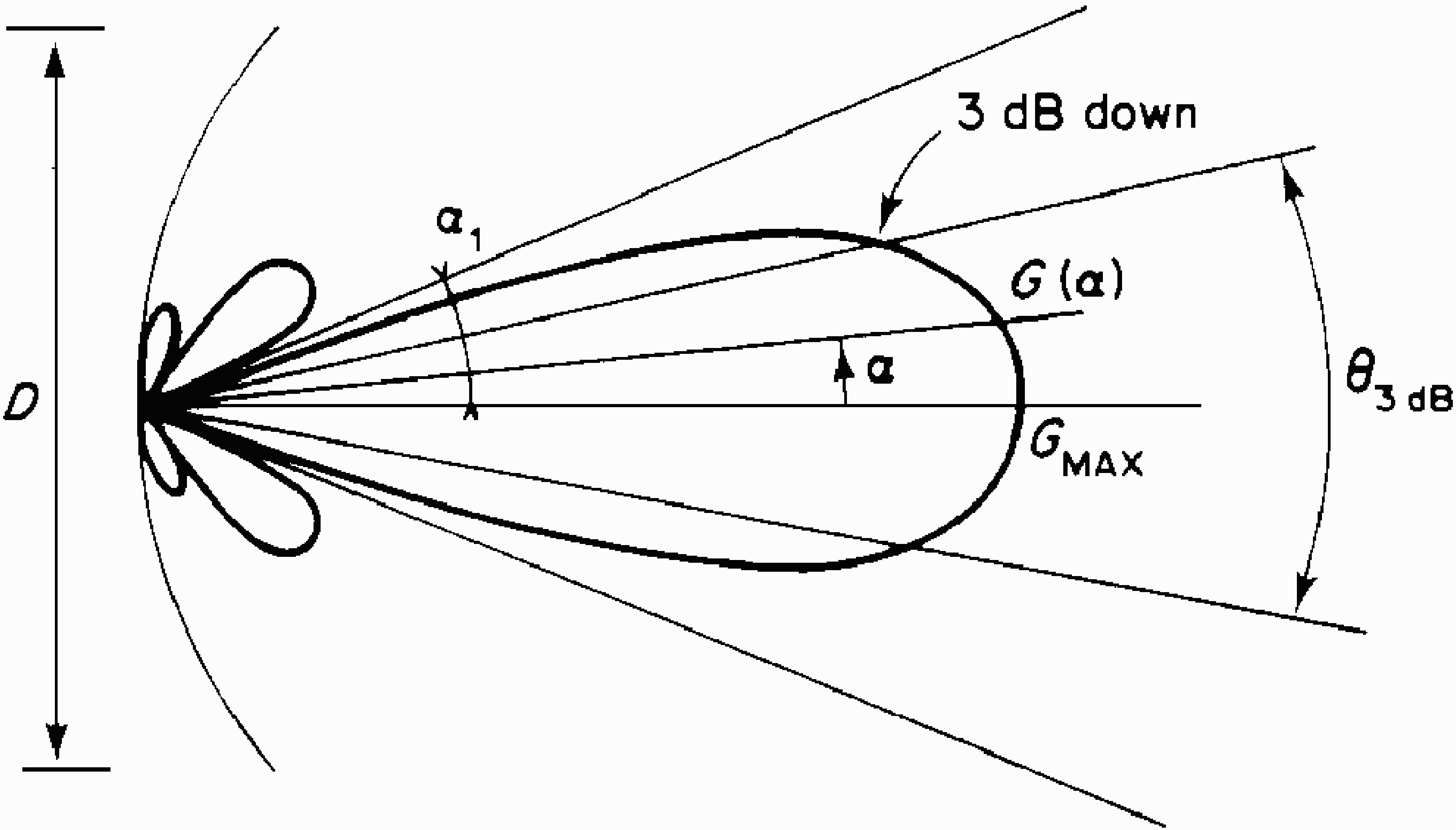
The largest "dish" antenna in the world, the radio telescope at Arecibo Observatory, Puerto Rico, 1000 feet (305 meters) in diameter. It has a gain of about 10 million, or 70 dBi, at 2.38 GHz. The dish is constructed into a valley in the landscape, so it is not steerable. To steer the antenna to point to different regions in the sky, the feed antenna suspended by cables over the dish is moved. The dish actually has a spherical rather than a parabolic shape, which reduces the aberrations caused by moving the feed point, but also means that the received energy comes to a focus along a line rather than a single point.







(b) Cross section of parabolic antenna showing reflective property


3 dB down
α1
G (α)
α
θ3 dB
D
GMAX

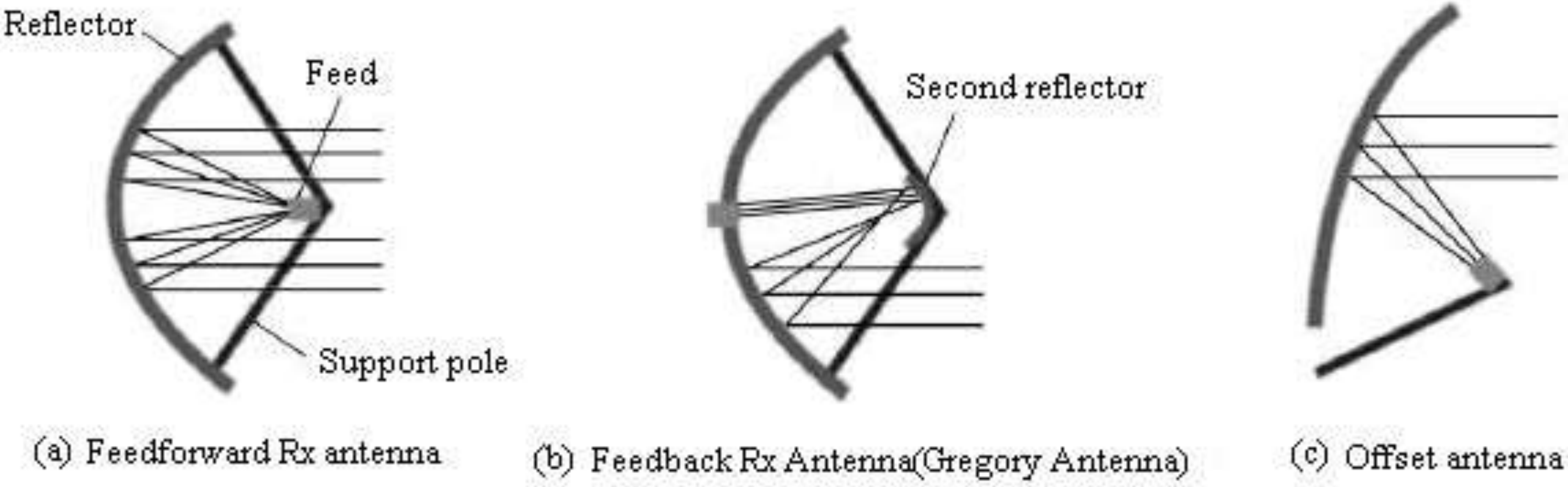


Fig.2-1 Illustrated drawing for three kinds of parabola antennas

Table 5.1 Antenna Beamwidths for Various Diameter Parabolic Reflective Antennas at $f = 12$ GHz [FREE97]

Antenna Diameter (m)	Beam Width (degrees)
0.5	3.5
0.75	2.33
1.0	1.75
1.5	1.166
2.0	0.875
2.5	0.7
5.0	0.35

Table 5.2 Antenna Gains and Effective Areas [COUC01]

Type of Antenna	Effective Area A_e (m²)	Power Gain (relative to isotropic)
Isotropic	$\lambda^2/4\pi$	1
Infinitesimal dipole or loop	$1.5\ \lambda^2/4\pi$	1.5
Half-wave dipole	$1.64\ \lambda 2/4\pi$	1.64
Horn, mouth area *A*	$0.81\ A$	$10\ A/\lambda^2$
Parabolic, face area *A*	$0.56\ A$	$7\ A/\lambda^2$
Turnstile (two crossed, perpendicular dipoles)	$1.15\ \lambda^2/4\pi$	1.15

in free space (ε_0,μ_0):

$$rot\mathbf{H} = j\omega\varepsilon_0\mathbf{E}$$

$$rot\mathbf{E} = -j\omega\mu_0\mathbf{H}$$

plane-wave solution

$$\mathbf{E} = \frac{1}{j\omega\varepsilon_0} rot\mathbf{H} = \frac{-1}{j\omega\varepsilon_0}\mathbf{e}_x \frac{\partial}{\partial z} H_y = \frac{-\mathbf{e}_x}{j\omega\varepsilon_0} H_y^0(-j\beta)e^{-j\beta z} = E_x\mathbf{e}_x$$

1. electric and magnetic field vectors are perpendicular

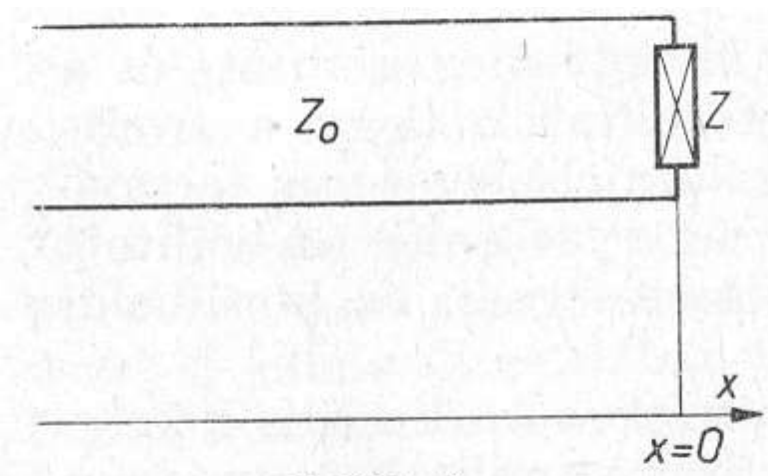
2. ratio of their amplitudes is a constant and called as free-space wave impedance

$$\frac{E_x}{H_y} = \frac{\beta}{\omega\varepsilon_0} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi$$

characteristic impedance

$$Z_0 = \sqrt{\frac{R + j\,\omega\,L}{G + j\,\omega\,C}}$$

Reflection coefficient



$$r = U_0^- / U_0^+$$

$$r = \frac{Z - Z_0}{Z + Z_0}.$$

Free space radio link (LOS)

$$P_R = \frac{P_T G_T}{4\pi d^2} A_e = \frac{P_T G_T}{4\pi d^2} \cdot \frac{\lambda^2 G_R}{4\pi}$$

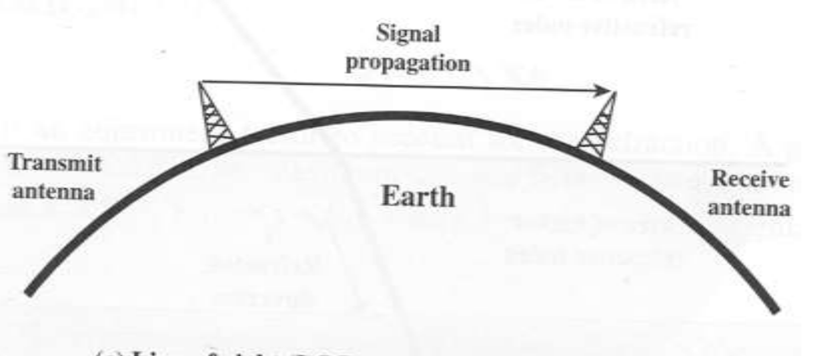
P_T transmitted power

A_e effective area of antenna

G gain of antenna

λ wavelength

d distance



(c) Line-of-sight (LOS) propagation (above 30 MHz)

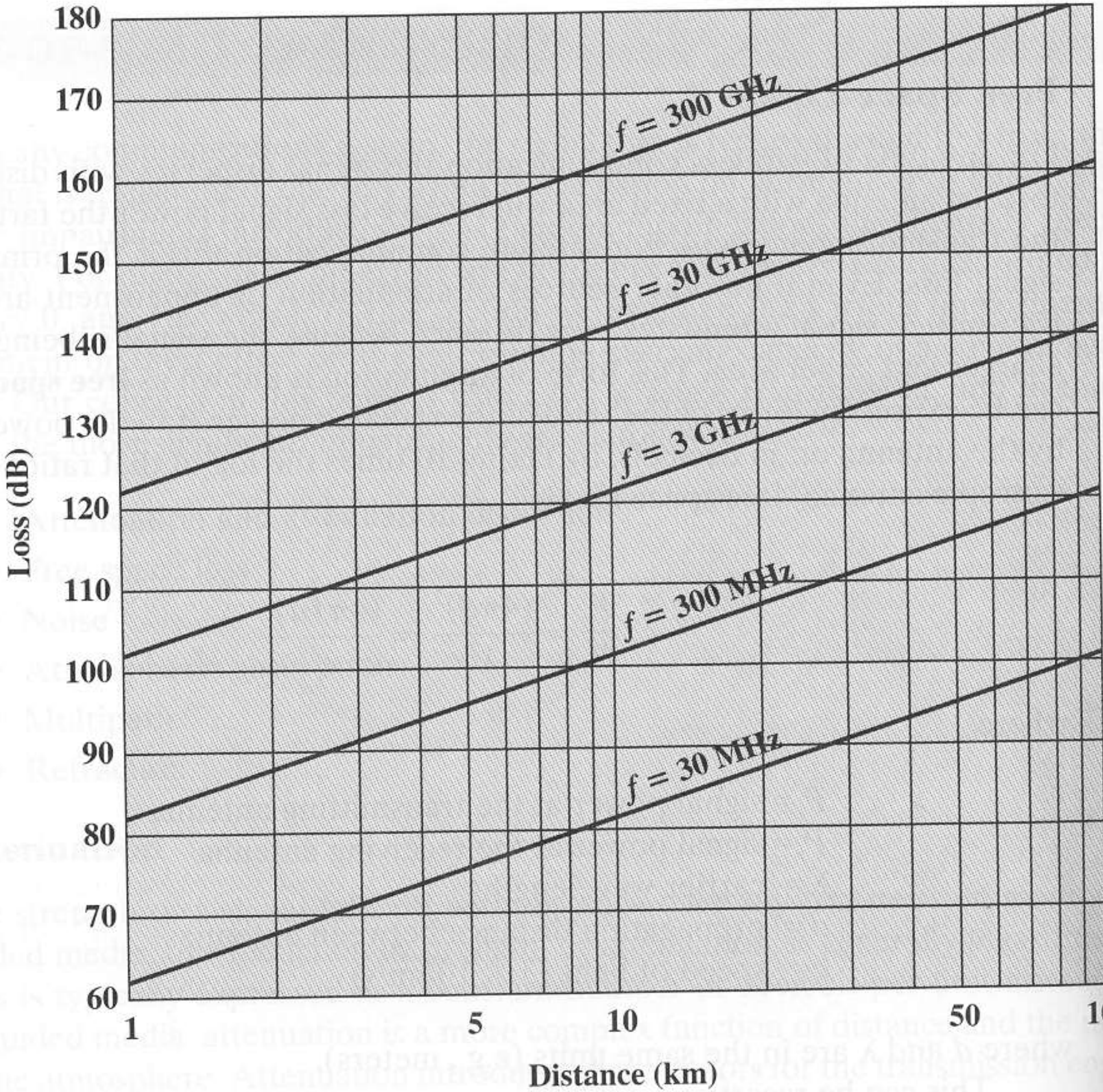
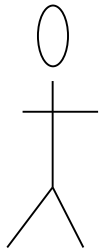


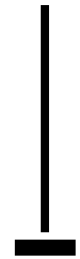
Figure 5.8 Free Space Loss

Example by GSM mobile system

$$P_r = kP_T/d^2$$



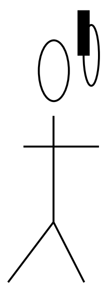
d=30m



Base station

P=50W

$$P_r = k \times 0{,}0555$$



d=3cm

P=5W

$$P_r = k \times 5555$$

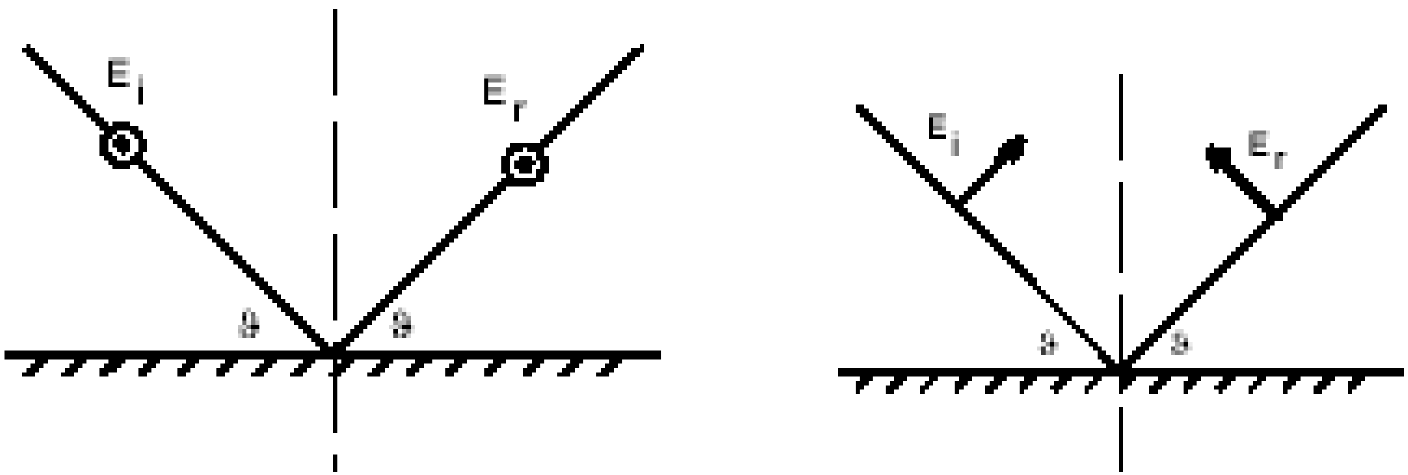
100000×

Polarization:

- Property of a radiated electromagnetic wave describing the time varying direction and relative magnitude of the electric-field vector
- In general the field is elliptically polarized
- Linear and circular polarizations are special cases

Reflection

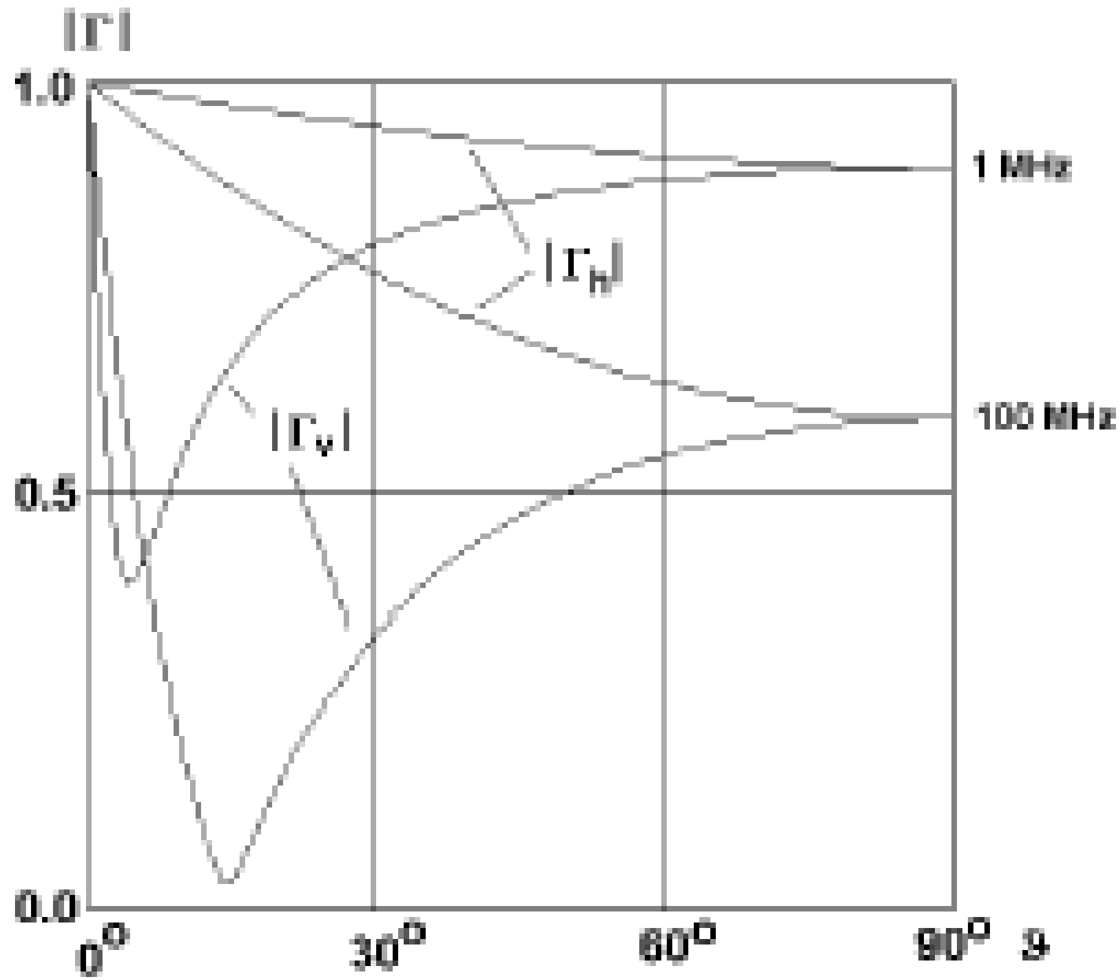
- The amplitude, phase and polarization of the reflected wave is determined by the material parameters of the medias and the surface irregularity.



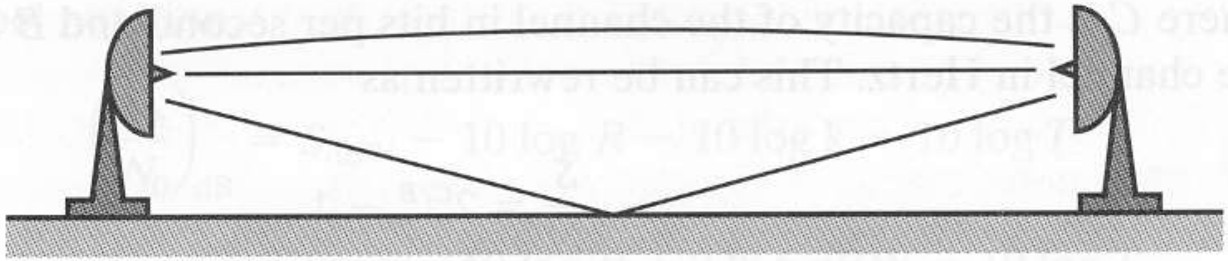
Horizontal polarization *Vertical*

$$\Gamma = \frac{E_r}{E_i}$$

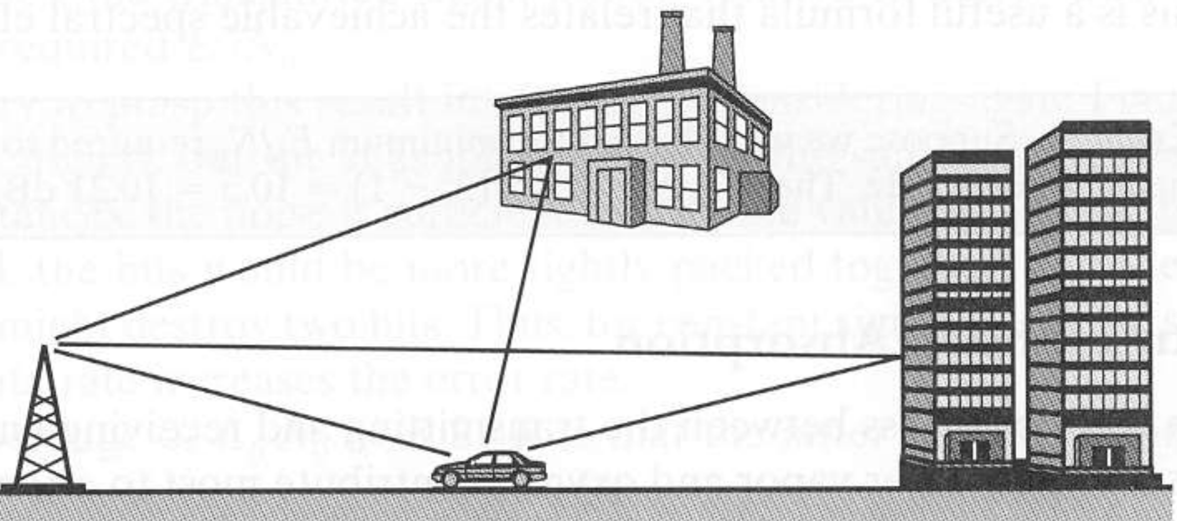
ϑ_s incoming angle



Magnitude of Earth reflection coefficient



(a) Microwave line of sight



(b) Mobile radio

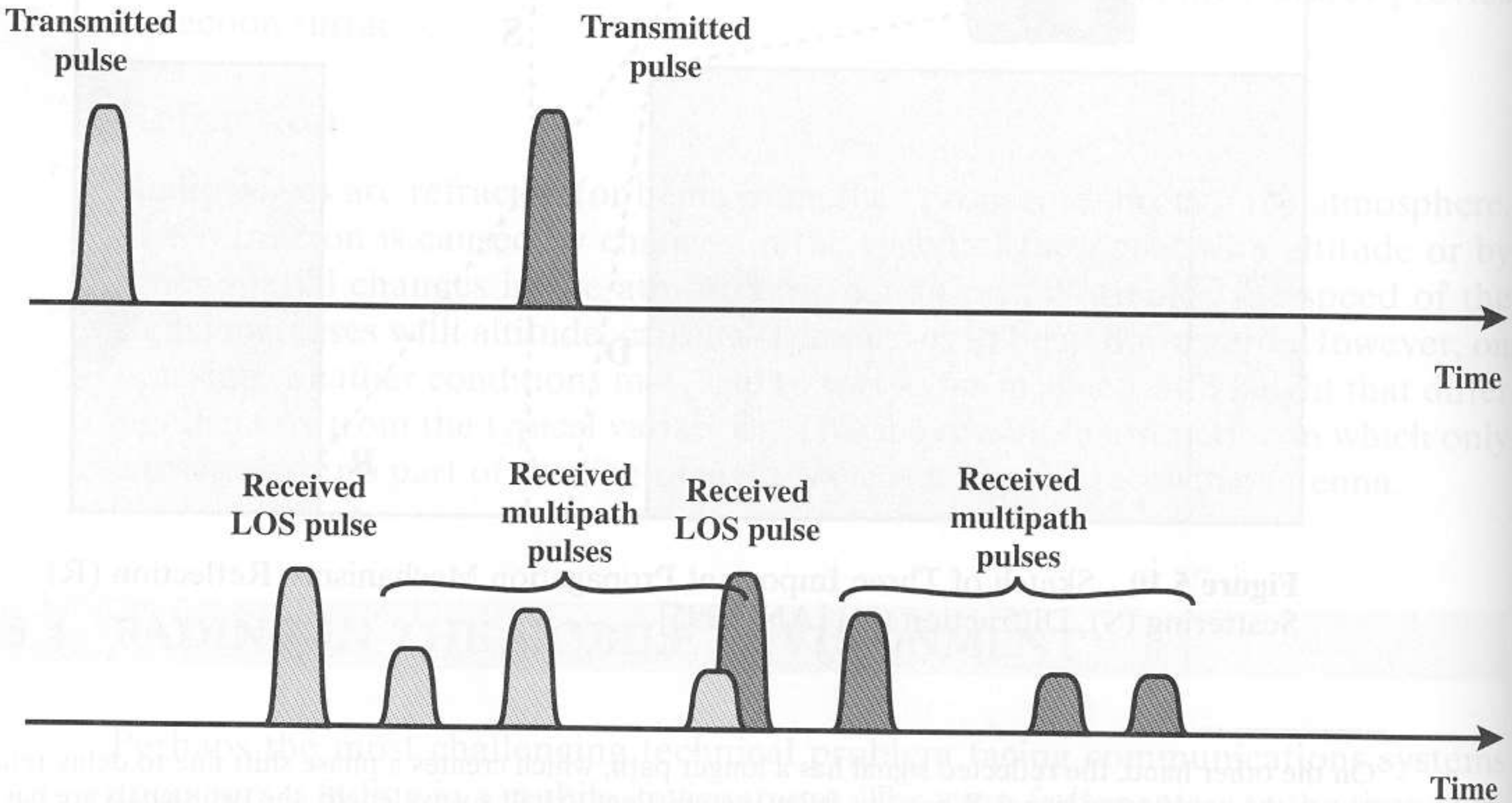
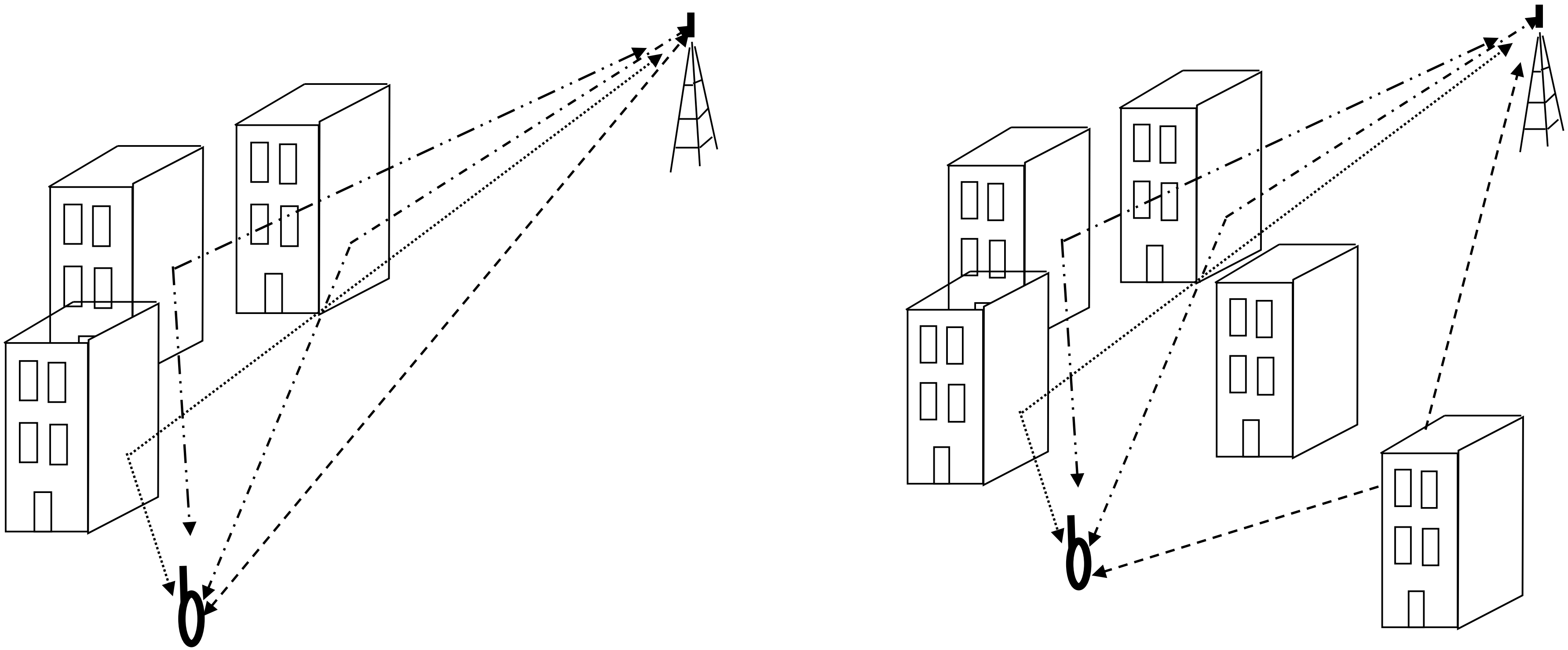
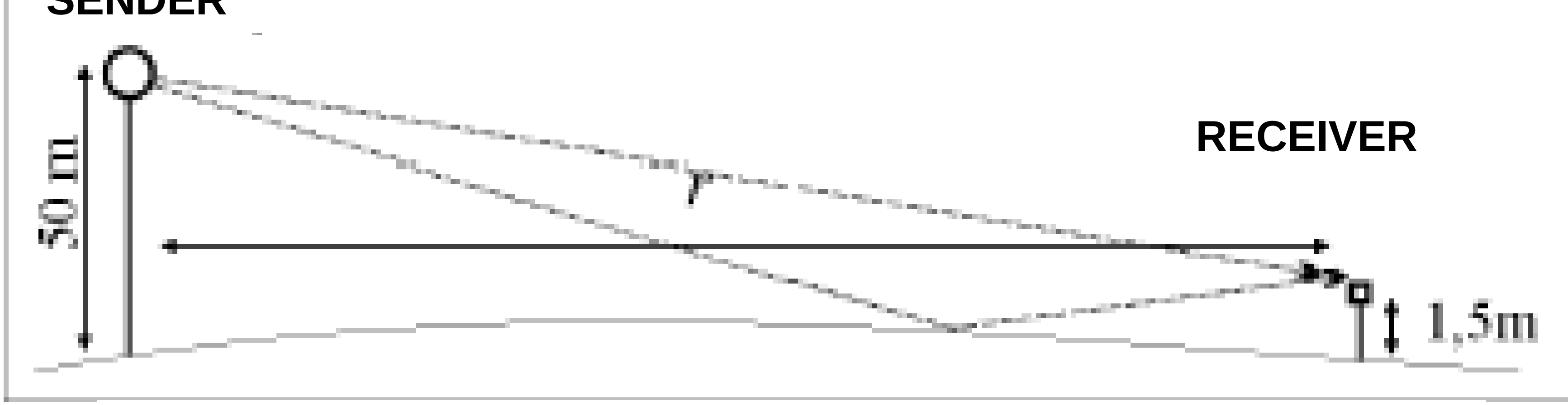


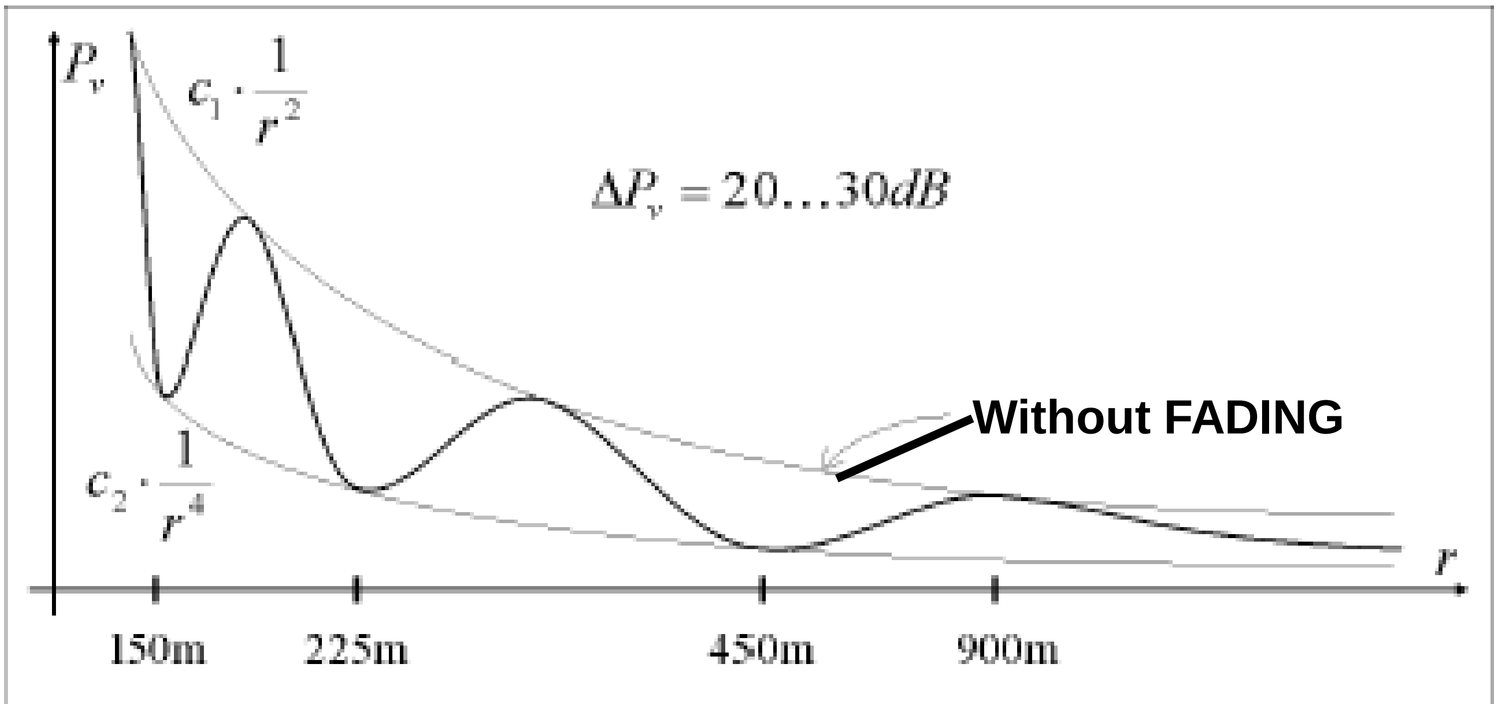
Figure 5.11 Two Pulses in Time-Variant Multipath

Propagation with direct and reflected waves and reflected only waves

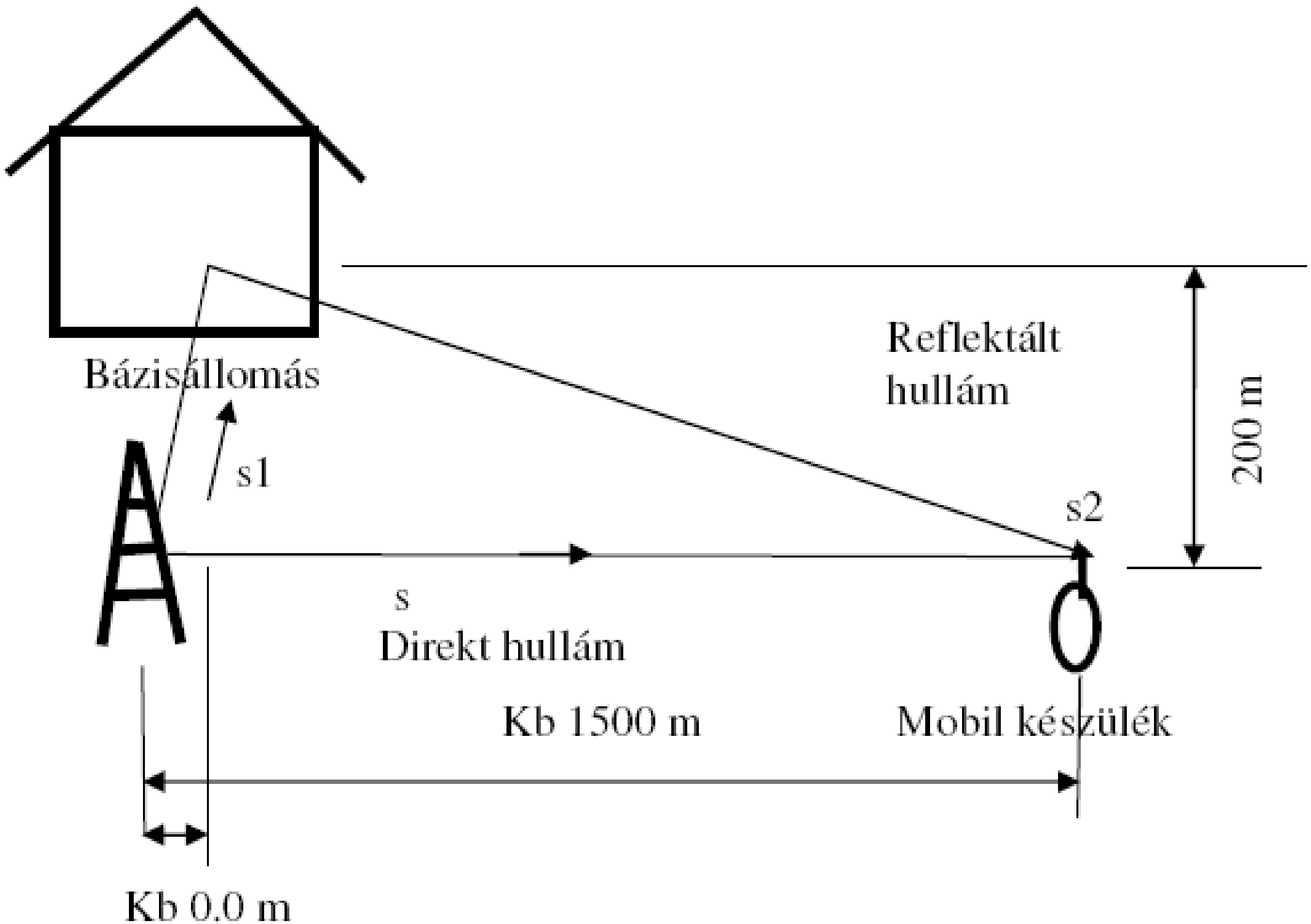


RADIO FOR MOBILES

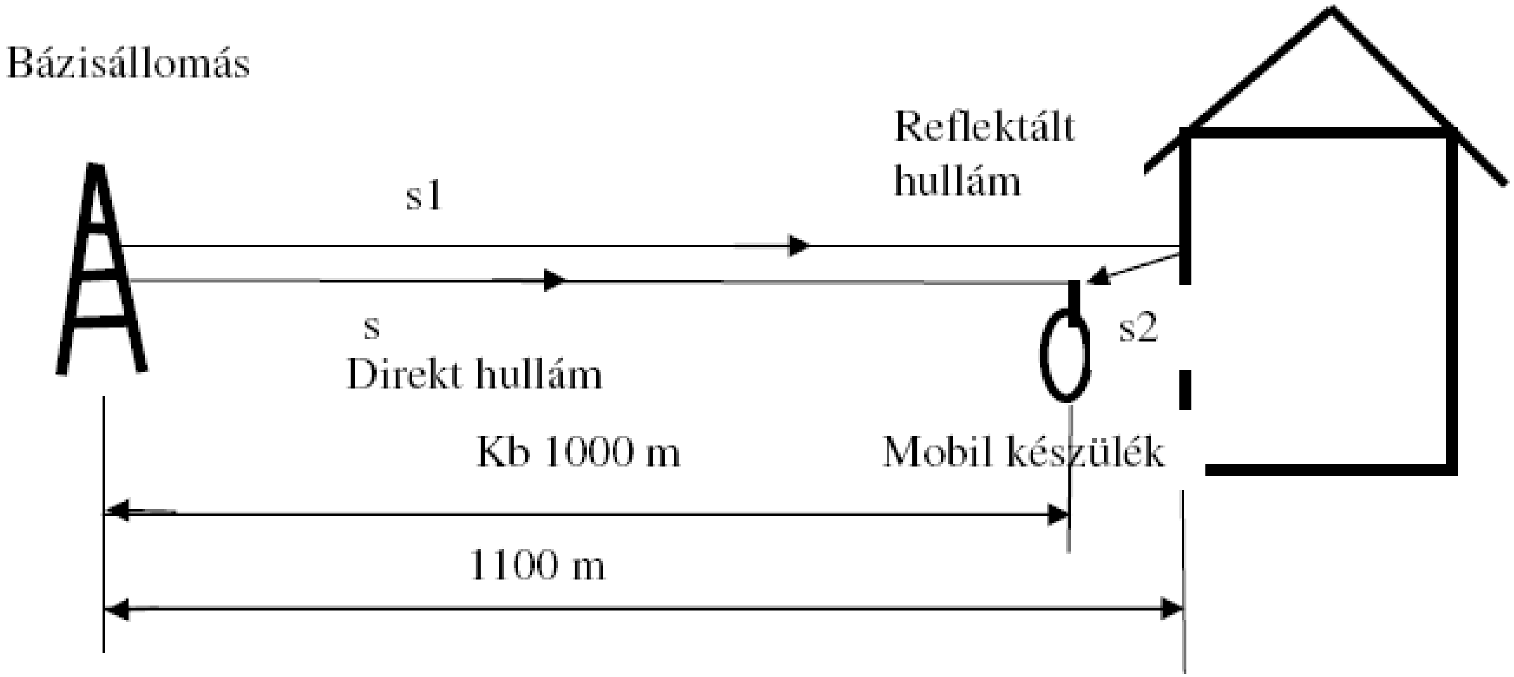




Fading számolási feladat - hétfői csoport



Fading számolási feladat - szerdai csoport



A mobilkészüléknél az elektromos térerősség a két hullám által keltett tér összege

$$E = E_{dir} + E_{refl}$$

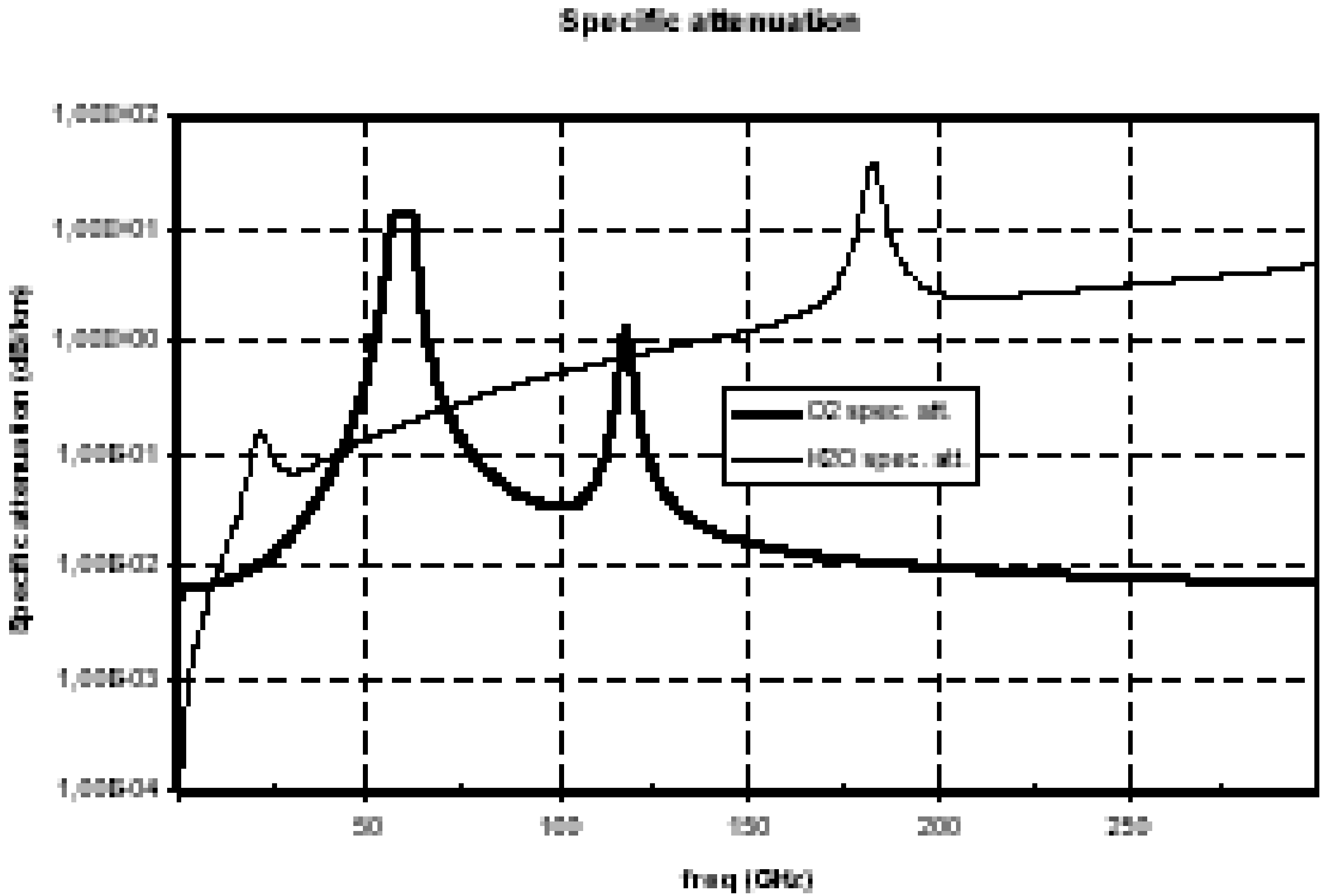
$$f = 900 MHz$$

$$c = 3 * 10^{8} m/s$$

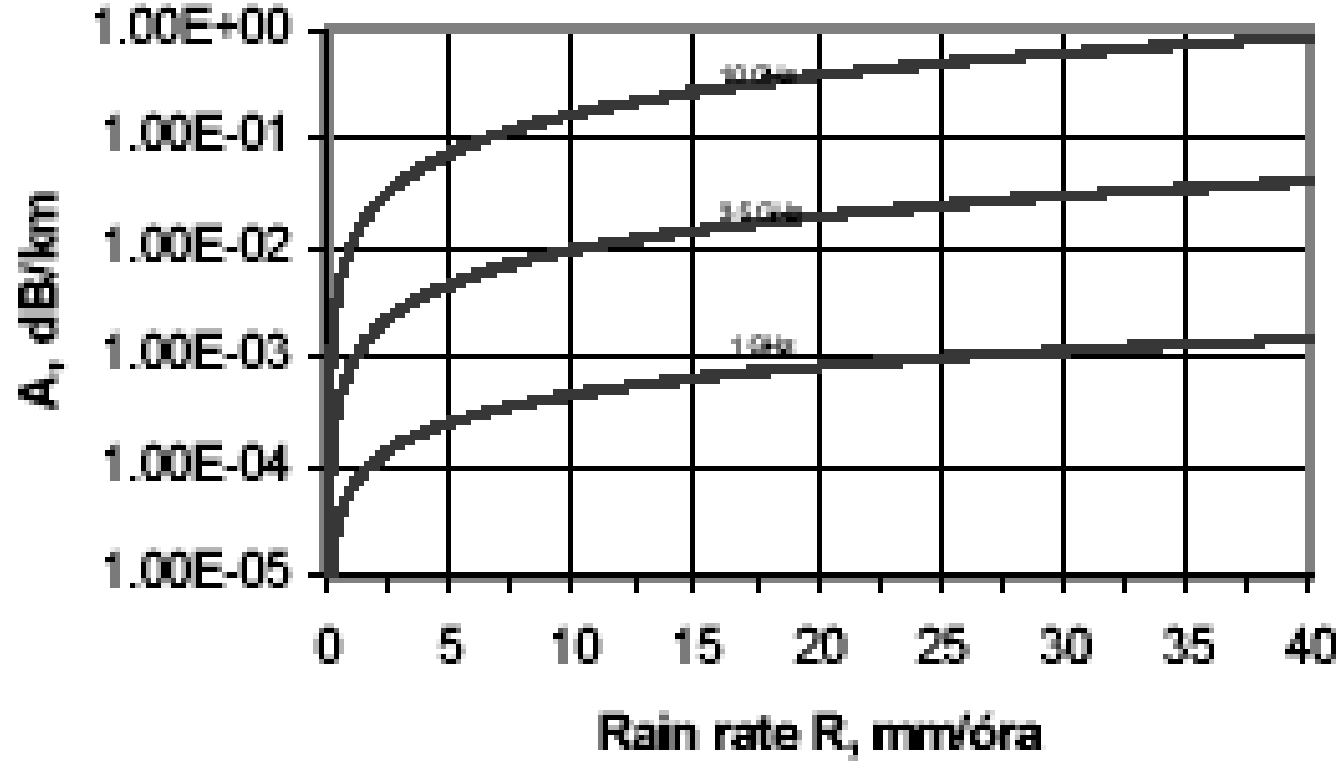
$$s \cong 1000 m$$

$$E_{dir} \cong E_0 \frac{k}{s} \sin(2\pi f (t - \frac{s}{c}))$$

$$E_{refl} \cong E_0 \frac{k}{s_1 + s_2} \sin(2\pi f (t - \frac{s_1 + s_2}{c}))$$



Attenuation of the atmospheric gases



Attenuation by rain at 1, 3.5 and 10 GHz as a function of rain rate

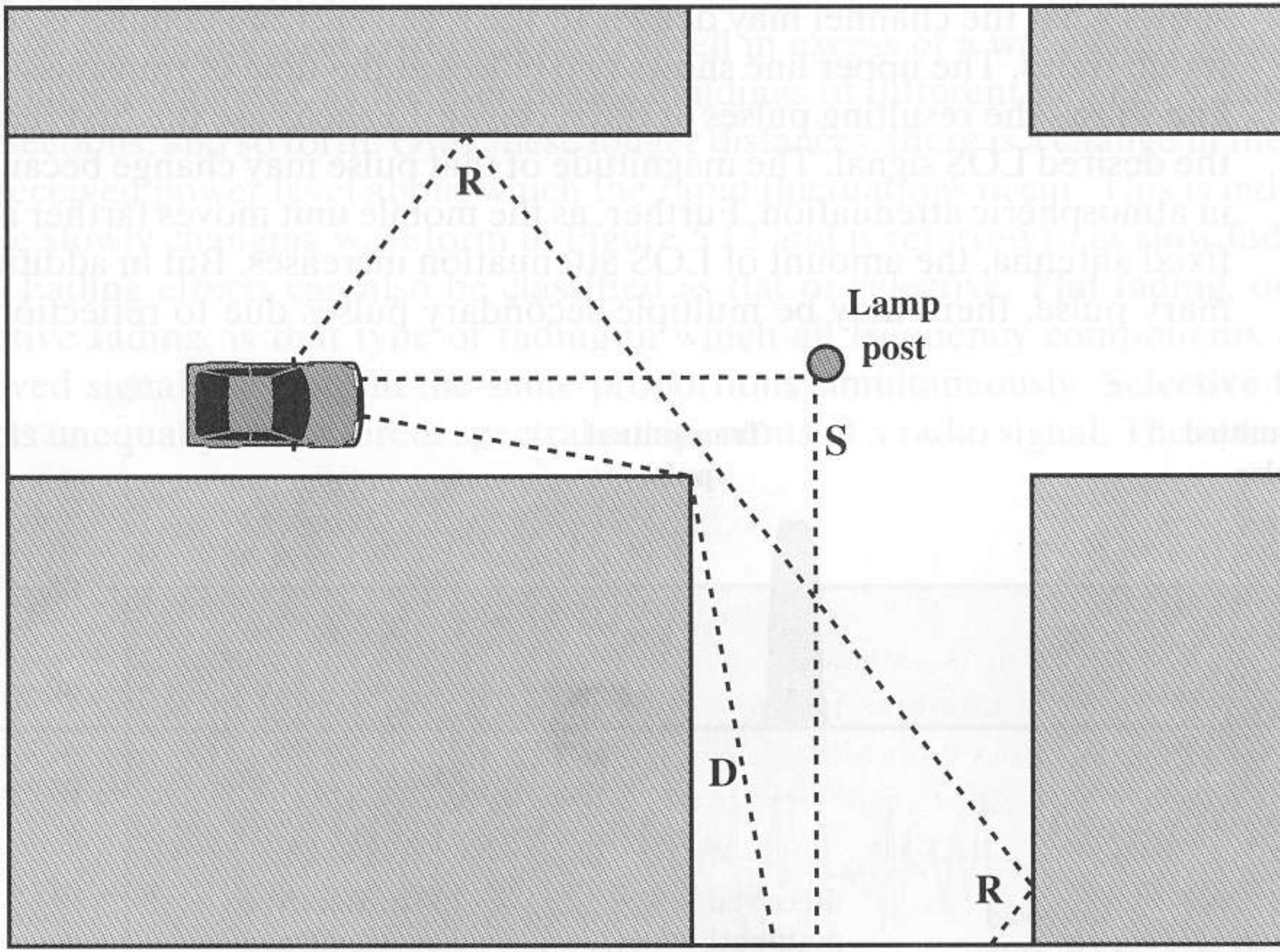
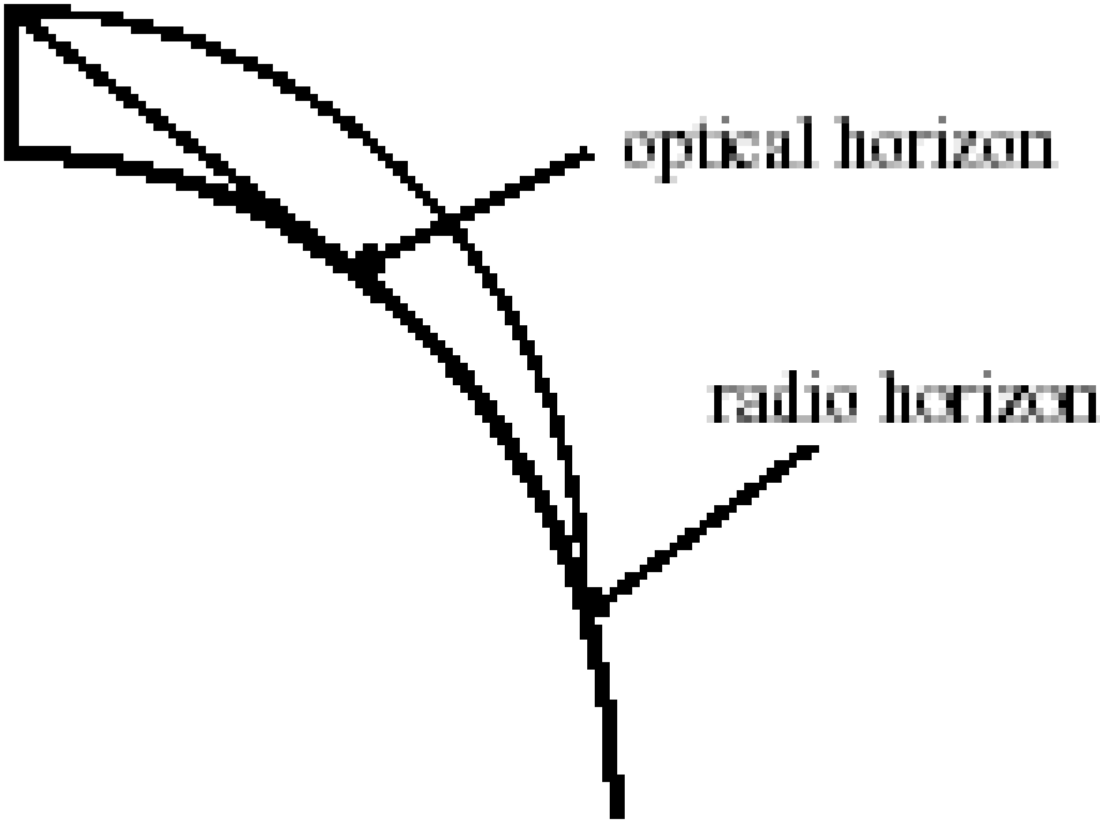


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]



Refraction of radio waves

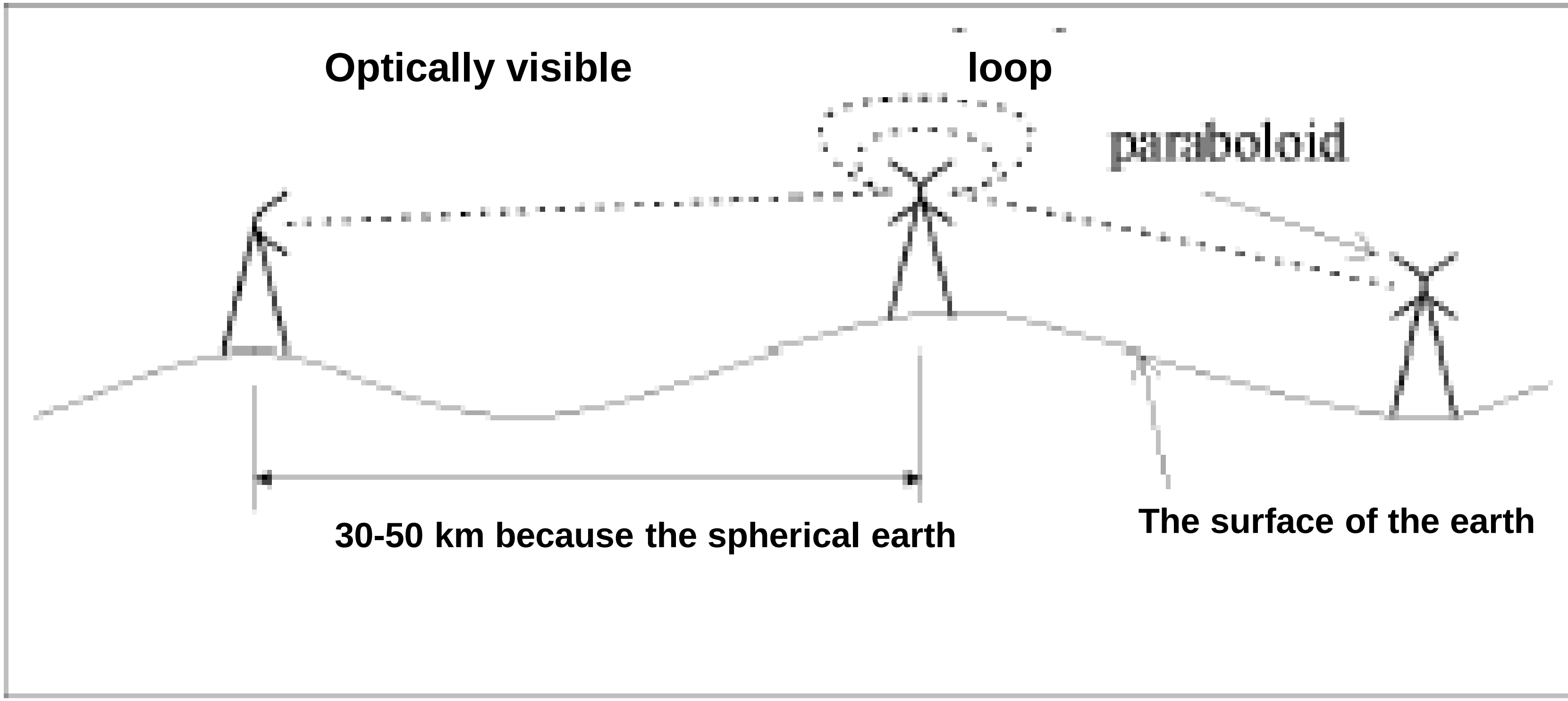
„Good” frequencies? Bandwidth issues?

- Low attenuation (loss)
- High bandwidth
- Beaming – circular characteristic
- Cheap or free
- No interference
- Exclusive usage

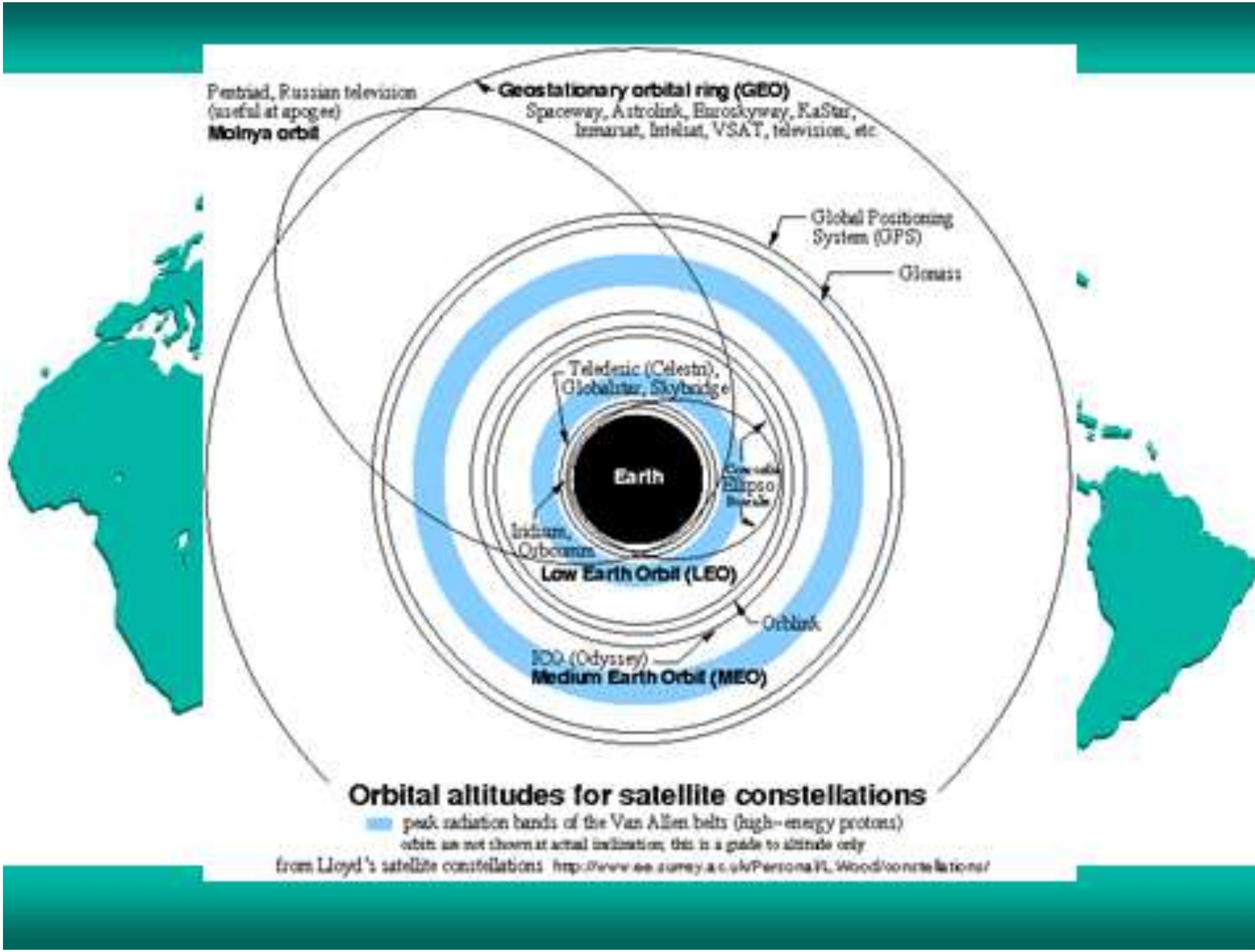
- „Good” frequencies are not existing -- Only compromise of limitations

Radio link types

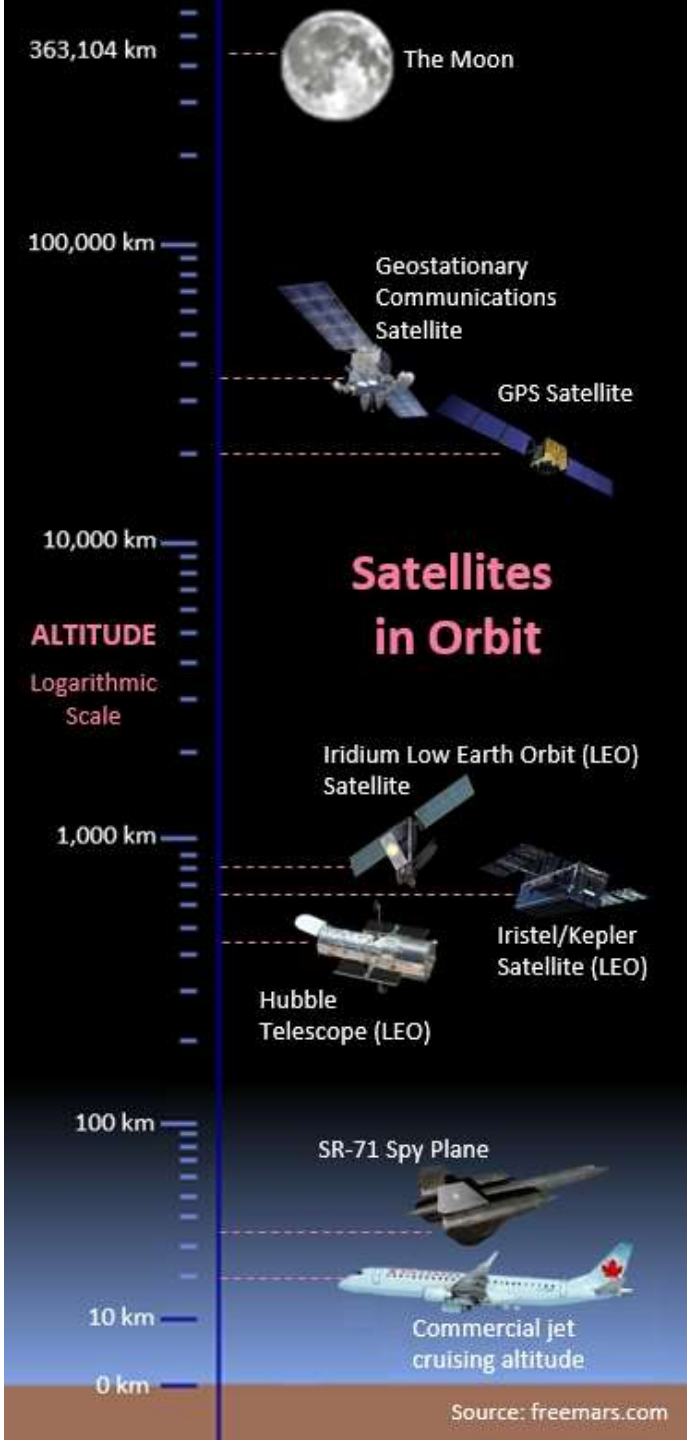
- Point-point connections
- Point multipoint connections
- Cellular systems



Terrestrial microwave connections



Pentriad, Russian television
(useful at apogee)
Molnya orbit
Geostationary orbital ring (GEO)
Spaceway, Astrolink, Euroskyway, KaStar,
Inmarsat, Intelsat, VSAT, television, etc
Global Positioning System (GPS)
Glonass
Teledesic (Celestri),
Globalstar, Skybridge
Earth
Ellipso
Iridium,
Orbcomm
Low Earth Orbit (LEO)
Orblink
ICO (Odyssey)
Medium Earth Orbit (MEO)
Orbital altitudes for satellite constellations
peak radiation bands of the Van Allen belts (high-energy protons)
from Lloyd's satellite constellations


363,104 km
The Moon
100,000 km
Geostationary Communications Satellite
GPS Satellite
10,000 km
Satellites in Orbit
ALTITUDE
Logarithmic Scale
Iridium Low Earth Orbit (LEO) Satellite
1,000 km
Iristel/Kepler Satellite (LEO)
Hubble Telescope (LEO)
100 km
SR-71 Spy Plane
10 km
Commercial jet cruising altitude
0 km
Source: freemars.com

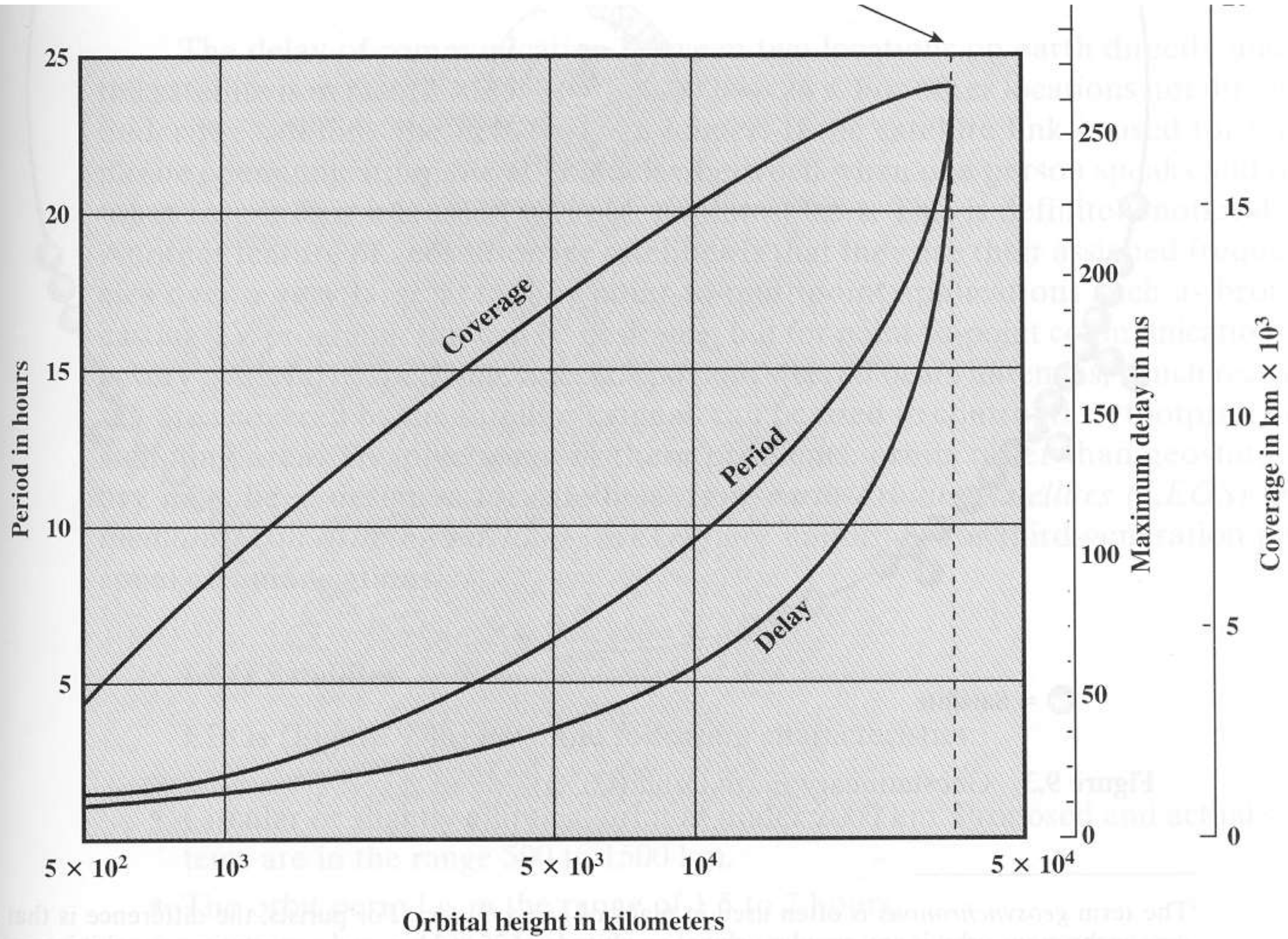


Figure 9.2 Satellite Parameters as a Function of Orbital Height

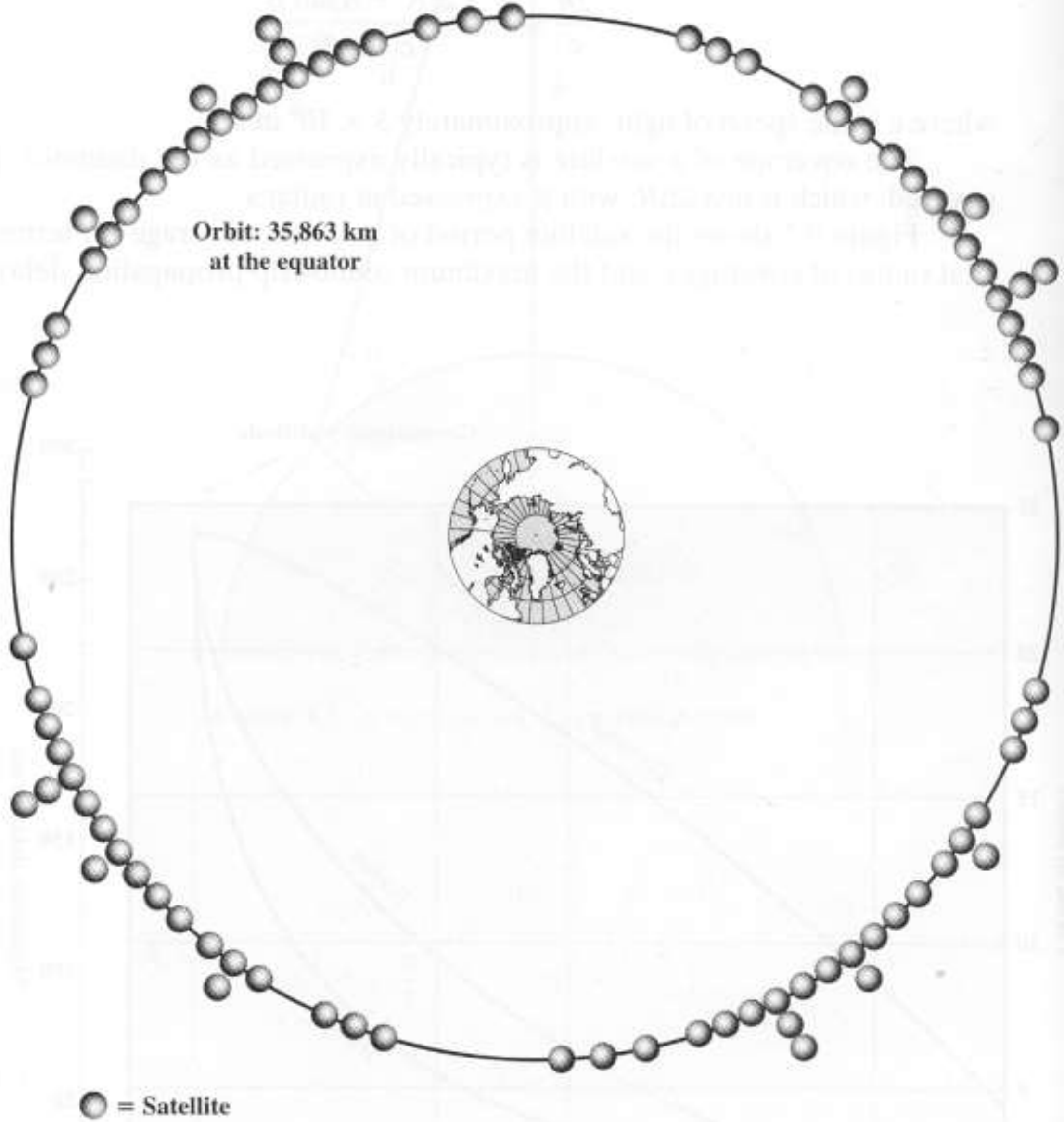
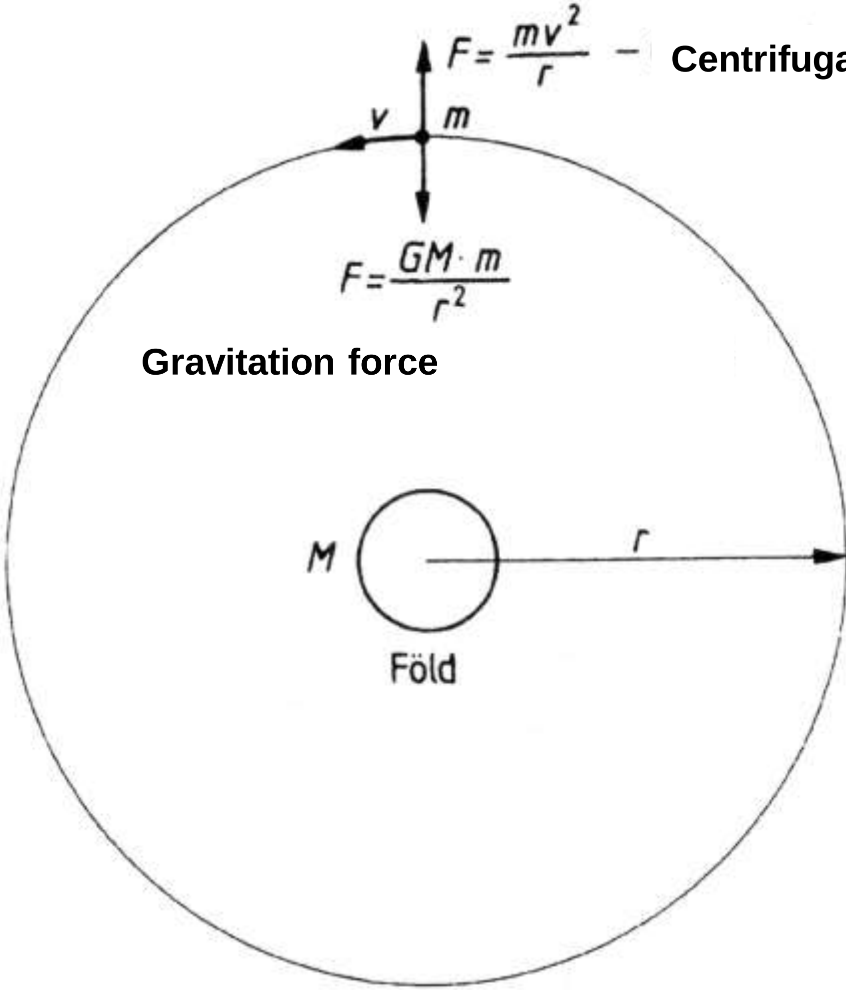


Figure 9.3 Geostationary Earth Orbit (GEO)



$m =$ Mass of the satellite, kg

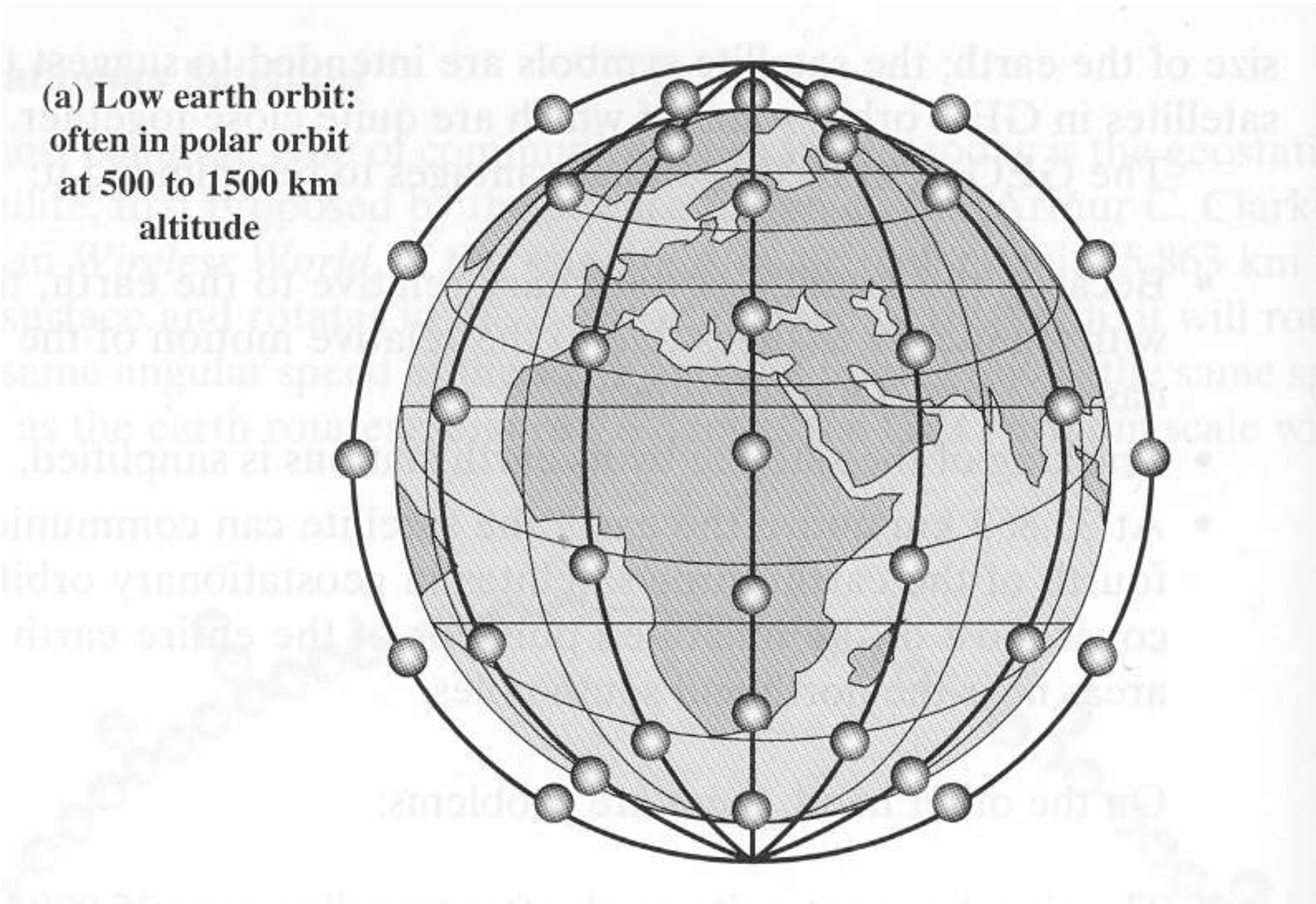
$M =$ Mass of the earth

$G =$ Gravitational constant

$v =$ Speed of the satellite, m/s

$r =$ 42164 km

Geostationary satellite characteristics


(a) Low earth orbit:
often in polar orbit
at 500 to 1500 km
altitude

(b) Medium earth orbit: inclined to the equator, at 5000 to 12,000 km altitude

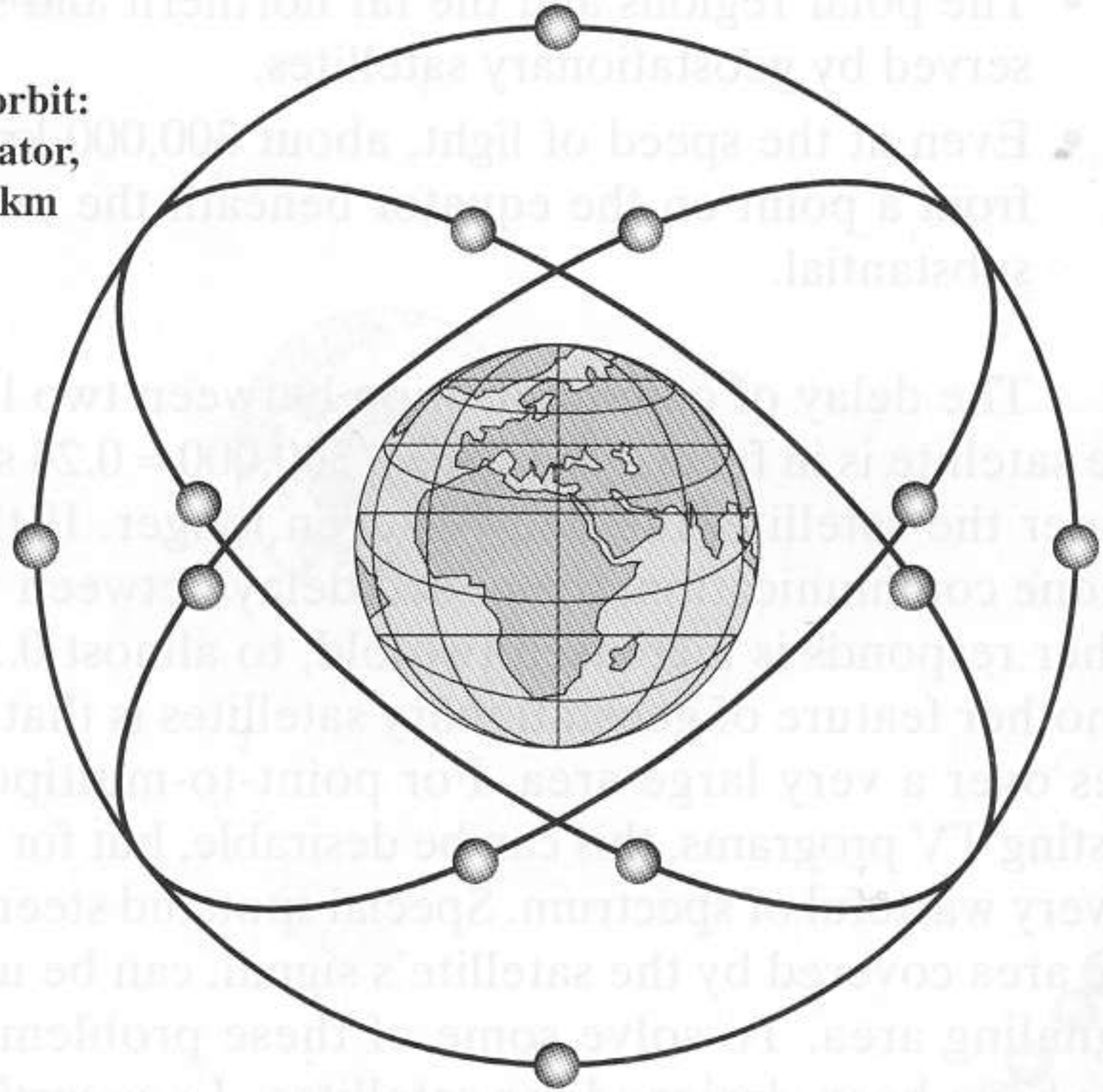


Table 9.1 Frequency Bands for Satellite Communications

Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

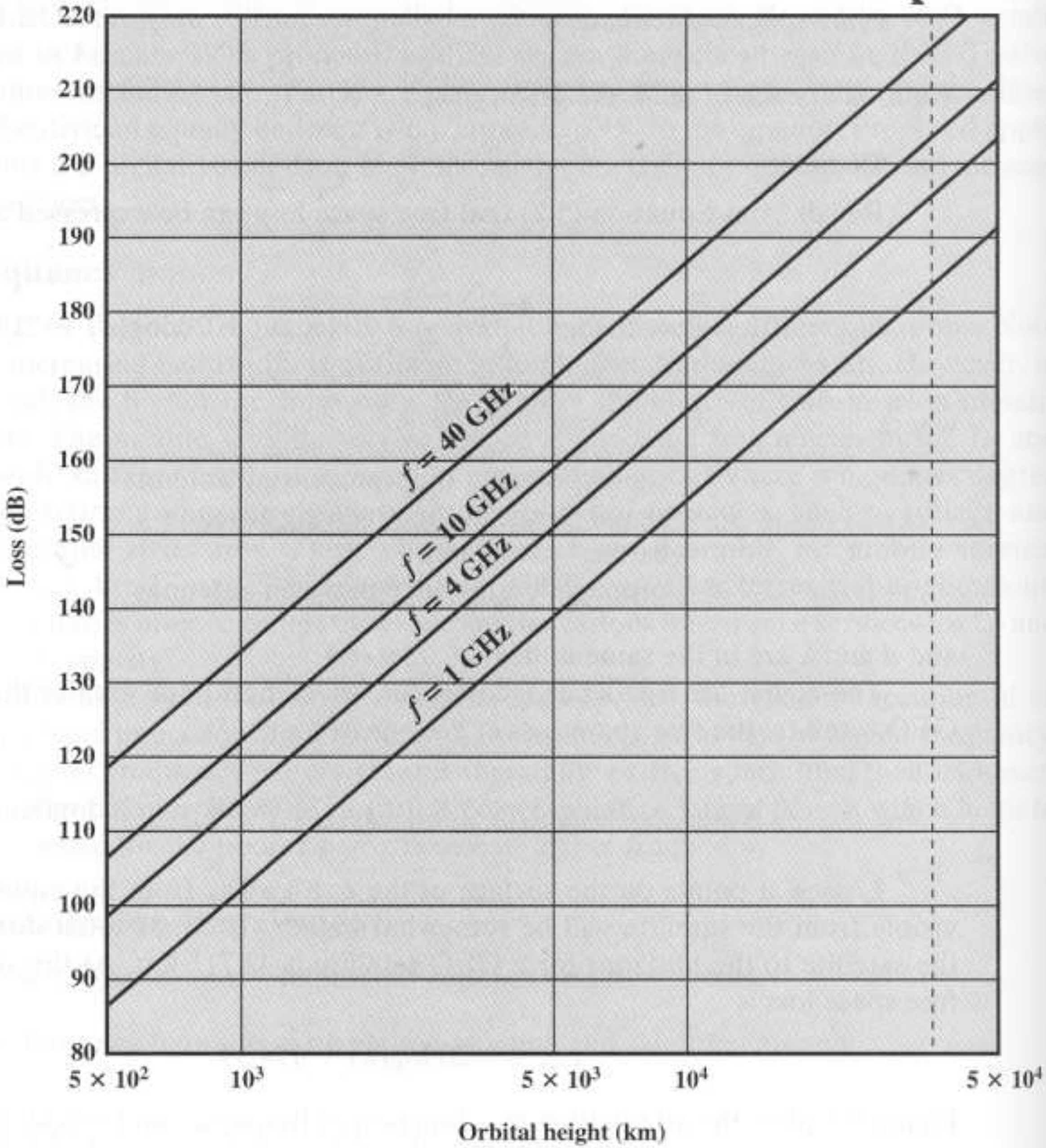


Figure 9.5 Minimum Free Space Loss as a Function of Orbital Height

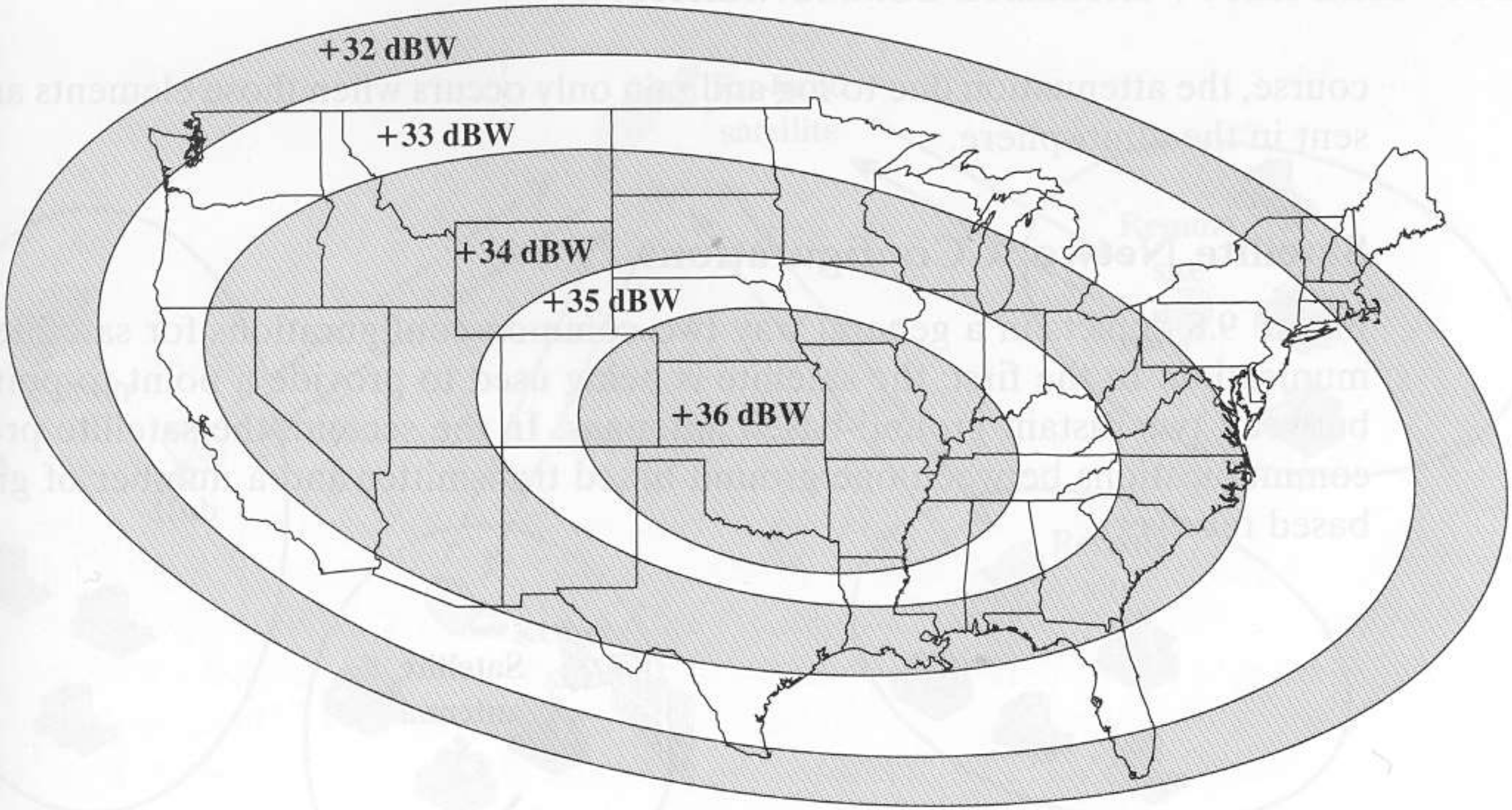
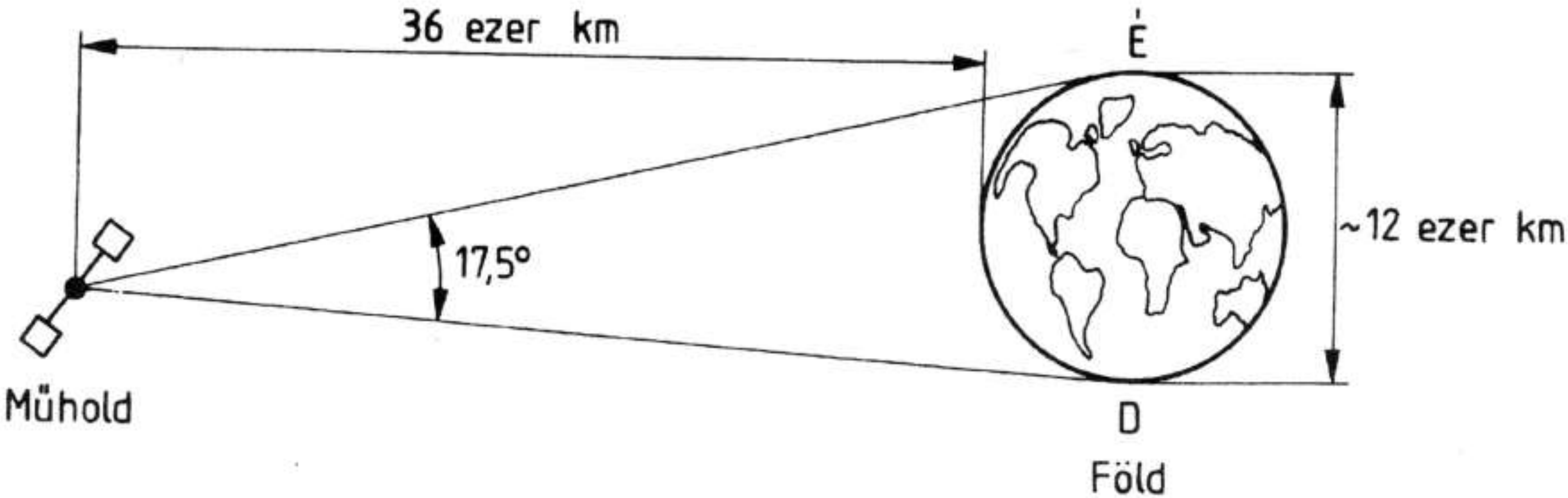
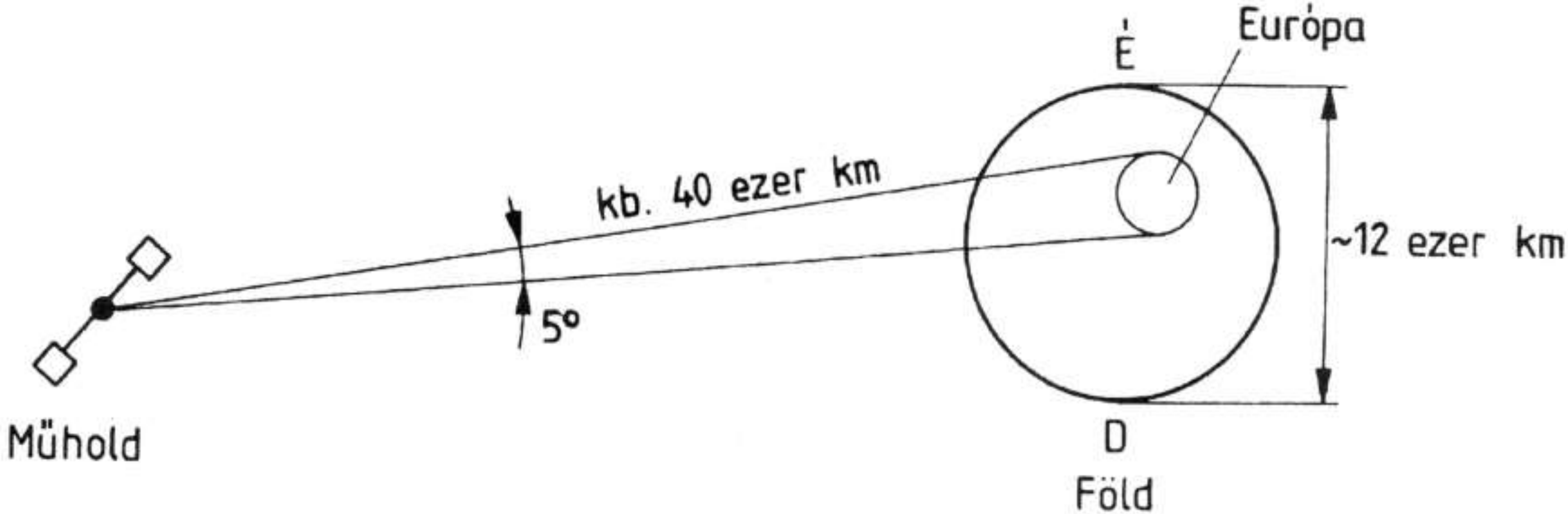
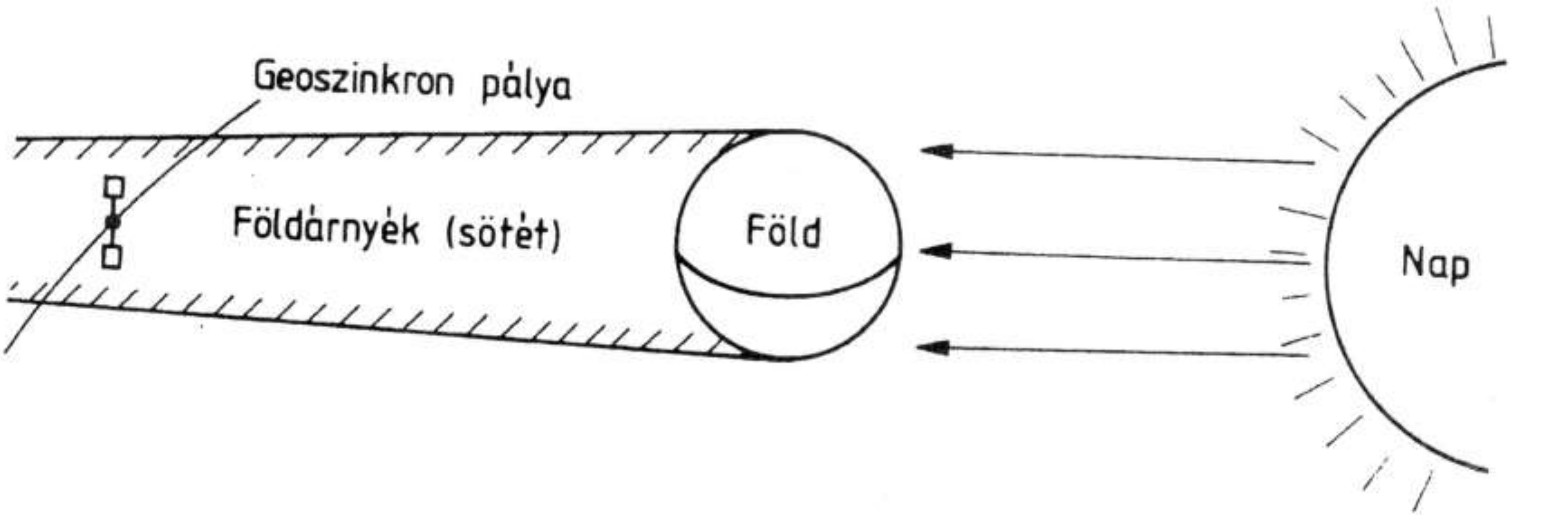


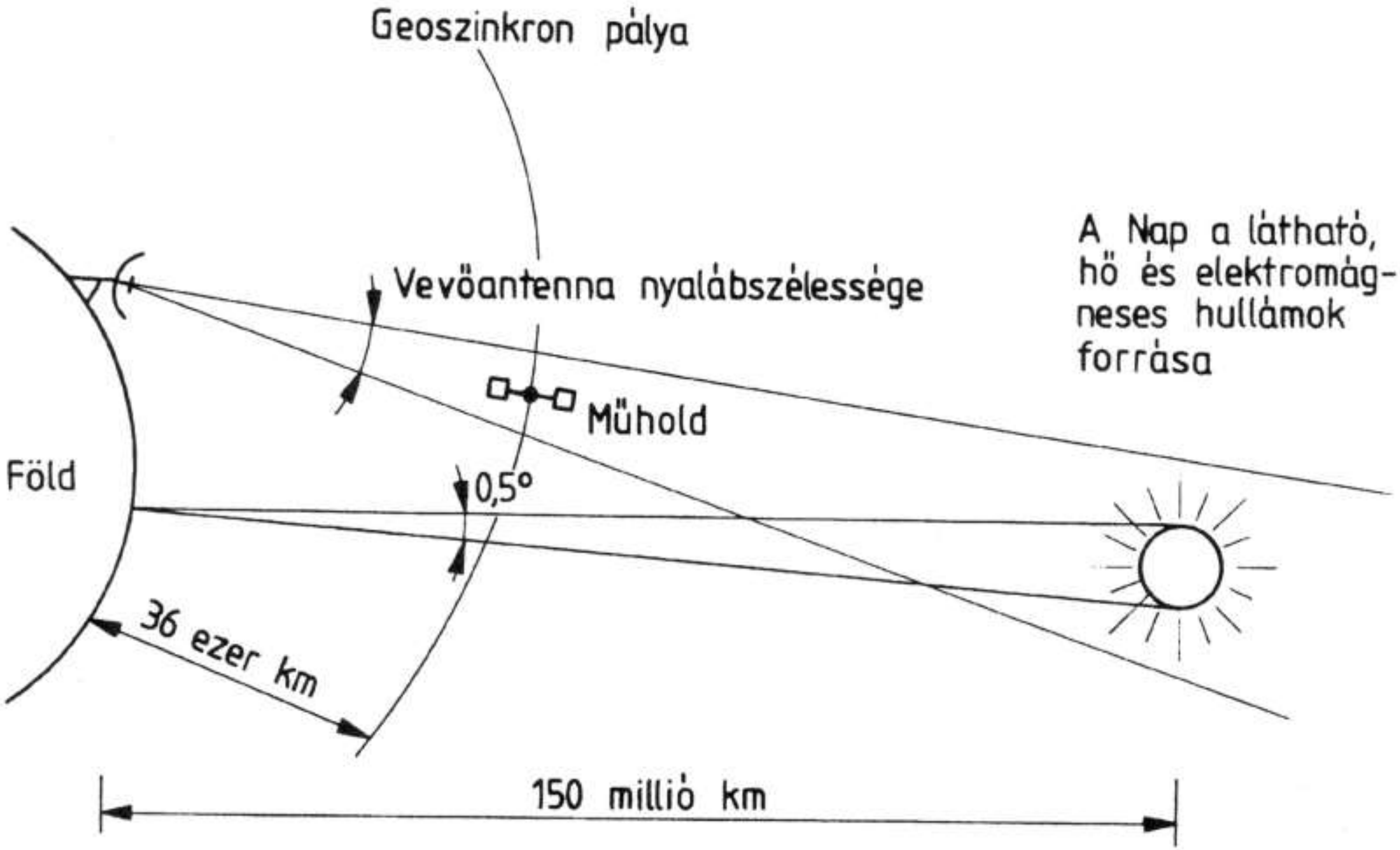
Figure 9.6 Typical Satellite Footprint

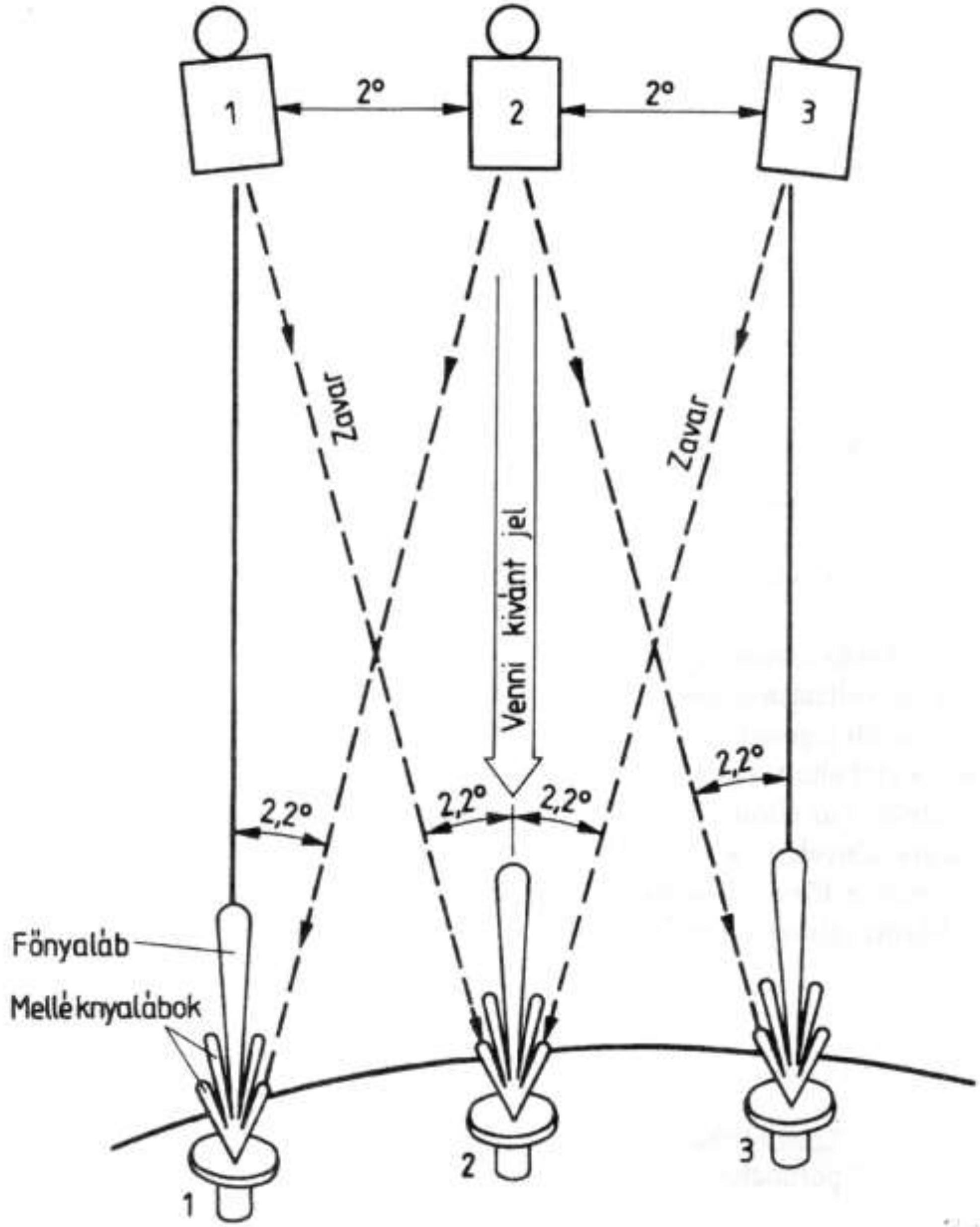


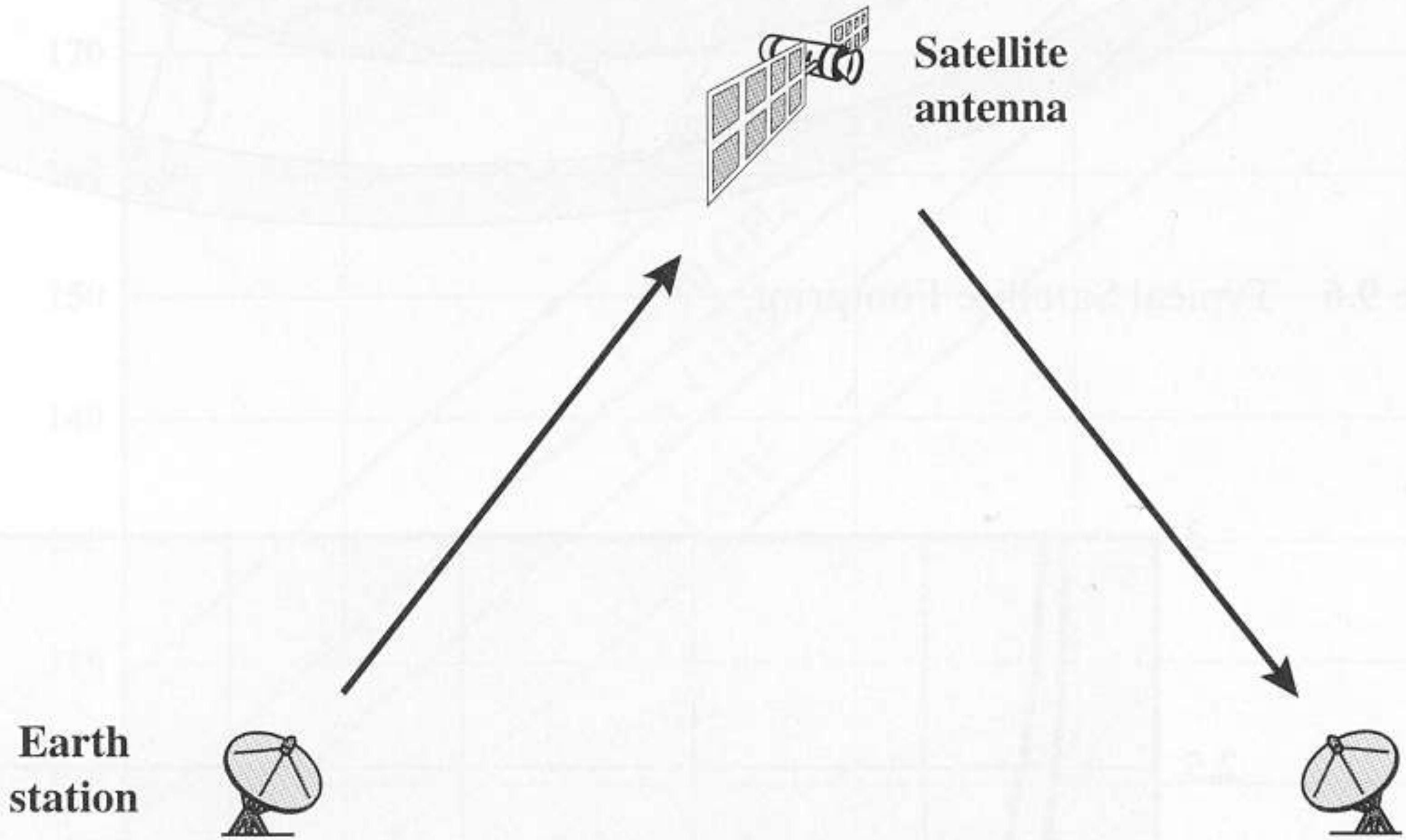
A Föld képe a geostacioner pályáról. A teljes gömböt 17,5°-os szöggel látjuk.


Európa
É
kb. 40 ezer km
~12 ezer km
5°
Mühold
D
Föld

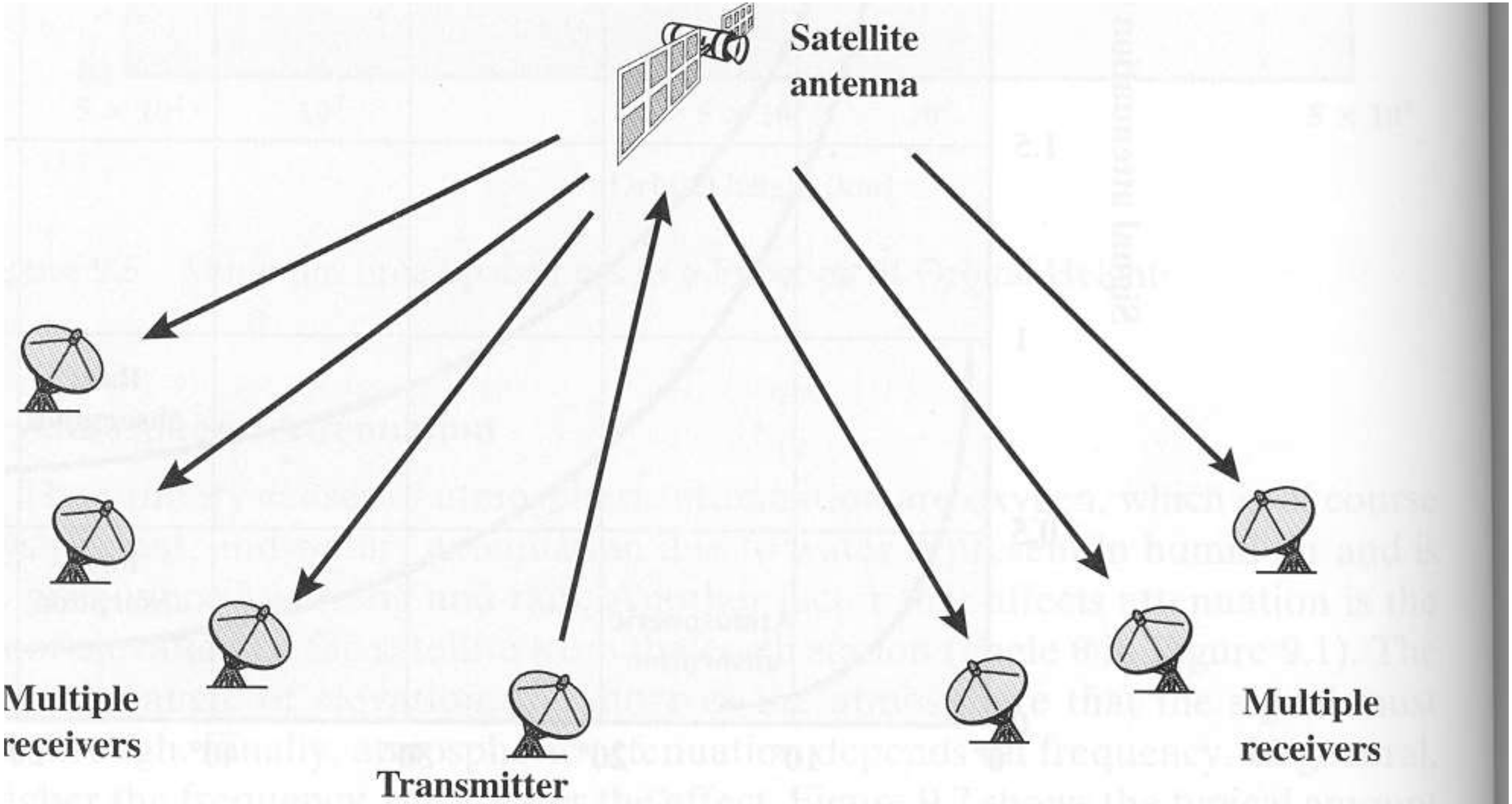

Geoszinkron pálya
Földárnyék (sötét)
Föld
Nap


Geoszinkron pálya
Vevöantenna nyalábszélessége
A Nap a látható, hö és elektromágneses hullámok forrása
Mühold
Föld
0,5°
36 ezer km
150 millió km


1
2
3
2°
2°
Zavar
Zavar
Venni kívánt jel
2,2°
2,2°
2,2°
2,2°
Fõnyaláb
Mellékn yalábok
1
2
3



(a) Point-to-point link



(b) Broadcast link

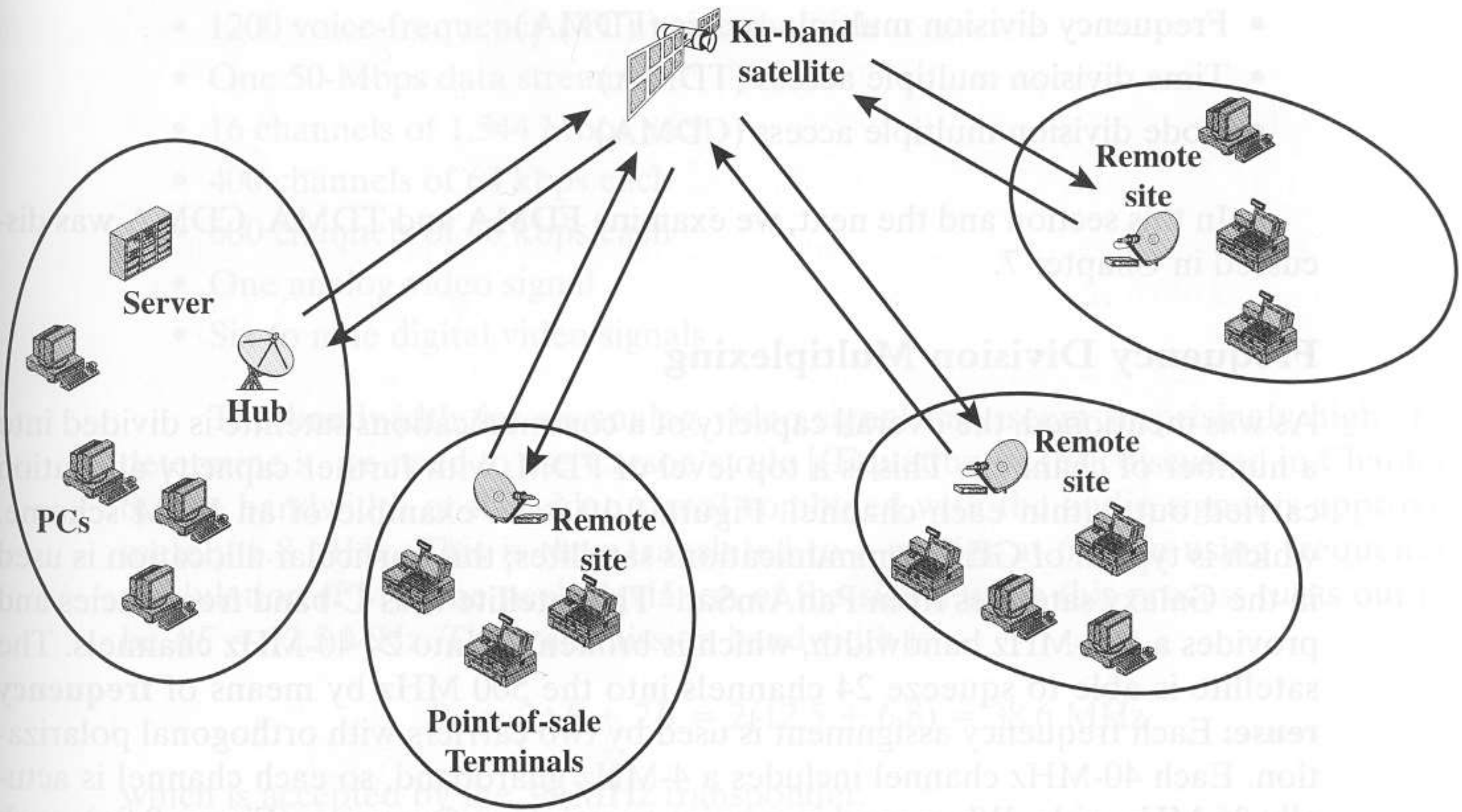
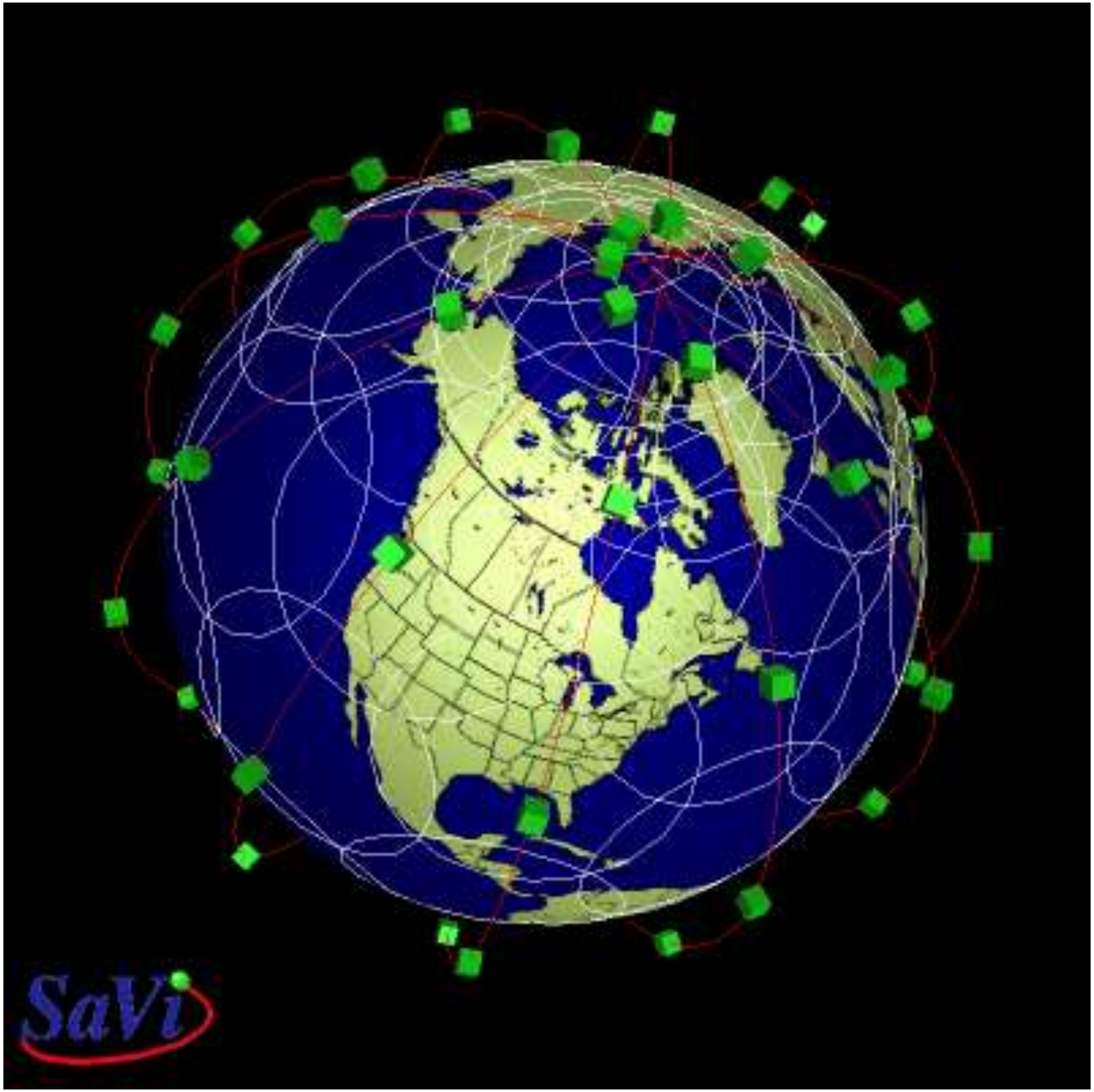


Figure 9.9 Typical VSAT Configuration

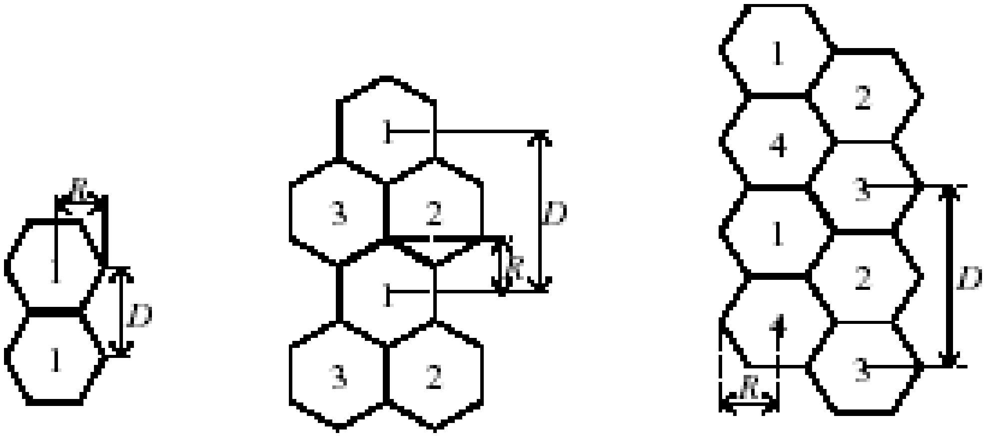

SOI-ASIA Partners Satellite Antenna
Brawijaya University, Indonesia
Hasanuddin University, Indonesia
Sam Ratulangi University, Indonesia
Laos National University, Laos
University of Computer Studies, Yangon, Myanmar
Asian Youth Fellowship, Malaysia
Asian Institute of Technology, Thailand
Chulalonkorn University, Thailand
Institute of Information Technology, Vietnam
SOI-ASIA Partners Satellite Antenna


SaVi

Cellular systems

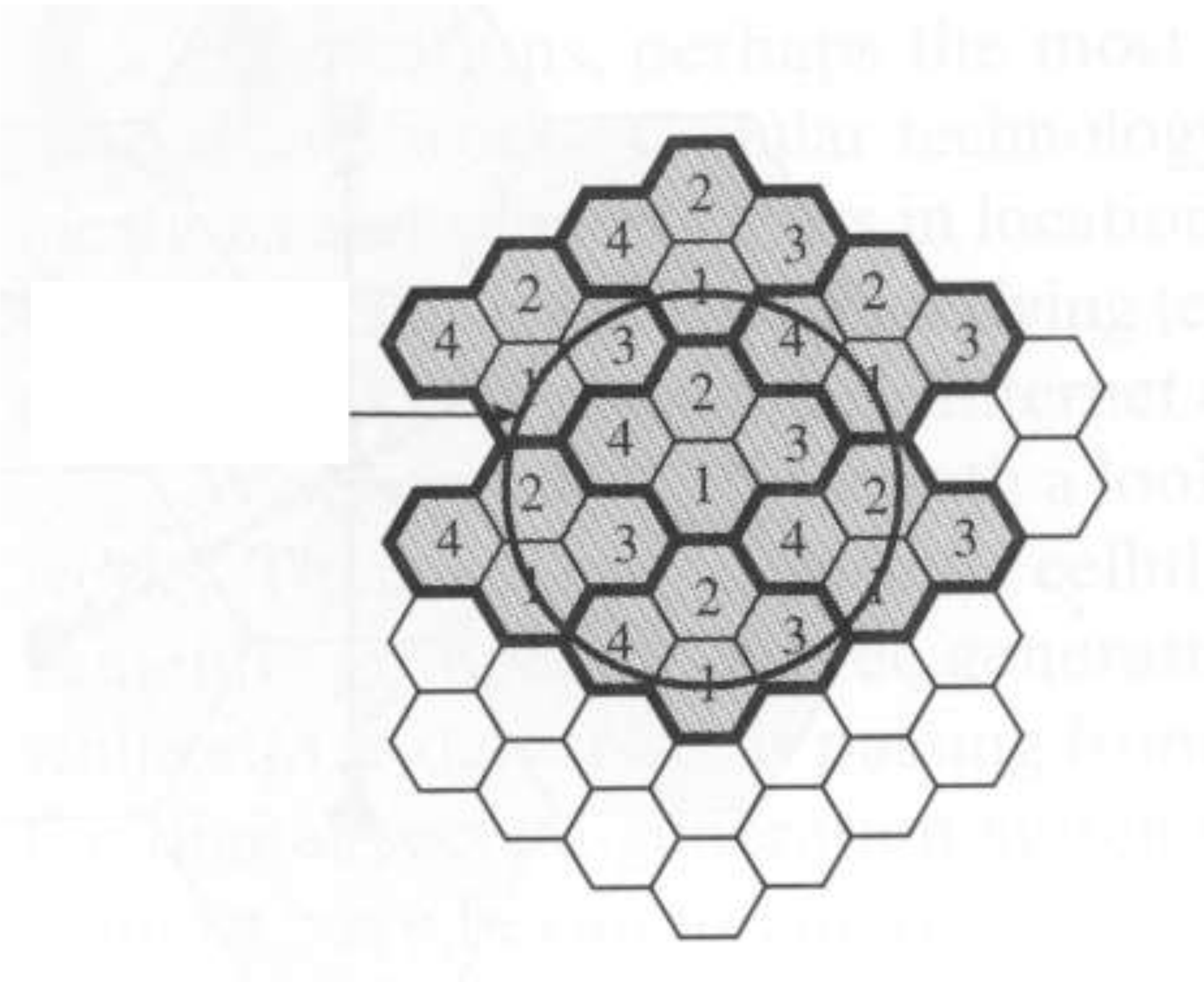
- in a cluster each cell has a separate frequency
- *a* is the area of one cell
- *A* is the cluster area
- *R* is the cell diameter
- D is the distance between clusters (the distance between cells with identical frequencies)
- K is the number of the cluster cells

Examples for generating clusters

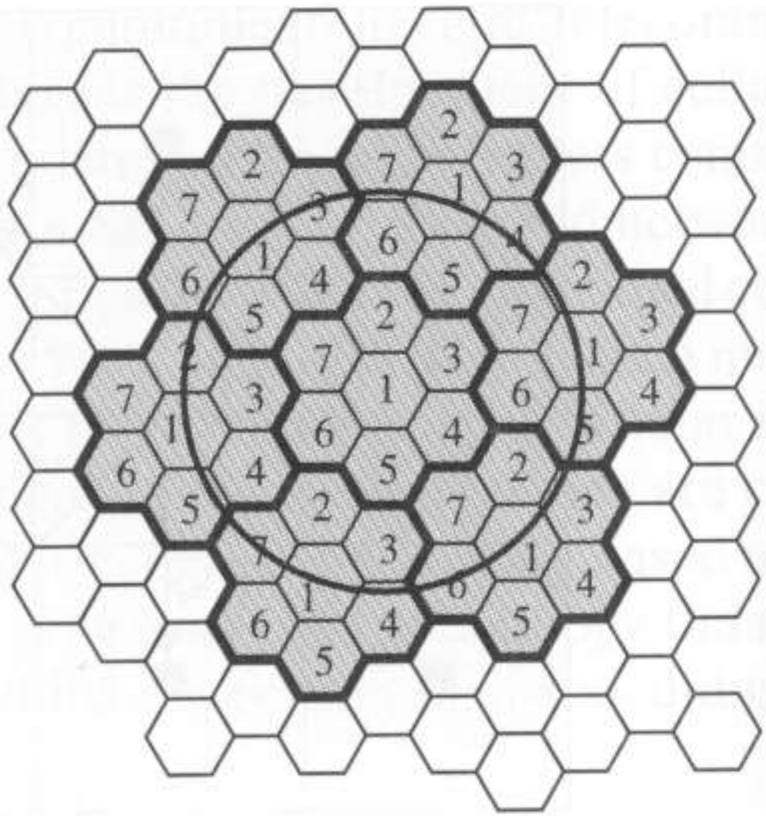


$$K = \frac{A}{a} = \left(\frac{D}{\sqrt{3}R} \right)^2$$

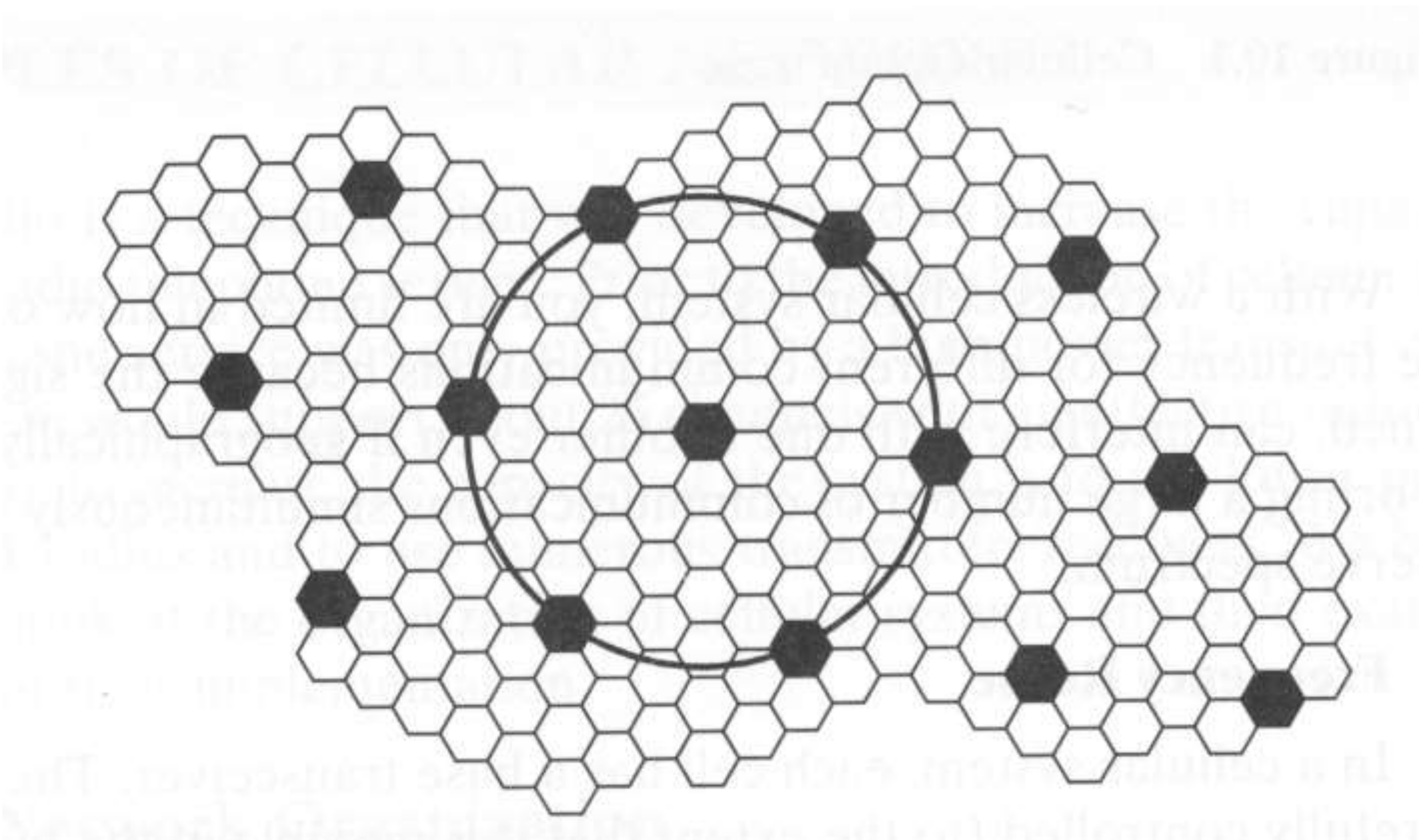
Frequency reuse pattern for K=4



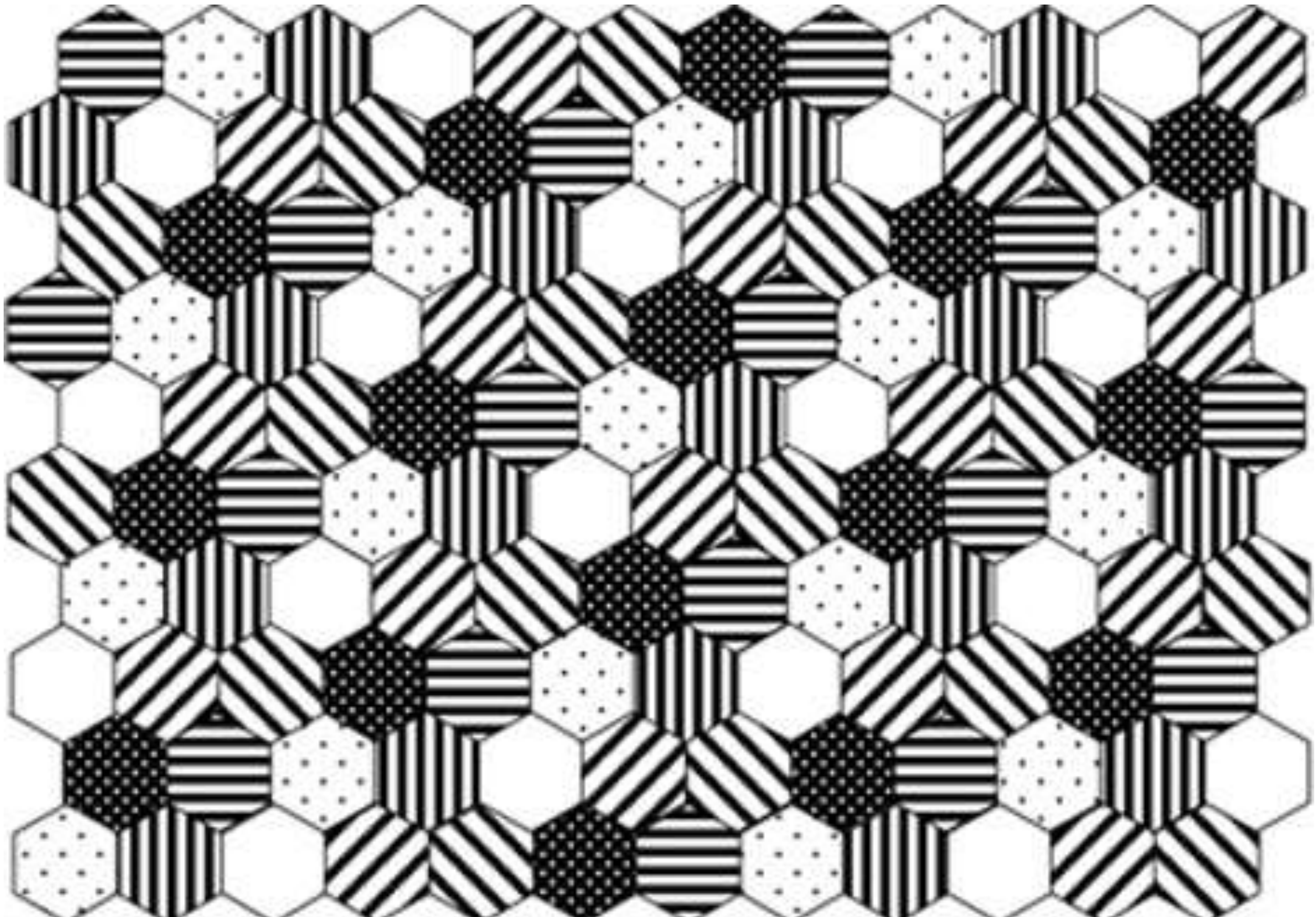
Frequency reuse pattern for K=7



Frequency reuse pattern for K=19



K=?



Increasing capacity in cellular systems

- Adding new channels
- Frequency borrowing
- Cell splitting
- Cell sectoring
- Microcells

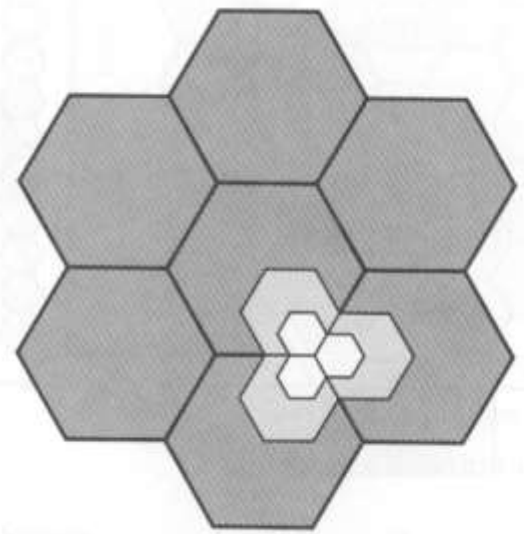
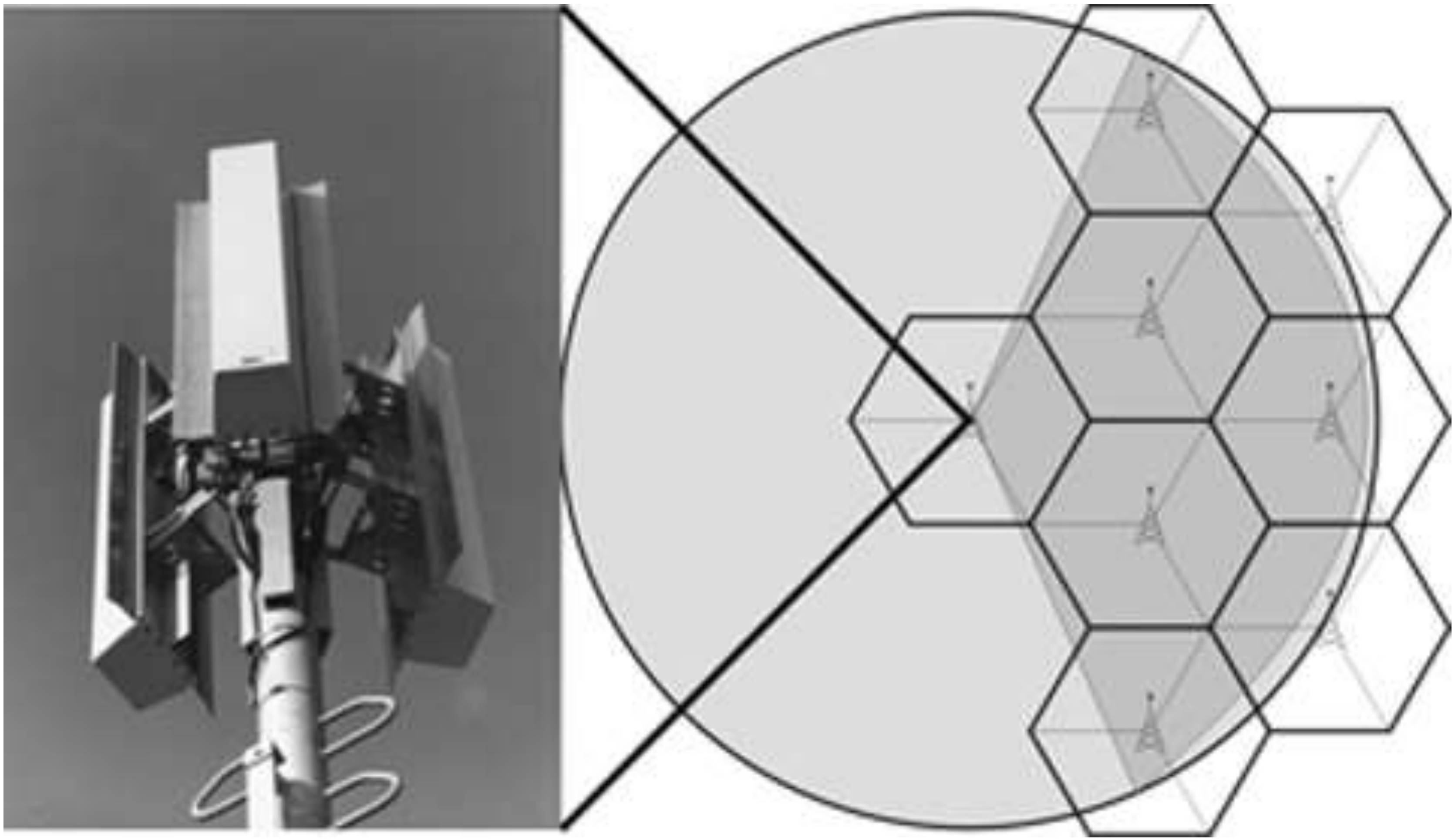
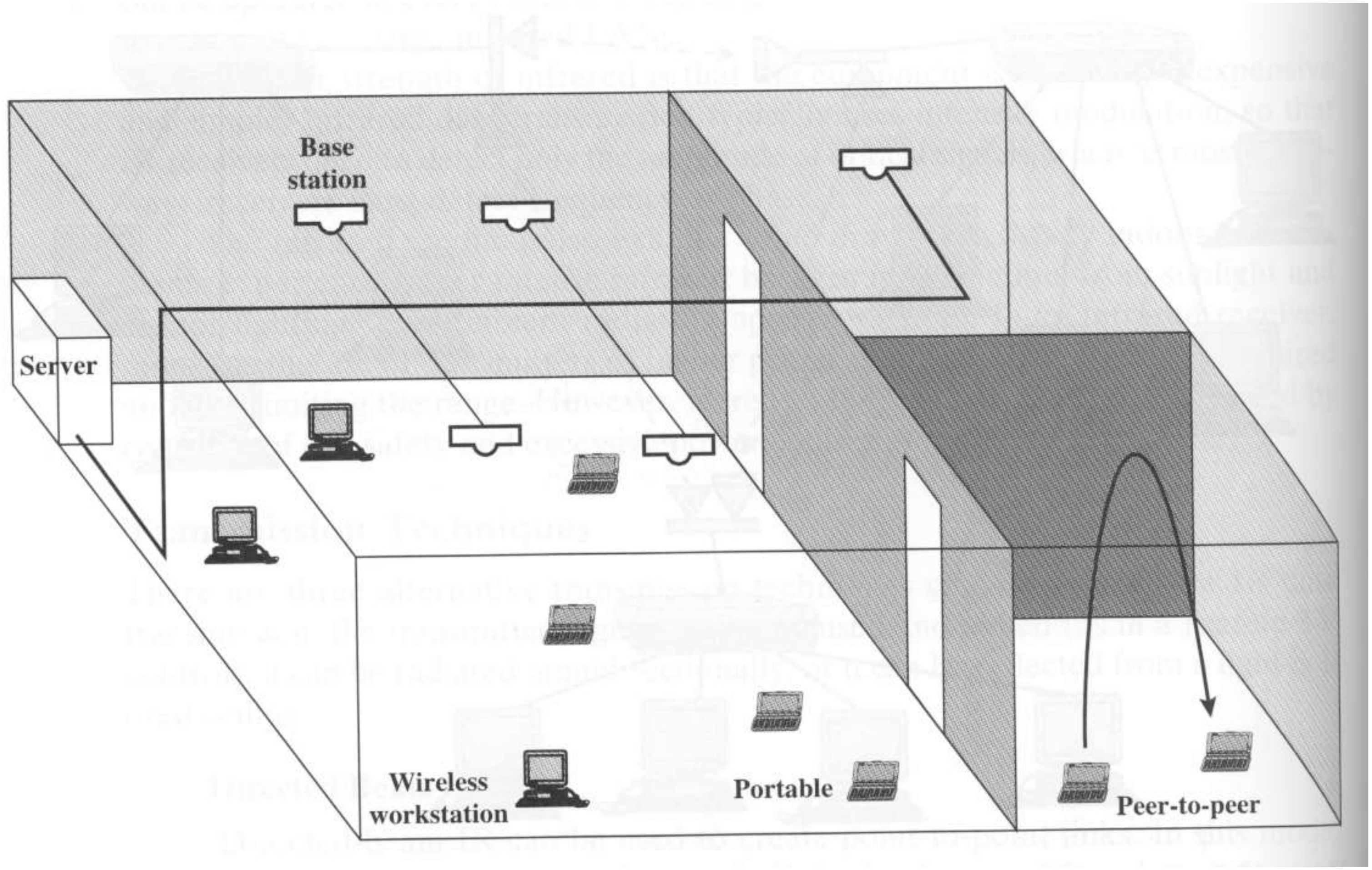


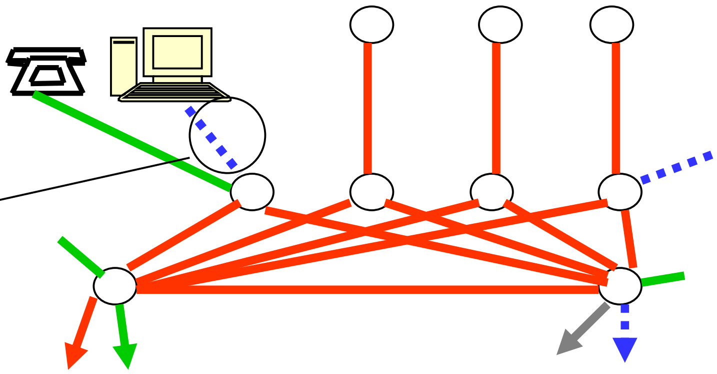
Figure 10.3 Cell Splitting

Sectoring

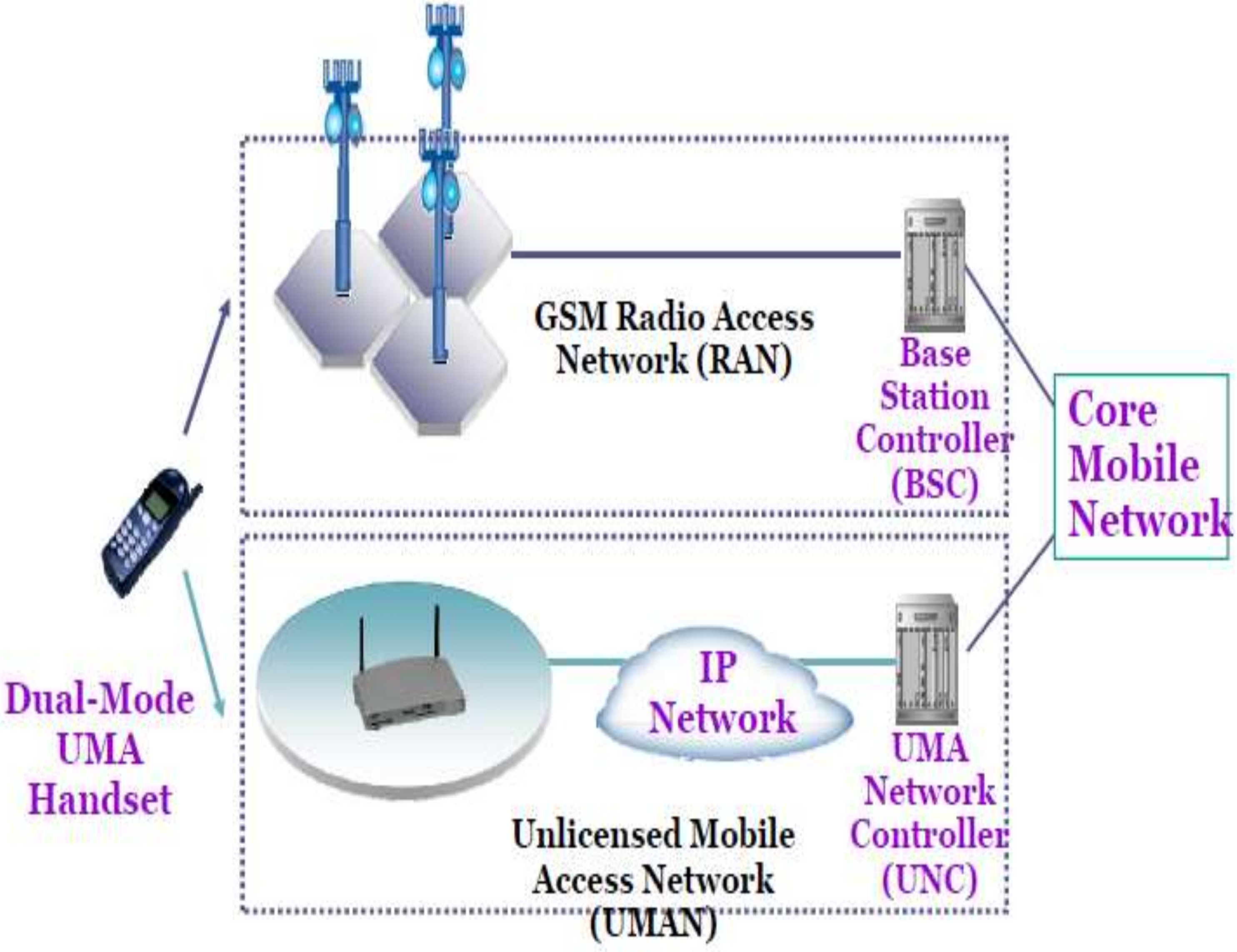


In-door wireless connections



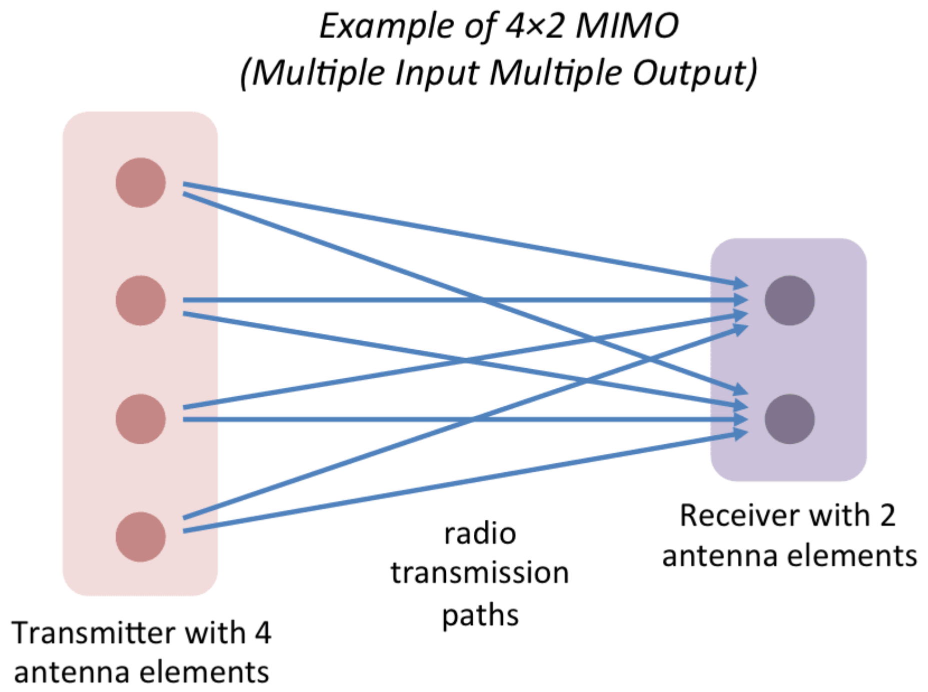


A vezetéknélküli adathálózat bázisállomásainak helye elő van készítve minden folyosón

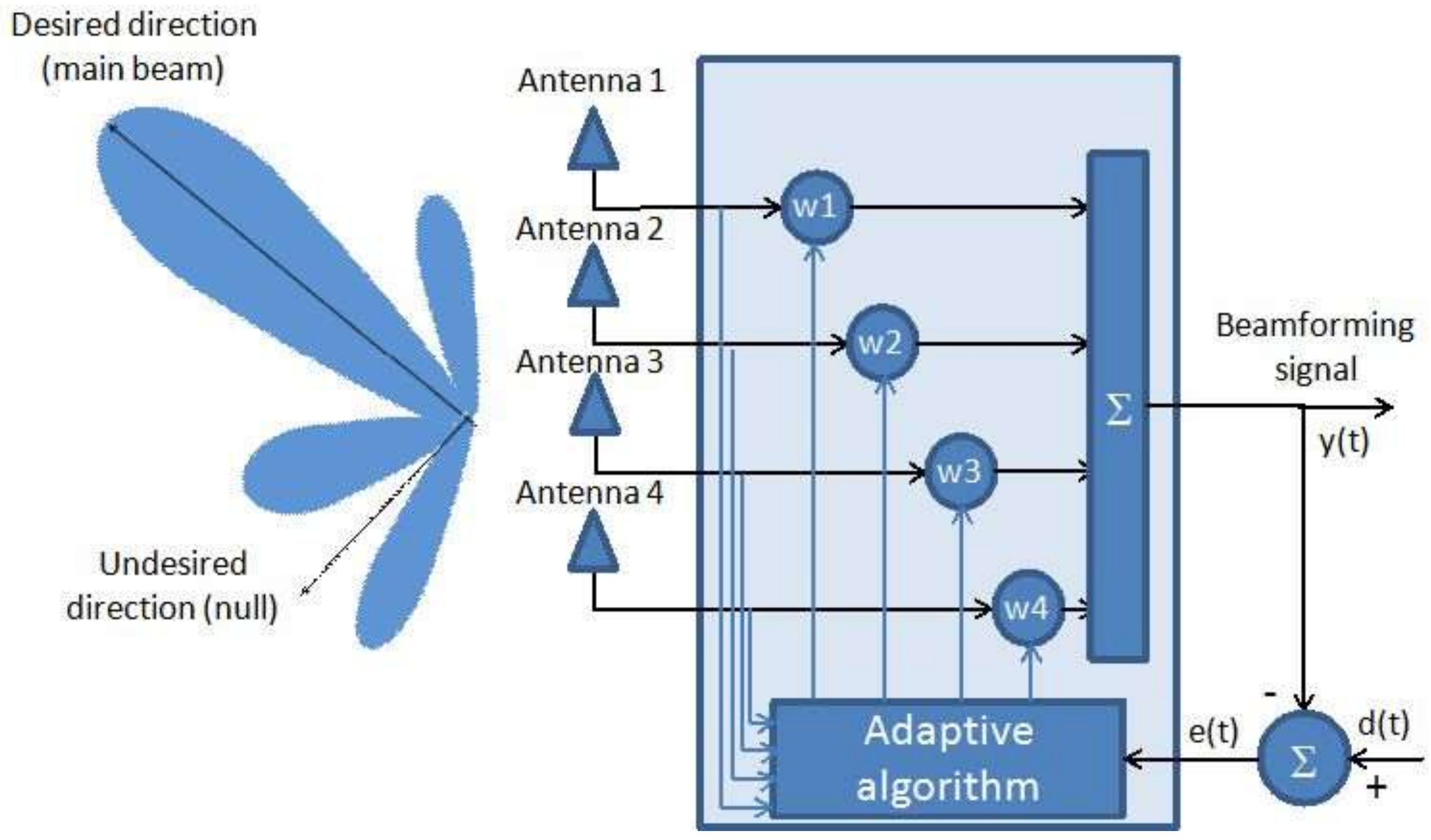

GSM Radio Access
Network (RAN)
Base
Station
Controller
(BSC)
Core
Mobile
Network
Dual-Mode
UMA
Handset
IP
Network
UMA
Network
Controller
(UNC)
Unlicensed Mobile
Access Network
(UMAN)

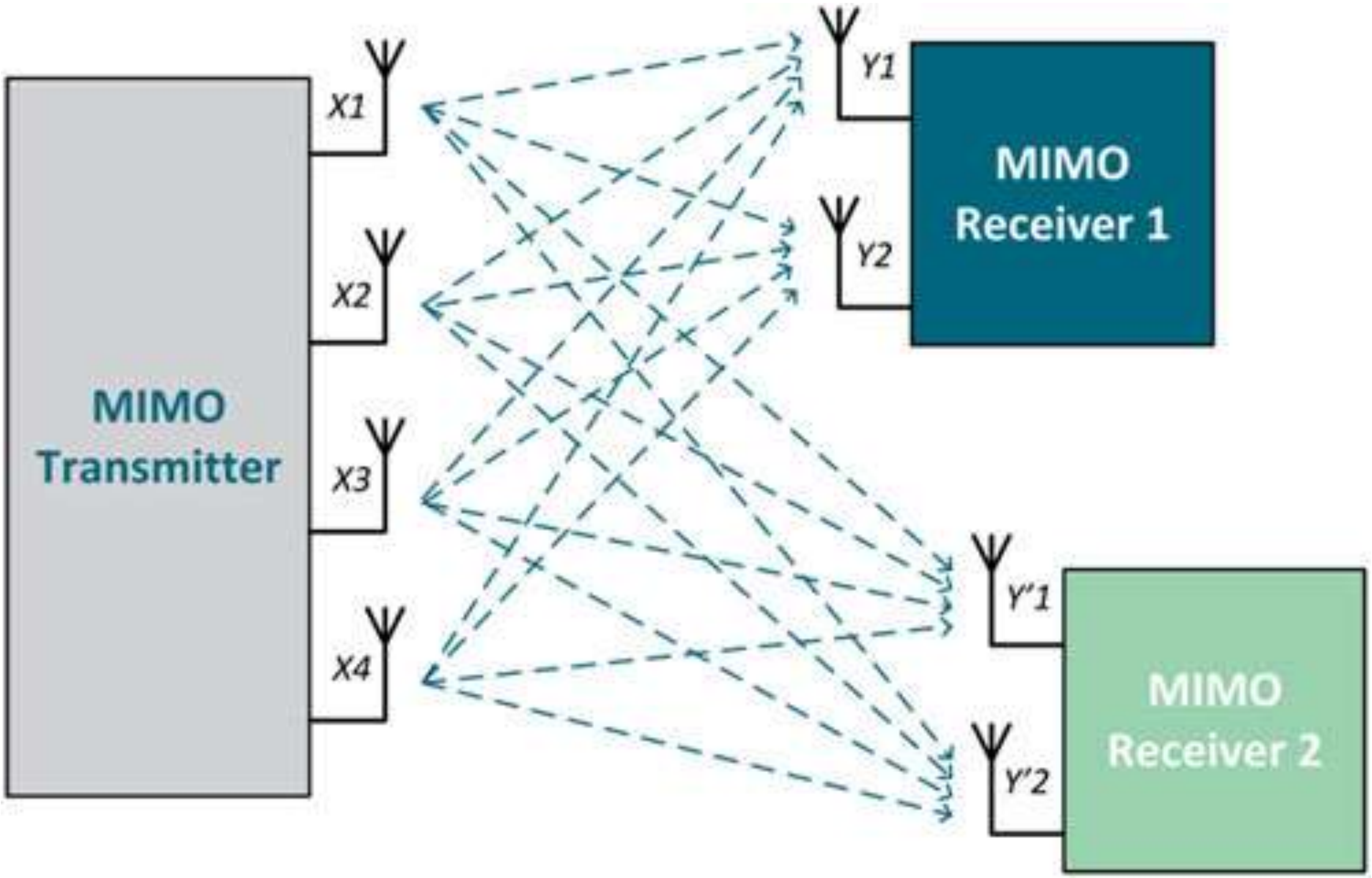

Wireless-G
Access Point
LINKSYS®

Several antennas at the transmitter, several antennas at the receiver

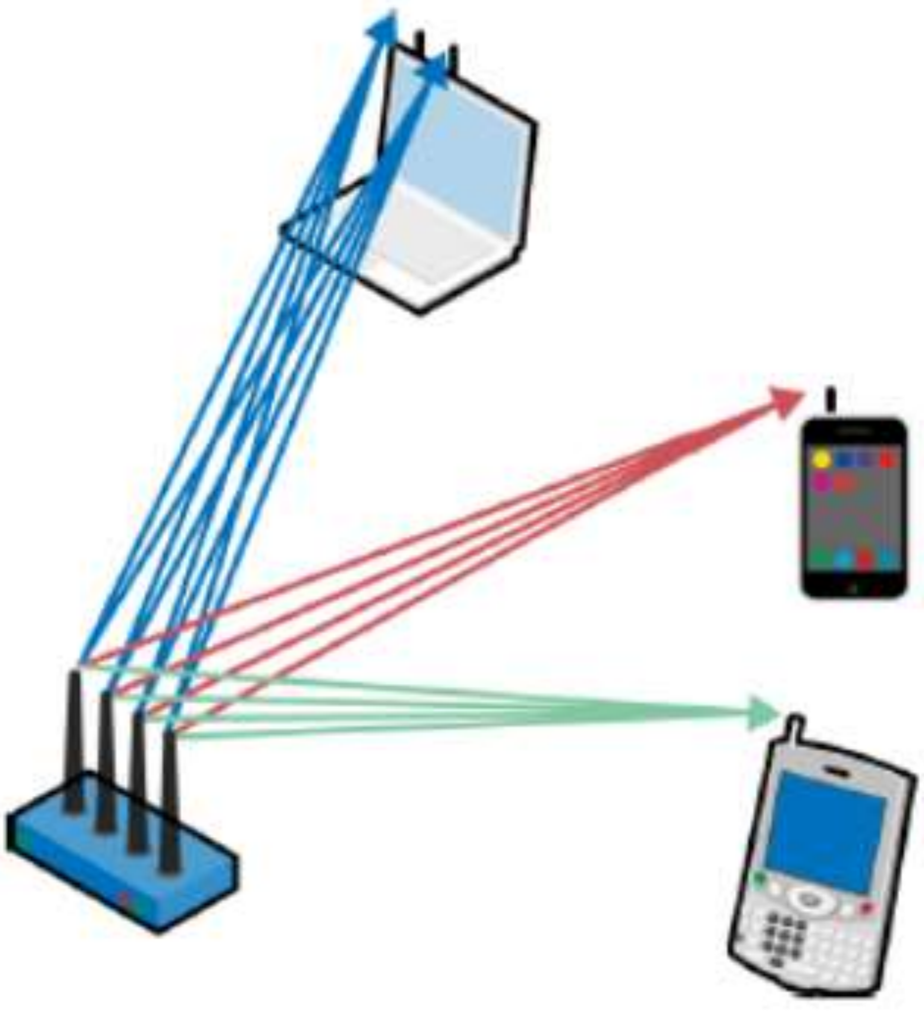


Beamforming based on antenna vector

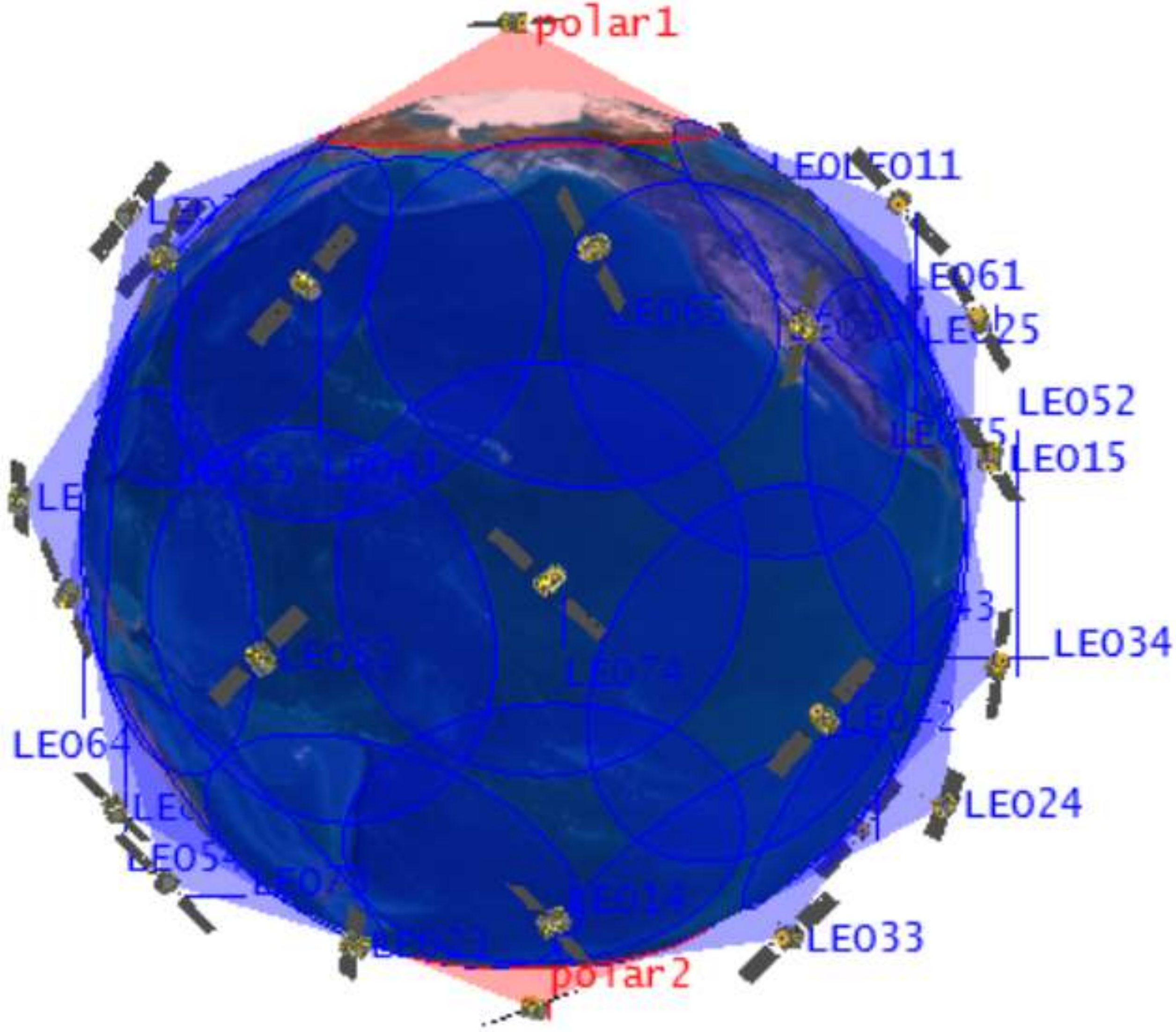



MIMO
Transmitter
X1
X2
X3
X4
Y1
Y2
MIMO
Receiver 1
Y'1
Y'2
MIMO
Receiver 2

4x2 and 4x1 MU-MIMO application in 802.11.ac WiFi
Several client can be served simultaneously using the same frequency band



New Wave: LEO satellite in IOT



LEO Satellites:

Benefits:

Low loss 500km, 10 GHz – 118 dB

(GEO 38000km 10 GHz – 204 dB)

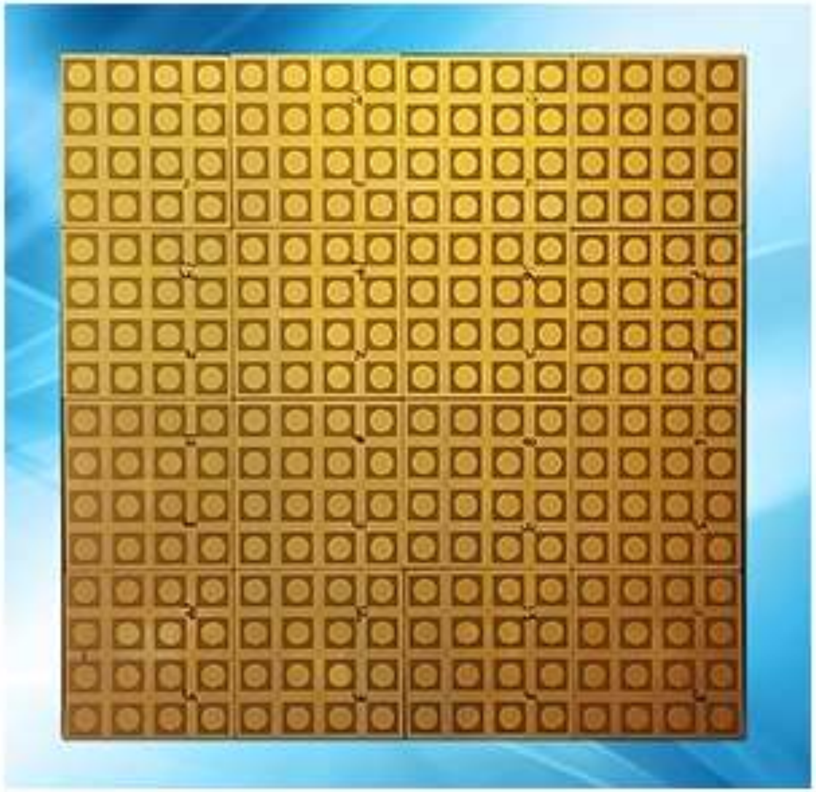
Low delay 500 km 1,67 ms

(GEO 38000 km 126 ms)

Problem: satellites are not in fixed position!

Beamforming in LEO satellites

(21 June 2018 - C-COM Satellite Systems) C-COM Satellite Systems announced today that it has successfully tested its 16×16 subarray phased array antenna using 4×4 Transmit and Receive building block modules. The panels were developed and tested at the Centre for Intelligent Antenna and Radio Systems (CIARS) at the University of Waterloo.



16×16 Tx subarray (courtesy: C-COM Satellite Systems)

Farnborough Airshow, 16-22 July, 2018:
Arralis, world leaders in building millimetre wave technologies and products – seen as the future of precision radar and satellite communications – today announced their new Ka band analogue phase shifters that enable true electronically steerable, low profile antenna to be offered to the commercial and defence aircraft markets.

Interferences