



# Mobile Networks Introduction

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2023/2024



# Trends in communications

- Current telecommunication industry has been the result of different trends in the last 40 years:
  - The saturation of the telephone market, at the end of the 80's
  - The coming of age of the data world, in the early 90's
  - The pervasiveness of mobility, in the mid 90's.
  - IP (Internet) is a must-have, in the 00's
  - Data everywhere, in 10's
  - Digital world, starting in the early 10's

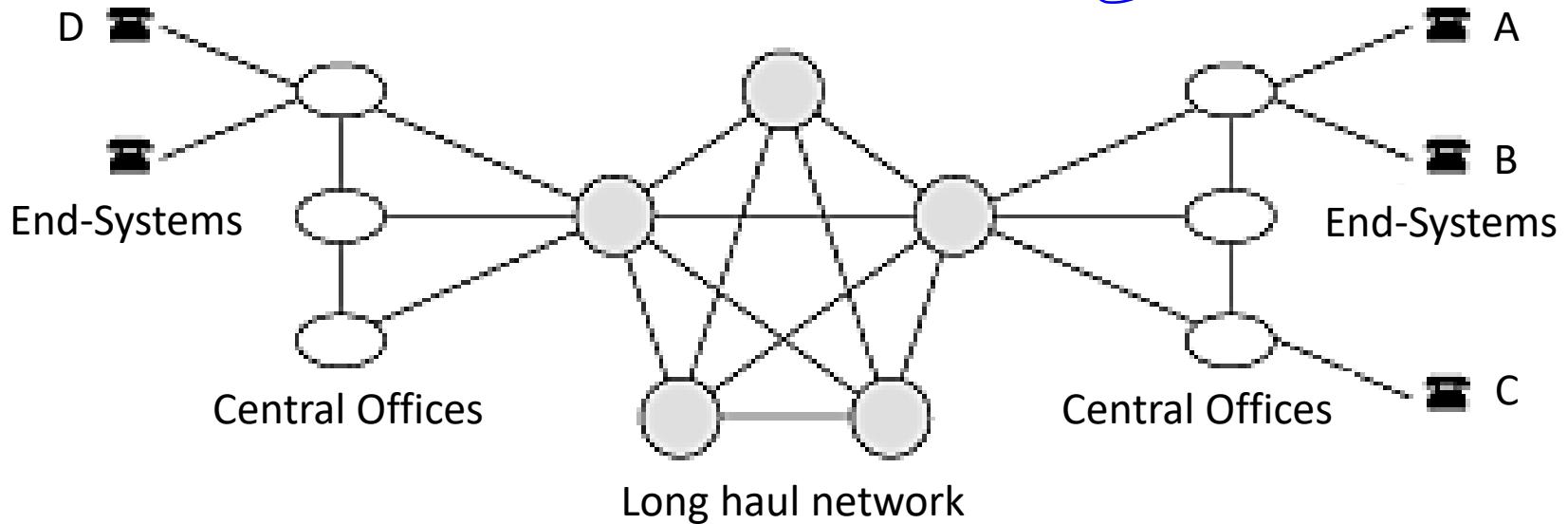


# The communication network

Before mobile Communications, there were Fixed Communications



# Telephone System

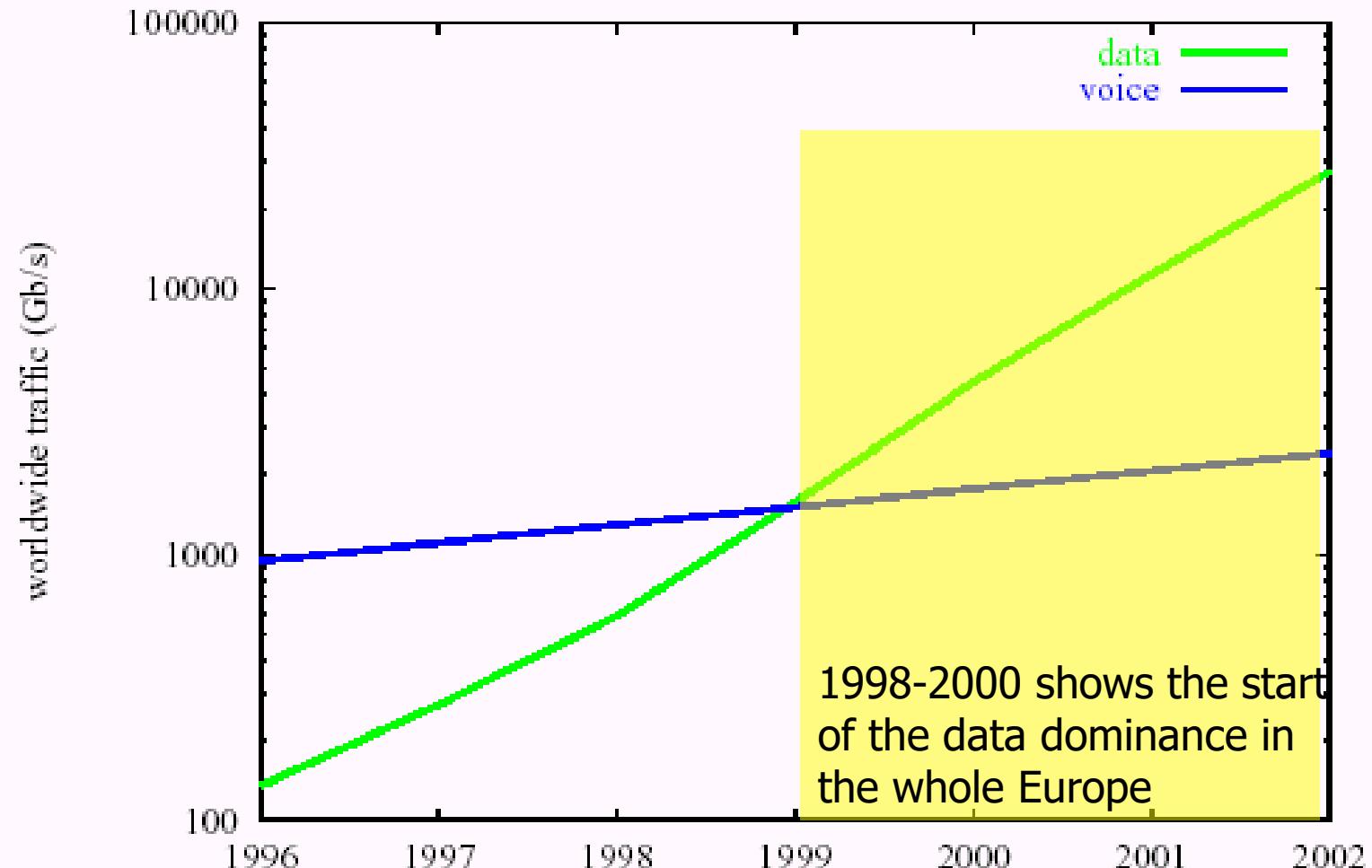


- Uses switched circuits (virtuals...)
- Access via low bandwidth circuits
- “out-of-band” call establishment using signaling system based in packets (SS7)
- Channels between switching exchanges carry multiple calls
  - Multiplexing (analogue or digital)





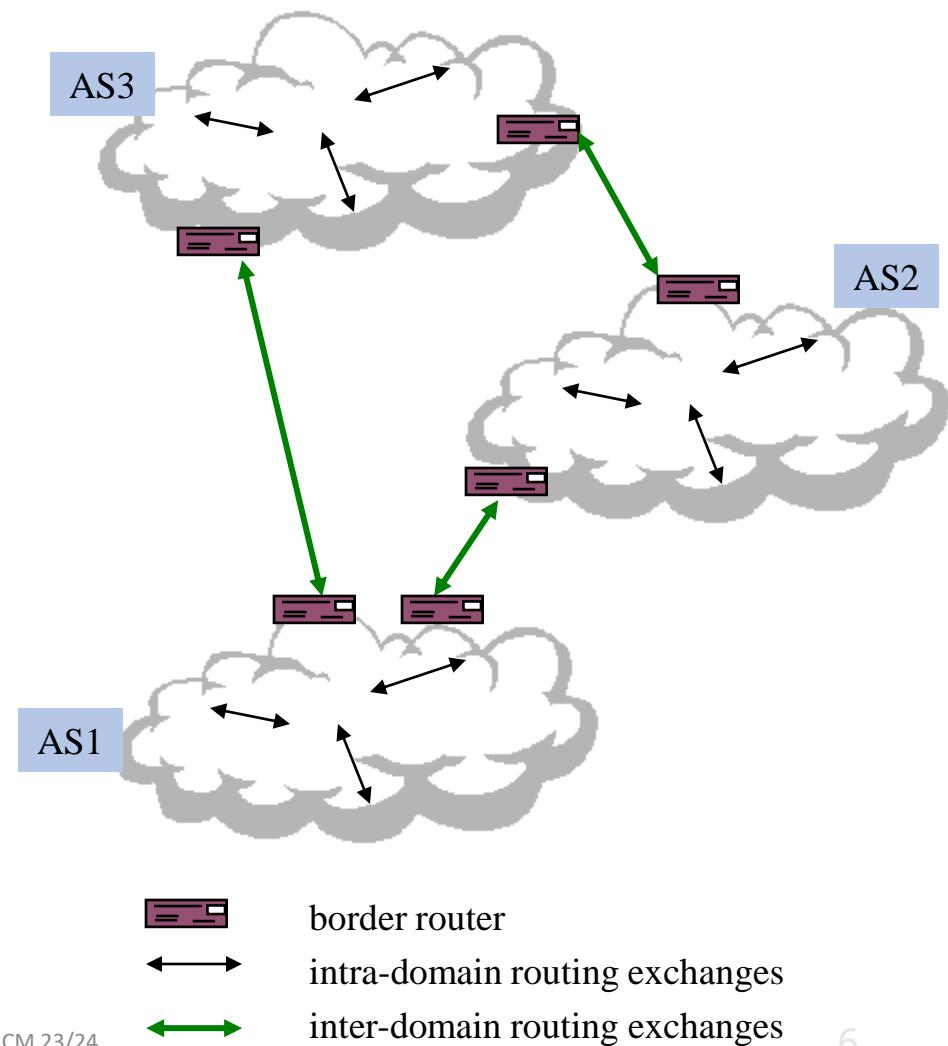
# Evolution: Voice vs Data





# Internet structure

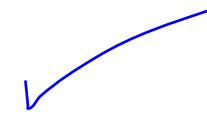
- Administrative borders define
  - Autonomous Systems (AS)
  - **Intra-domain routing**
  - Individual internal policies
  - May use different metrics between domains
  - protocols: RIPv2, OSPFv2
- AS interconnections
  - **Inter-domain routing**
  - Connectivity information
  - protocols: BGP





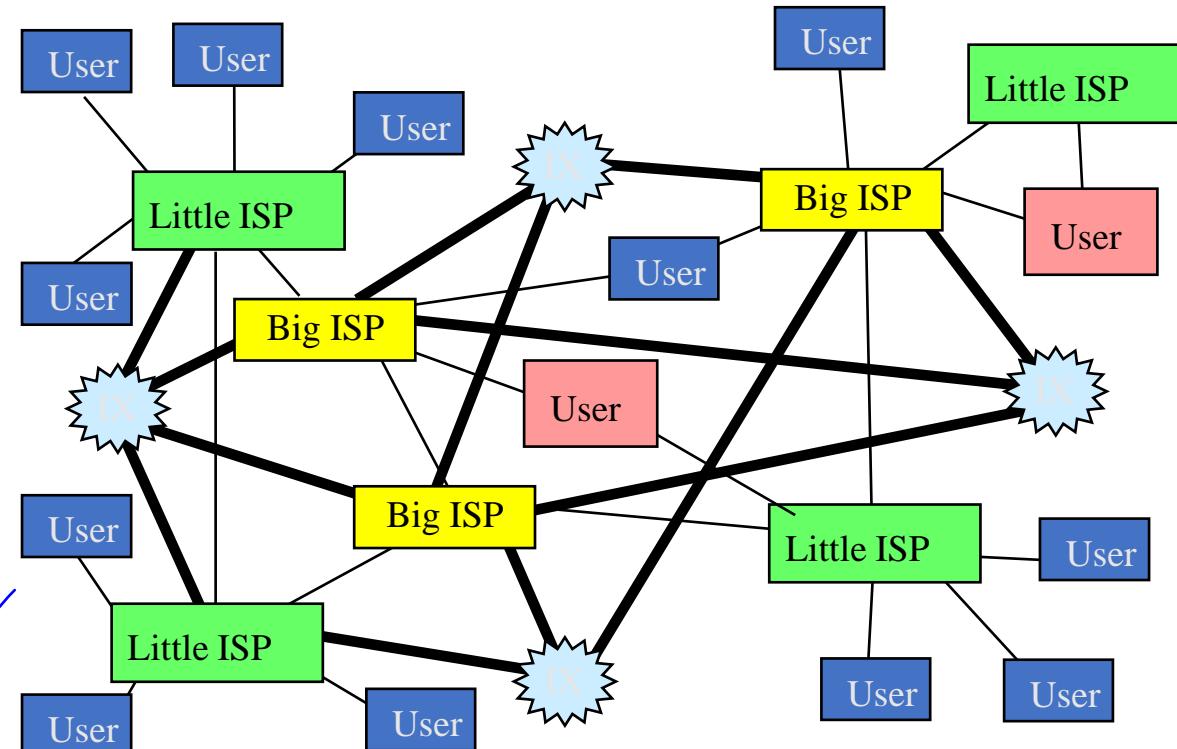
# Internet: currently

- Self-organized set of interconnected autonomous components
  - More than 60.000 autonomous domains (with more than 100K numbers allocated)
    - Single guarantee is running TCP-IP
    - Works by packet switching
    - More than 340 millions of registered domains (URL)!
- Commercial traffic larger than non-commercial
  - Exponential growth in all numbers (number of users, traffic)
- Different machines (networks) can offer different services
  - Each user can select what it uses
- Only bi-directional media that support communications
  - One to one (unicast, e.g. email); one to many (multi-cast, e.g., electronic news)
- NB: Internet networks are operated AUTONOMOUSLY
  - After connecting to the Internet, the network **becomes PART of the Internet**





# Real structure



- Apparently hierarchical
  - Backbone ISP provides service to increasingly smaller ISPs
  - Smaller ISPs eventually providing service to end users.
- But hierarchy is not respected
  - Private connection agreements
  - Mechanisms for improvement of the network
  - All companies provide service to (some) users
  - Service providers connect to multiple connection provider
  - Users connect to multiple ISPs



# “Data vs voice”: packet switching vs circuit switching

Packet switching solves everything?

- Great for burst information
  - Resource sharing
  - No call setup time
- When excessive congestion: delays and losses
  - Needs reliable data transfer protocols
- Providing circuit switching services?
  - For multimedia applications we need bandwidth and delay
    - Problem not yet completely solved

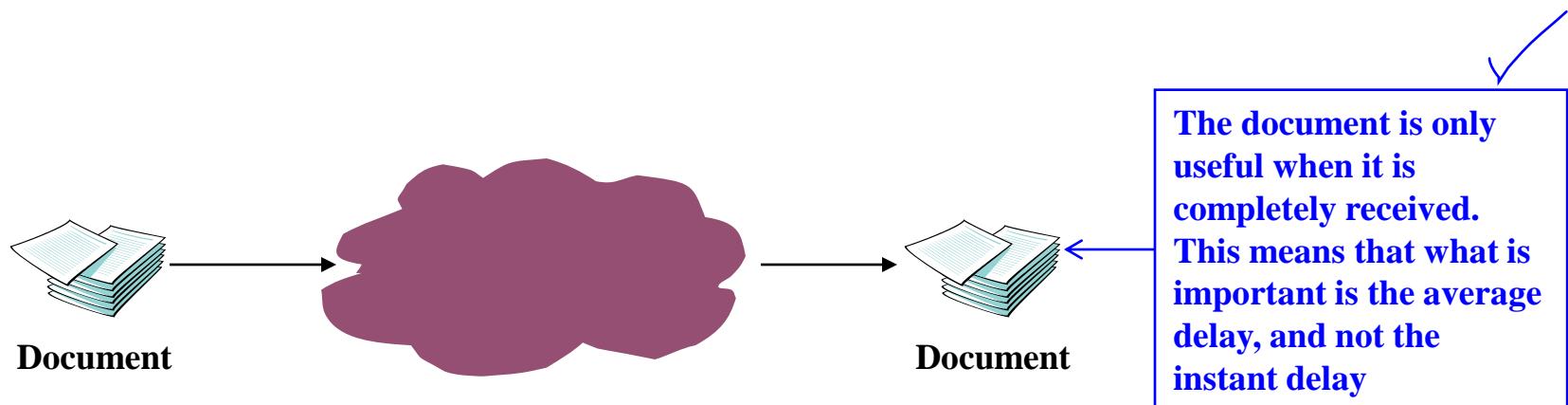


# Transport service (operator/ISP) vs applications

- Packet loss
  - Some apps (audio/video real time) handle losses
  - Other applications (file transfer, telnet) require 100% of success in transmission
- Bandwidth
  - Some applications (multimedia) need a minimum bandwidth to be effective
  - Other applications (“elastic applications”, ex. email, file transfer) use the bandwidth available
- Timing
  - Some applications (Internet voice, multiuser games) require low delays to be effective
  - Other applications (without real time requirements) do not have strict delays end-to-end.



# Elastic operations (Performance): All traffic has not the same requirements

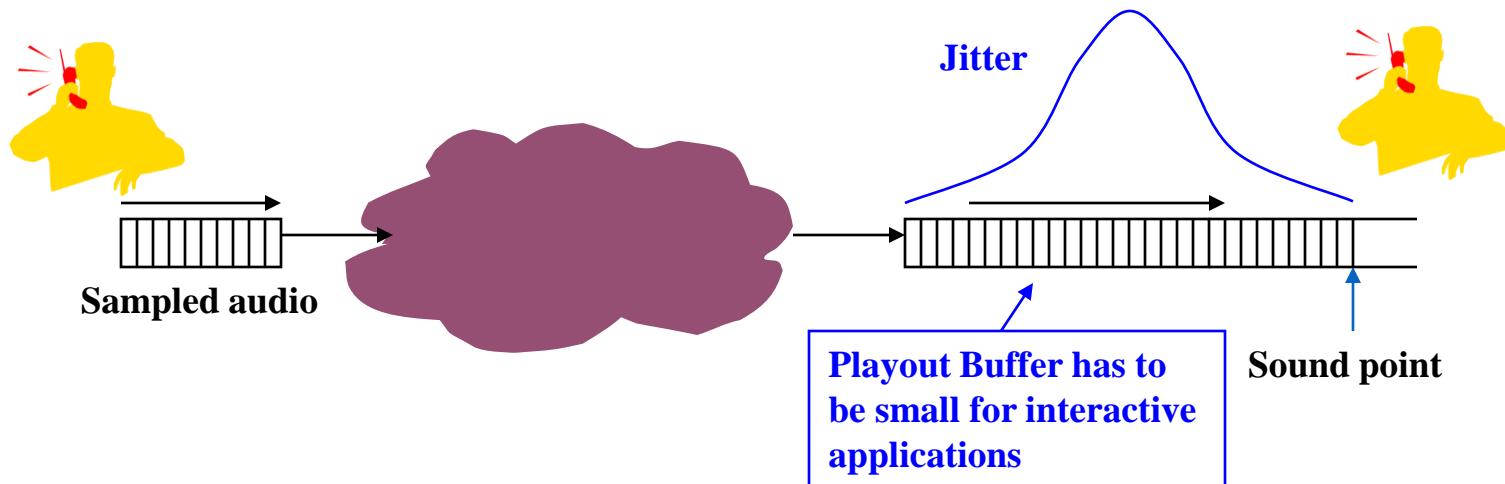


- Elastic applications

- Interactive data transfer (e.g. HTTP, FTP)
  - Sensitive to the medium delay, not to rare occurrences
- Bulk data transfer (e.g. mail, news)
  - Not sensitive to delay
  - Best effort works...



# Inelastic applications



- Interactive applications
  - Sensitive to packet delay (telephony, gaming)
  - Maximum delay may be limited
- Non-interactive applications
  - Adapt to larger ranges of delays (streaming audio, video)



# Application requirements

Applications	Losses	BW	Timing
File transfer	lossless	elastic	no
e-mail	lossless	elastic	no
Web documents	lossless	elastic	no
Real time audio/video	supports	audio: 5K-1Mbps video:10K-5Mbps	yes, 100's ms
Streamed audio/video	supports	See above	yes, few secs
Interactive gaming	supports	Some Kbps	yes, 100's ms
Finance applications	lossless	elastic	Yes and no

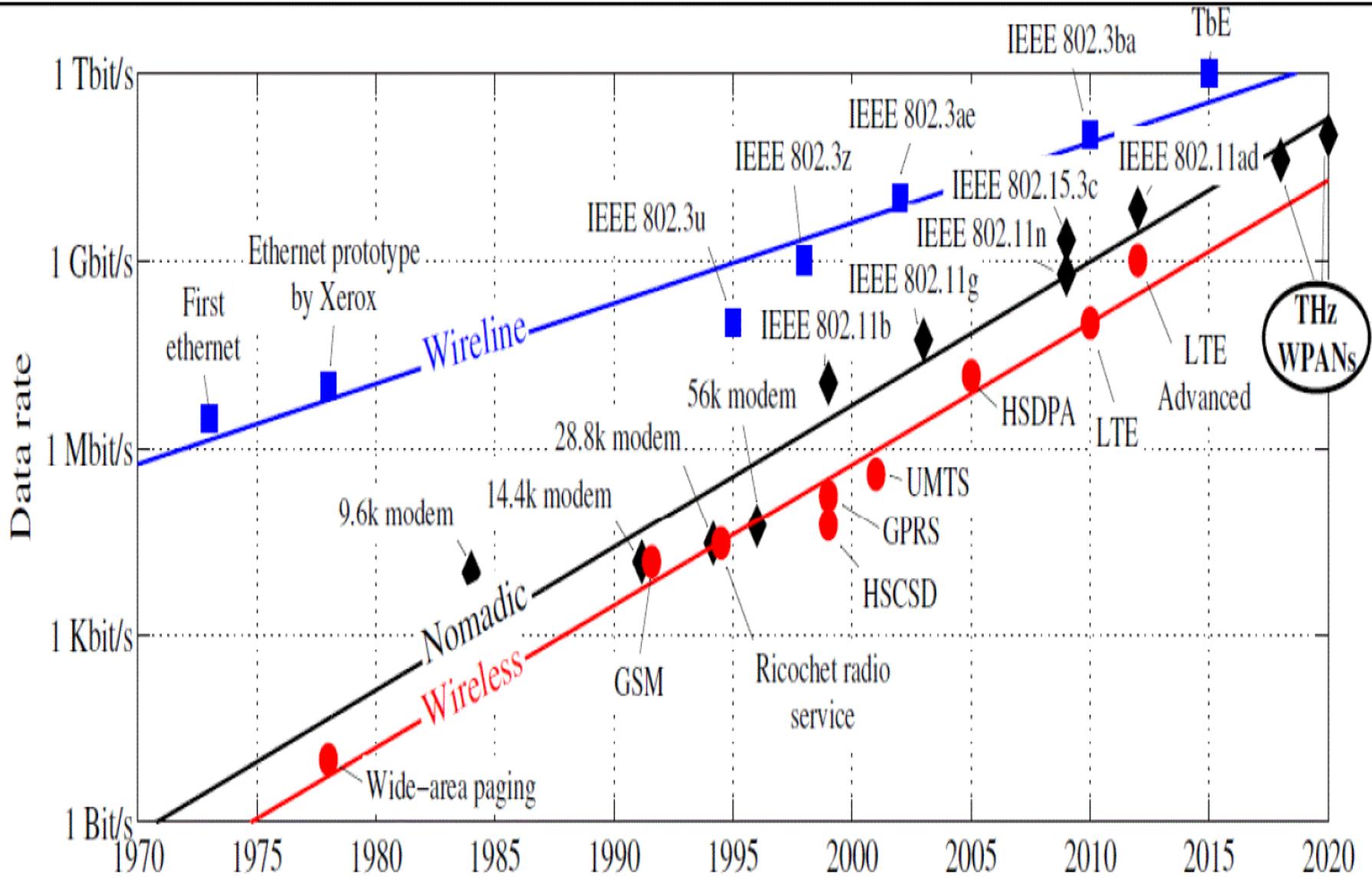


# The Mobile Network

Economical and societal motivations



# Edholm's Law

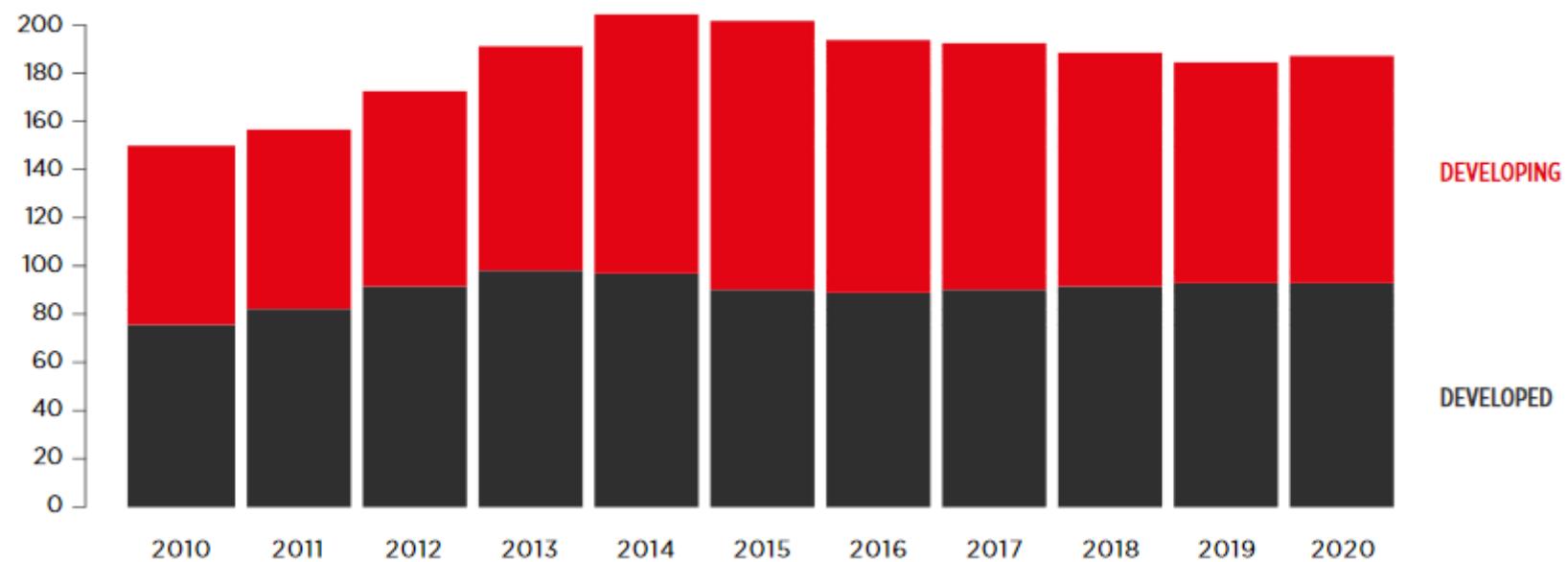




# Cost of investment in telecom

Global mobile operator capex

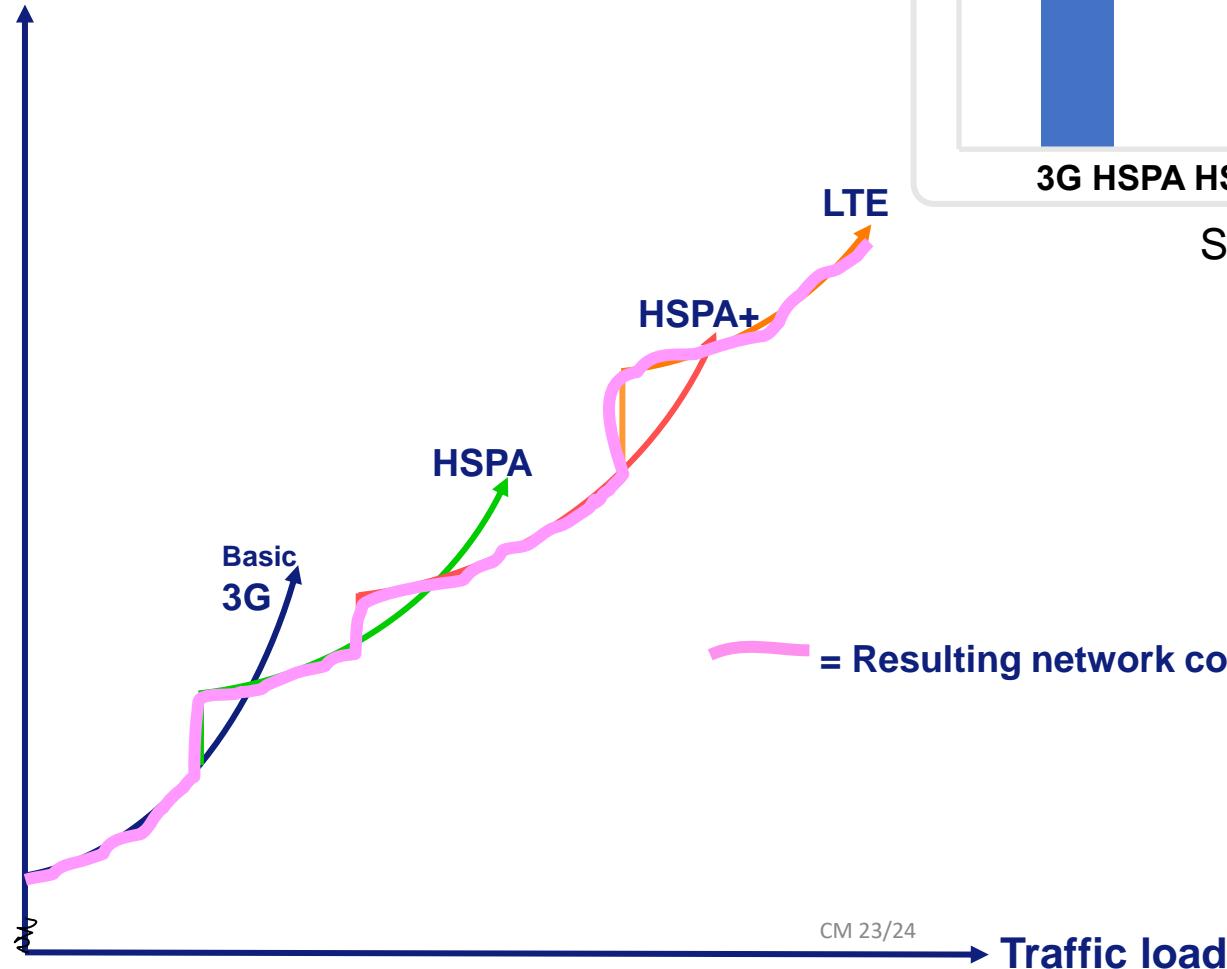
(\$ billion)





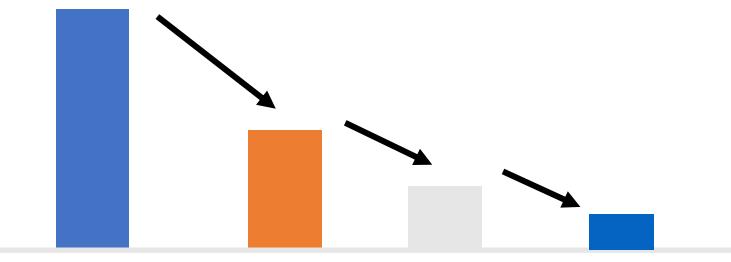
# Motivations for technologies

Network cost

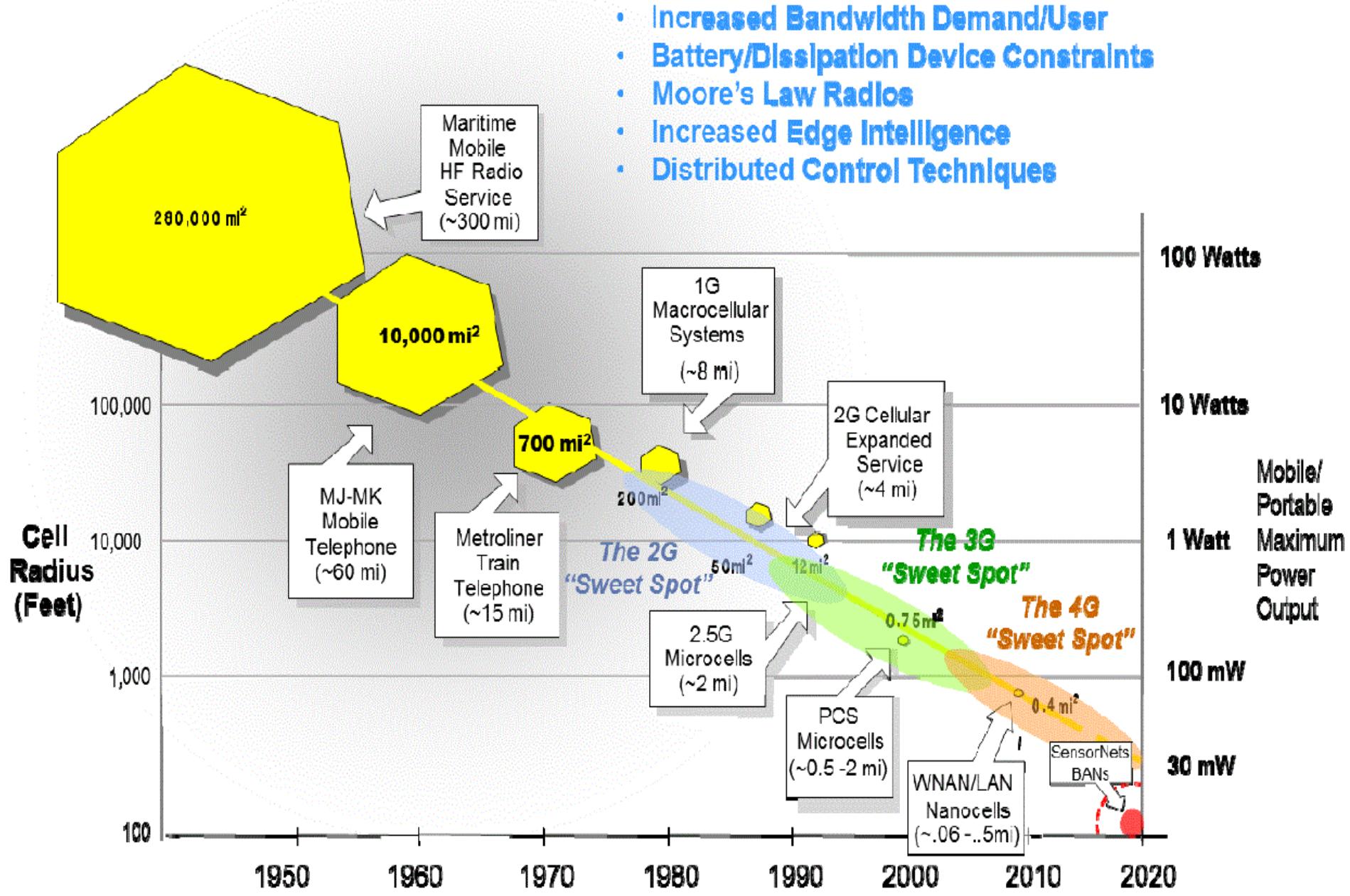


Lower production cost per bit

Cost per Mbyte

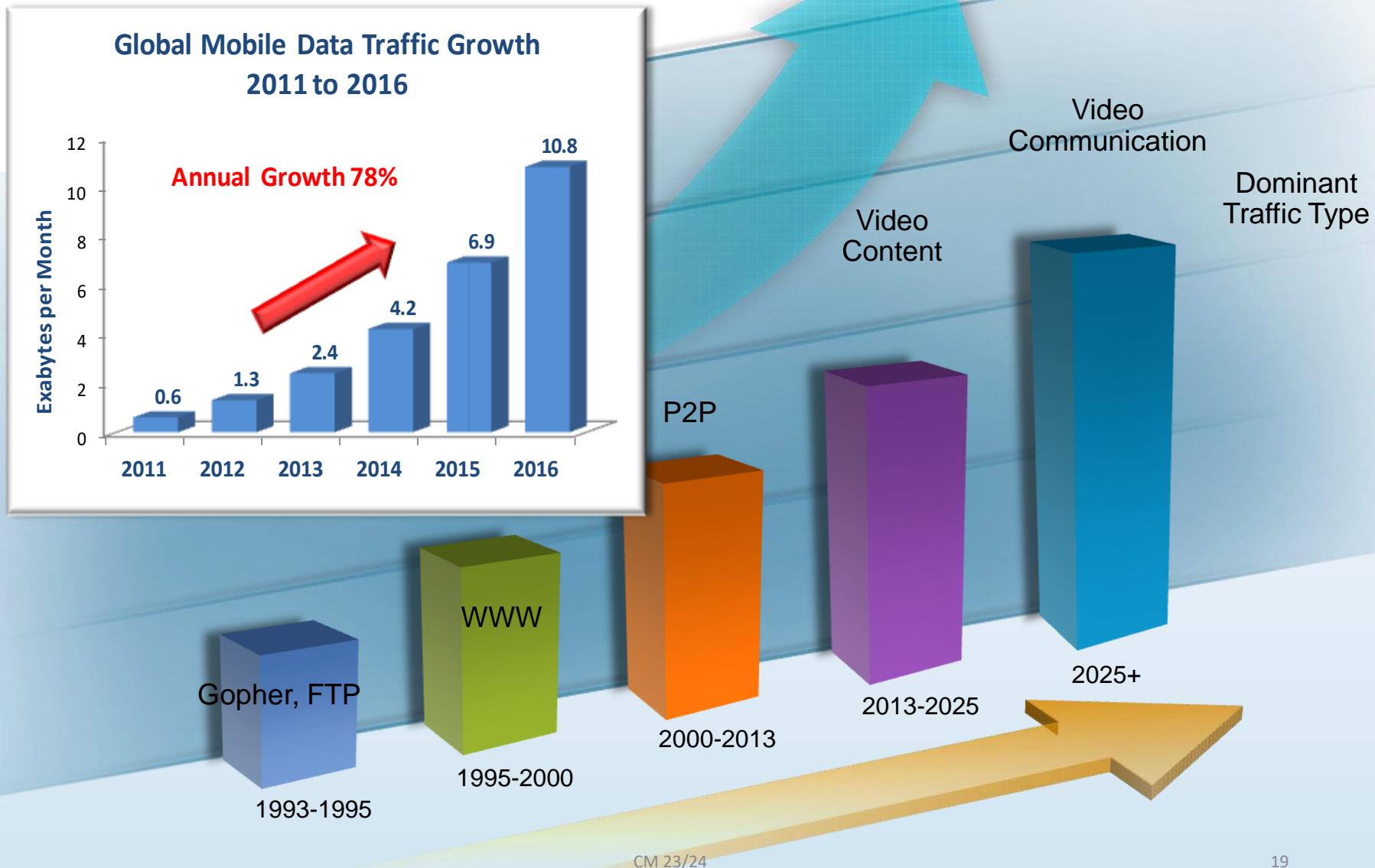


Source: NSN





# Dramatic Traffic Growth Fueled by Video





# The things that surround us





# Network is now more than bits and bytes – it adapt to users





GIGAOM

# THE APP STORE ECONOMY

THE APP STORE  
CONTAINS  
**133,979**  
**APPS** 

AVAILABLE FOR 

MADE BY OVER  
**28,000**  
DEVELOPERS

WHO WAIT AN AVERAGE OF  
**4.78** DAYS  
FOR THEIR APP'S APPROVAL

APP STORE USERS

DOWNLOADED AN AVERAGE OF

**3.7**  
APPS EACH  
IN DECEMBER

The market turned to SERVICES (+/- 2016)

Mobile Services are now a major contention between operators and manufacturers (AppleStore, OviStore, Android Market, Palm App Catalog)

Source: GigaOM

ONE QUARTER OF WHICH WERE PAID

TOP 50 PAID APP PRICES

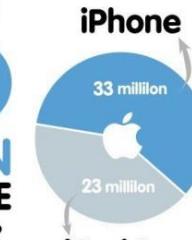
99¢	25
\$1.99	6
\$2.99	8
\$3.99	1
\$4.99	3
\$5.99	2
\$6.99	4
\$7.99	0
\$8.99	0
\$9.99	1

AT AN AVERAGE COST OF **\$2.59**

EACH iPhone USER SPENDS AN AVERAGE OF **\$10** ON APPS EVERY MONTH.

WITH OVER

**56** MILLION APP STORE USERS,



200 MILLION APPS ARE BEING DOWNLOADED

MONTHLY, GENERATING MORE THAN

**\$500 MILLION IN REVENUES** OF WHICH 30% GOES TO

APPLE & 70% TO DEVELOPERS... EACH MONTH.

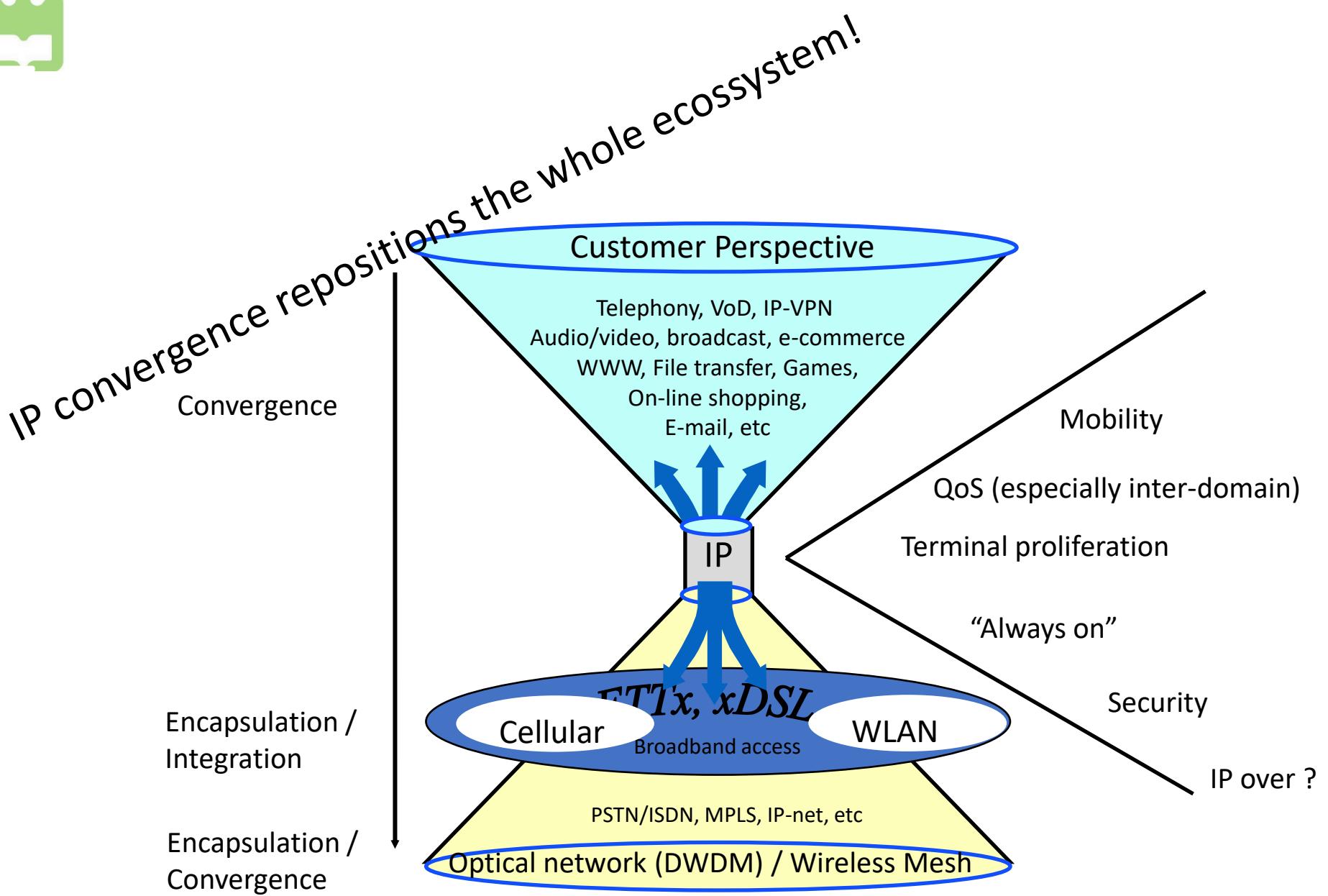


ifury.com, Admob.com, Apple.com



# User behaviour and trends

- Increased Internet—based services
  - Phone market is now saturated
  - “Everything” came to “data communications”
- Increased broadband requirements
  - P2P being replaced by service-based
  - Internet access 2x every 2 years – fiber access now blooming
  - 70% broadband penetration
- Increased mobility and roaming
  - Always on and session continuity
  - Increased end-user content
    - Both WLAN and 4G
  - Increased context information
    - Increased personalization
    - Increased machine/vehicle/object communications





# A Mobile Storage Revolution .....



Embedded Flash  
128MB >>> 64GB



- Small size to minimise handset cost
- Used for storing system data: applications, messages, contacts, ring-tones



Embedded  
(SD/H)DD  
2GB >>> 256GB

- Large storage for user content
- But high impact on terminal cost



Memory Card  
128MB >>> 1TB

- Large and removable storage for easy transfer of user content
- Interoperable with other consumer electronic devices
- Provides a distribution channel for selling content



... and a Multiplicity of Local Connectivity...



## Today

- Bluetooth
- WiFi
- Memory cards
- USB
- Near Field Communications
  - device pairing & local network configuration
  - service discovery/initiation

## Tomorrow

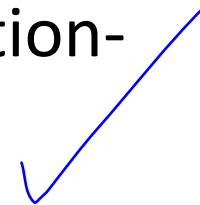
*All of the above with the addition of:*

- WLAN+ (802.11g++)
  - home and office connectivity
  - wireless extension of DSL in the home
- UWB
  - wireless USB
- TV/DVB



# The wireless framework (Summary)

- Mobile systems is THE major business
- Operators are becoming increasingly focused on mobile customers
  - Most of market will be wireless anyway on the access
- Services are now a dominant aspect in this arena
  - Large economic fights ongoing
- Mobility brought a novel importance to Location-based Services (LBS)
  - Now proximity is a dynamic variable for the user





# The Mobile Network

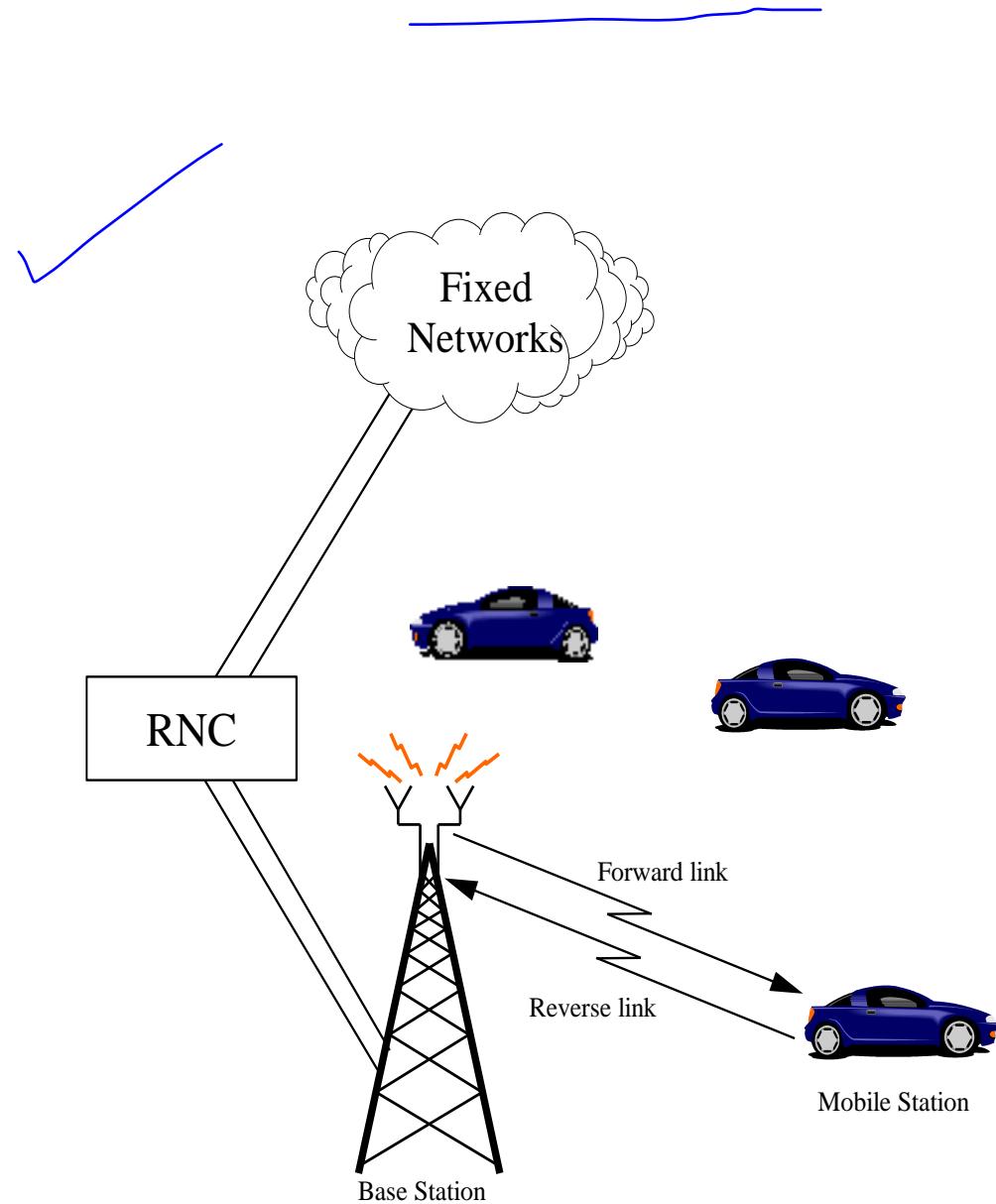
Generic technical aspects and challenges



# Wireless Systems

CM 23/24

- Mobile users communicate through fixed points (Base Stations/Access Points)
- Rely on radio transmission - final link between terminals and network
  - Finite resource, spectrum available is strictly limited
  - Multipath propagation, fading & interference
  - Terminal mobility complicates the system





# Mobile hassles

## 1. Wireless connections limitations

- Multiple independent access networks and technologies
- (frequent) connection dropouts
- (More) limited bandwidth
- Lacking of mobility awareness by system/applications

## 2. Spectrum limitations

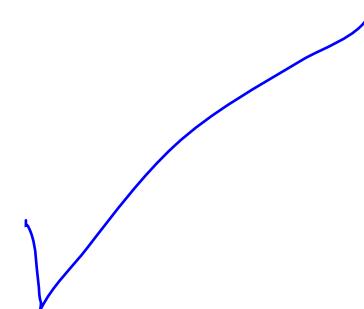
- Bandwidth cannot be improved just by adding parallel connections
- Spectrum is highly regulated

## 3. Mobile device limitations

- Battery lifetime
- Limited capabilities

## 4. Scaling considerations

- Mobile devices counted by the 1.000 millions
- Cost(s) needs to be low
- Energy is becoming a problem



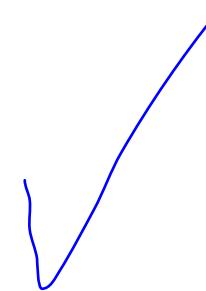


# Device Issues

- By their own nature:

**SMALL!  
LOW POWER!**

- Potentially Low Power devices
  - Limited computing performance
  - Low quality displays
- Potential Loss of Data
  - Easily lost
  - Must be conceived as being “network-integrated”
- Potentially small and limited User Interface
  - Limited real estate for keyboards
  - Icon intensive/handwriting/speech
- Potentially Small Local Storage
  - Flash memory rather than disk drive





# Scaling: You mean *Everywhere*?!?





# Scaling: You mean *Everywhere*?!?

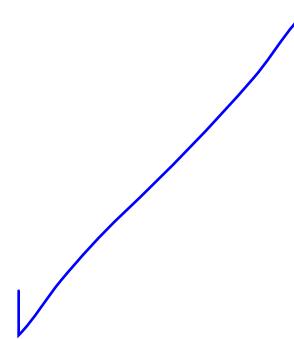
- 6.000 million users
- x10 sensors
- x2 general purpose computers
- x5 special purpose devices





# Remember!

- Addressing
  - Total number of IPv4 addresses is ~4 200 millions
- Routing
  - Routing tables are already quite large
- Security
  - Securing everything? With certificates?
- Multimedia bandwidths
  - In wireless?!?
- Sensors and actuators
  - Electric grid on the net?!?





# Why is mobile hard?

- Mobile communications are hard to handle, specially because spectrum is a scarce good
  - One critical economic issue from the governments point of view
- Also the whole nature of mobile systems is problematic – including the device specific issues
  - Although it is improving, power is still a problem
- As mobile systems became dominant (even into broadband!), scaling is a problem
  - We never dreamed with such a large success



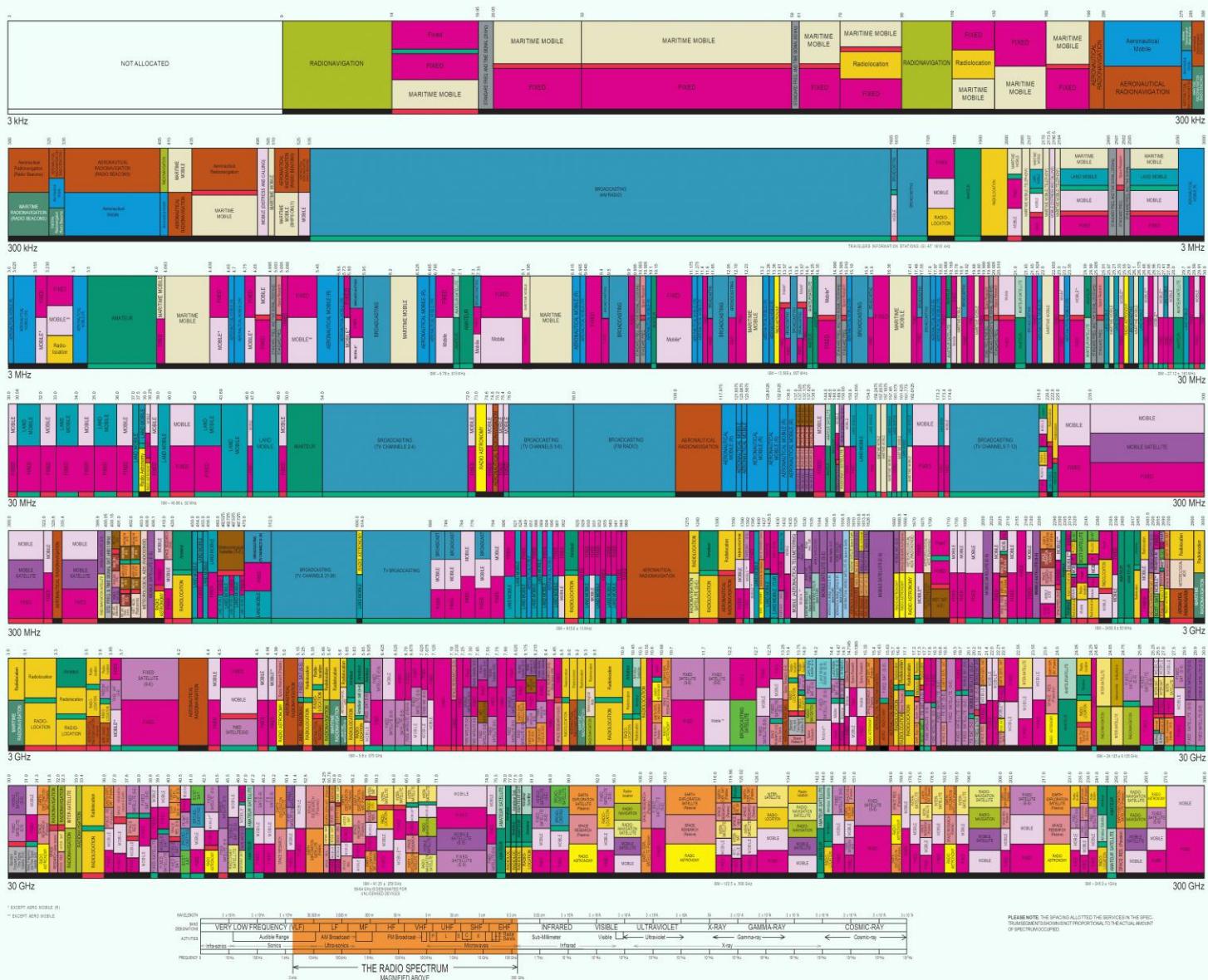
# Spectrum (only) looks like a lot!

- 300 GHz is huge amount of spectrum!
  - Spectrum can also be reused in space
- Not quite that much:
  - Most of it is hard or expensive to use!
  - Noise and interference limits efficiency
  - Most of the spectrum is allocated by Regulators
  - ISM bands unlicensed – but subject to multiple constraints
- Governments control who can use the spectrum and how it can be used.
  - (ITU-T WRC. Anacom, Oftel, FCC...)
  - Need a license for most of the spectrum
  - Limits on power, placement of transmitters, coding, ..
  - Need rules to optimize benefit: guarantee emergency services, simplify communication, return on capital investment, ...



~~UNITED STATES FREQUENCY ALLOCATIONS~~

~~THE RADIO SPECTRUM~~

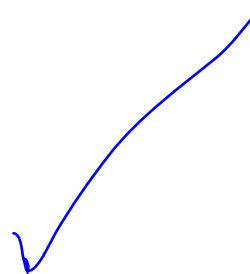


 U.S. DEPARTMENT OF COMMERCE  
National Telecommunications and Information Administration  
Office of Spectrum Management  
October 2003



# General Frequency Ranges

- Microwave frequency range
  - 1 GHz to 40 GHz and higher
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly,  $3 \times 10^{11}$  to  $2 \times 10^{14}$  Hz
  - Useful in local point-to-point multipoint applications within confined areas

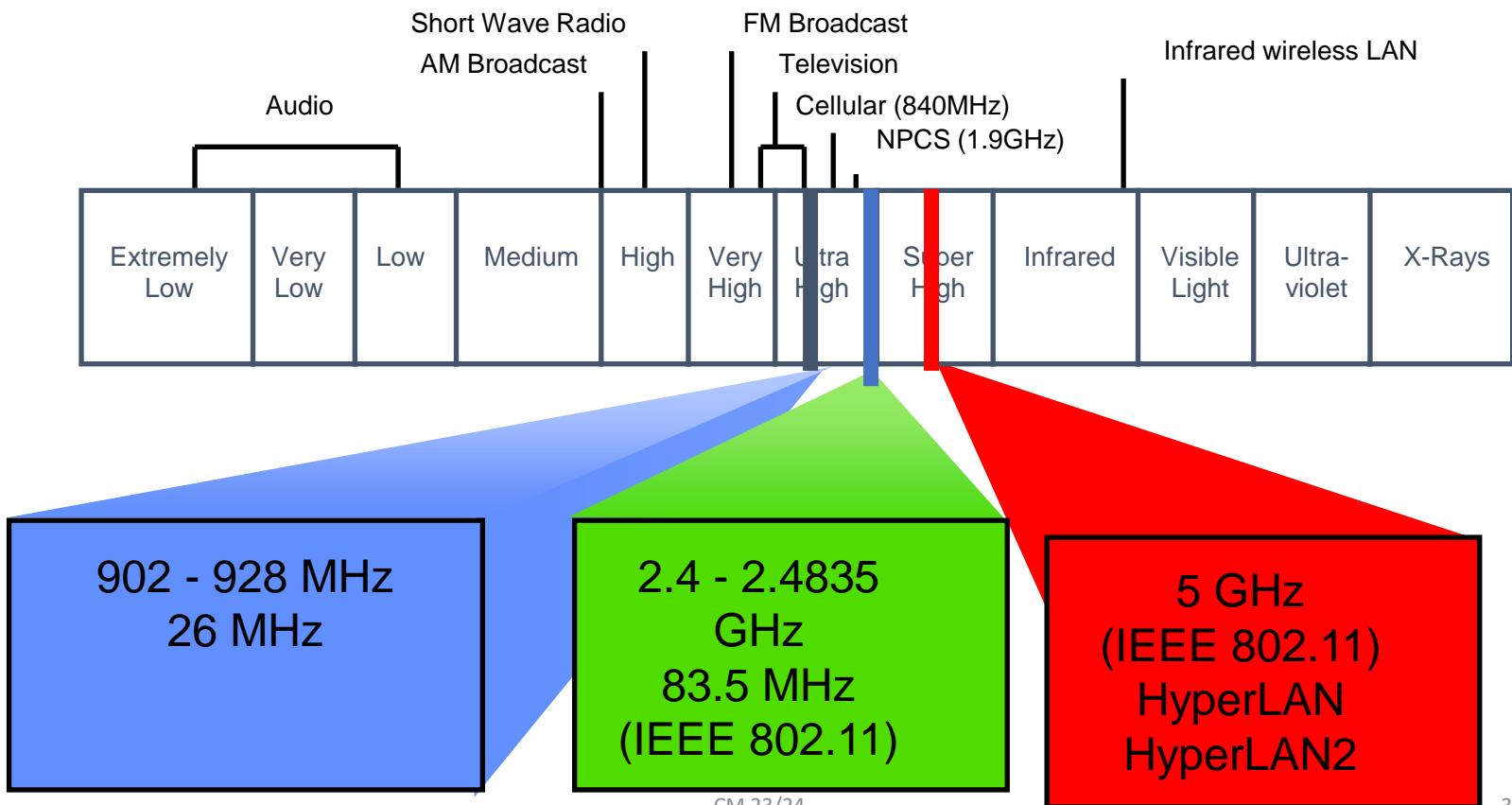




# Frequency Bands



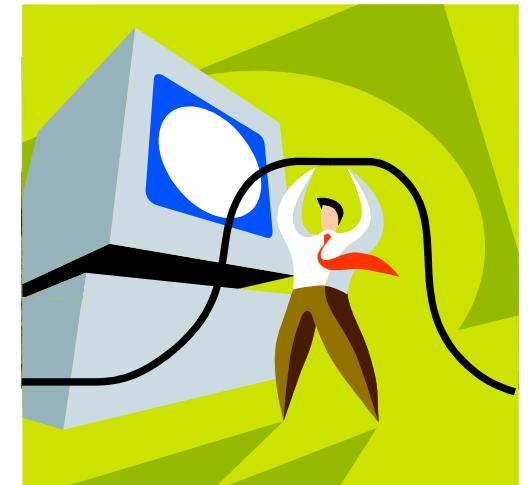
- Industrial, Scientific, and Medical (ISM) bands
- Unlicensed, 22 MHz channel bandwidth





# Physical Layer

Problems we face

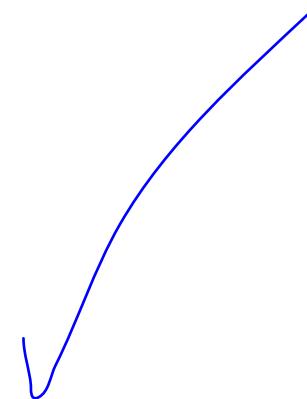




# Classifications of Transmission Media

CM 23/24

- Copper: twisted pair versus coax cable
  - Variety of modulation techniques are used
- Fiber: modulate an optical signal
  - Lots of capacity available!
  - Typically uses simple modulation schemes
- Wireless: no solid medium to guided signal
  - Wide variety of distances: frequencies, distances, ...
  - Often uses very aggressive modulation techniques (later)





# Why Use Wireless?

**There are no wires!**

Has several significant advantages:

- No need to install and maintain wires
  - Reduces cost – important in offices, hotels, ...
  - Simplifies deployment – important in homes, hotspots, ...
- Supports mobile users
  - Move around office, campus, city, ... - users get hooked
  - Remote control devices (TV, garage door, ..)
  - Cordless phones, cell phones, ..

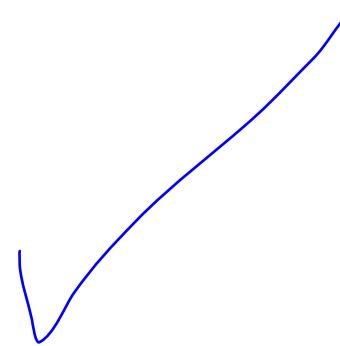


# What is Hard about Wireless?

**There are no wires!**

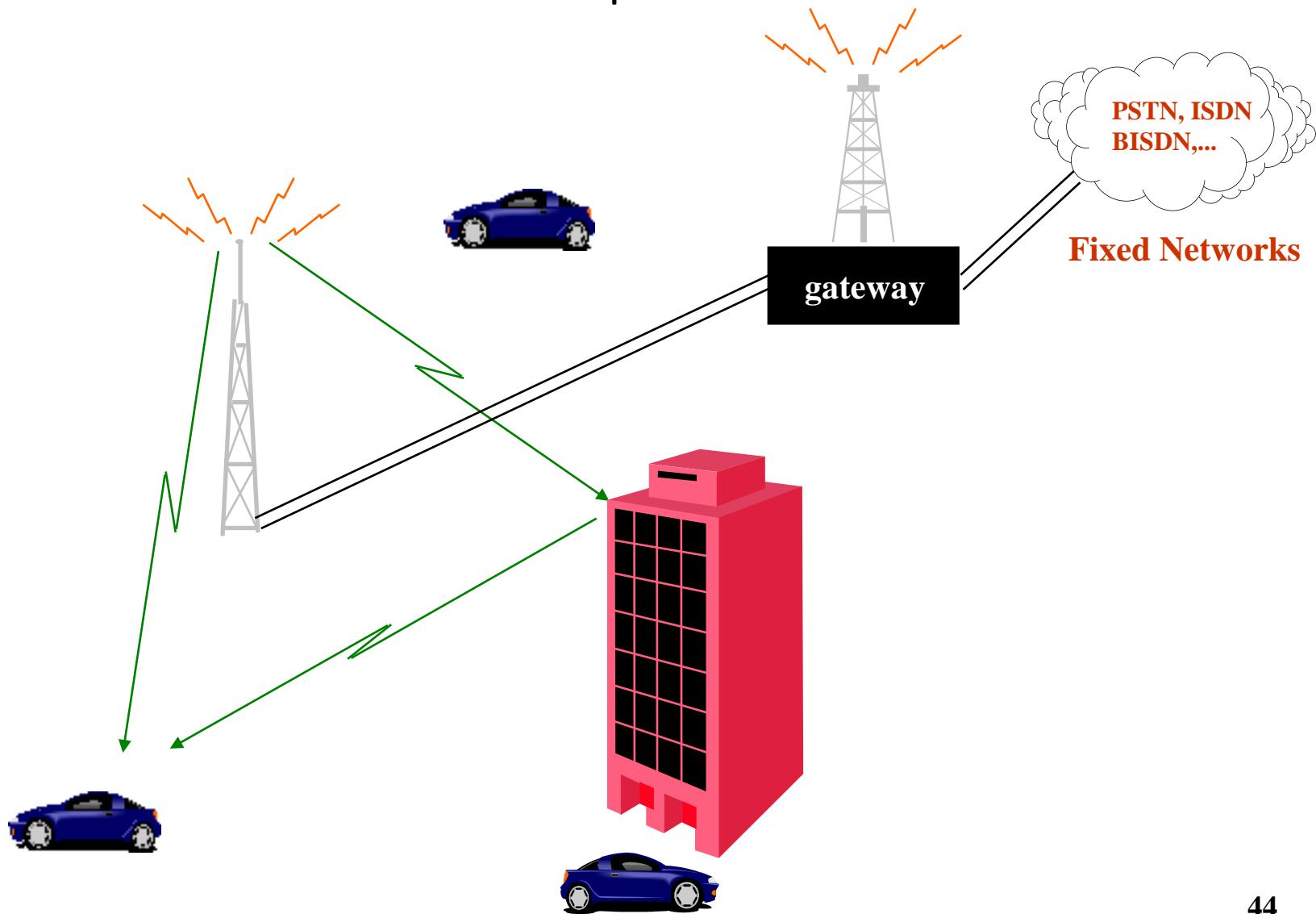
Causes problems in many areas:

- Quality of transmission
- Interference and noise
- Capacity of the network
- Effects of mobility



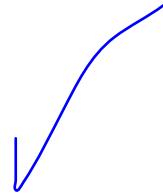


# Radio Transmission Impairments

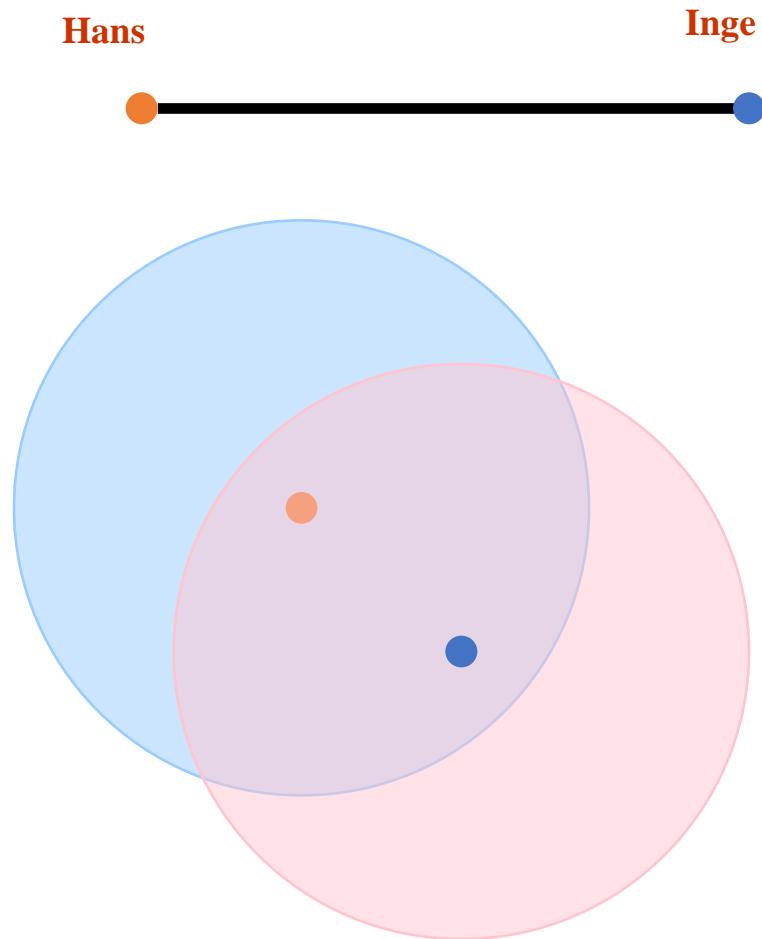




# Communication based on Broadcasting



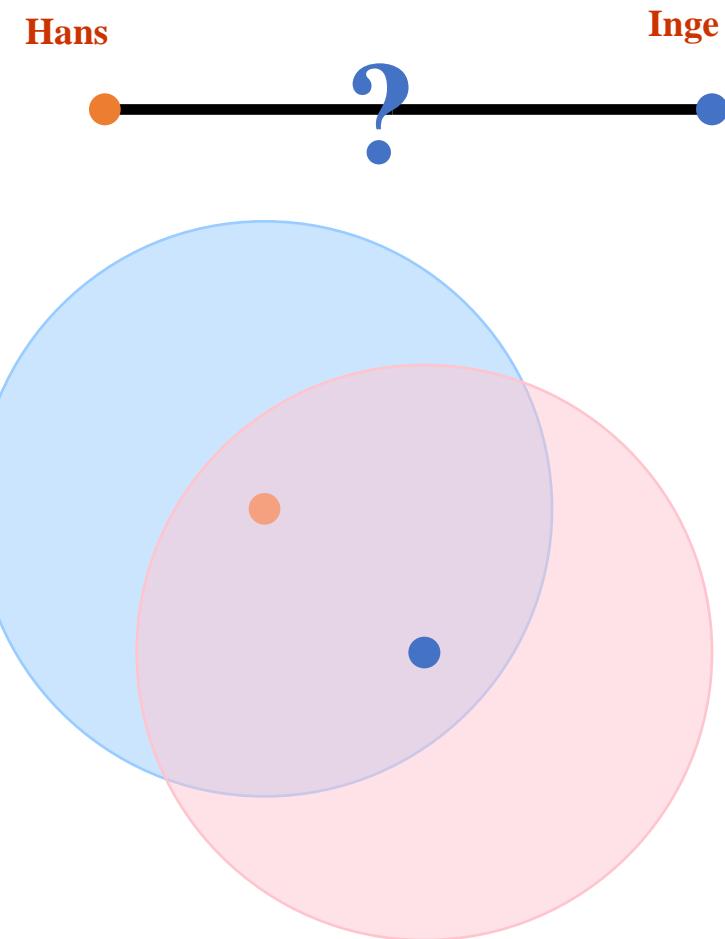
- Wired communication is usually point-to-point.
  - Broadcast is hard to scale
- Wireless communication is inherently broadcast.
  - Well, usually
- Of course: it does allow nodes to move





# Mobility

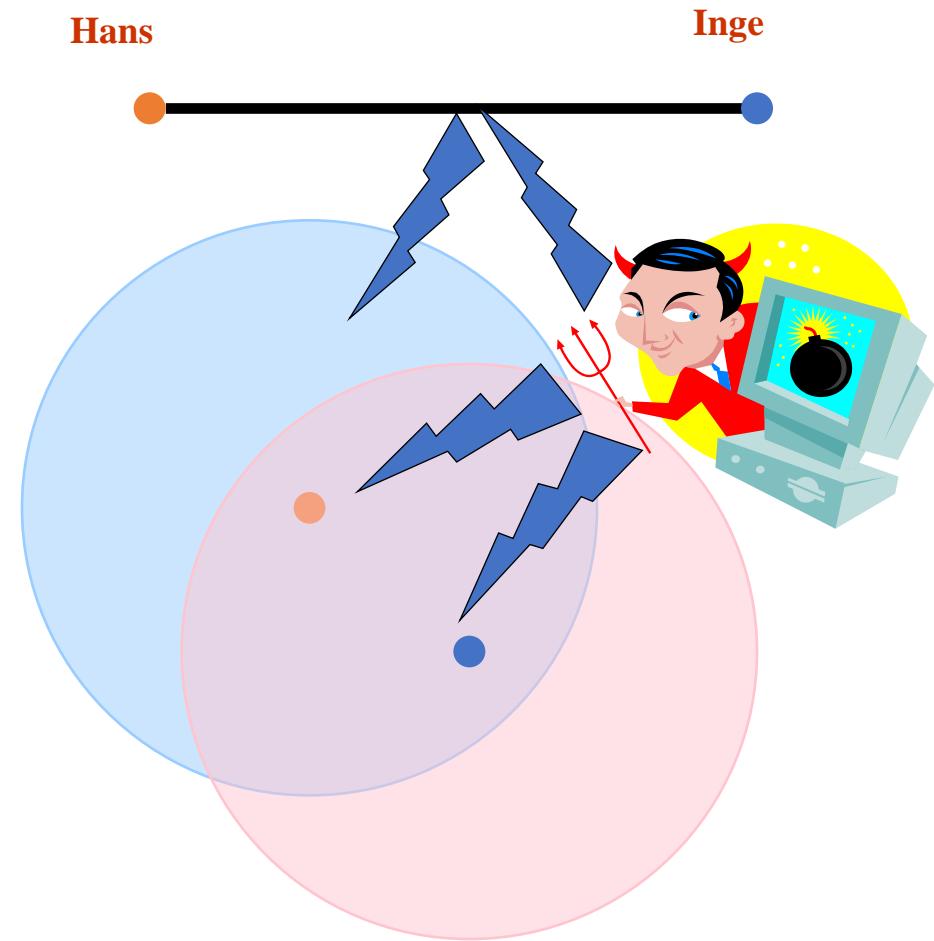
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# Wireless is very Sensitive to Noise ...

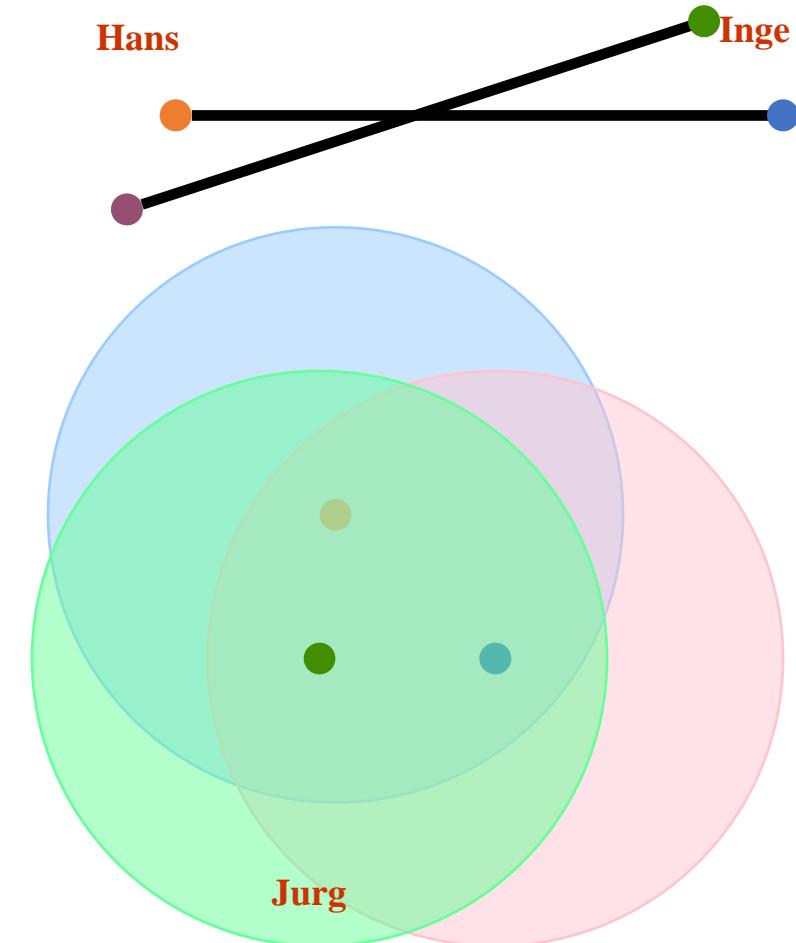
- Noise is naturally present in the environment from many sources.
- Interference can be from other users or from malicious sources.
- Impacts the throughput users can achieve.





# ... and Interference

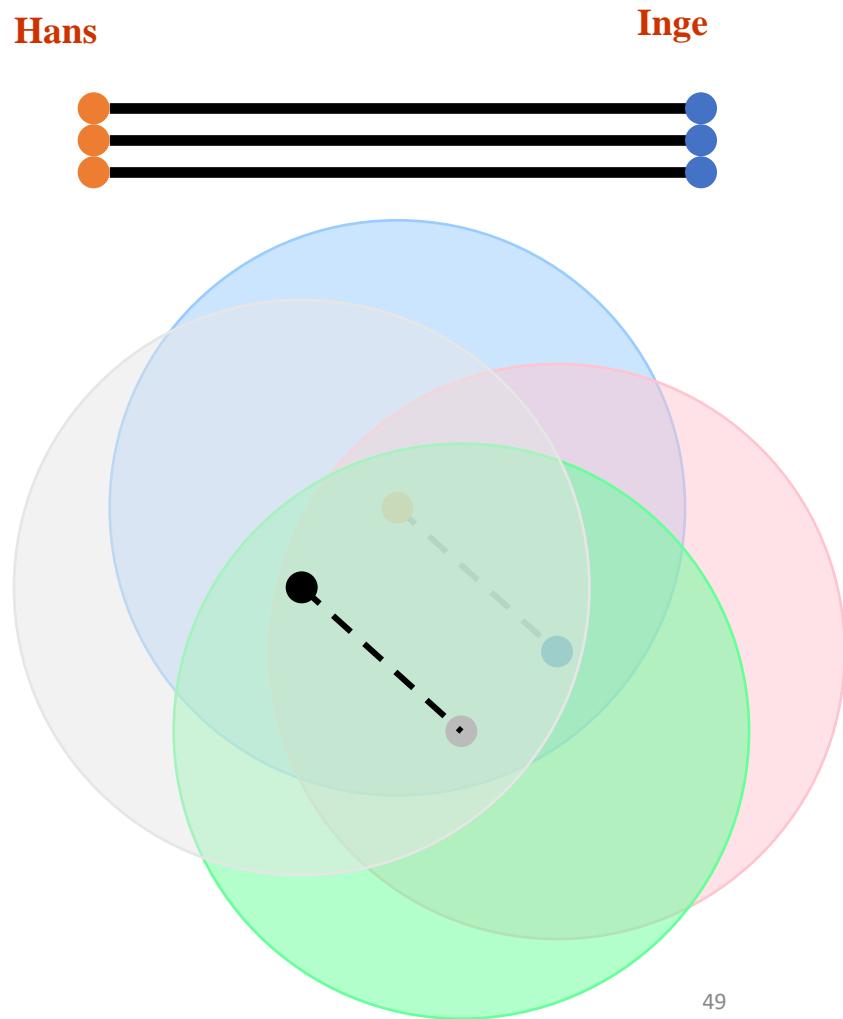
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# How Do We Increase Network Capacity?

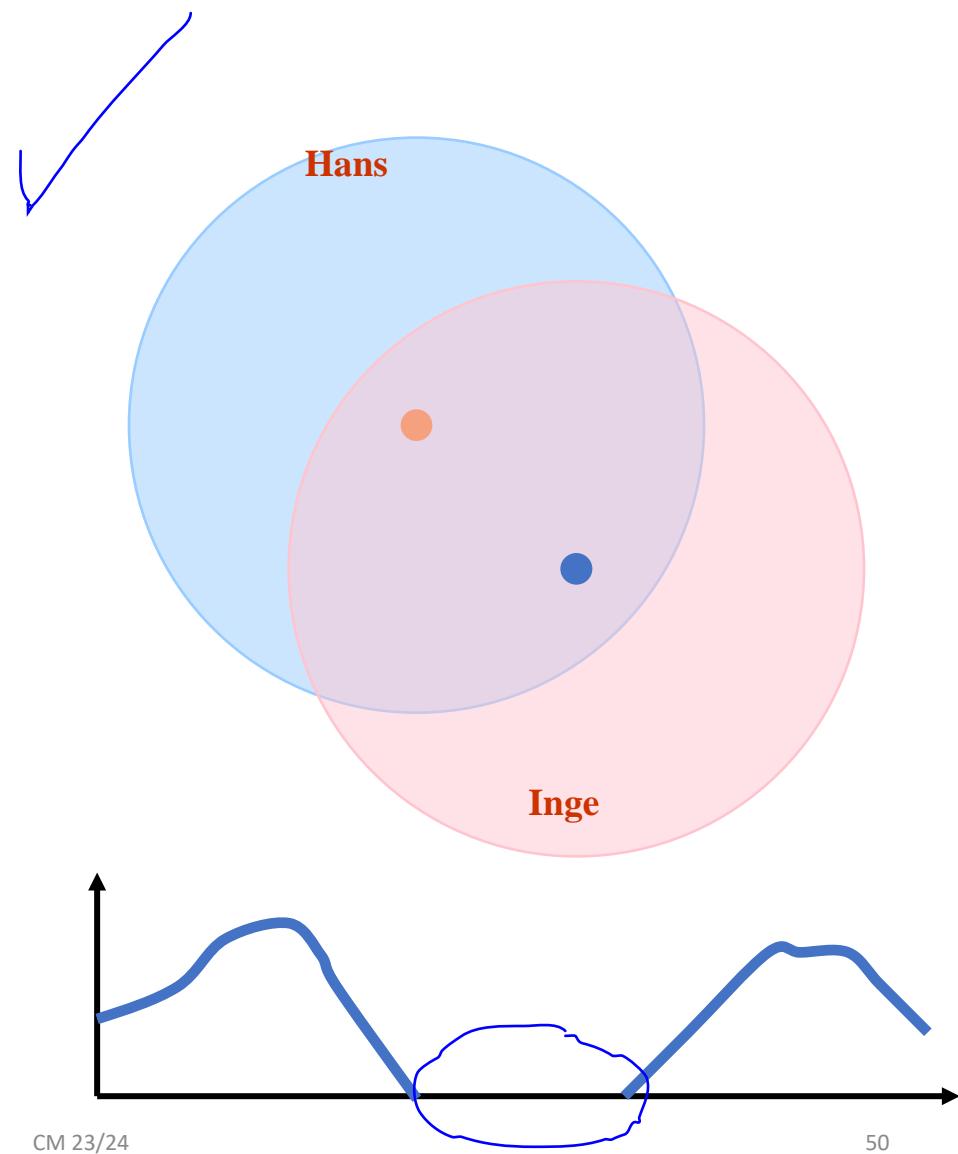
- Easy to do in wired networks: simply add wires.
  - Fiber is especially attractive
- Adding wireless “links” increases interference.
  - Frequency reuse can help ... subject to spatial limitations
  - Or use different spaces ... subject to frequency limitations
- The capacity of the wireless network is fundamentally limited.





# Mobility Affects the Link Throughput

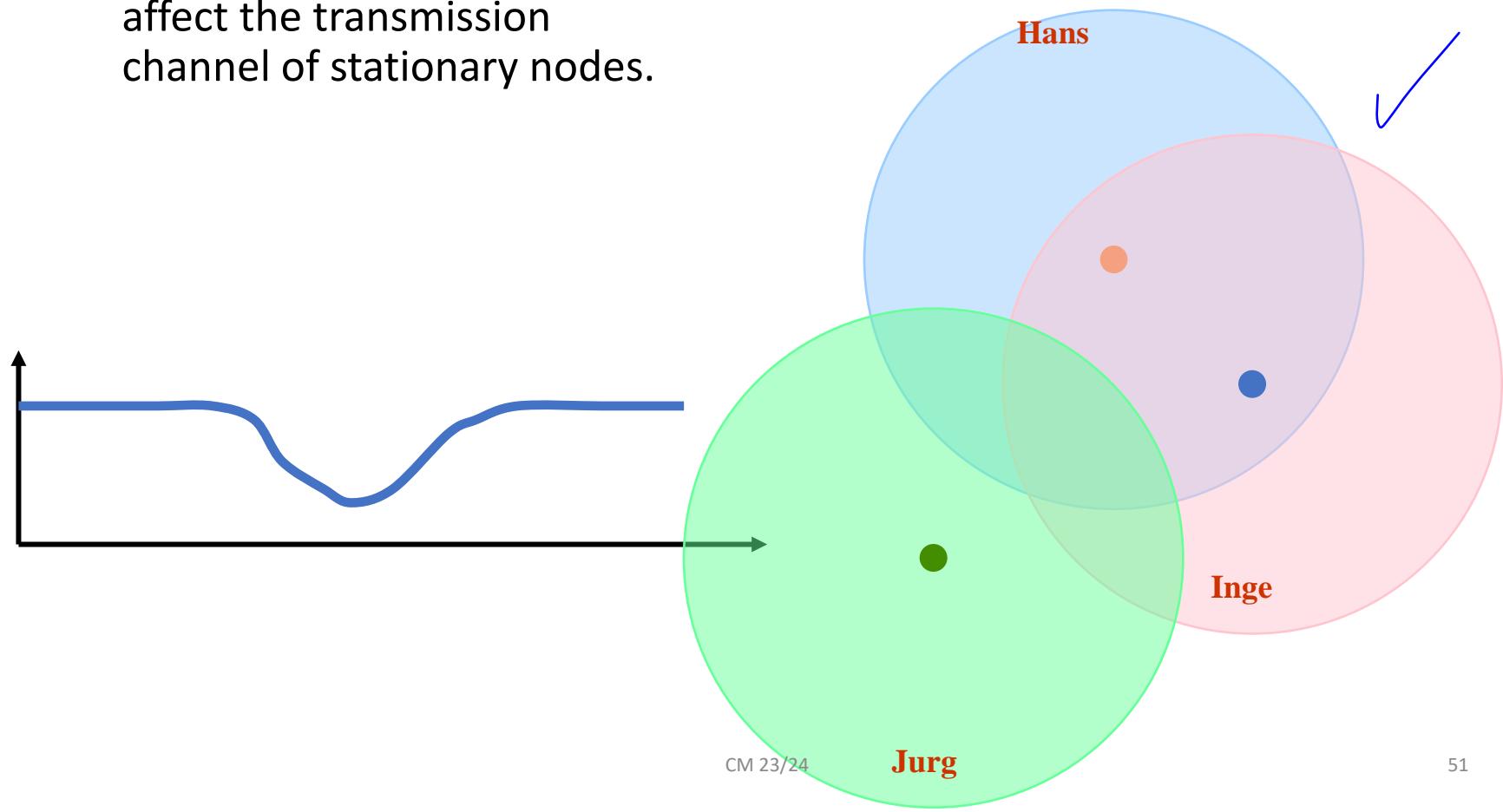
- Quality of the transmission depends on distance and other factors.
- Affects the throughput mobile users achieve.
- Worst case is periods with no connectivity!





# Mobility is an Issue even for Stationary Users

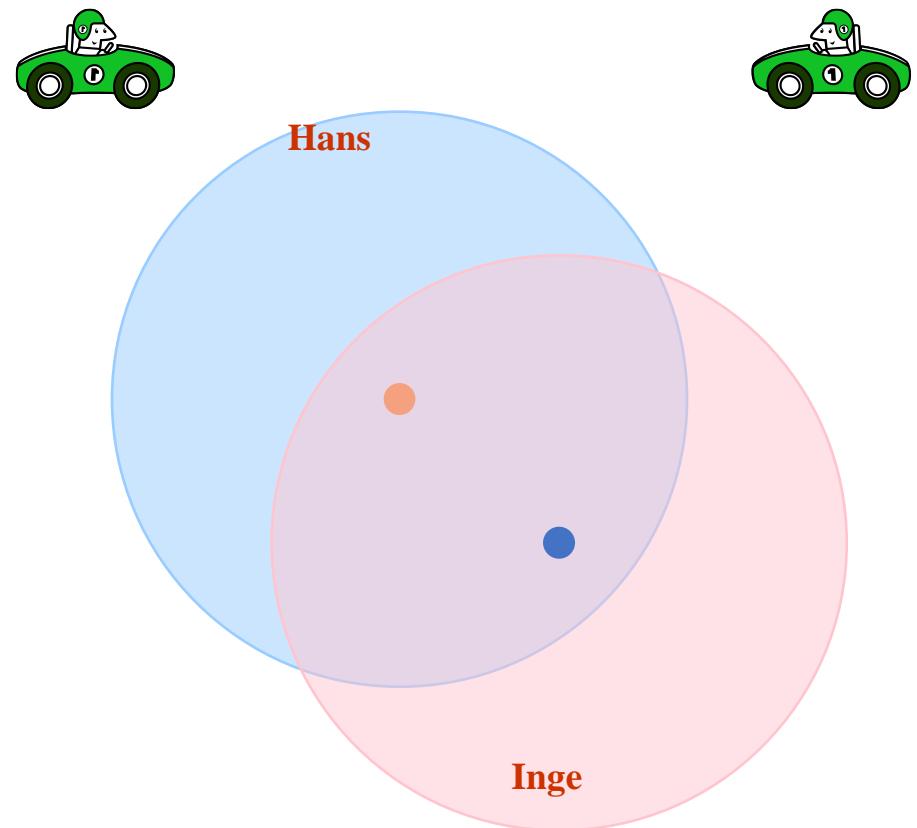
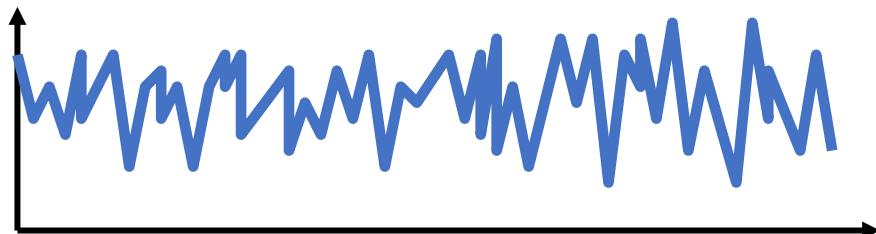
- Mobile people and devices affect the transmission channel of stationary nodes.





# And It Gets Worse ...

- The impact of mobility on transmission can be complex.
- Mobility also affects addressing and routing.



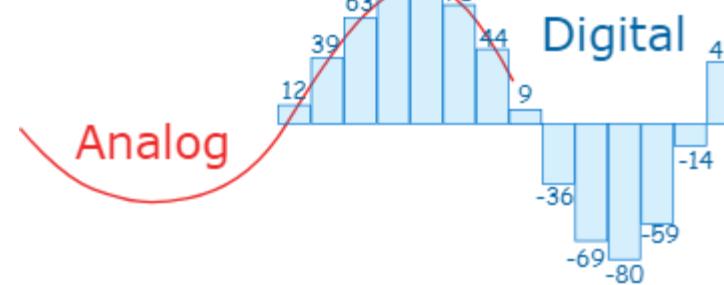


# The Mobile Network

Basic principles of wireless signal properties



## Time-Domain View



- Can be used to represent both an analog and a digital signal.
- **Analog signal** - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
  - E.g. voice signal traveling over traditional phone line
- **Digital signal** - signal intensity maintains a constant level for some period of time and then changes to another constant level.
  - E.g. stream of 1 and 0 values represented as “low” and “high” signal

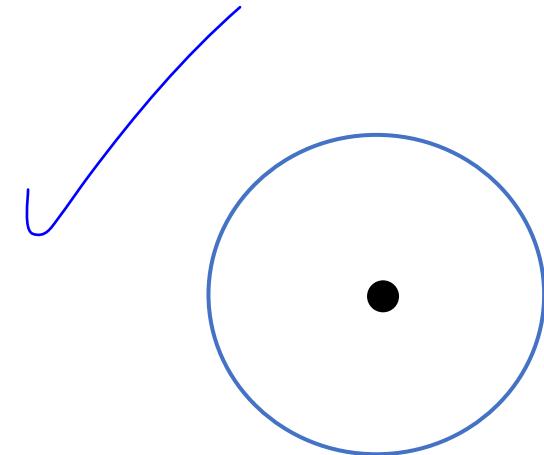
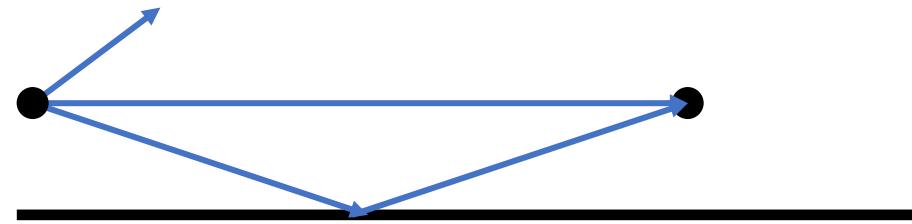




# Two Graphical Views of an Electromagnetic Signal

CM 23/24

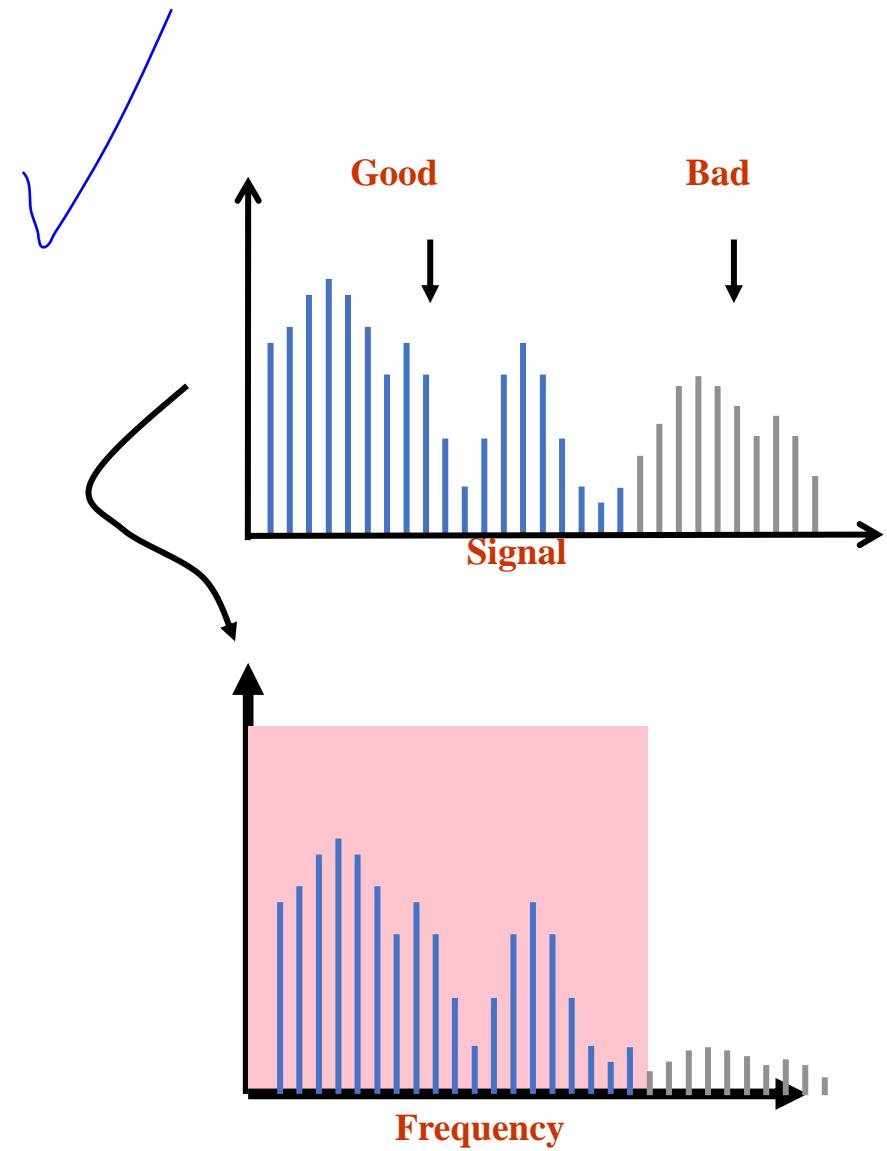
- Both are real in some way
- Think of it as energy that radiates from an antenna and is picked up by another antenna.
  - Helps explain properties such as attenuation
- Can also view it as a “ray” that propagates between two points.
  - Helps explain properties such as reflection and multipath





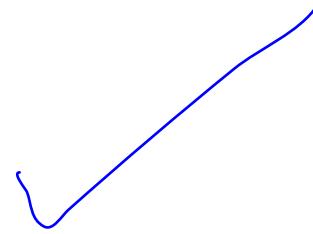
# Transmission Channel Considerations

- For wired networks, channel limits are an inherent property of the channel
  - Different types of fiber and copper have different properties
- As technology improves, these parameters change, even for the same wire
  - Electronics rule
- For wireless networks, limits are often imposed by policy
  - Can only use certain part of the spectrum
  - Regulatory/business considerations





# Channel Capacity

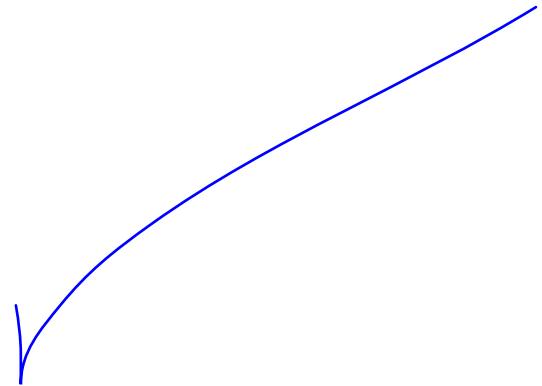


- Data rate - rate at which data can be communicated (bps)
  - Channel Capacity – the maximum rate at which data can be transmitted over a given channel, under given conditions
- Bandwidth (signal theory)- the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1



# Propagation Modes

CM 23/24



- Line-of-sight (LOS) propagation.
  - Most common form of propagation
  - Happens above  $\sim 30$  MHz
  - Subject to many forms of degradation (next set of slides)
- Ground-wave propagation.
  - More or less follows the contour of the earth
  - For frequencies up to about 2 MHz, e.g. AM radio
- Sky wave propagation.
  - Signal “bounces” off the ionosphere back to earth – can go multiple hops
  - Used for amateur radio and international broadcasts

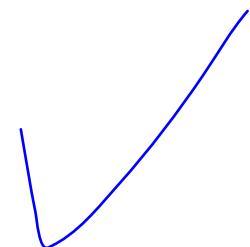


# Propagation Degrades RF Signals



CM 23/24

- Attenuation in free space: signal gets weaker as it travels over longer distances
  - Radio signal spreads out – free space loss
  - Refraction and absorption in the atmosphere
  - Frequency dependent!
- Obstacles can weaken signal through absorption or reflection.
  - Part of the signal is redirected
- Multi-path effects: multiple copies of the signal interfere with each other.
- Mobility: moving receiver causes another form of self interference.
  - Big change in signal strength

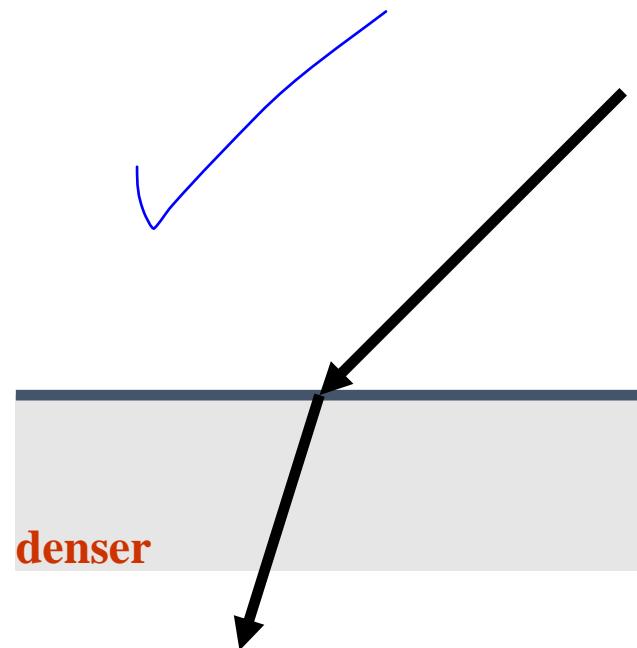




# Refraction

CM 23/24

- Speed of EM signals depends on the density of the material
  - Vacuum:  $3 \times 10^8$  m/sec
  - Denser: slower
- Density is captured by refractive index
- Explains “bending” of signals in some environments
  - E.g. sky wave propagation
  - But also local, small scale differences in the air





# Noise Sources

CM 23/24

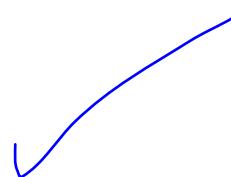
- **Thermal noise:** caused by agitation of the electrons
  - Function of temperature
  - Affects electronic devices and transmission media
- **Intermodulation noise:** result of mixing signals
- **Cross talk:** picking up other signals
  - E.g. from other source-destination pairs)
- **Impulse noise:** irregular pulses of high amplitude and short duration
  - Harder to deal with

Fairly Predictable  
➤Can be planned for or avoided



# Other LOS Factors

- Absorption of energy in the atmosphere.
  - Very serious at specific frequencies, e.g. water vapor (22 GHz) and oxygen (60 GHz)
  - Obviously objects also absorb energy

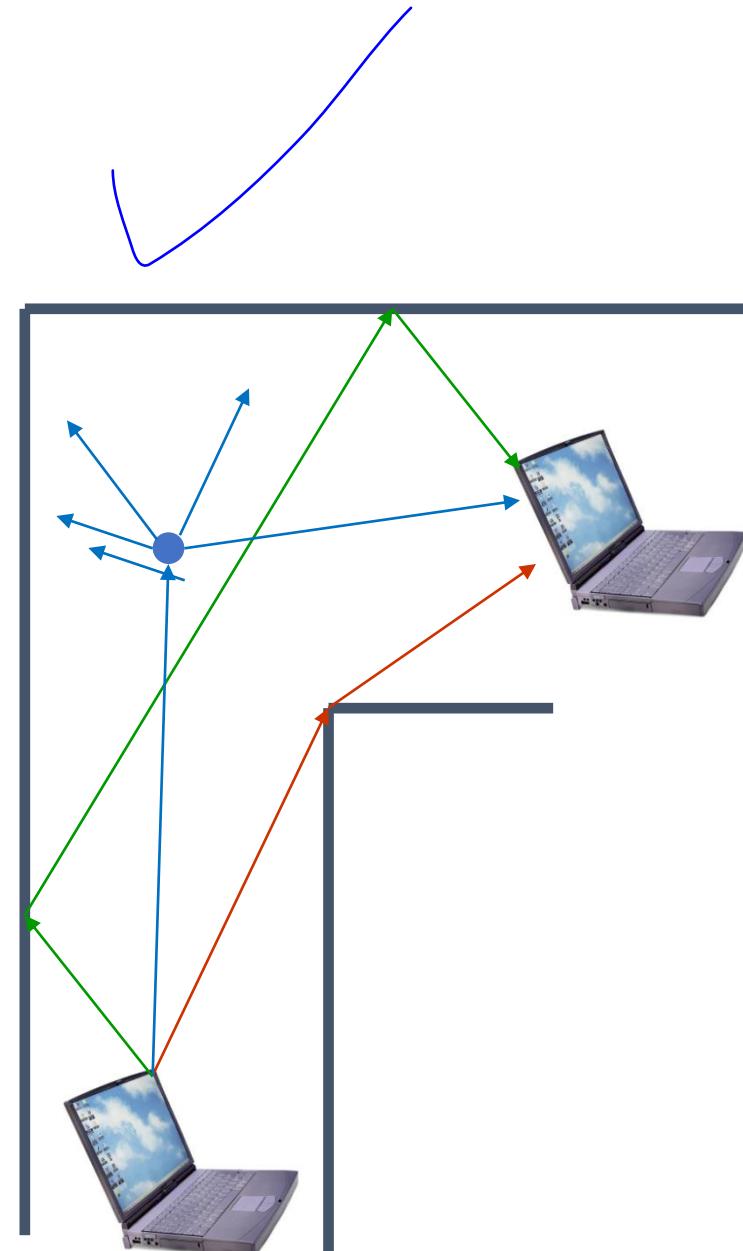




# Propagation Mechanisms

CM 23/24

- Besides line of sight, signal can reach receiver in three other “indirect” ways.
- **Reflection**: signal is reflected from a large object.
- **Diffraction**: signal is scattered by the edge of a large object – “bends”.
- **Scattering**: signal is scattered by an object that is small relative to the wavelength.

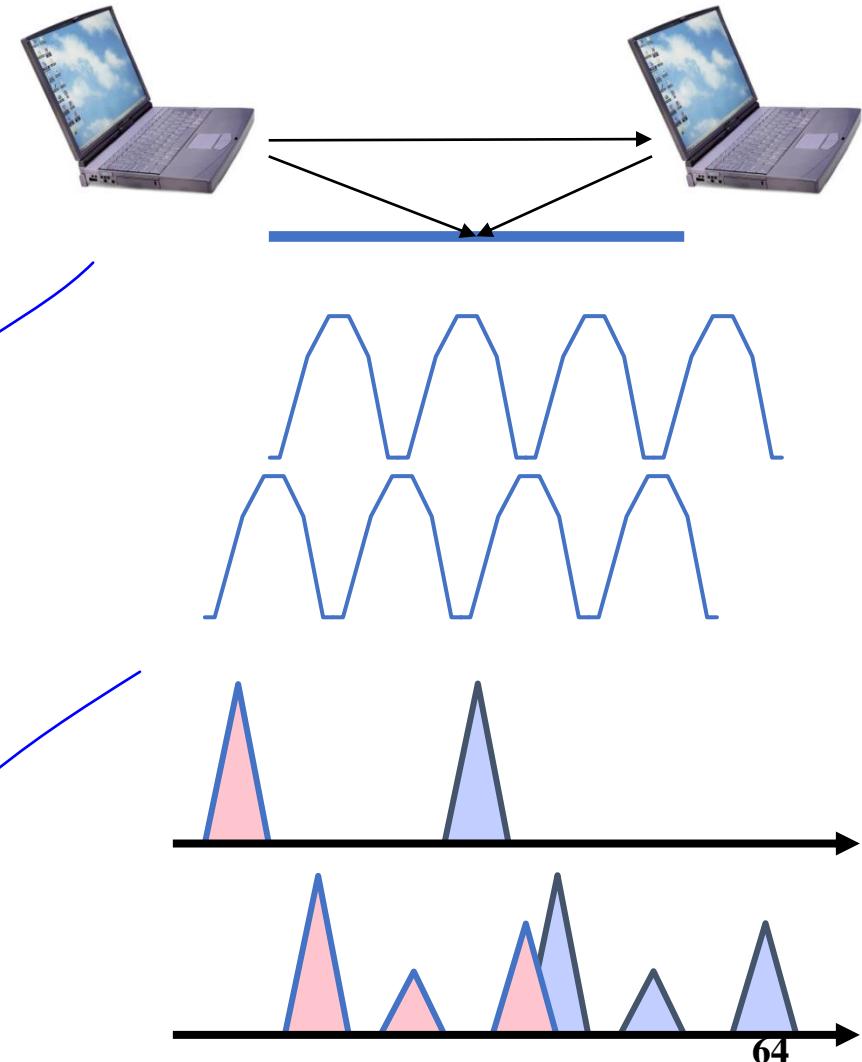




# Multipath Effects

CM 23/24

- Receiver receives multiple copies of the signal, each following a different path.
- Copies can either strengthen or weaken each other.
- Small changes in location can result in big changes in signal strength.
- Difference in path length can cause intersymbol interference (ISI).





# Introducing Redundancy

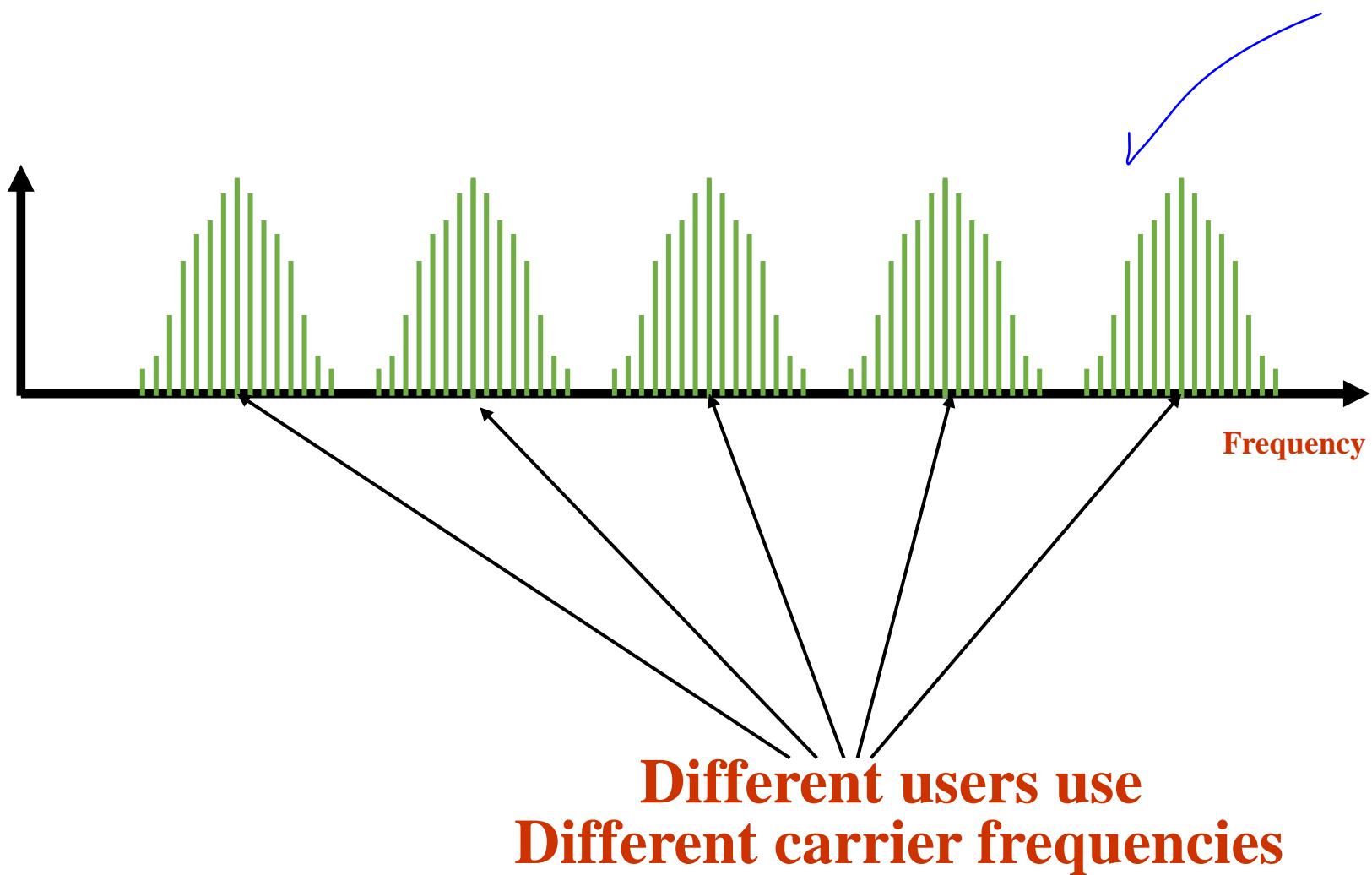
CM 23/24

- Protects digital data by introducing redundancy in the transmitted data.
  - Error detection codes: can identify certain types of errors
  - Error correction codes: can fix certain types of errors
- **Block codes** provide Forward Error Correction (FEC) for blocks of data.
  - $(n, k)$  code:  $n$  bits are transmitted for  $k$  information bits
  - Simplest example: parity codes
  - Many different codes exist: Hamming, cyclic, Reed-Solomon, ...
- **Convolutional codes** provide protection for a continuous stream of bits.
  - Coding gain is  $n/k$
  - Turbo codes: convolutional code with channel estimation



# Multiple Users Can Share the Spectrum

CM 23/24





# So Why Don't we Always Send a High Bandwidth Signal?

CM 23/24

- Channels have a limit on the type of signals it can carry
  - Good transmission of signals only in certain frequency range
  - Signals outside of that range get distorted, e.g. attenuated
- Distortion can make it hard for receiver to extract the information
  - It is beneficial to match the signal to the channel
  - Limits the throughput of the channel





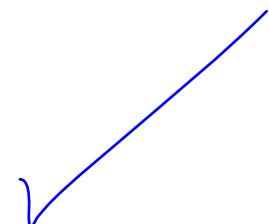
# Spread Spectrum

- Spread transmission over a wider bandwidth
  - Don't put all your eggs in one basket!
- Good for military: jamming and interception becomes harder
- Also useful to minimize impact of a “bad” frequency in regular environments
- What can be gained from this apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
    - Including jamming
  - Can be used for hiding/encrypting signals
    - Only receiver who knows SS code can retrieve signal
  - Several users can independently share the same higher bandwidth with very little interference (later)
    - Code division multiple access (CDMA)



# Spread Spectrum Concept

- Input fed into channel encoder
  - Produces narrow bandwidth analog signal around central frequency
- Signal modulated using sequence of digits
  - Spreading code/sequence
  - Typically generated by pseudonoise/pseudorandom number generator
    - Not actually random
    - If algorithm good, results pass reasonable tests of randomness
    - Need to know algorithm and seed to predict sequence
- Increases bandwidth significantly
  - Spreads spectrum
- Receiver uses same sequence to demodulate signal
- Demodulated signal fed into channel decoder



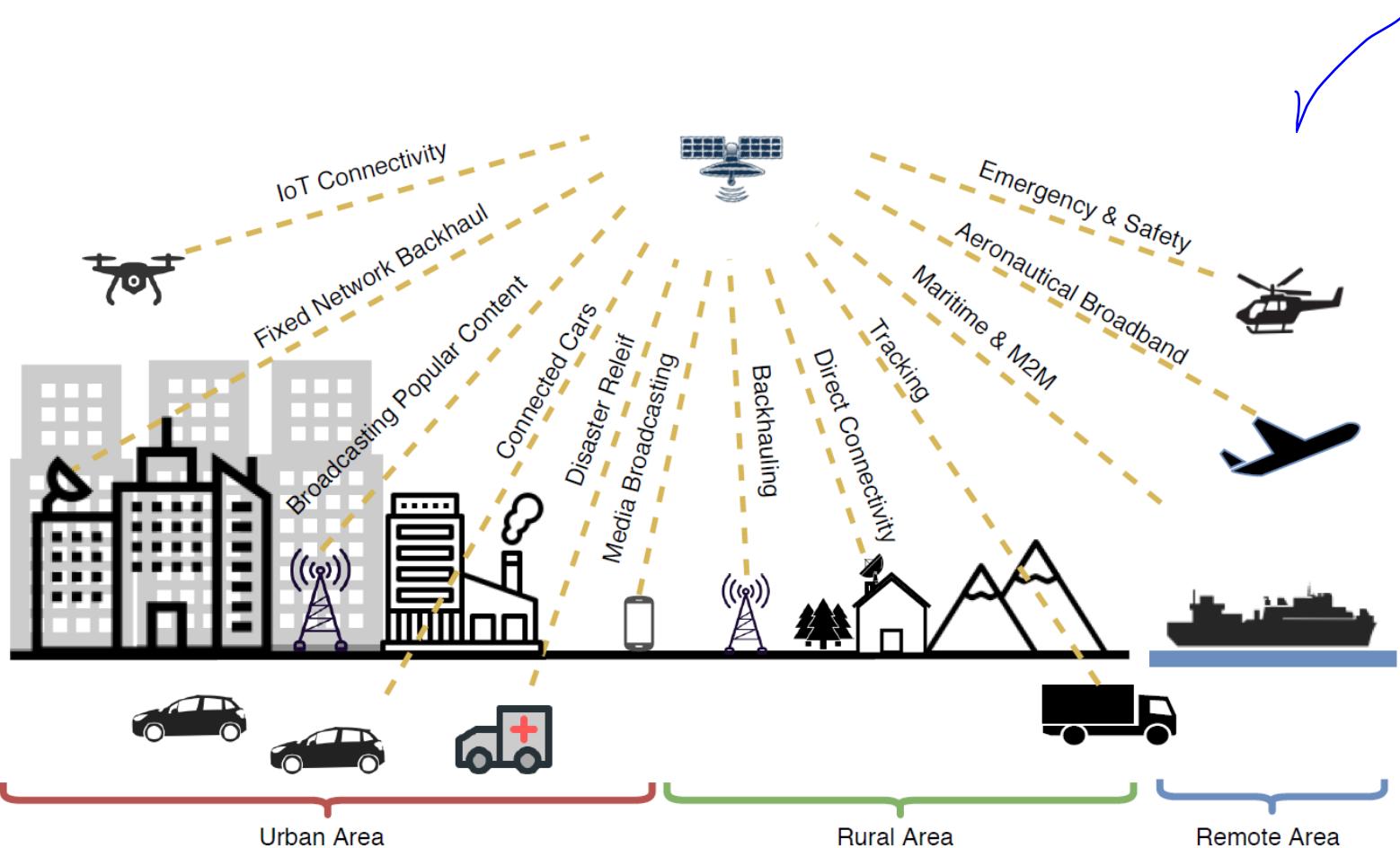


# Satellite networks



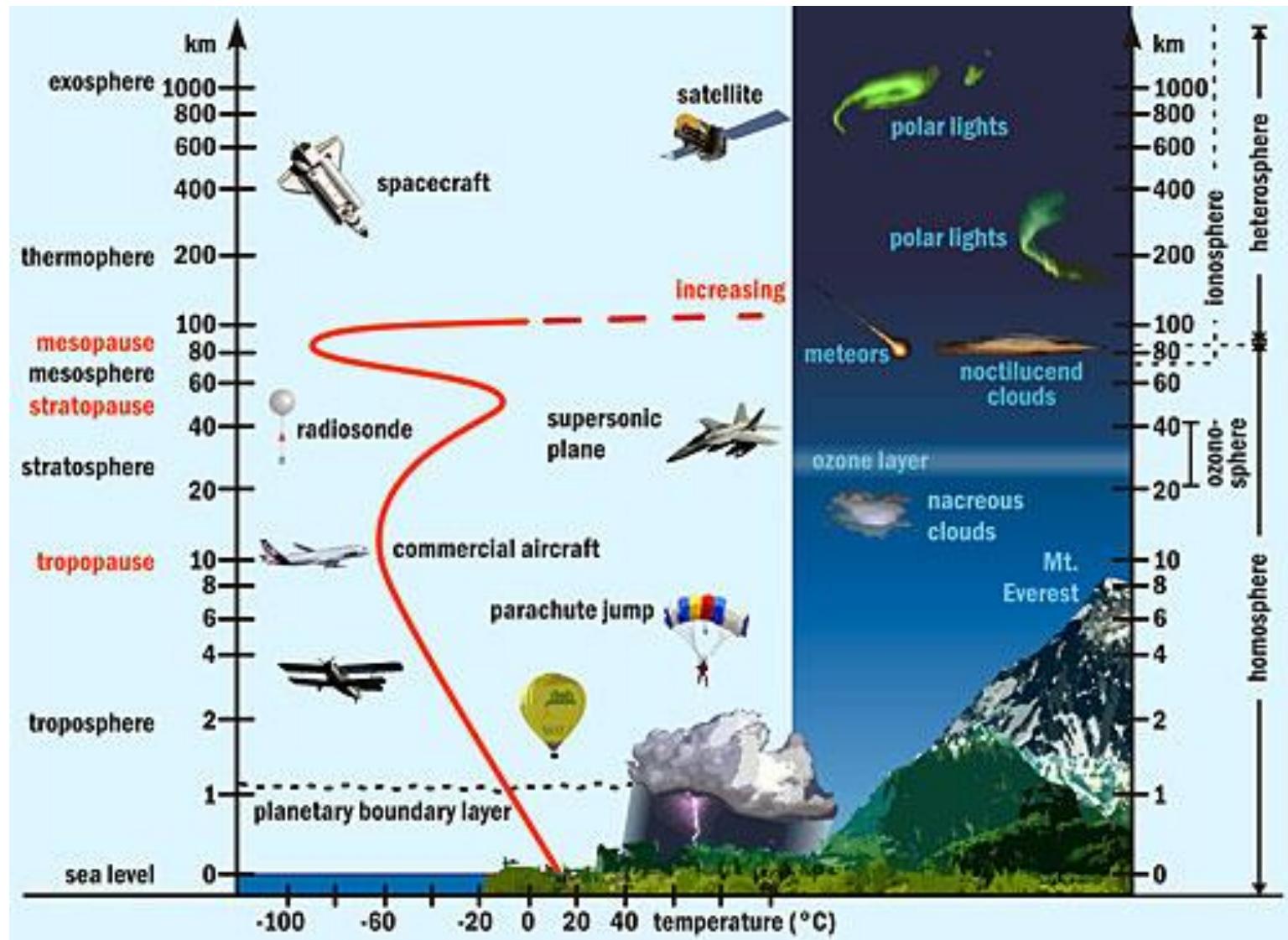
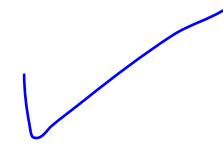
# SATELLITES







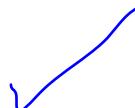
# Earth's atmosphere





# Basics

- ❑ elliptical or circular orbits
- ❑ complete rotation time depends on distance satellite-earth
- ❑ **inclination**: angle between orbit and equator
- ❑ **elevation**: angle between satellite and horizon
- ❑ **LOS** (Line of Sight) to the satellite necessary for connection
  - ➔ high elevation needed, less absorption due to e.g. buildings
- ❑ **Uplink**: connection base station - satellite
- ❑ **Downlink**: connection satellite - base station
- ❑ typically separated frequencies for uplink and downlink
  - transponder used for **sending/receiving and shifting of frequencies**
  - transparent transponder: only shift of frequencies
  - regenerative transponder: additionally signal regeneration





# Features of Satellite Networks

- Effects of satellite mobility

- Topology is dynamic.
- Topology changes are predictable and periodic.
- Traffic is very dynamic and non-homogeneous.
- Handovers are necessary.

- Limitations and capabilities of satellites

- Power and onboard processing capability are limited.
- Implementing the state-of-the-art technology is difficult.
- Satellites have a broadcast nature.

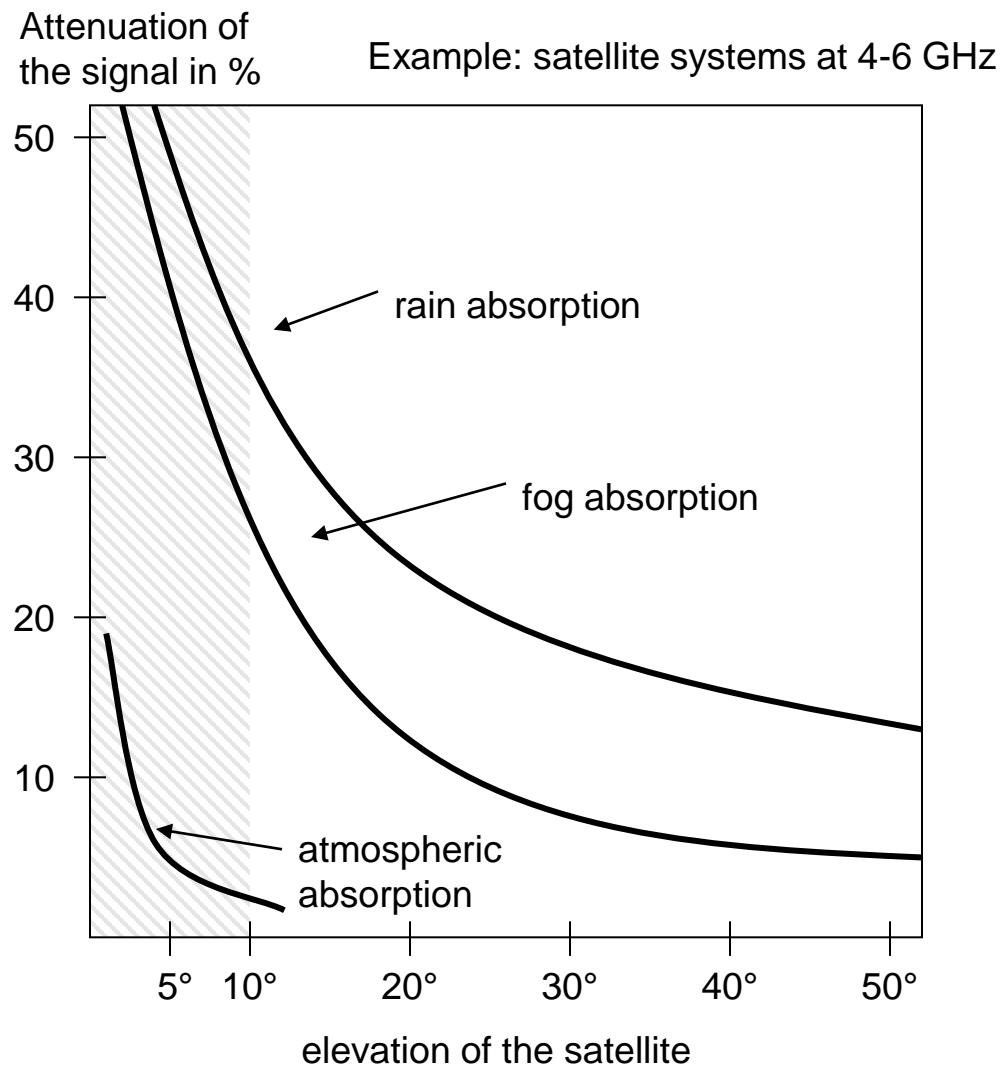
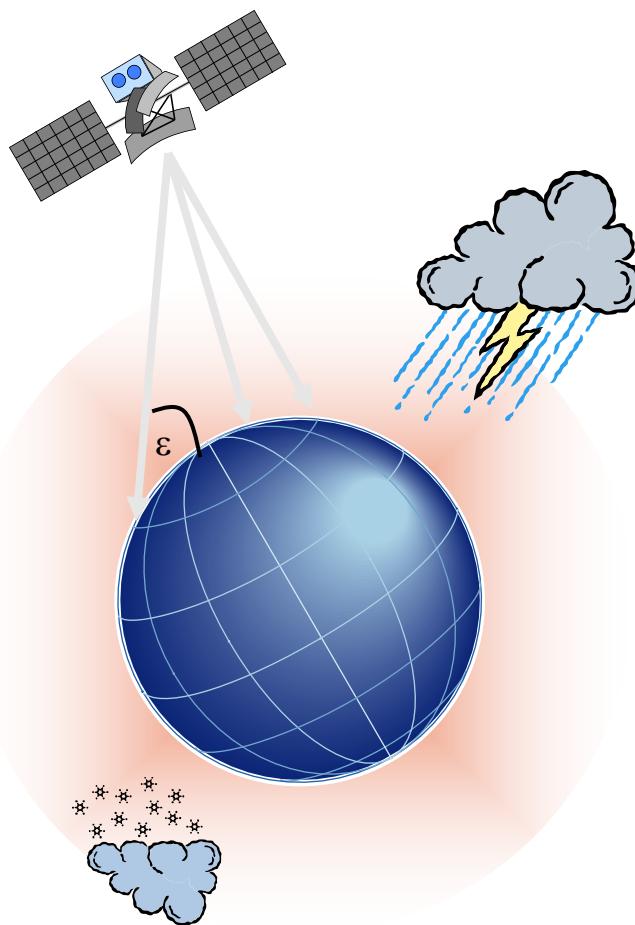
- Nature of satellite constellations

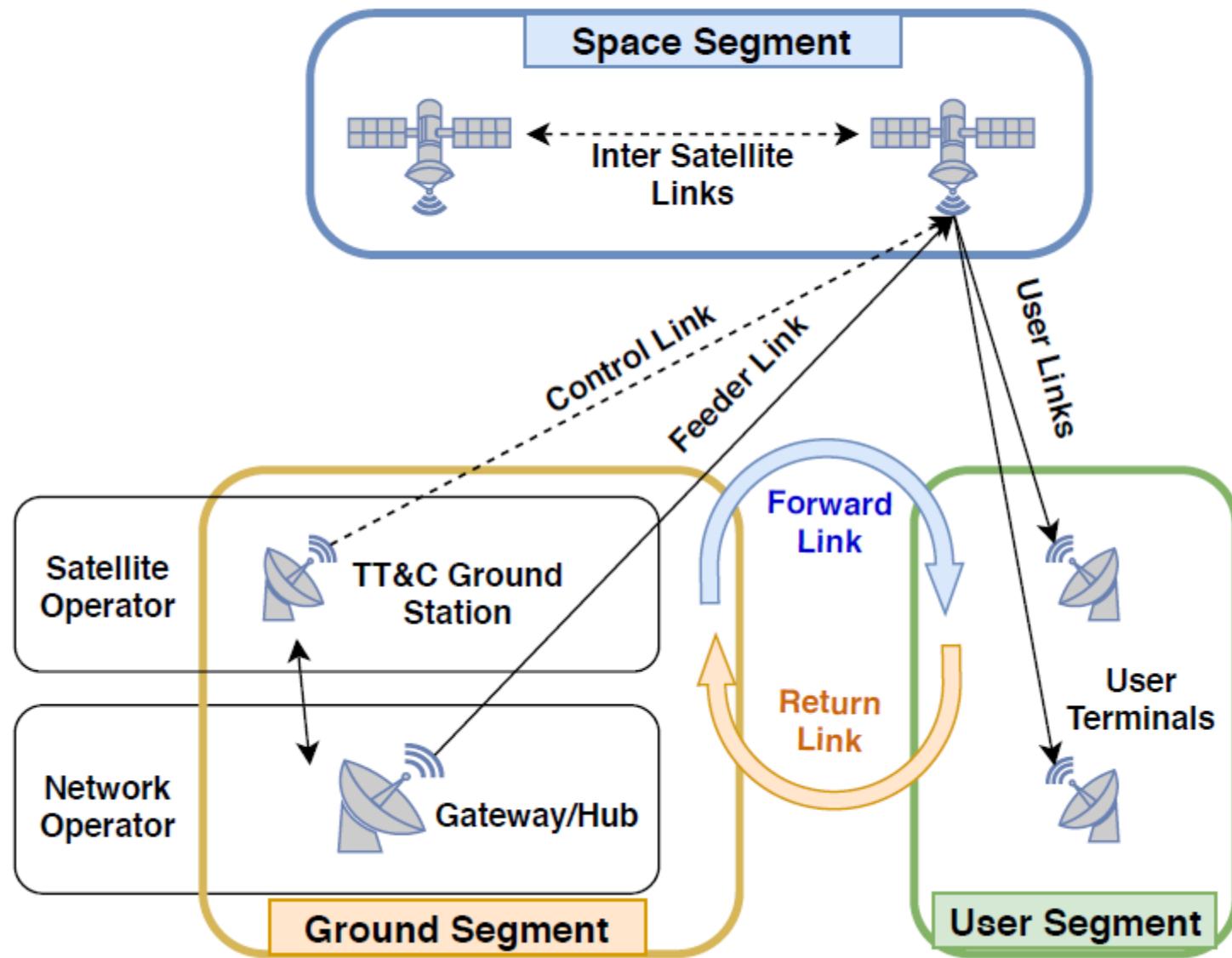
- Higher propagation delays.
- Fixed number of nodes.
- Highly symmetric and uniform structure.





# Atmospheric attenuation







# Satellite Transmission Links

- Earth stations communicate by sending signals to the satellite on an uplink
- The satellite then repeats those signals on a downlink
- The broadcast nature of downlink makes it attractive for services such as the distribution of TV programs



- Satellite up links and down links can operate in different frequency bands:

Band	Up-Link (Ghz)	Down-link (Ghz)	ISSUES
C	3,700-4,200 MHz	5,925-6,425 MHz	Interference with ground links.
Ku	11.7-12.2 GHz	14.0-14.5 GHz	Attenuation due to rain
Ka	17.7-21.2 GHz	27.5-31.0 GHz	High Equipment cost

- The up-link is a highly directional, point to point link
- The down-link can have a footprint providing coverage for a substantial area "spot beam". 

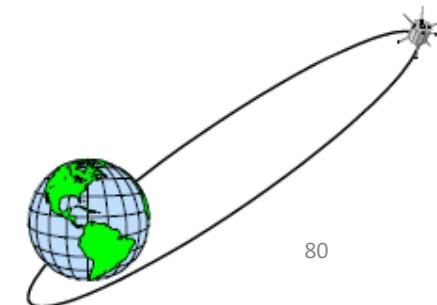
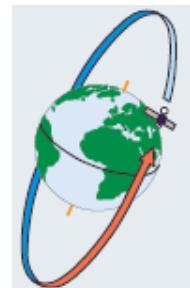
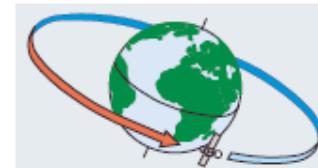
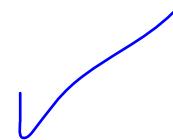
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# Types of Satellite Orbits

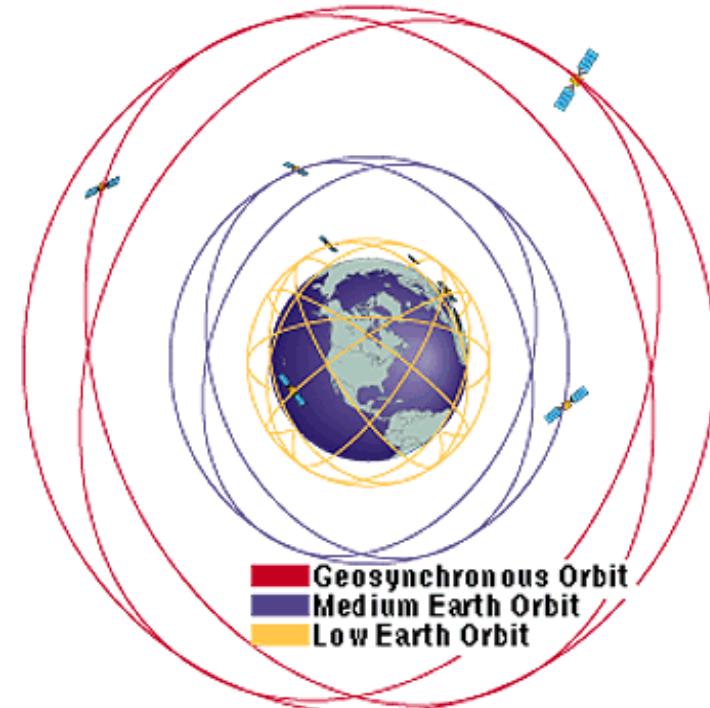
- Based on the inclination, “ $i$ ”, over the equatorial plane:
  - Equatorial Orbits above Earth’s equator ( $i=0^\circ$ )
  - Polar Orbits pass over both poles ( $i=90^\circ$ )
  - Other orbits called inclined orbits ( $0^\circ < i < 90^\circ$ )
- Based on Eccentricity
  - Circular with centre at the earth’s centre
  - Elliptical with one foci at earth’s centre





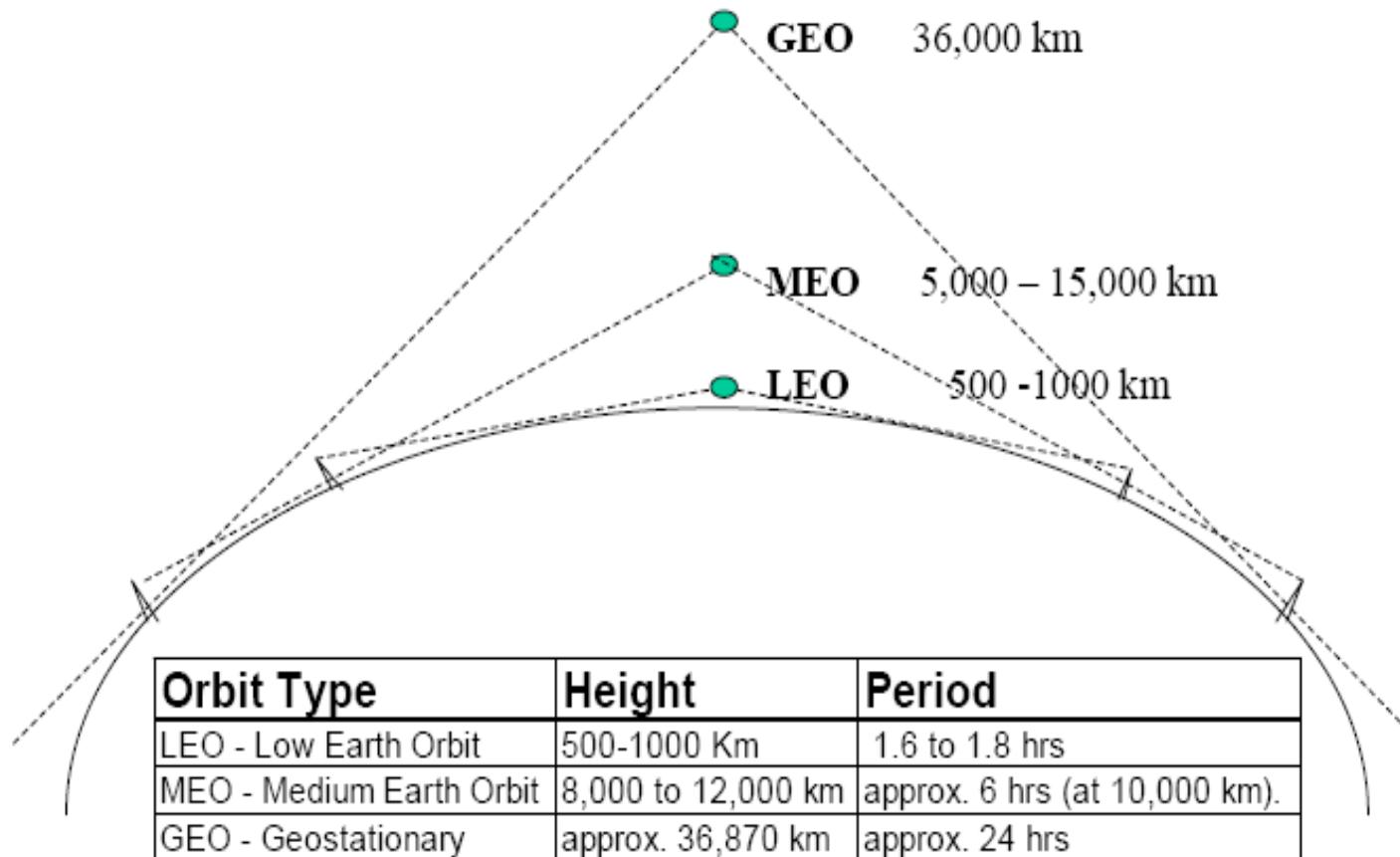
# Types of Satellite based Networks

- Based on the Satellite Altitude
  - GEO – Geostationary Orbits
    - 36000 Km = 22300 Miles, equatorial, High latency
  - MEO – Medium Earth Orbit
    - High bandwidth, High power, High latency
  - LEO – Low Earth Orbit
    - Low power, Low latency, More Satellites, Small Footprint
  - VSAT
    - Very Small Aperture Satellites
      - Private WANs





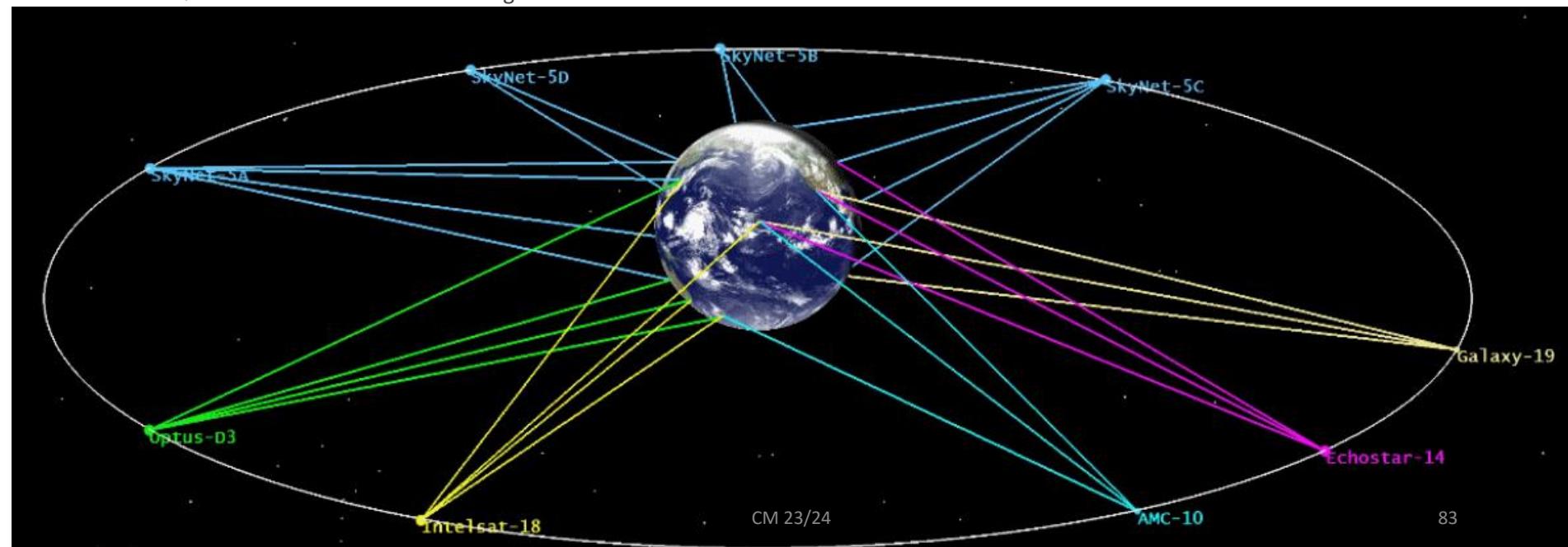
# Satellite Orbits – Another perspective





# GEO - Geostationary Orbit

- ▶ In the equatorial plane
- ▶ Orbital Period = 23 h 56 m 4.091 s
  - = 1 sidereal day\*
- ▶ Satellite appears to be stationary over any point on equator:
  - ▶ Earth Rotates at same speed as Satellite
  - ▶ Radius of Orbit  $r$  = Orbital Height + Radius of Earth





# GEO Satellites

- No handover
- One-way propagation delay: 250-280 ms
- 3 to 4 satellites for global coverage
- Mostly used in video broadcasting
- Another applications:
  - Weather forecast, global communications, military applications
- Advantage: well-suited for broadcast services
- Disadvantages: Long delay, high free-space attenuation



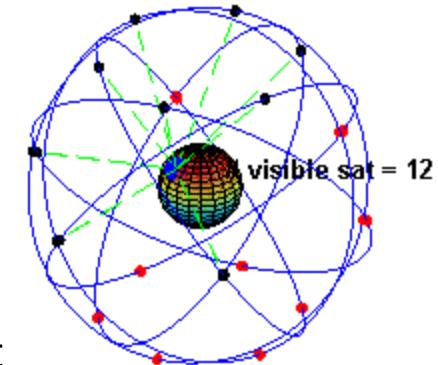
# MEO Satellites

- One-way propagation delay: 100 – 130 ms
- 10 to 15 satellites for global coverage
- Infrequent handover
- Orbit period: ~6 hr
- Mostly used in navigation
  - GPS, Galileo, Glonass
- Communications: Inmarsat, ICO



# MEO Example: GPS

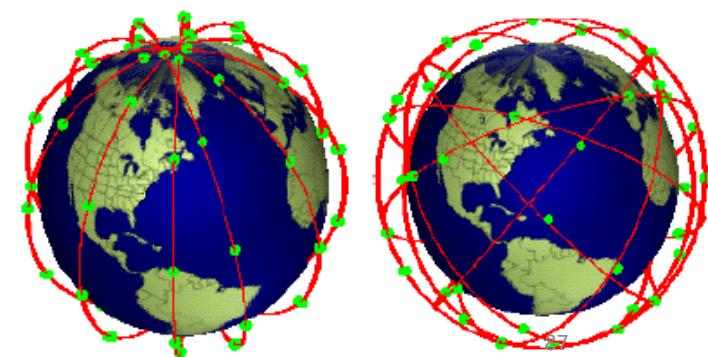
- Global Positioning System
  - Developed by US Dept. Of Defence
  - Became fully operational in 1993
  - Currently 31 satellites at 20.200 km.
    - Last lunch: March 2008
- It works based on a geometric principle
  - “Position of a point can be calculated if the distances between three objects with known positions can be measured”
- Four satellites are needed to calculate the position
  - Fourth satellite is needed to correct the receiver’s clock.
- Selective Availability
- Glonass (Russian): 24 satellites, 19.100 km
- Galileo (EU): 30 satellites, 23.222 km, under development (expected date: 2013)
- Beidou (China): Currently experimental & limited.





# LEO - Low Earth Orbits

- Circular or inclined orbit with < 1400 km altitude
  - Satellite travels across sky from horizon to horizon in 5 - 15 minutes => needs handoff
  - Earth stations must track satellite or have Omni directional antennas
  - Large constellation of satellites is needed for continuous communication (66 satellites needed to cover earth)
  - Requires complex architecture
  - Requires tracking at ground





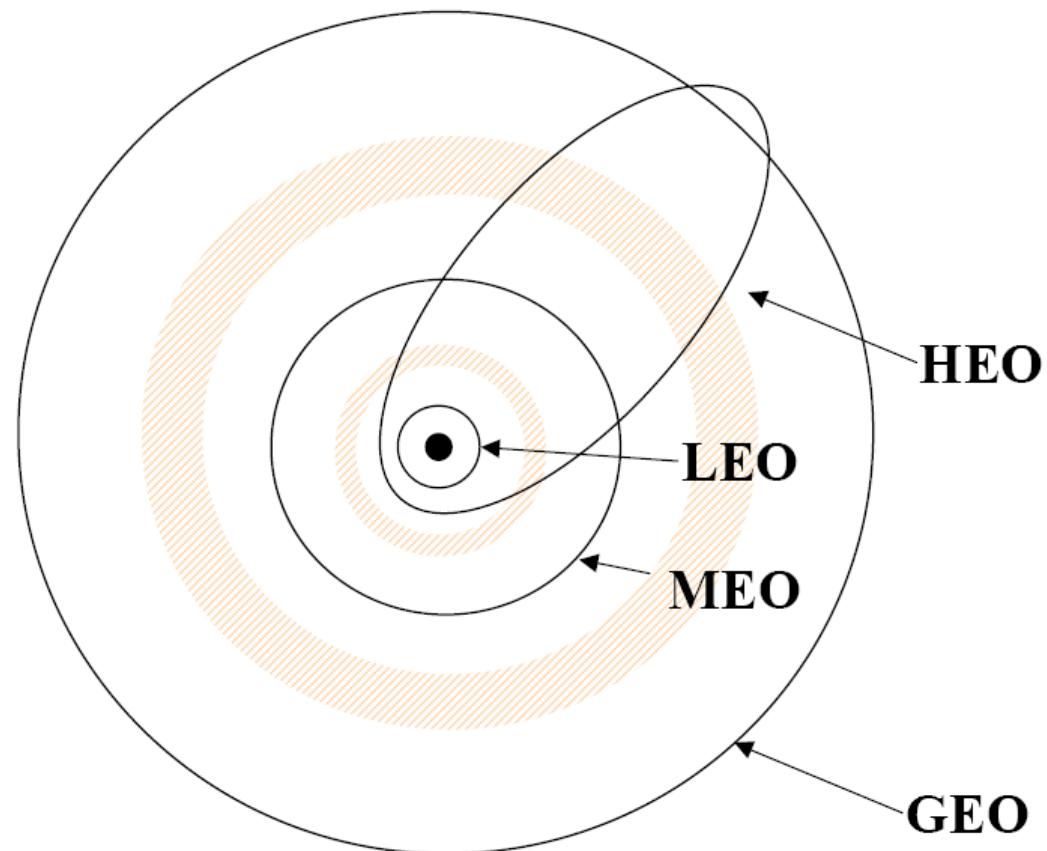
# LEO Satellites

- One-way propagation delay: 5 – 20 ms
- More than 32 satellites for global coverage
- Frequent handover
- Orbit period: ~2 hr
- Applications:
  - Earth Observation
    - GoogleEarth image providers (DigitalGlobe, etc.)
    - RASAT (First satellite to be produced solely in Turkey)
  - Communications
    - Globalstar, Iridium
  - Search and Rescue (SAR)
    - COSPAS-SARSAT



# NGSO - Non Geostationary Orbits

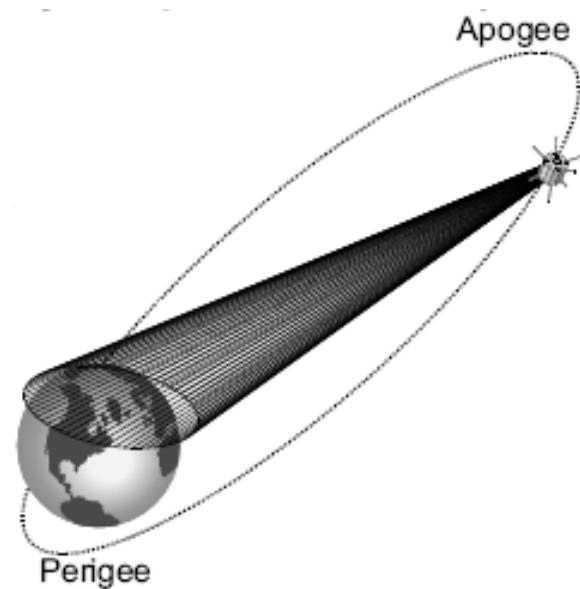
- Orbit should avoid Van Allen radiation belts:
  - Region of charged particles that can cause damage to satellite
  - Occur at
    - $\sim 2000\text{-}4000 \text{ km}$  and
    - $\sim 13000\text{-}25000 \text{ km}$





# HEO - Highly Elliptical Orbits

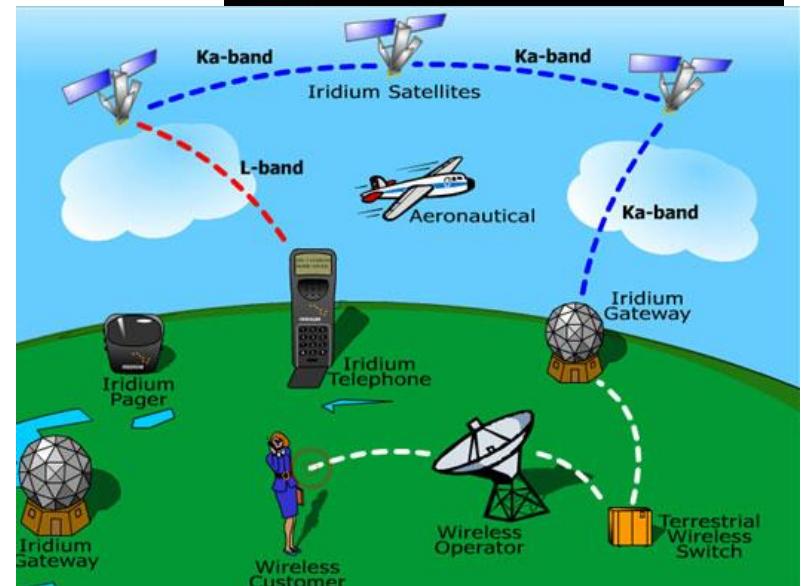
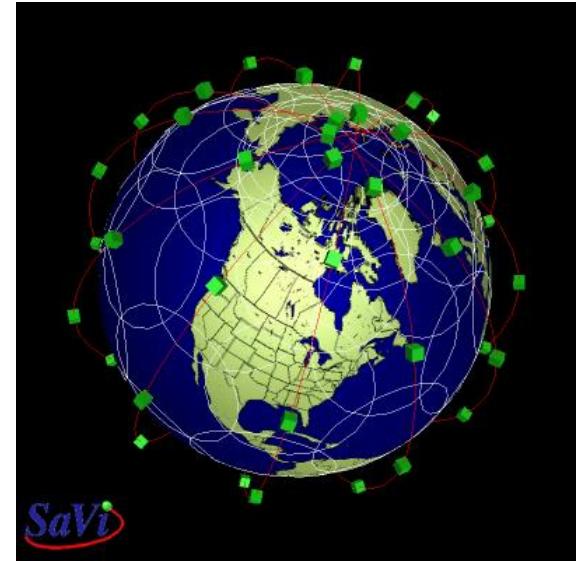
- HEOs ( $i = 63.4^\circ$ ) are suitable to provide coverage at high latitudes (including North Pole in the northern hemisphere)
- Depending on selected orbit (e.g. Molniya, Tundra, etc.) two or three satellites are sufficient for continuous time coverage of the service area.
- All traffic must be periodically transferred from the “setting” satellite to the “rising” satellite (Satellite Handover)





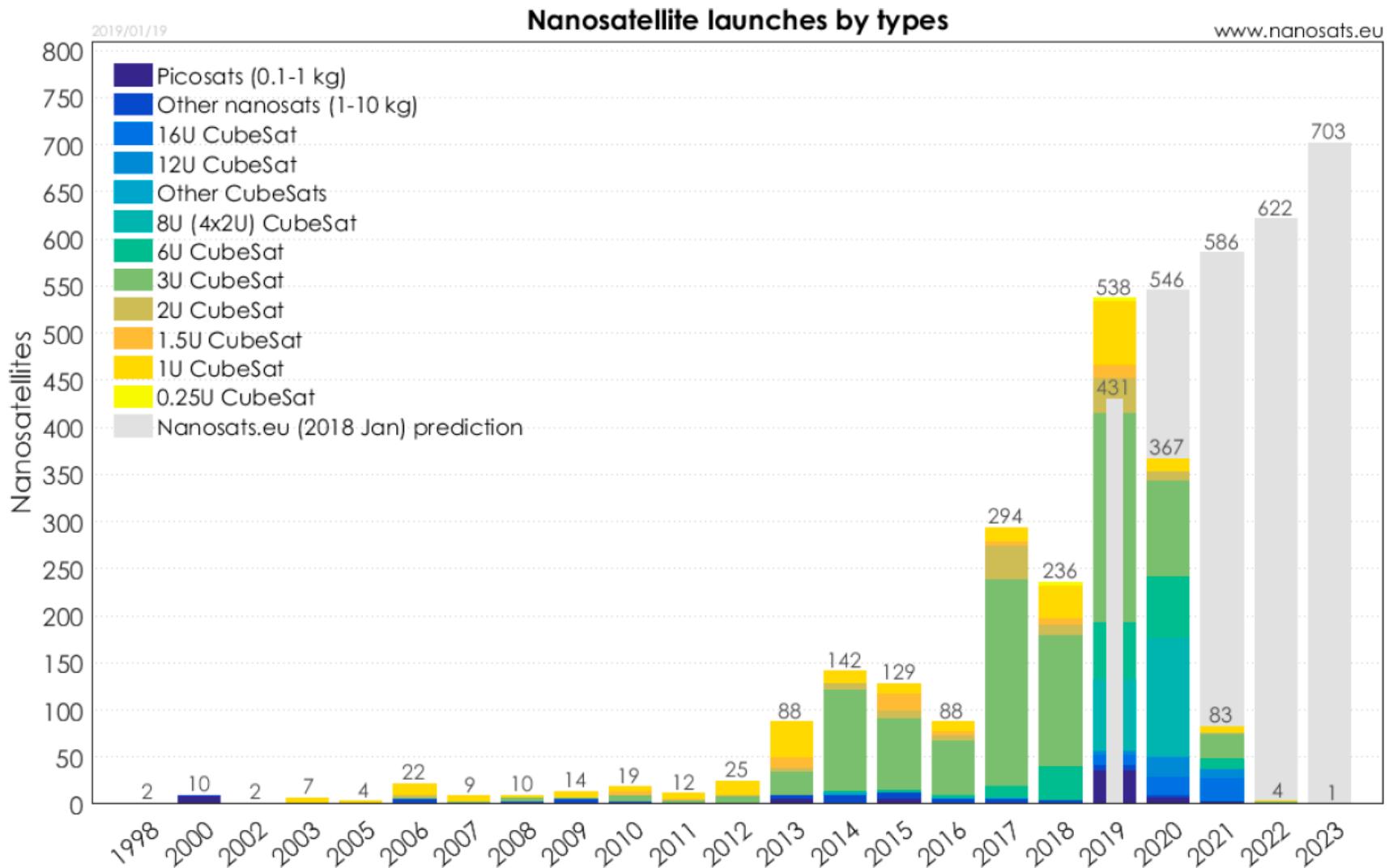
# Iridium

- 66 satellites (6 planes, 11 sat per plane) and 10 spares.
- 86.4° inclination: full coverage
- Altitude: 780 km
- Intersatellite links, onboard processing
- Satellite visibility time: 11.1 min
- Satellites launched in 1997-98.
- Initial company went into bankruptcy
  - Technologically flawless, however:
  - Very expensive; Awful business plan
  - Cannot compete with GSM
- Now, owned by Iridium satellite LLC.
- 280.000 subscribers (as of Aug. 2008)
- Multi-year contract with US DoD.
- Satellite collision (February 10, 2009).



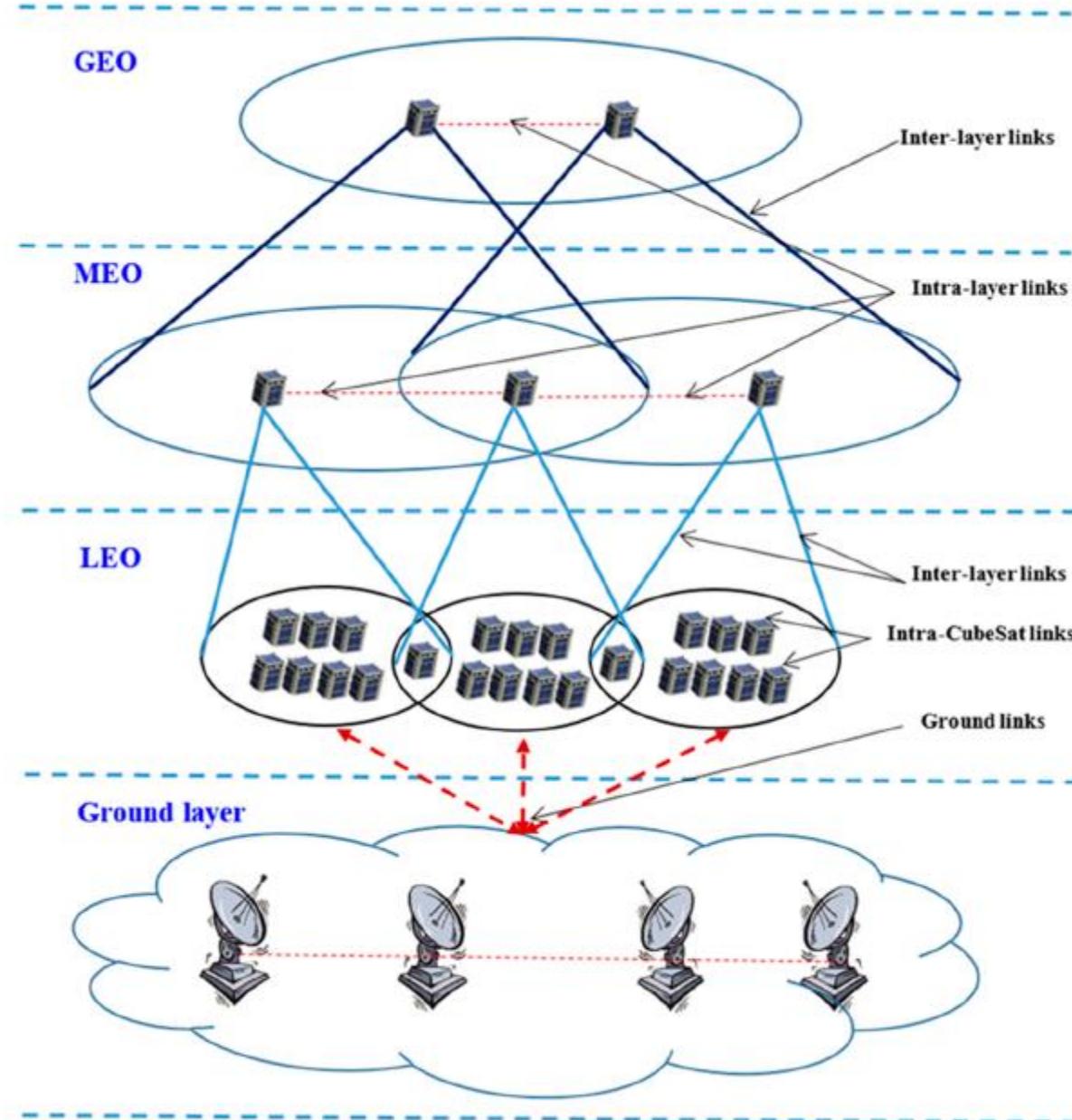


# The cubesat explosion





Challenges	Implications
Intermittent connectivity	<ul style="list-style-type: none"><li>- Satellites on this orbit are characterized by scheduled predictable/semi-predictable intermittent connectivity, whether for a satellite to ground links or inter-satellite links.</li><li>- There are no contemporary paths present for satellite and ground station communication or cross-link communication.</li></ul>
Orbital period	<ul style="list-style-type: none"><li>- LEO satellite orbital velocity <math>\approx 7800</math> m/s, based on the satellite altitude orbital period of about 90–110 minu for 160–1200 km altitudes respectively.</li><li>- Limited encounter time between satellites which in turns bounds data transfer rate.</li></ul>
Inter-CubeSat links	<ul style="list-style-type: none"><li>- Transmission range between two satellites, approximately 5–200 km.</li><li>- The transmission range of inter-CubeSats is bound by cross-link antenna transmission power.</li><li>- Limited antenna size and capability compared with the conventional satellites.</li><li>- Limited antenna coverage compared with the conventional satellites.</li></ul>
Up/Downlinks with the ground station	<ul style="list-style-type: none"><li>- Transmission range between satellite and ground station, approximately 200–1200 km</li><li>- The transmission range of CubeSats is bounded by the downlink antenna transmit power.</li><li>- Satellite revisit time Limited antenna size and capability</li></ul>
Altitude and inclination ranges	<ul style="list-style-type: none"><li>- Orbit altitude rang is 200–1200 km above the Earth and orbit inclination ranges <math>0^\circ</math>–<math>180^\circ</math>.</li></ul>
Natural drag	<ul style="list-style-type: none"><li>- Common de-orbiting behaviour leads to changes in orbital height and hence meeting time between CubeSats will also change over time.</li><li>- Orbiting at lower altitudes increases the drag process.</li><li>- The drag upsurges with increasing solar activity (sunspots).</li></ul>
High failure rate	<ul style="list-style-type: none"><li>- Space radiation effects on electronic components, particularly Commercial-off-the Shelf (COTS) components.</li><li>- Impossibility of recovery under failure.</li></ul>
Energy	<ul style="list-style-type: none"><li>- Solar cells limited space available on the small size of the CubeSat body.</li><li>- Small storage batteries.</li><li>- High power consumption of up/downlinks and cross-links.</li></ul>
Topology density	<ul style="list-style-type: none"><li>- Satellite dissemination and encounter times.</li></ul>
CubeSat stability on orbit	<ul style="list-style-type: none"><li>- There is no space on the CubeSats for advanced stability control devices.</li><li>- Antenna directionality and steering ability.</li></ul>
Data rate	<ul style="list-style-type: none"><li>- A single CubeSat has limited data rate</li><li>- CubeSat swarms and constellations can provide a higher overall system data rate, however, networking CubeSats in these systems is challenging and requires advanced routing protocols.</li></ul>





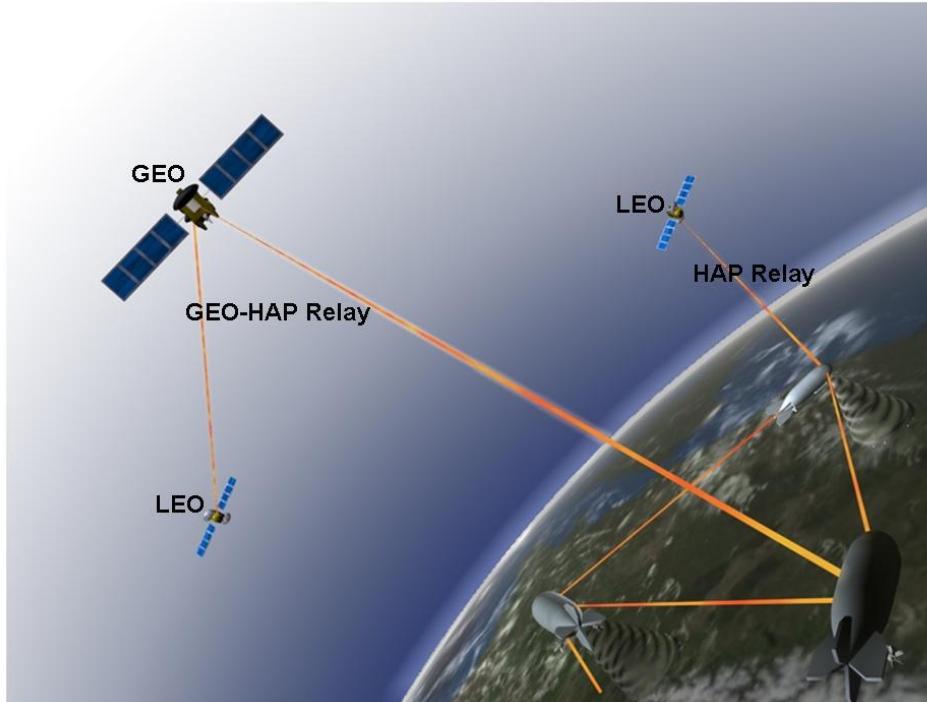
# High Altitude Platforms (HAPs)

- Aerial unmanned platforms
- Quasi-stationary position (at 17-22 km)
- Telecommunications & surveillance
- Advantages:
  - Cover larger areas than terrestrial base stations
  - No mobility problems like LEOs
  - Low propagation delay
  - Smaller and cheaper user terminals
  - Easy and incremental deployment
- Disadvantages:
  - Immature airship technology
  - Monitoring of the platform's movement

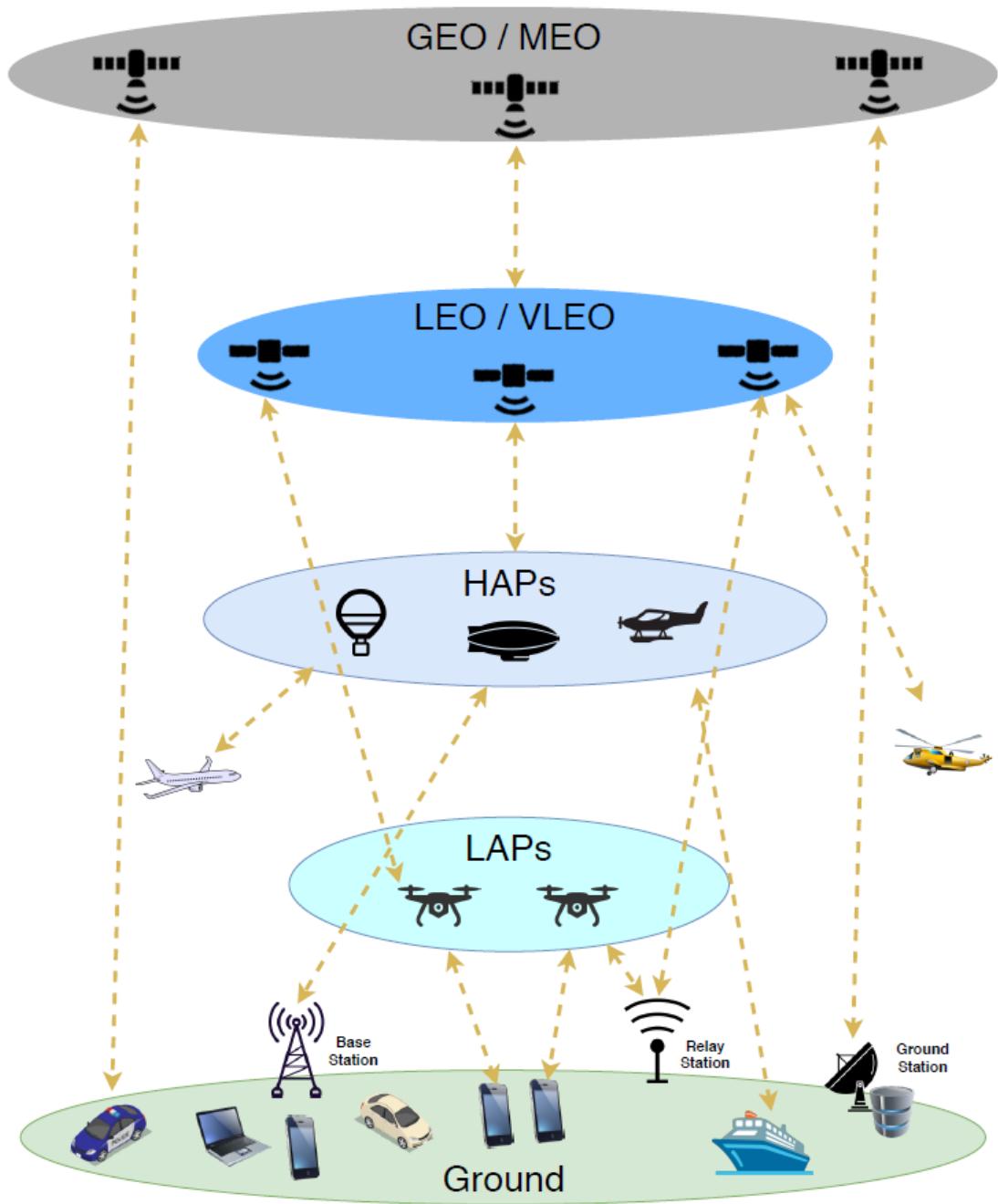




# HAP-Satellite Integration



- HAPs have significant advantages.
- Satellites still represent the most attractive solution for broadcast and multicast services
- Should be considered as complementary technologies.





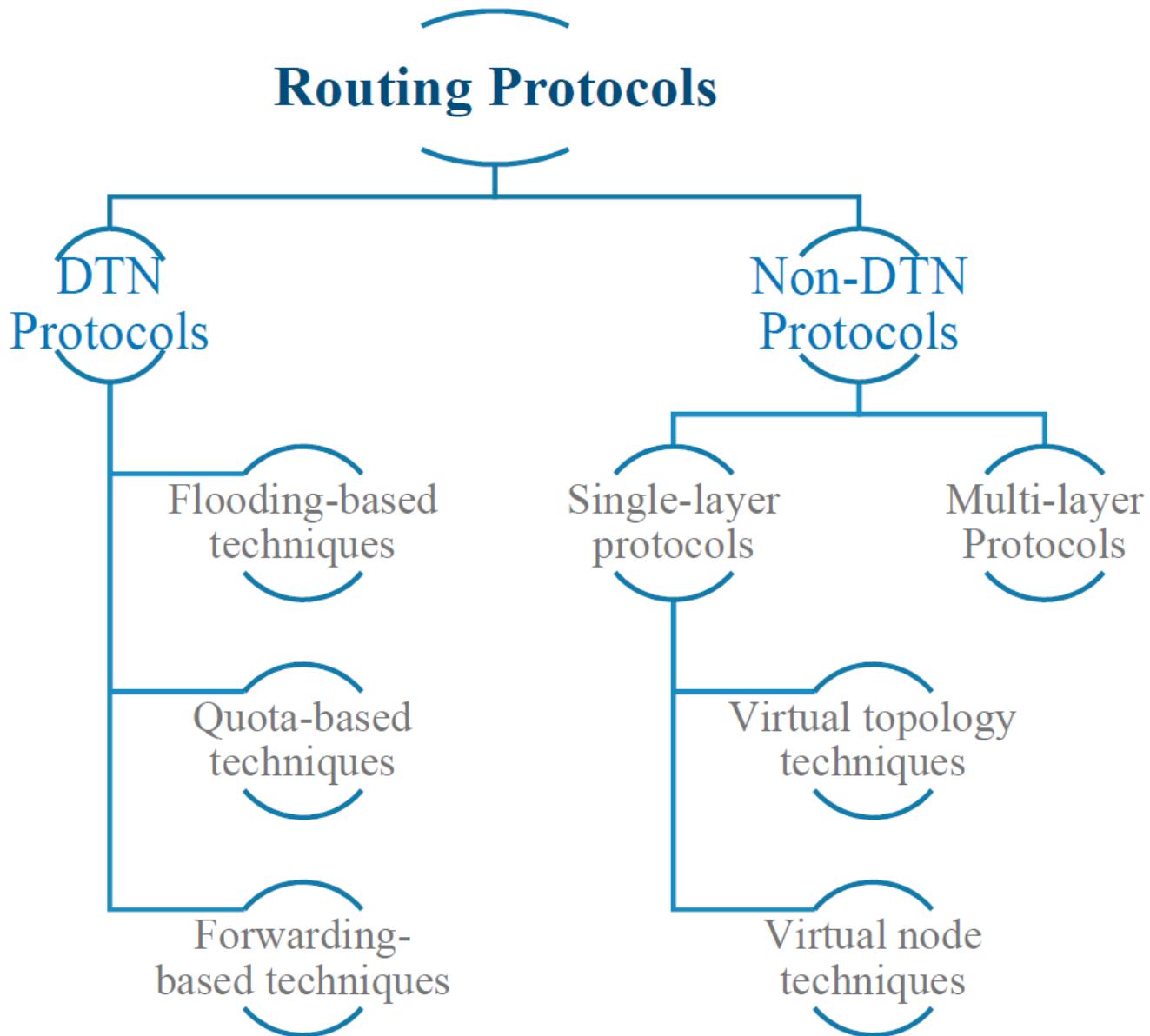
# Satellites - Overview

- GEOs have good broadcasting capability, but long propagation delay.
- LEOs offer low latency, low terminal power requirements.
- Inter-satellite links and on-board processing for increased performance and better utilization of satellites
  - From flying mirrors to intelligent routers on sky.
- Major problem with LEOs: Mobility of satellites
  - Frequent hand-over
- Another important problem with satellites:
  - Infeasible to upgrade the technology, after the satellite is launched



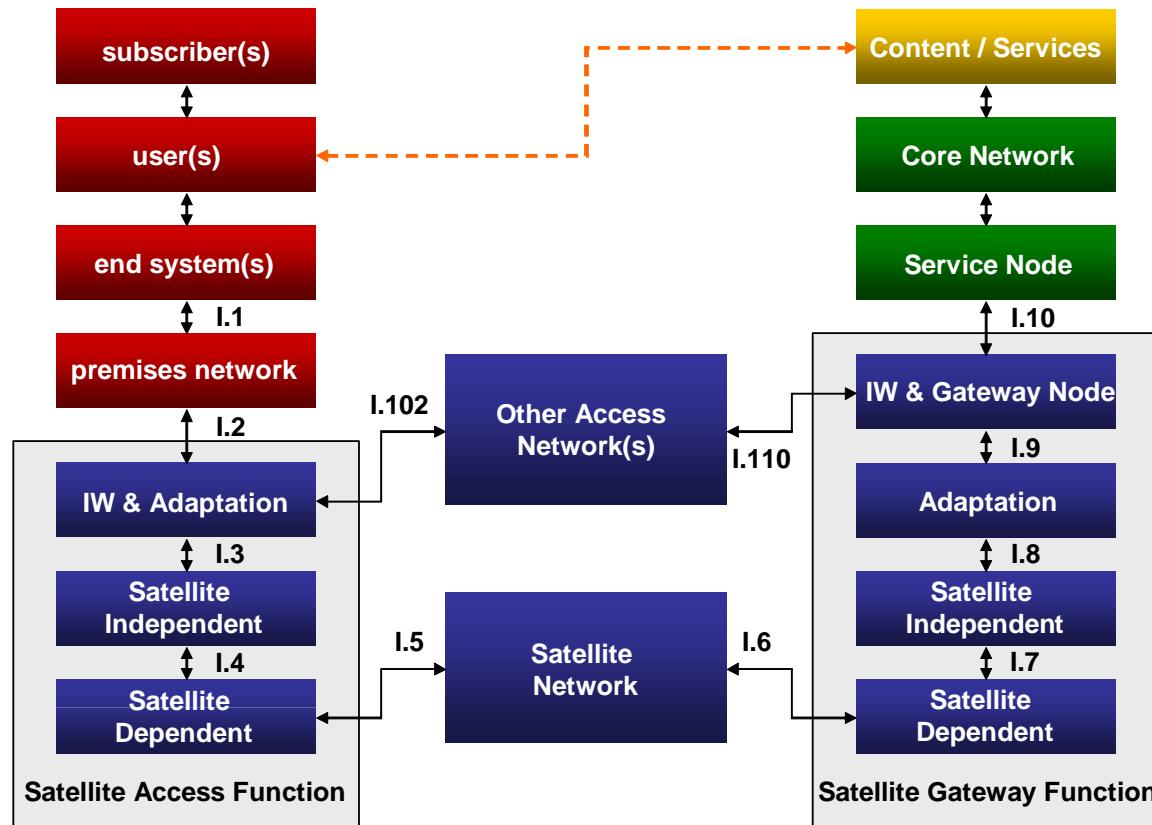
# Routing

- One solution: inter satellite links (ISL)
  - ❑ reduced number of gateways needed
  - ❑ forward connections or data packets within the satellite network as long as possible
  - ❑ only one uplink and one downlink per direction needed for the connection of two mobile phones
- Problems:
  - ❑ more complex focusing of antennas between satellites
  - ❑ high system complexity due to moving routers
  - ❑ higher fuel consumption
  - ❑ thus shorter lifetime
- Iridium and Teledesic planned with ISL
- Other systems use gateways and additionally terrestrial networks



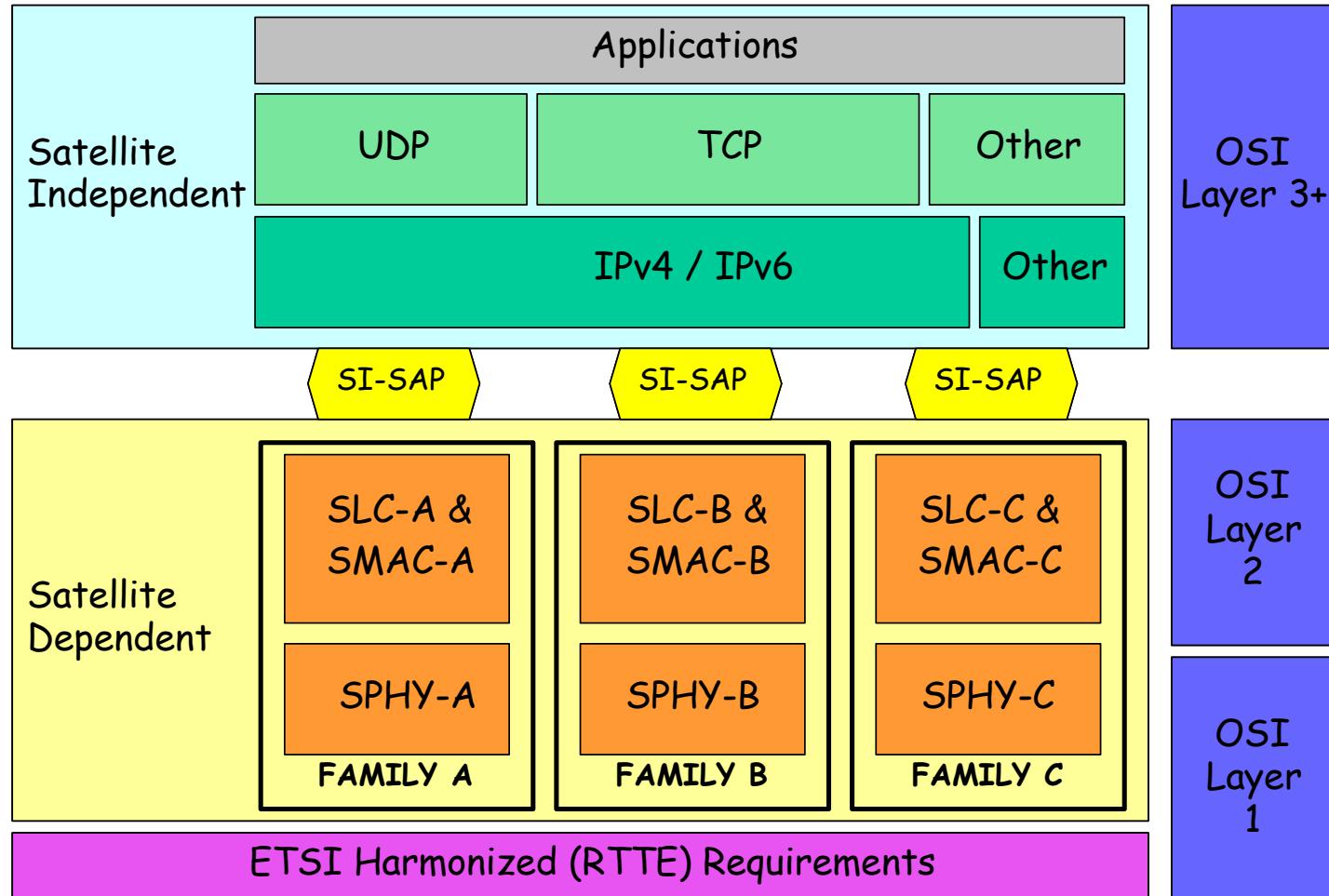


# Reference model for satellite access



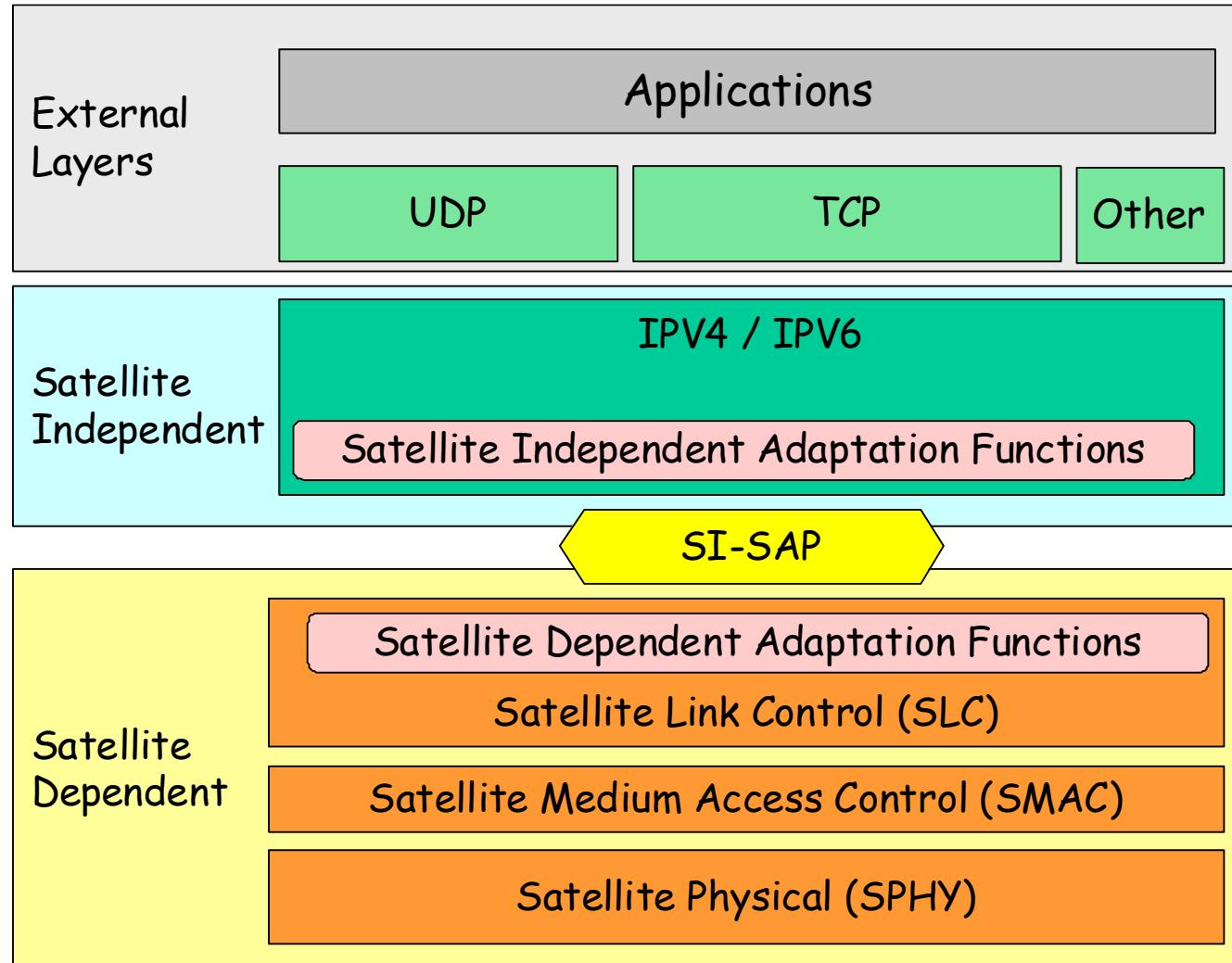


# Protocol architecture





# Protocol architecture





# IP interworking

