Mobile Networks Introduction

Daniel Corujo, dcorujo@ua.pt
Francisco Fontes, fontes@ua.pt
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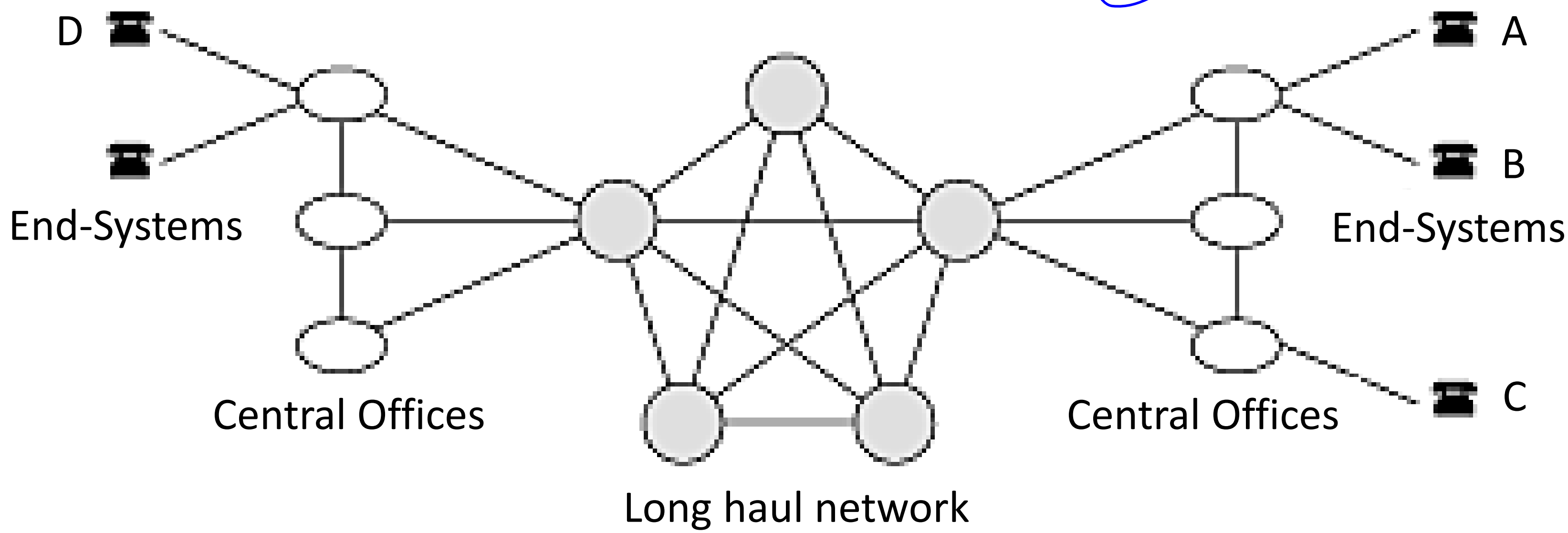
Trends in communications

- 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

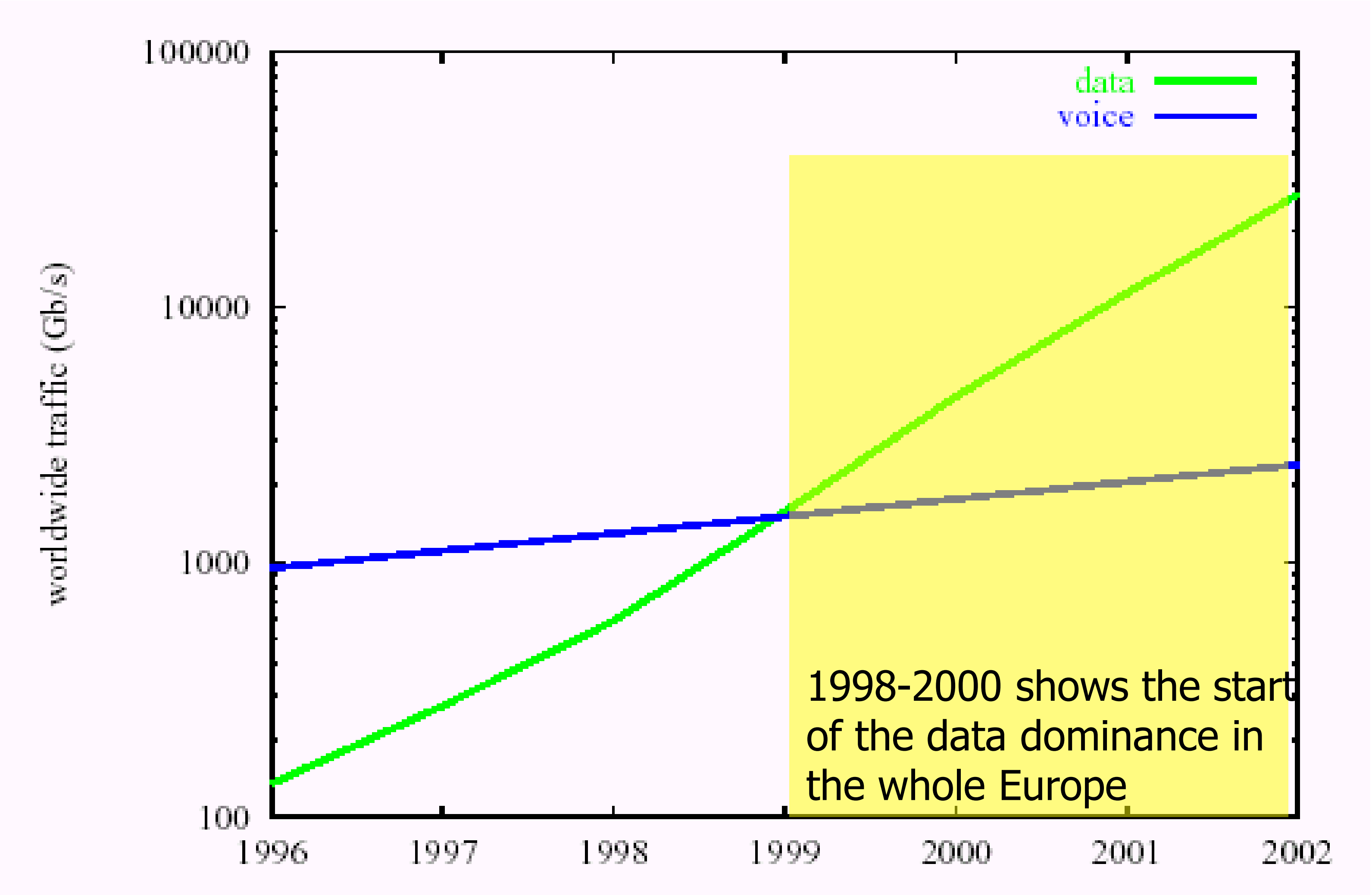
Before mobile Communications, there where Fixed Communications

Telephone System



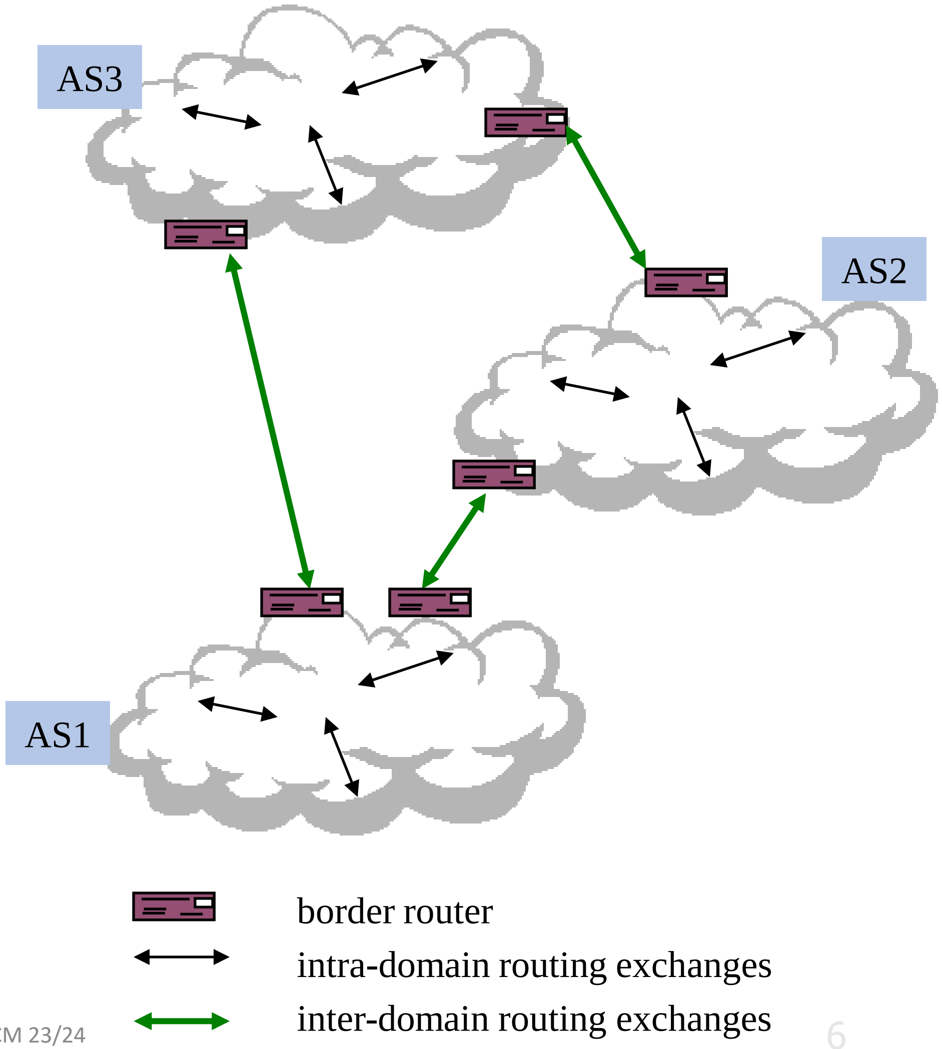
- Uses switched circuits (virtuals...)
- Access via low bandwidth circuits
- “out-of-band” call establishment using signaling system based in packets (SS7)
- Channels between switching exchanges carry multiple calls
  - Multiplexing (analogue or digital)

Evolution: Voice vs Data



Internet structure

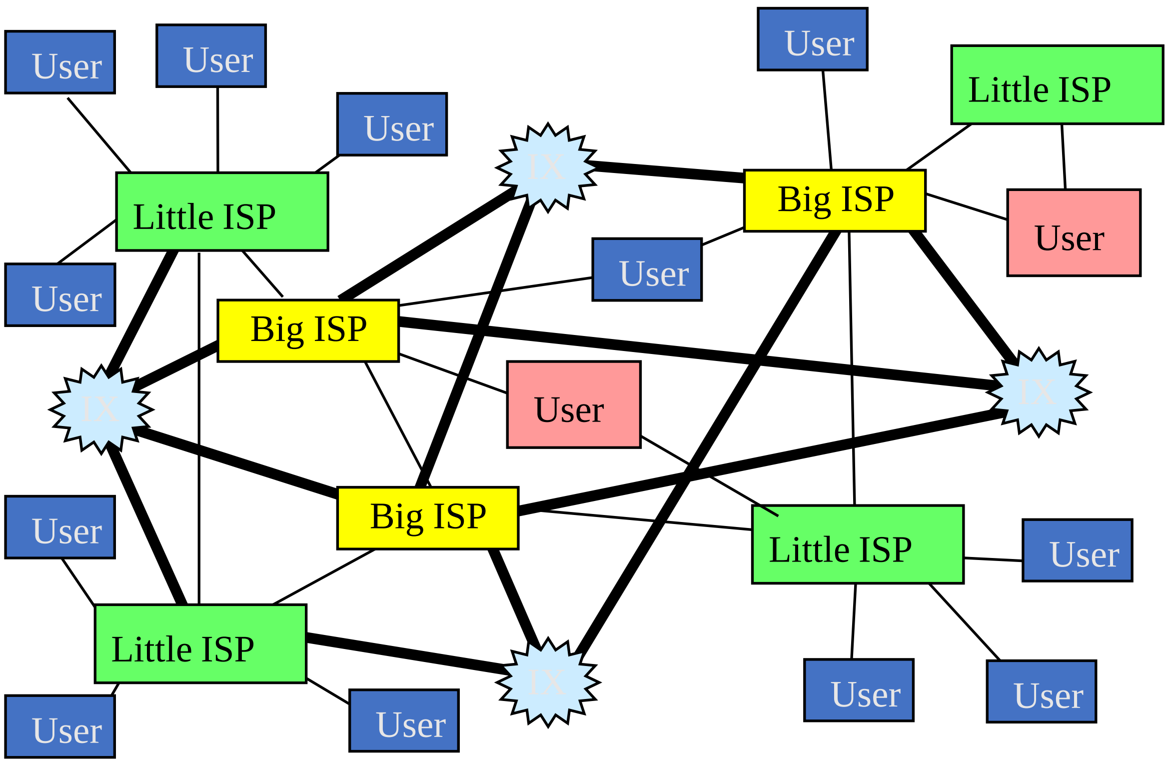
- Administrative borders define
  - Autonomous Systems (AS)
    - **Intra-domain routing**
    - Individual internal policies
    - May use different metrics between domains
    - protocols: RIPv2, OSPFv2
  - AS interconnections
    - **Inter-domain routing**
    - Connectivity information
    - protocols: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

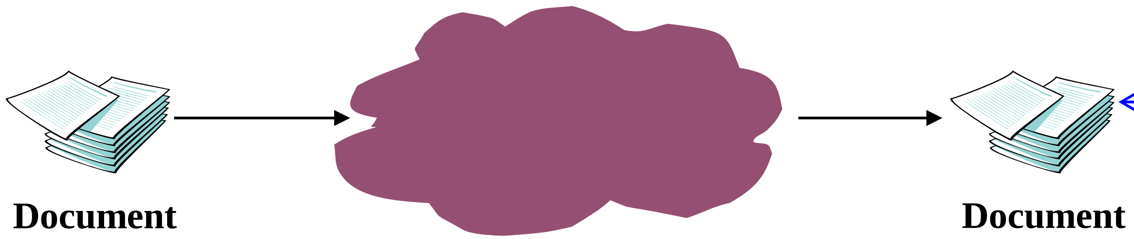
Packet switching solves everything?

- 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.

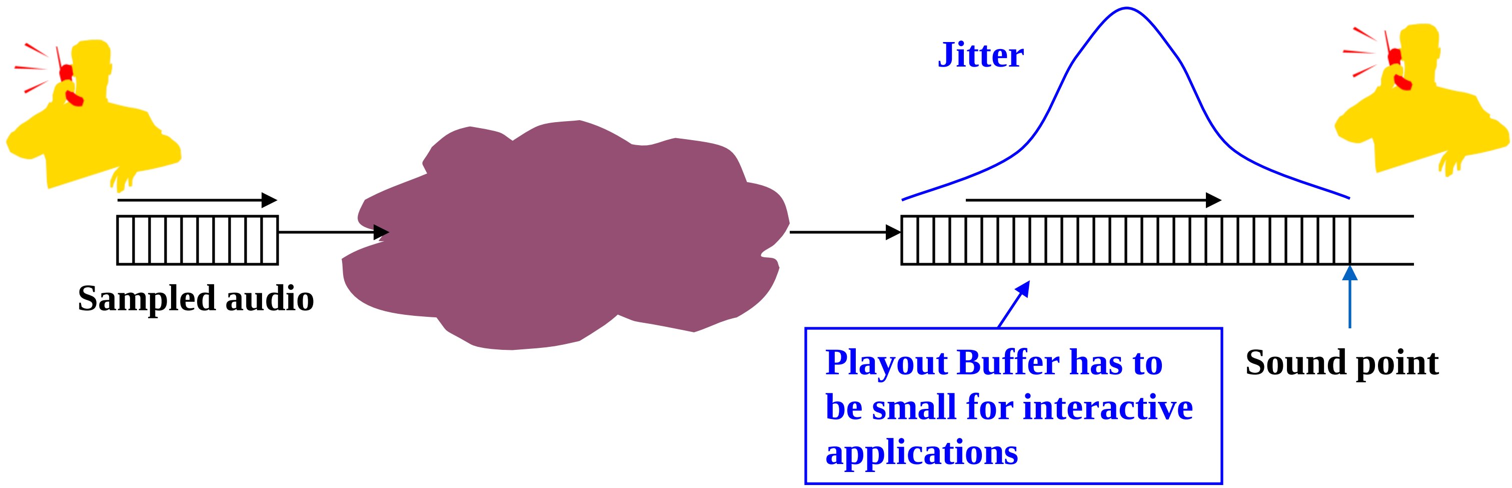
Elastic operations (Performance): All traffic has not the same requirements



The document is only useful when it is completely received. This means that what is important is the average delay, and not the instant delay

- 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)

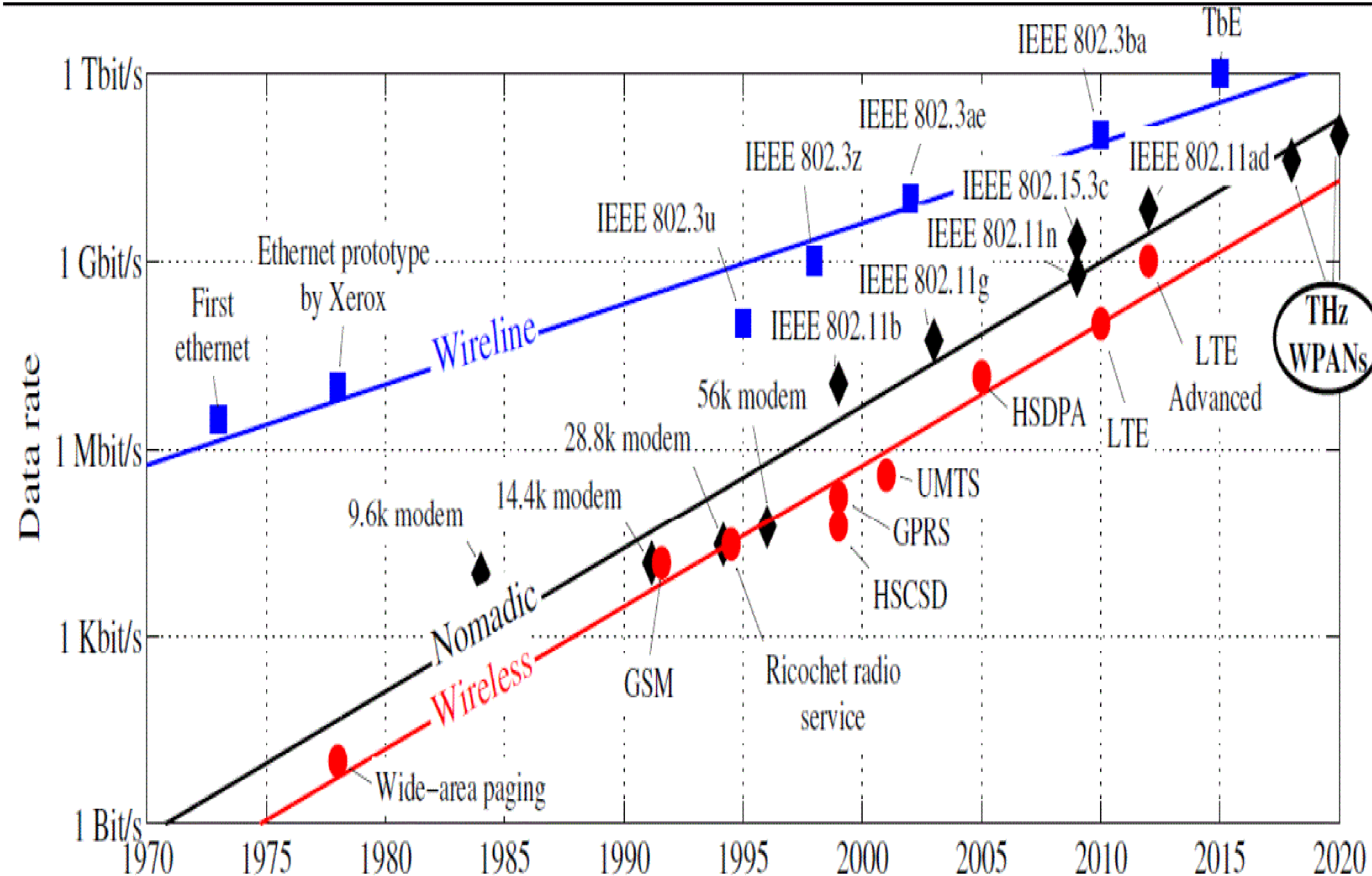
Application requirements

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

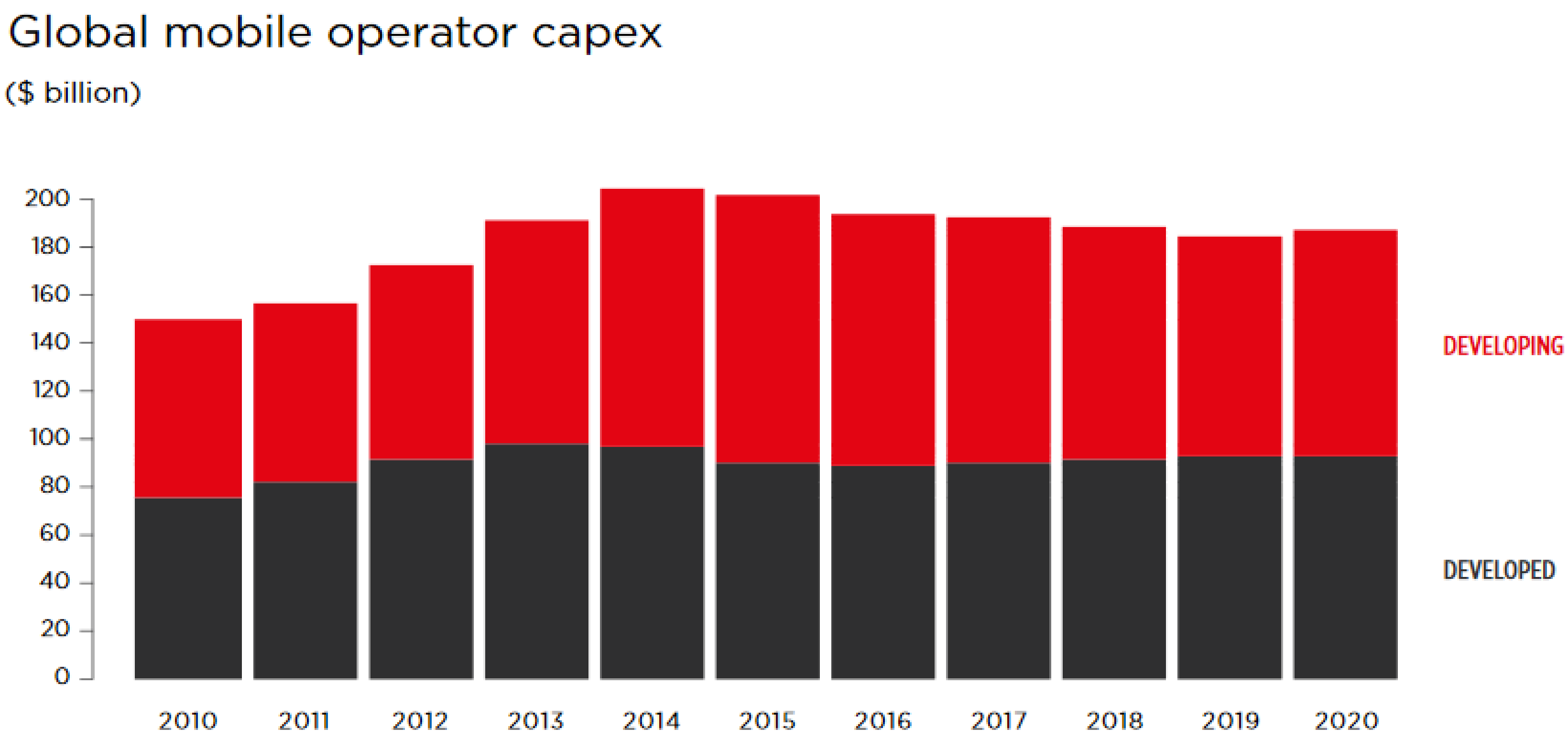
Economical and societal motivations

Edholm’s Law

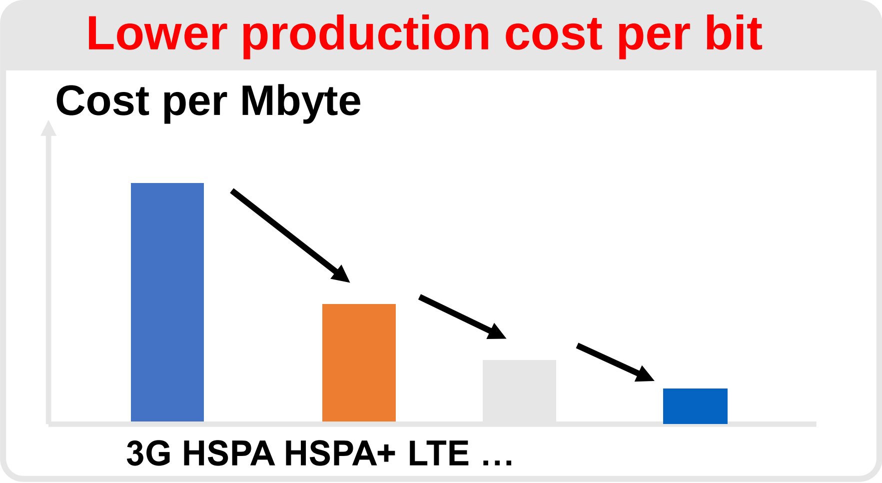


Data rate
1 Tbit/s
1 Gbit/s
1 Mbit/s
1 Kbit/s
1 Bit/s
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Wireline
Nomadic
Wireless
First ethernet
Ethernet prototype by Xerox
IEEE 802.3u
IEEE 802.3z
IEEE 802.3ae
IEEE 802.3ba
TbE
IEEE 802.15.3c
IEEE 802.11ad
IEEE 802.11n
IEEE 802.11g
IEEE 802.11b
56k modem
28.8k modem
14.4k modem
9.6k modem
THz WPANs
LTE Advanced
LTE
HSDPA
UMTS
GPRS
HSCSD
GSM
Ricochet radio service
Wide–area paging

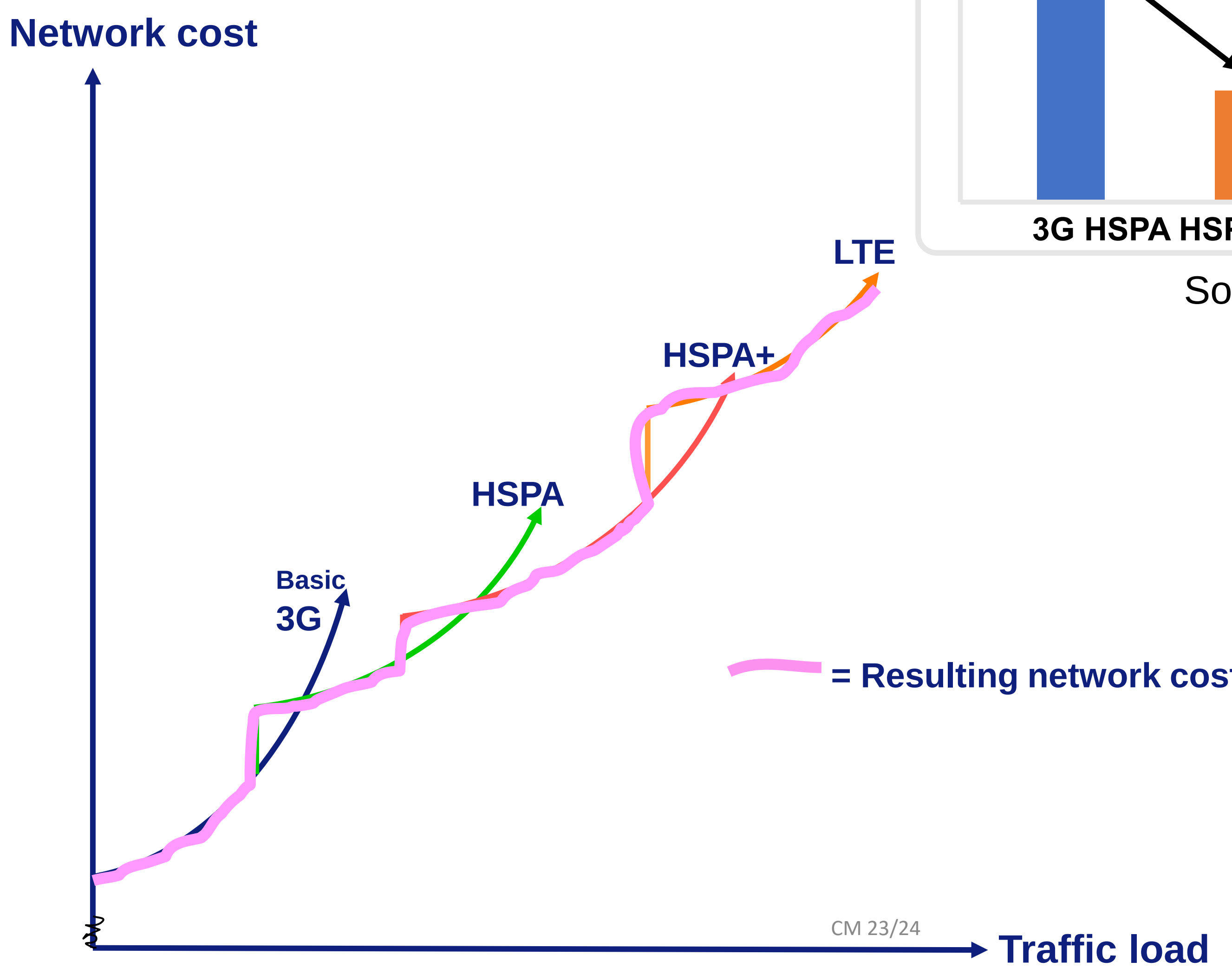
Cost of investment in telecom



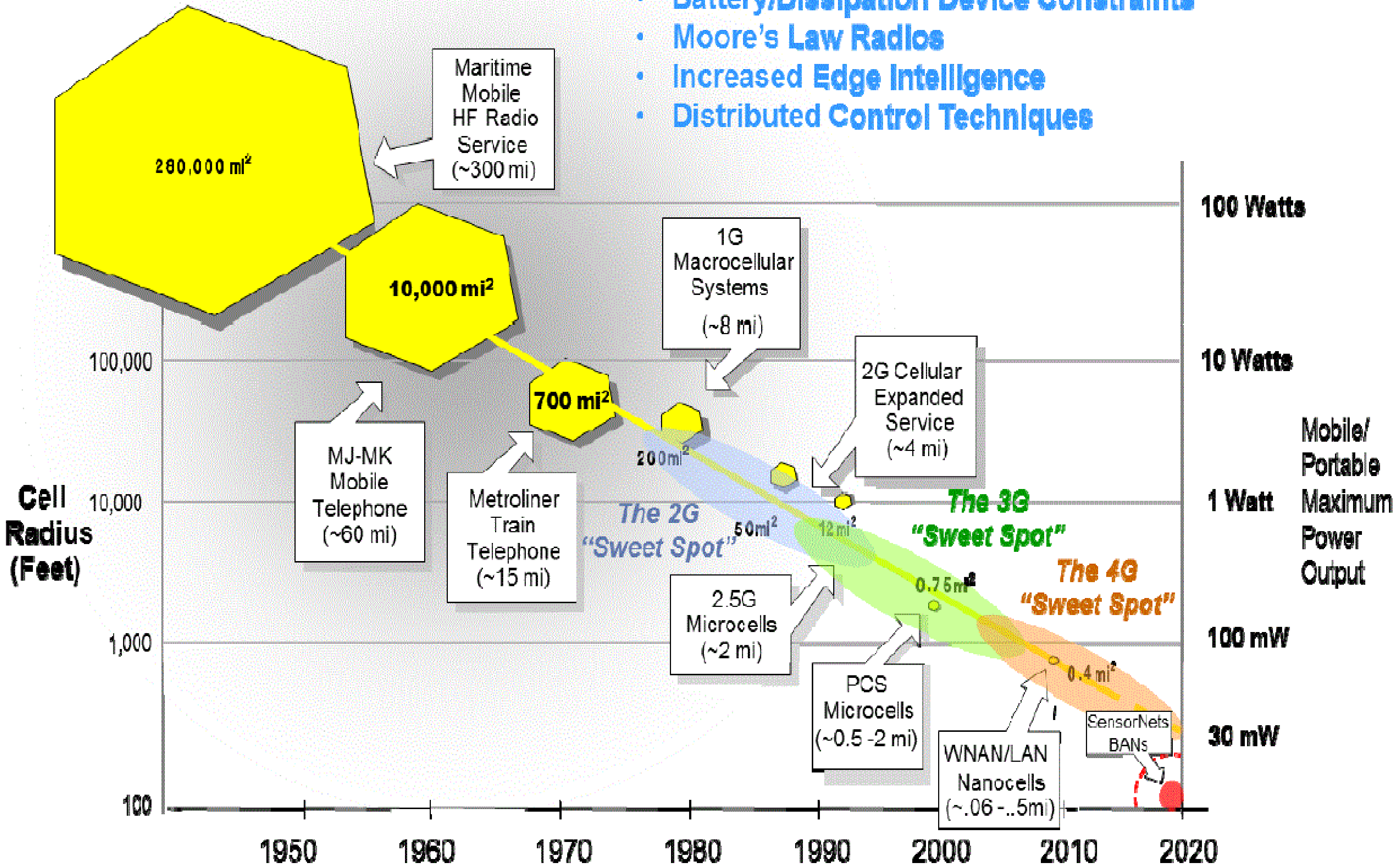
Motivations for technologies



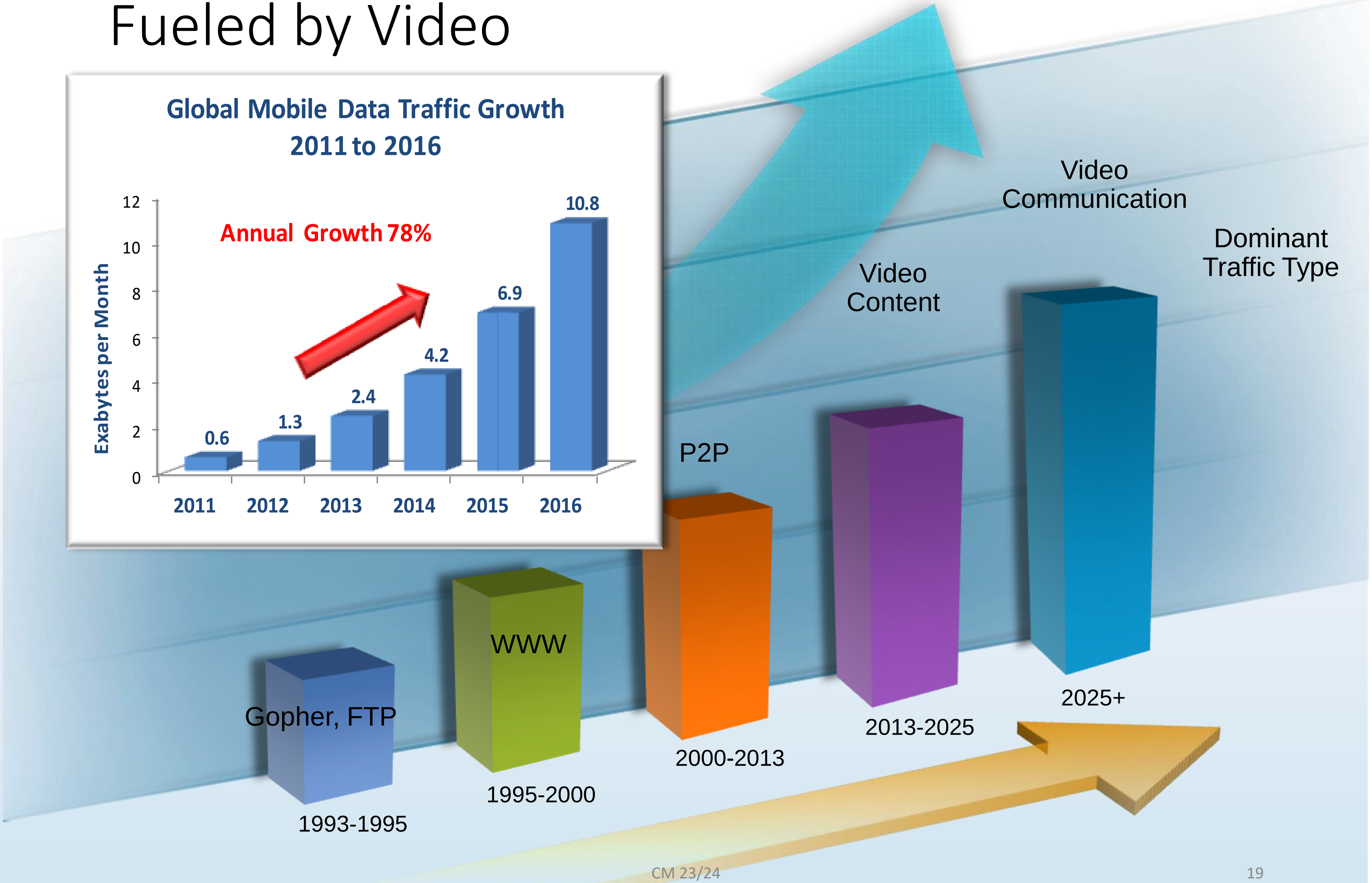
Source: NSN



- Increased Bandwidth Demand/User
- Battery/Dissipation Device Constraints
- Moore's Law Radios
- Increased Edge Intelligence
- Distributed Control Techniques



Dramatic Traffic Growth Fueled by Video



Source: Cisco Global IP Traffic Forecast, 2007

The things that surrond us

Source: EC

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

Context

Security

Identity

Authentication

Services

Mobility

Quality of Experience

Charging

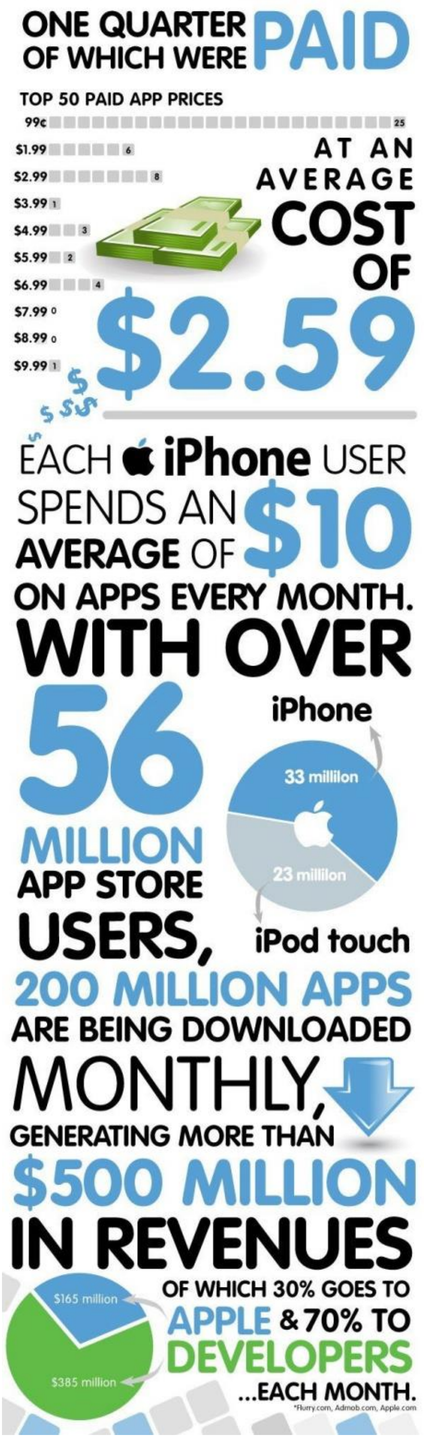
Accounting

… and many others …

The market turned to SERVICES (+/- 2016)

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

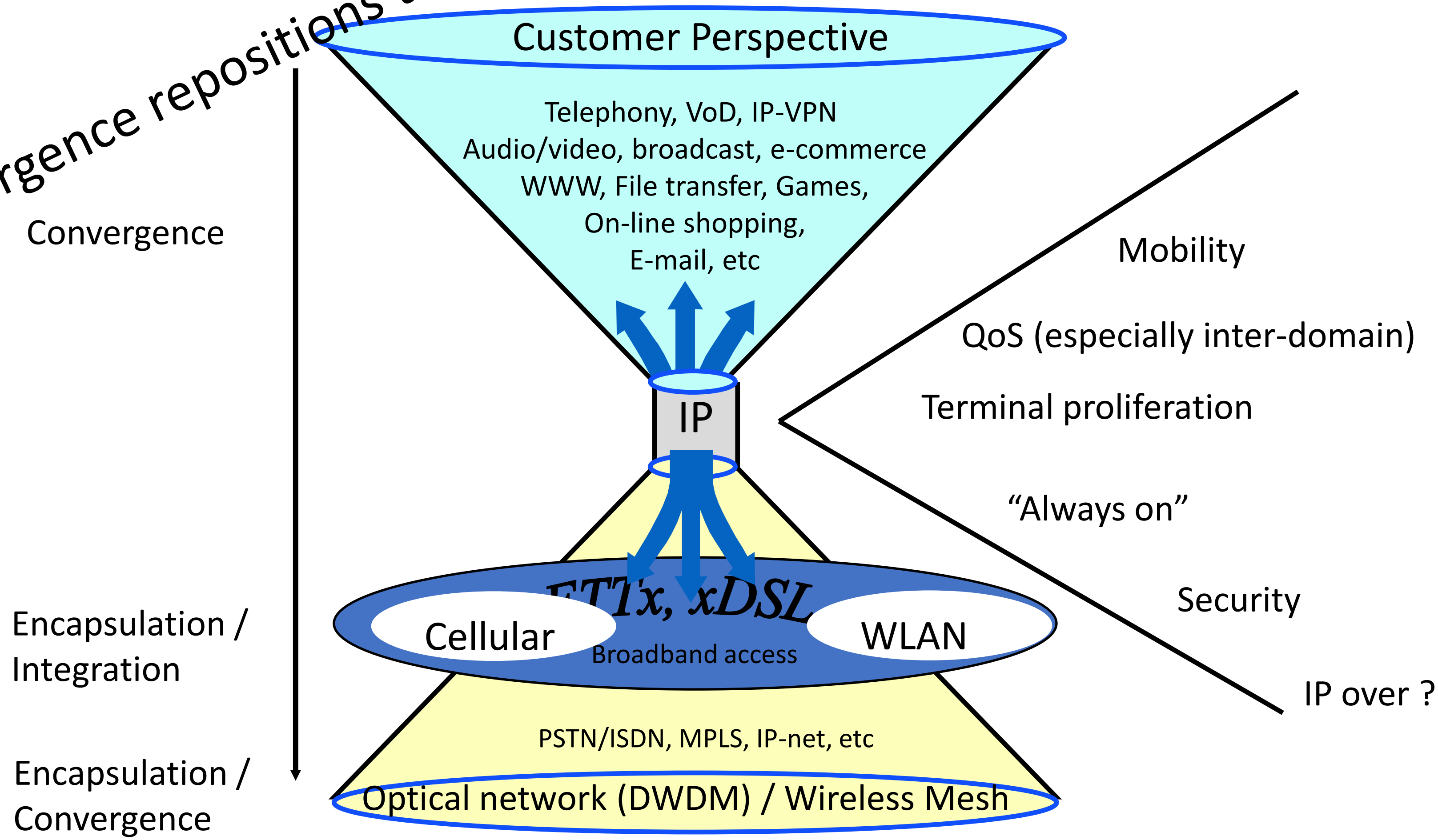
Source: GigaOM



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**

IP convergence repositions the whole ecossystem!



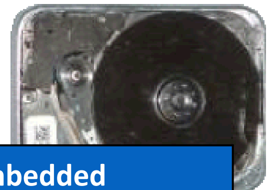
Source: Siemens

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

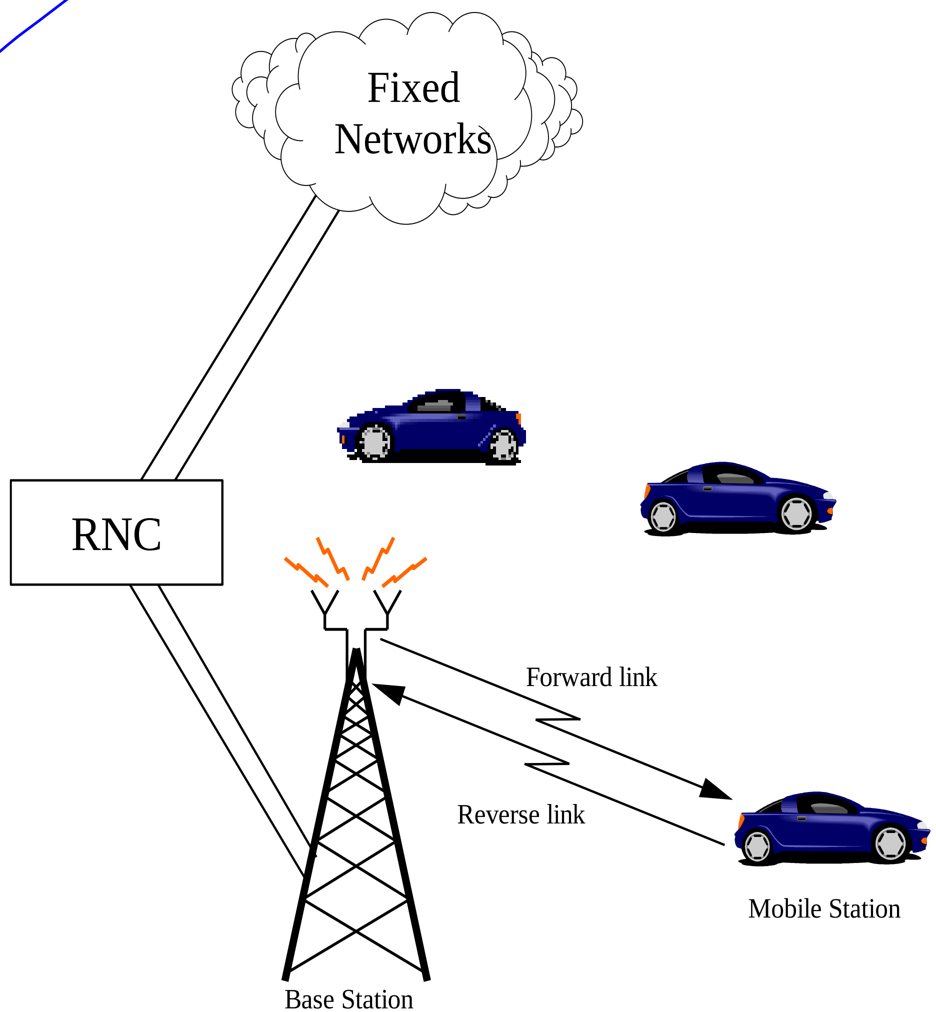
The Mobile Network

Generic technical aspects and challenges

Wireless Systems

CM 23/24

- Mobiles 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!

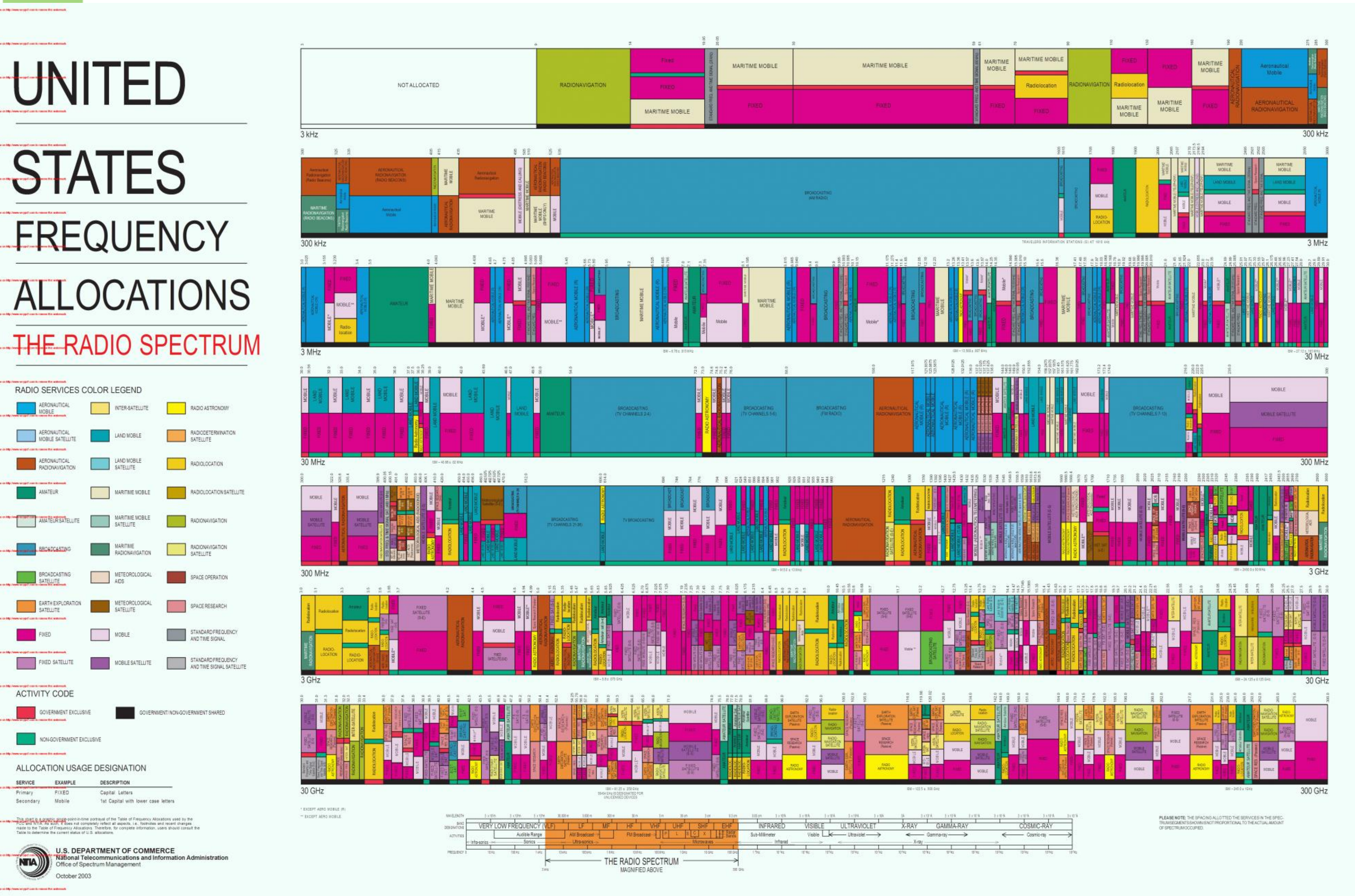
- Addressing
  - Total number of IPv4 addresses is ~4 200 millions
- Routing
  - Routing tables are already quite large
- Security
  - Securing everything? With certificates?
- Multimedia bandwidths
  - In wireless?!?
- Sensors and actuators
  - Electric grid on the net?!?!

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
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
THE RADIO SPECTRUM

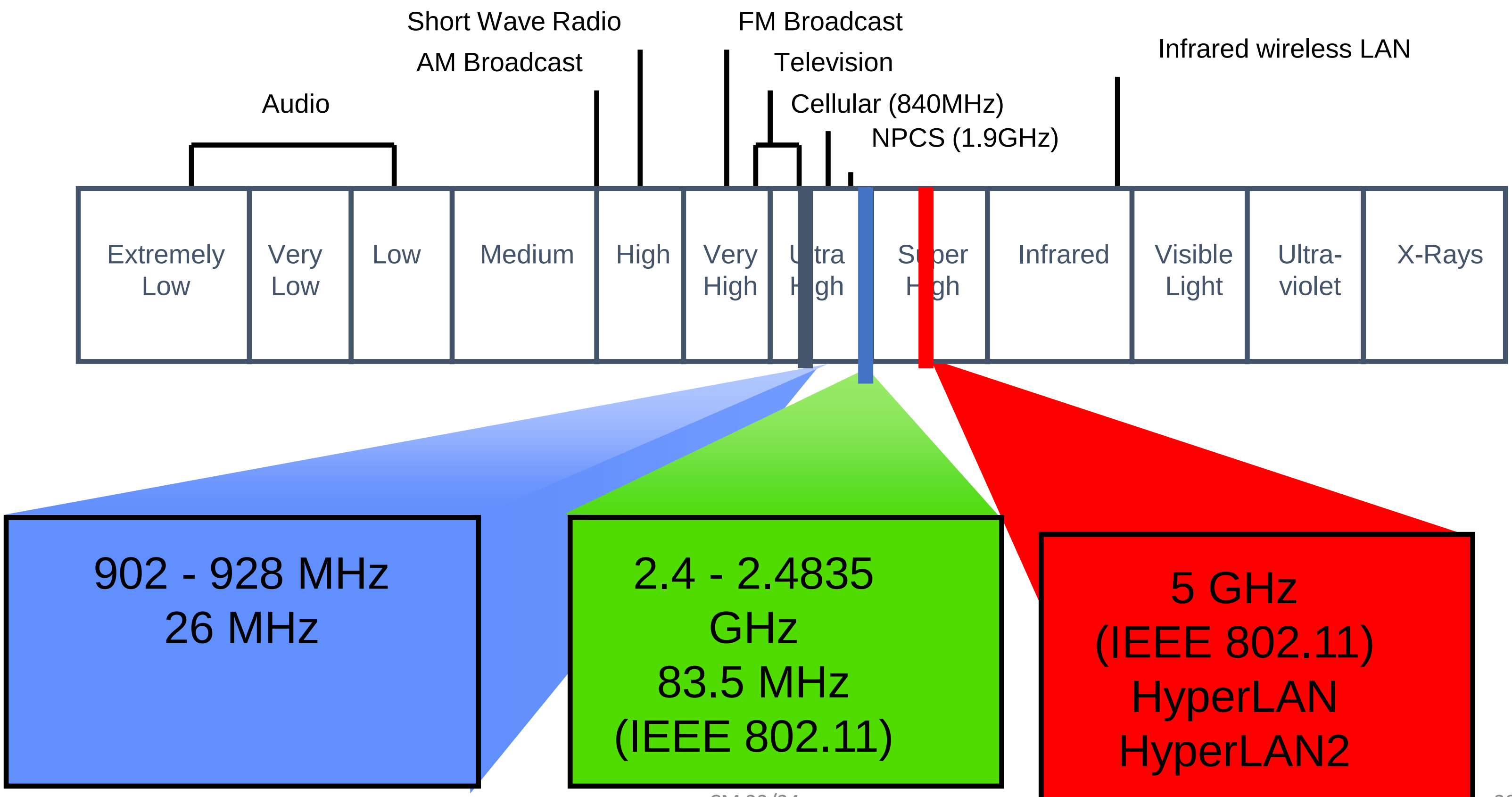
Source: FCC

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, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

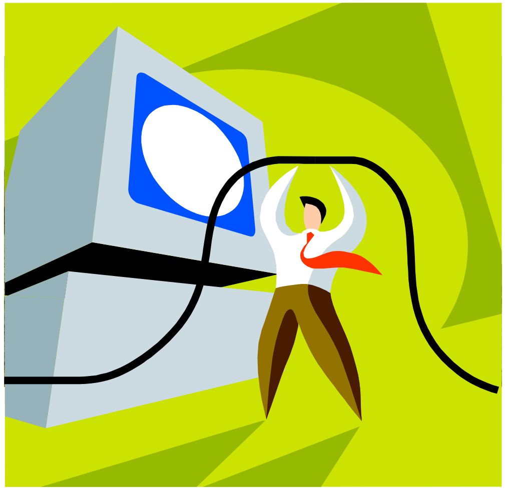
Frequency Bands

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



Physical Layer

Problems we face



Classifications of Transmission Media

- 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, ..

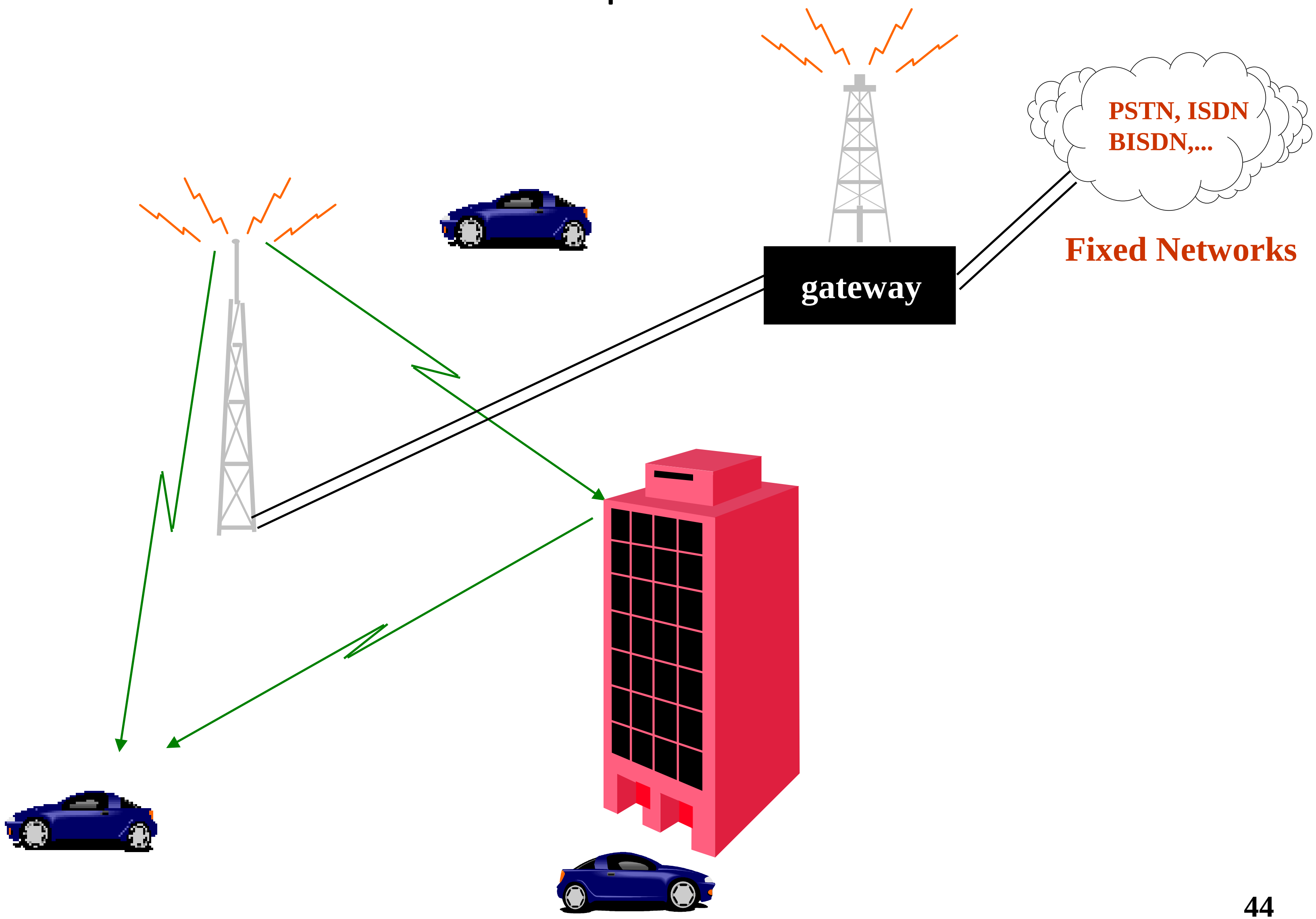
What is Hard about Wireless?

There are no wires!

Causes problems in many areas:

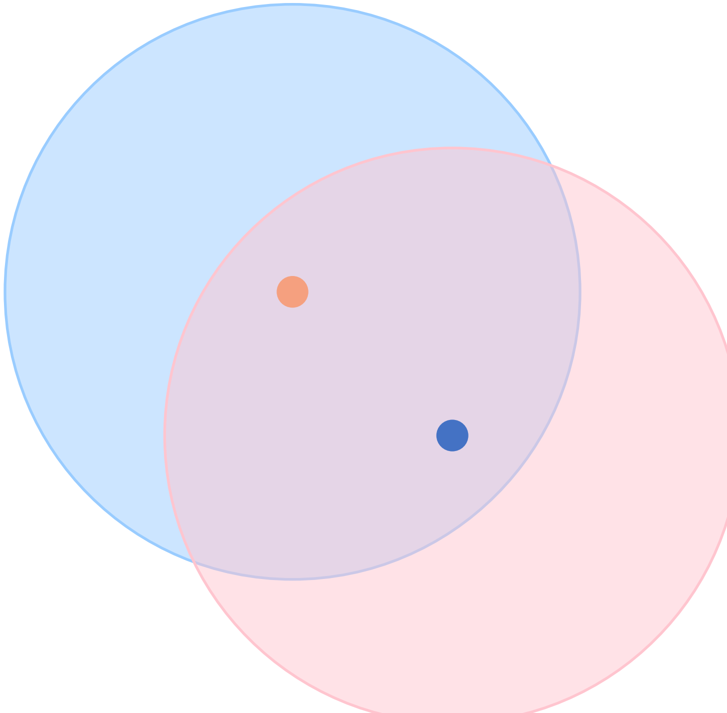
- Quality of transmission
- Interference and noise
- Capacity of the network
- Effects of mobility

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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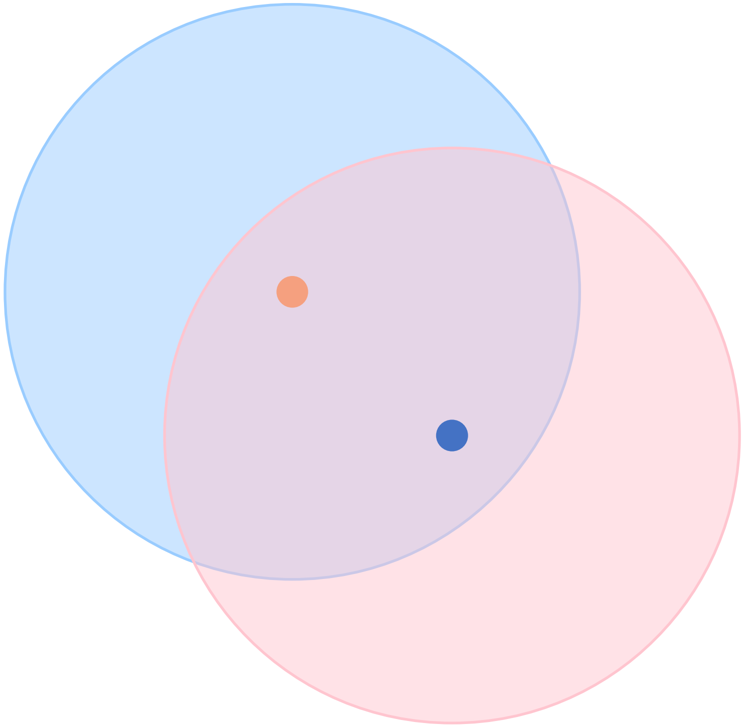
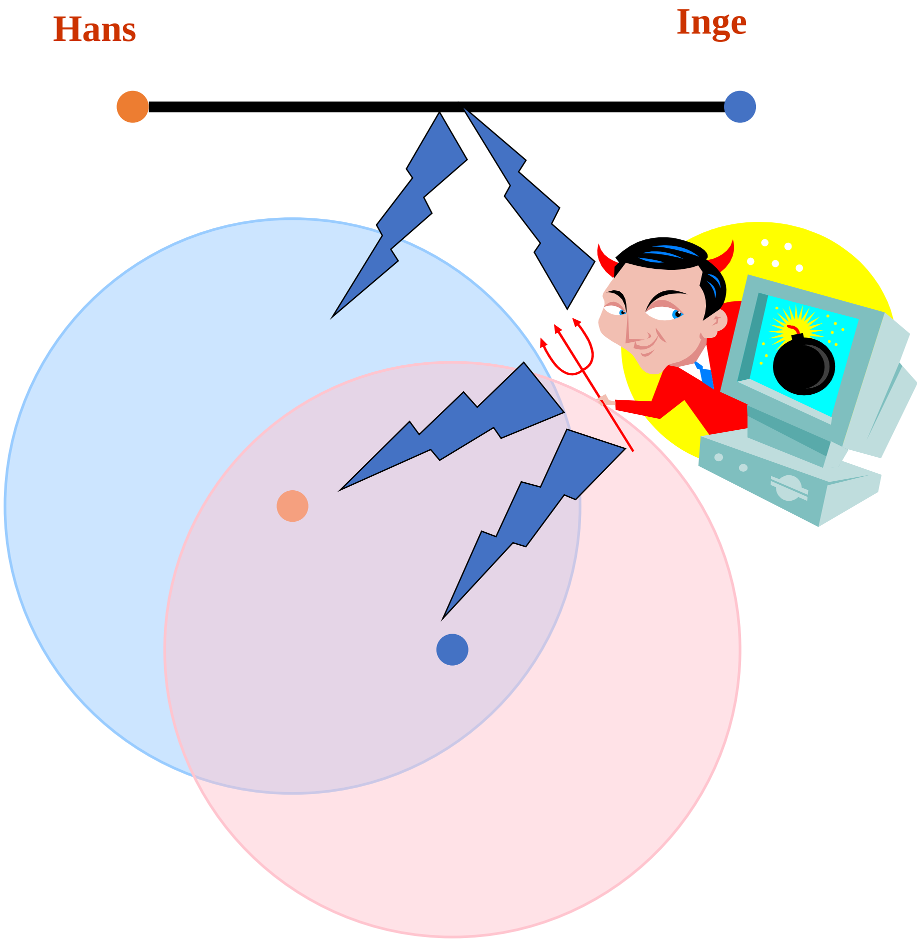


Wireless is very Sensitive to Noise …

- 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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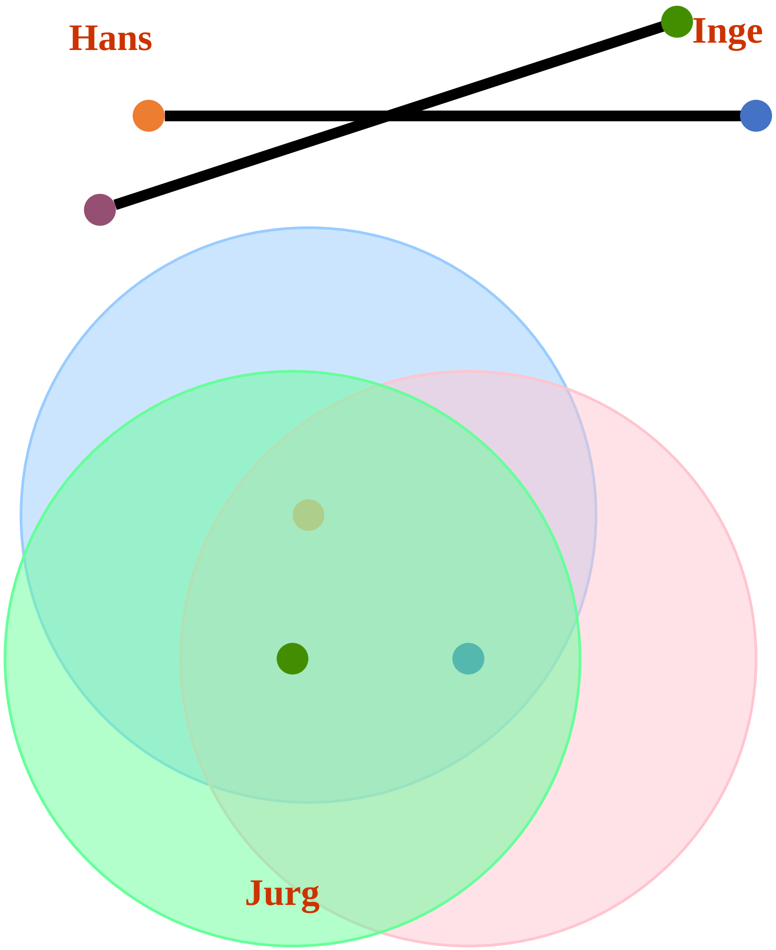
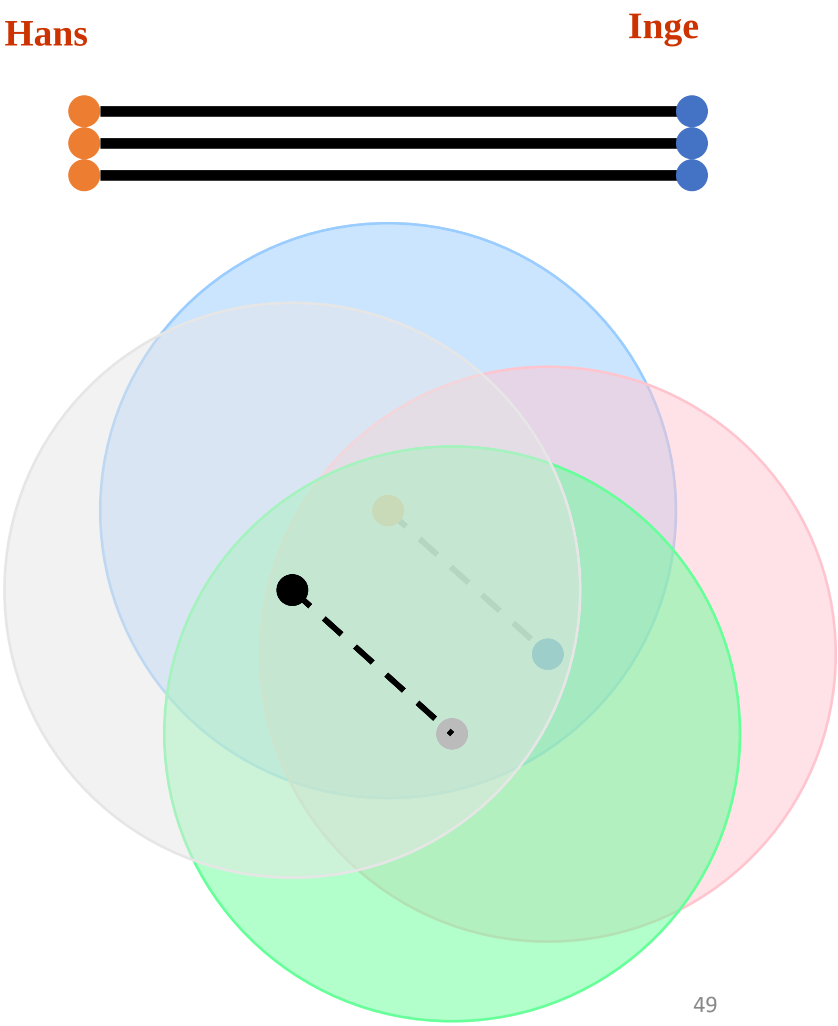


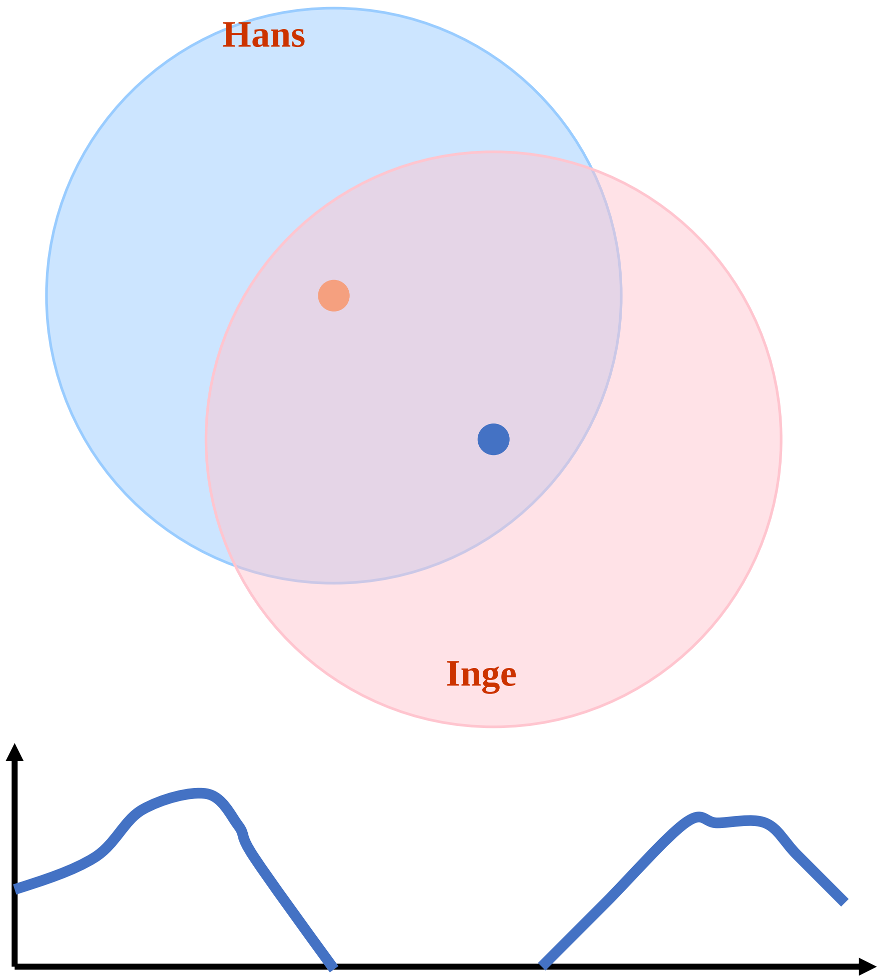
How Do We Increase Network Capacity?

- 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.



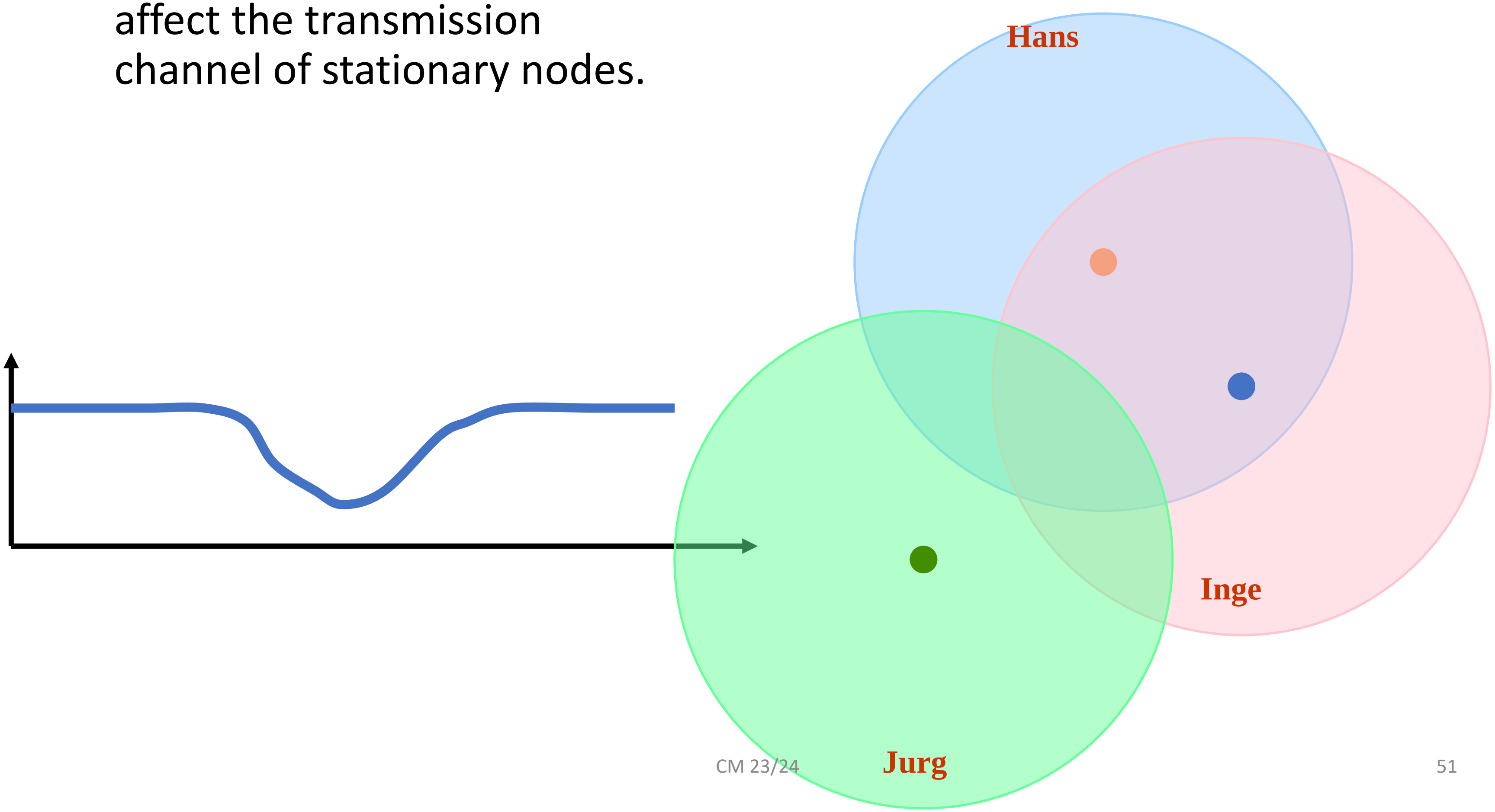
Mobility Affects the Link Throughput

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



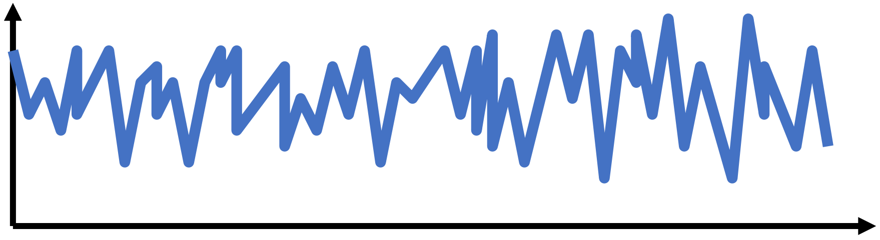
Mobility is an Issue even for Stationary Users

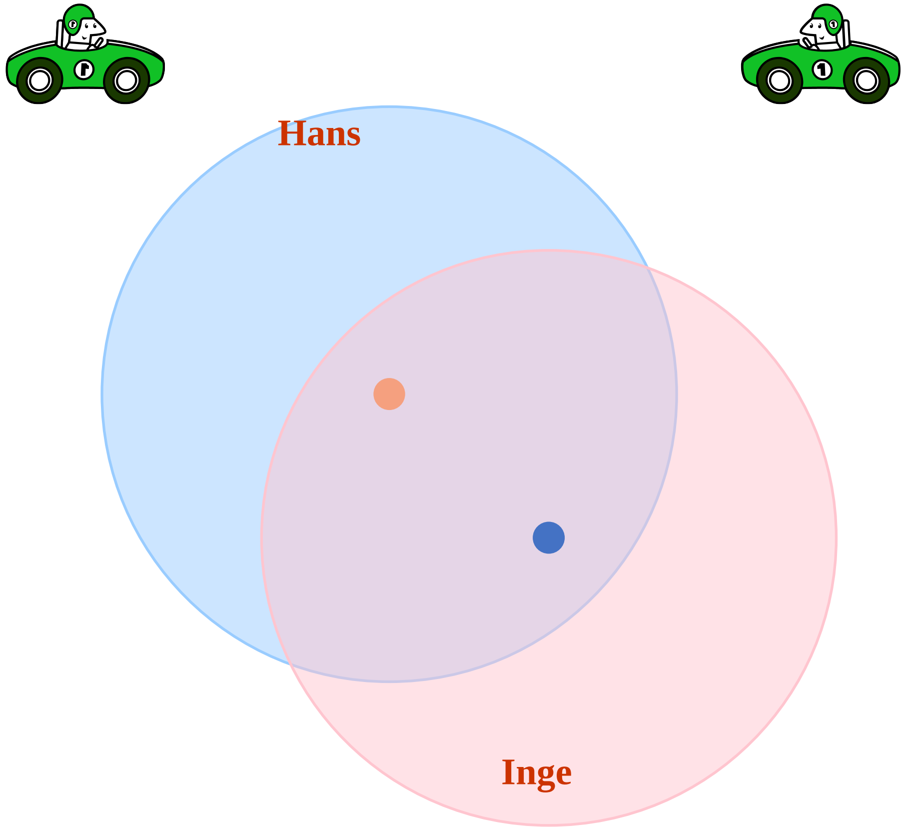
- Mobile people and devices affect the transmission channel of stationary nodes.



And It Gets Worse …

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

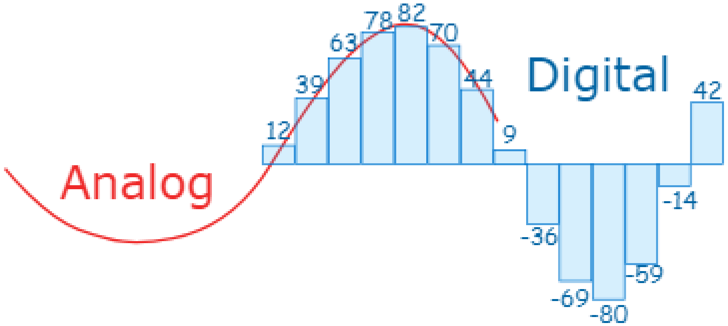




The Mobile Network

Basic principles of wireless signal properties

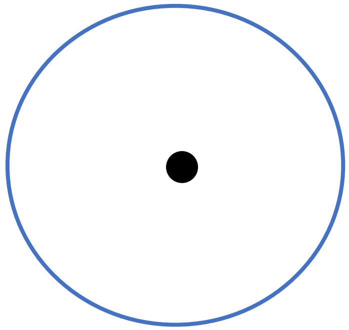
Time-Domain View

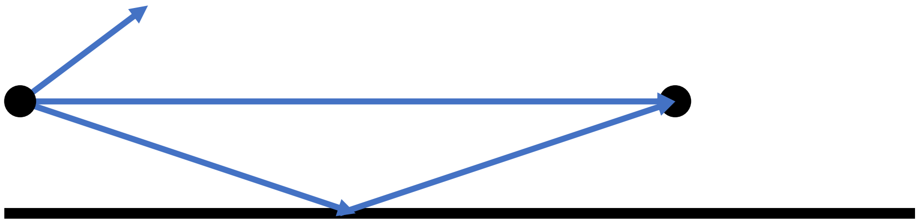


- Can be used to represent both an analog and a digital signal.
- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
  - E.g. voice signal traveling over traditional phone line
- Digital signal - signal intensity maintains a constant level 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

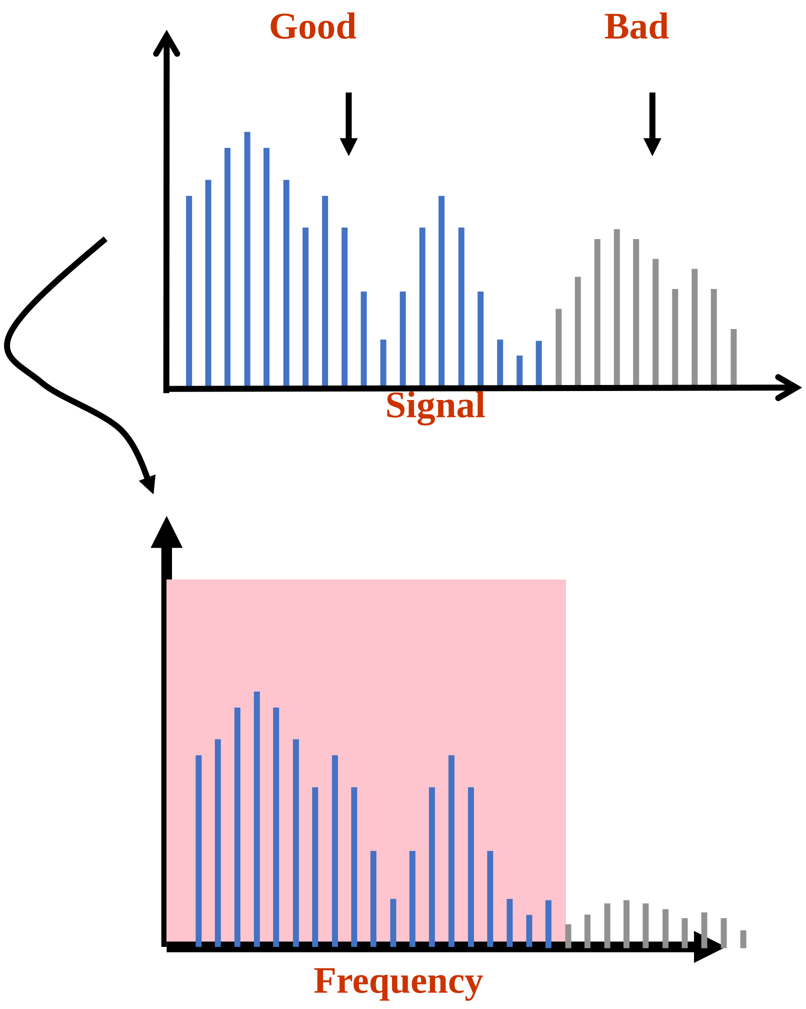
- Both are real in some way
- Think of it as energy that radiates from an antenna and is picked up by another antenna.
  - Helps explain properties such as attenuation
- Can also view it as a "ray" that propagates between two points.
  - Helps explain properties such as reflection and multipath





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

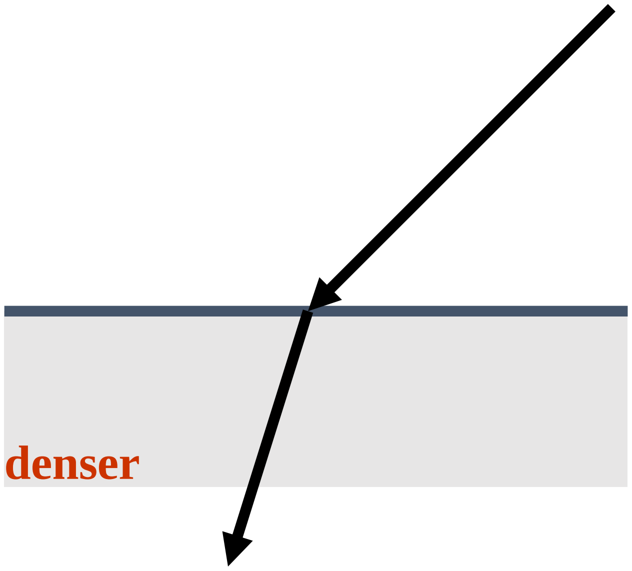
- Line-of-sight (LOS) propagation.
  - Most common form of propagation
  - Happens above ~ 30 MHz
  - Subject to many forms of degradation (next set of slides)
- Ground-wave propagation.
  - More or less follows the contour of the earth
  - For frequencies up to about 2 MHz, e.g. AM radio
- Sky wave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

Propagation Degrades RF Signals

- 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

- Speed of EM signals depends on the density of the material
  - Vacuum: 3×10^8 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

- 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

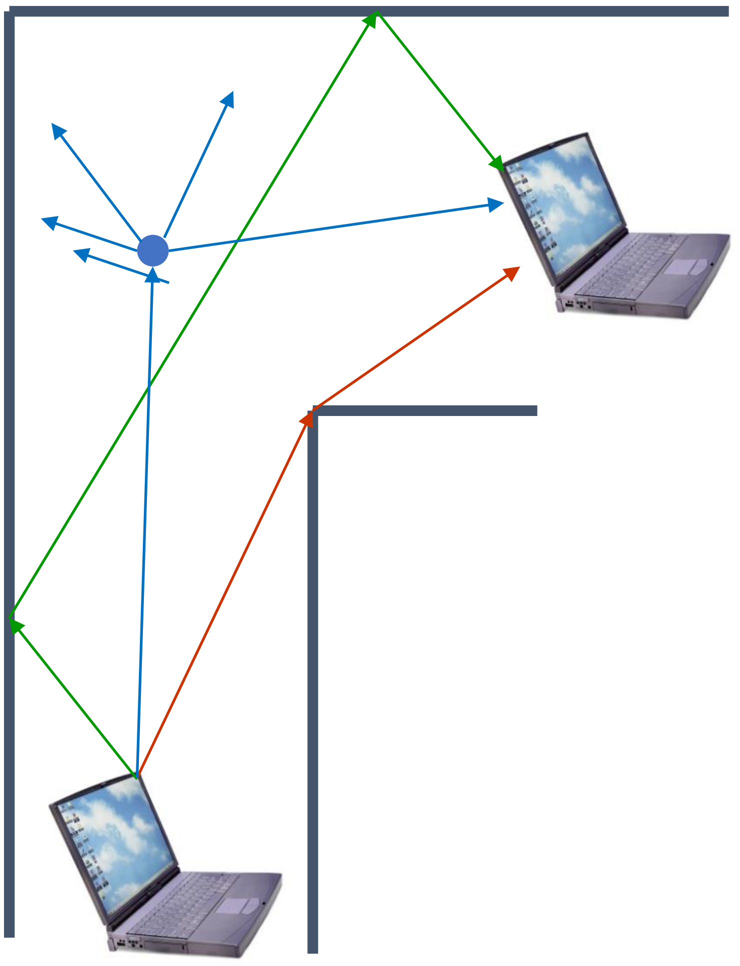
Fairly Predictable
➢Can be planned for or avoided

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

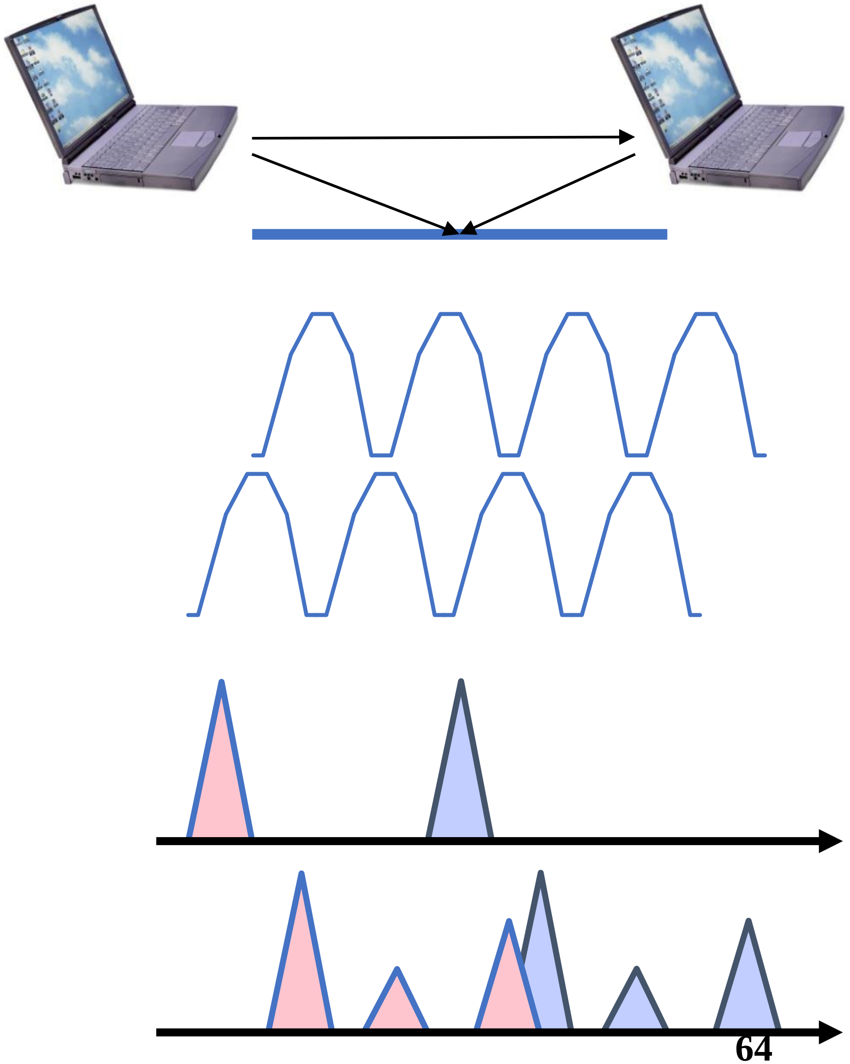
Propagation Mechanisms

- 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

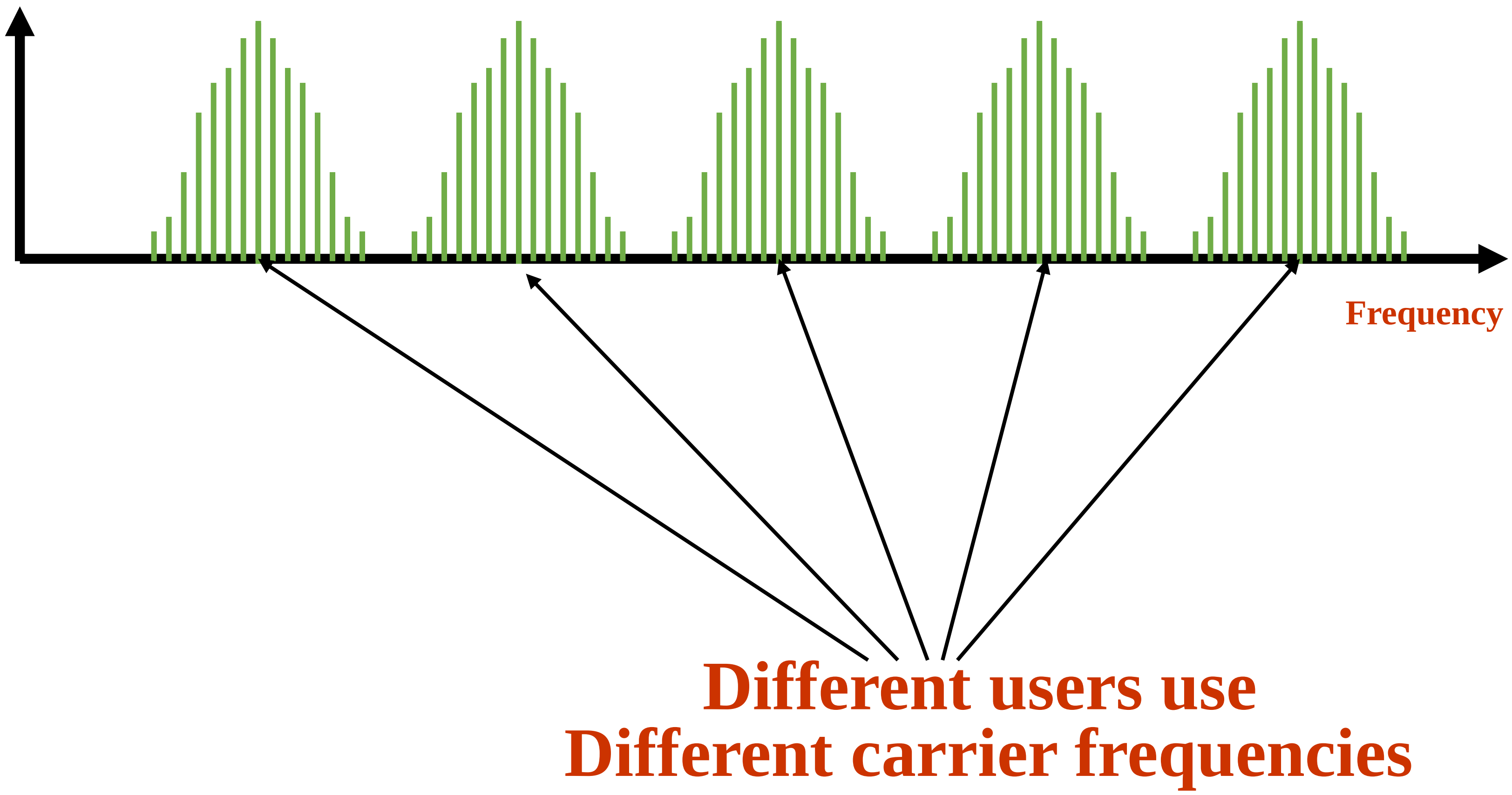
- Receiver receives multiple copies of the signal, each following a different path.
- Copies can either strengthen or weaken each other.
- Small changes in location can result in big changes in signal strength.
- Difference in path length can cause intersymbol interference (ISI).



Introducing Redundancy

- 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

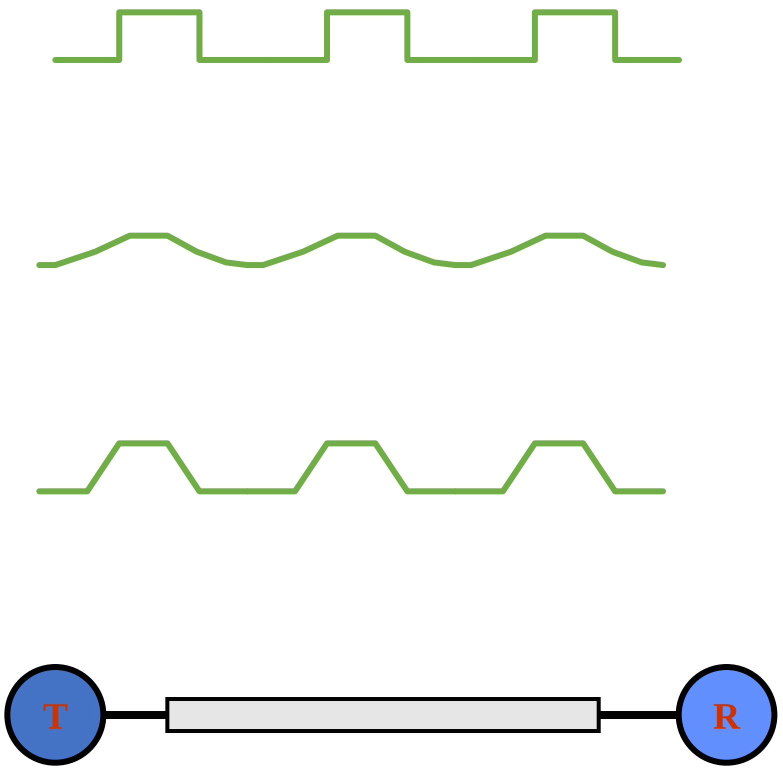
Multiple Users Can Share the Spectrum



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

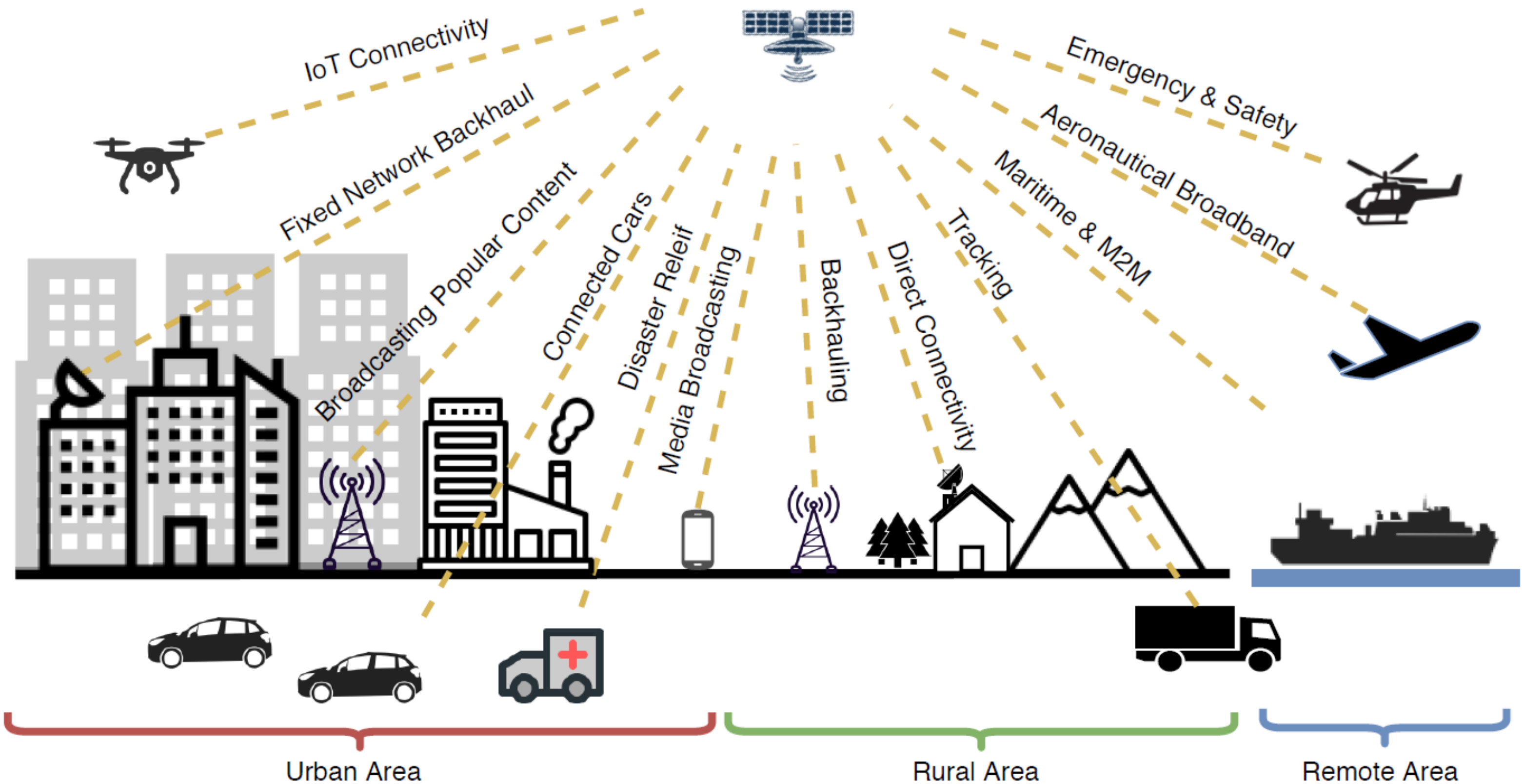
- Spread transmission over a wider bandwidth
  - Don’t put all your eggs in one basket!
- Good for military: jamming and interception becomes harder
- Also useful to minimize impact of a “bad” frequency in regular environments
- What can be gained from this apparent waste of spectrum?
  - Immunity from 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

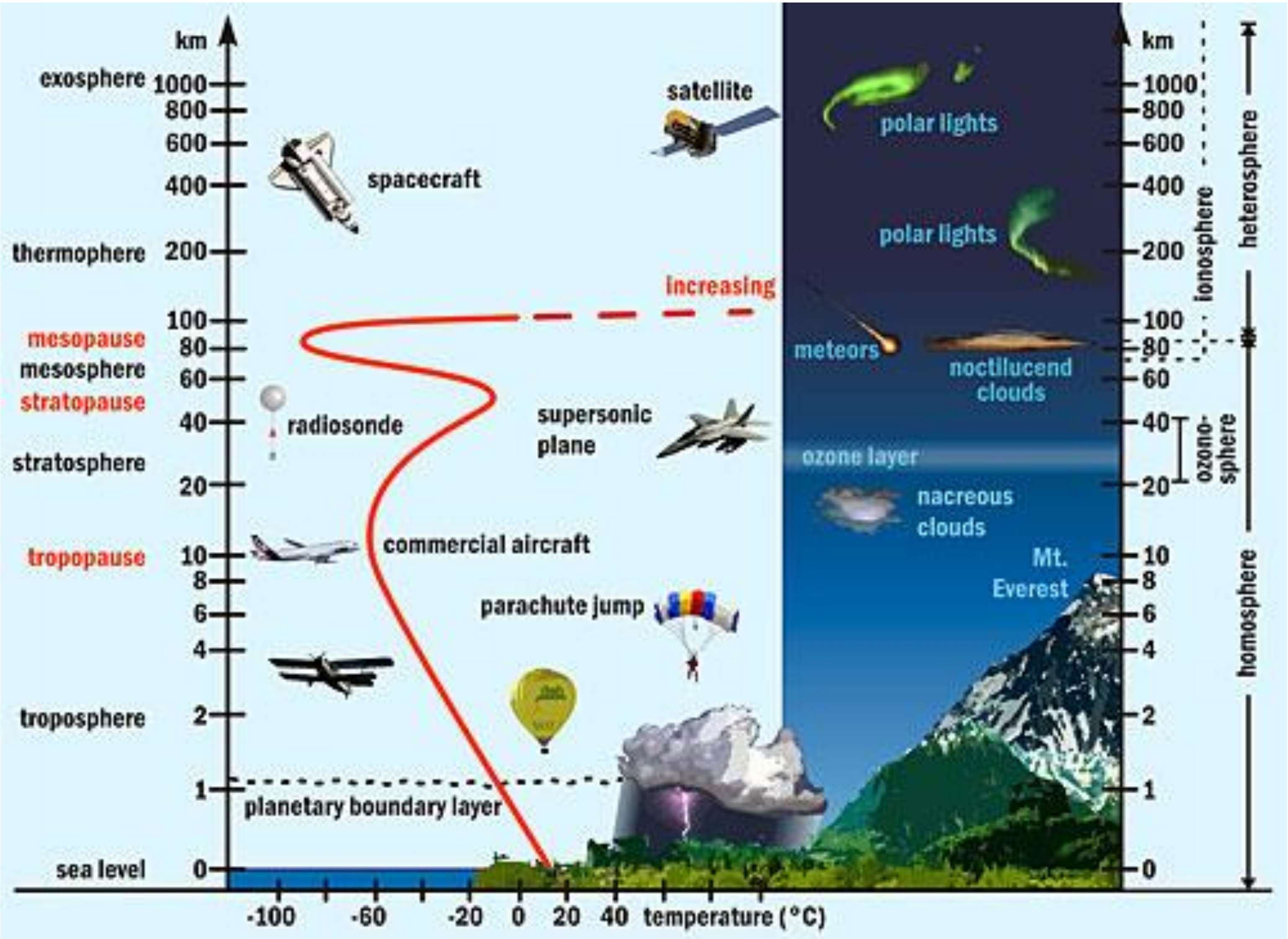
Satellite networks

SATELLITES



IoT Connectivity
Fixed Network Backhaul
Broadcasting Popular Content
Connected Cars
Disaster Releif
Media Broadcasting
Backhauling
Direct Connectivity
Tracking
Maritime & M2M
Aeronautical Broadband
Emergency & Safety
Urban Area
Rural Area
Remote Area

Earth’s atmosphere



Source: All about GPS [www.kowoma.de]

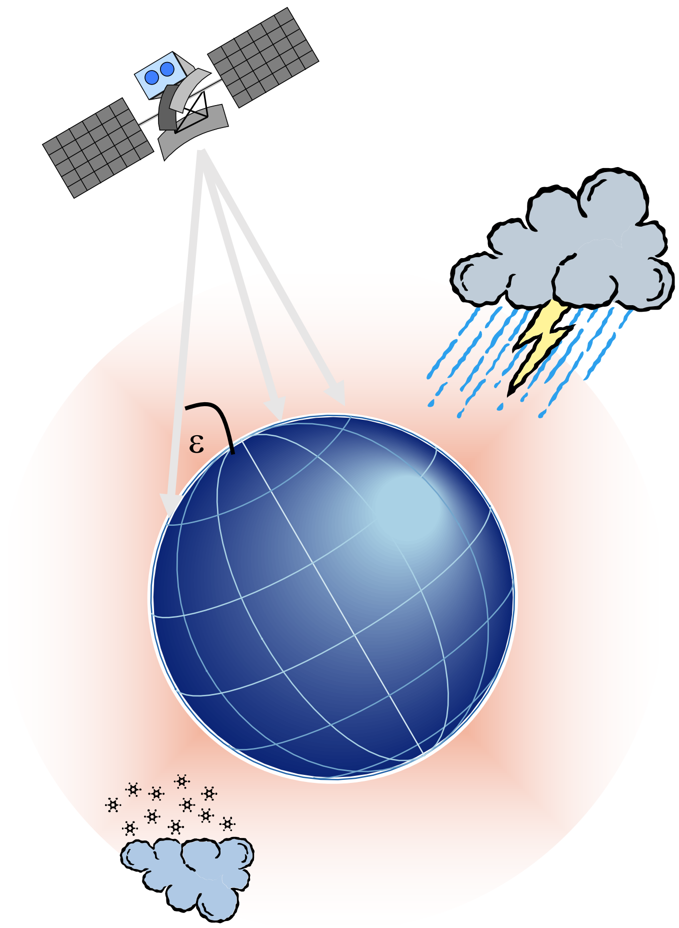
Basics

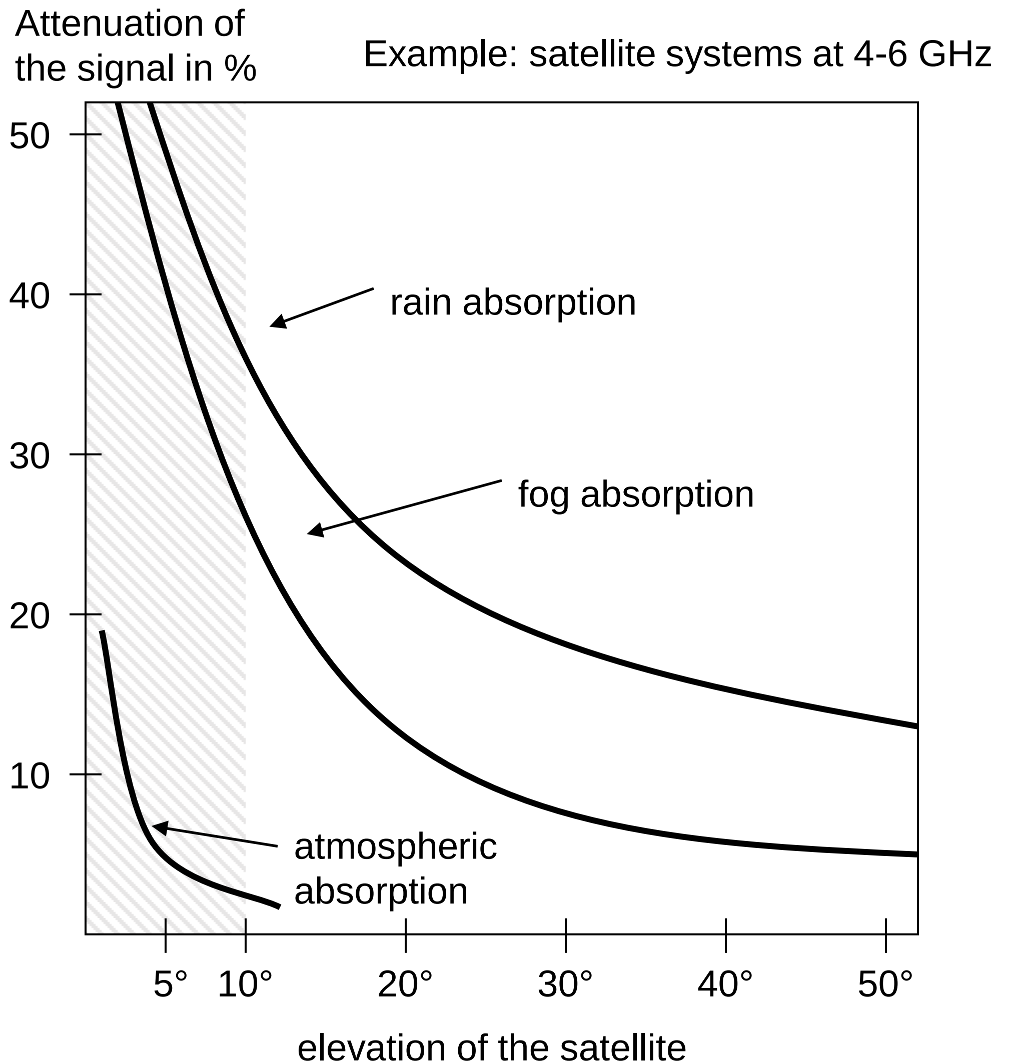
- ❑elliptical or circular orbits
- ❑complete rotation time depends on distance satellite-earth
- ❑inclination: angle between orbit and equator
- ❑elevation: angle between satellite and horizon
- ❑LOS (Line of Sight) to the satellite necessary for connection
  ➔ high elevation needed, less absorption 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

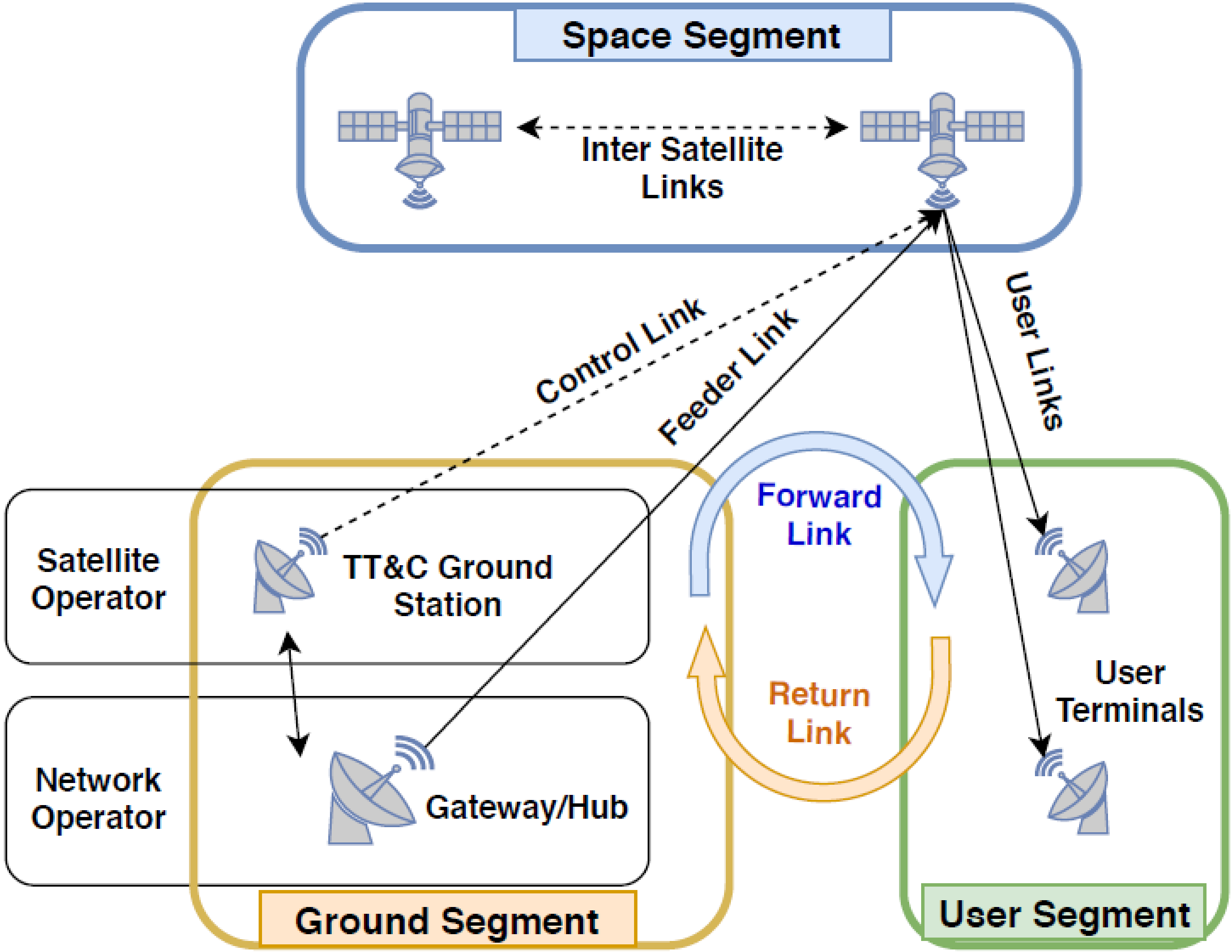
Features of Satellite Networks

- 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






Space Segment
Inter Satellite Links
Control Link
Feeder Link
User Links
Satellite Operator
TT&C Ground Station
Network Operator
Gateway/Hub
Forward Link
Return Link
User Terminals
Ground Segment
User Segment

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:

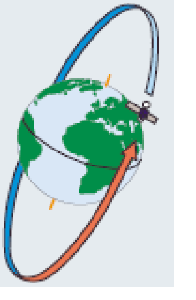
Band	Up-Link (Ghz)	Down-link (Ghz)	ISSUES
C	3,700-4,200 MHz	5,925-6,425 MHz	Interference with ground links.
Ku	11.7-12.2 GHz	14.0-14.5 GHz	Attenuation due to rain
Ka	17.7-21.2 GHz	27.5-31.0 GHz	High Equipment cost

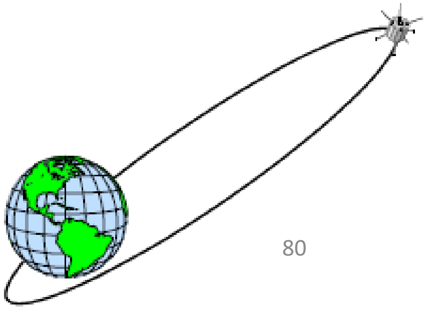
- The up-link is a highly directional, point to point link
- The down-link can have a footprint providing coverage for a substantial area "spot beam“.

Types of Satellite Orbits

- Based on the inclination, “i”, over the equatorial plane:
  - Equatorial Orbits above Earth’s equator (i=0°)
  - Polar Orbits pass over both poles (i=90°)
  - Other orbits called inclined orbits (0°<i<90°)

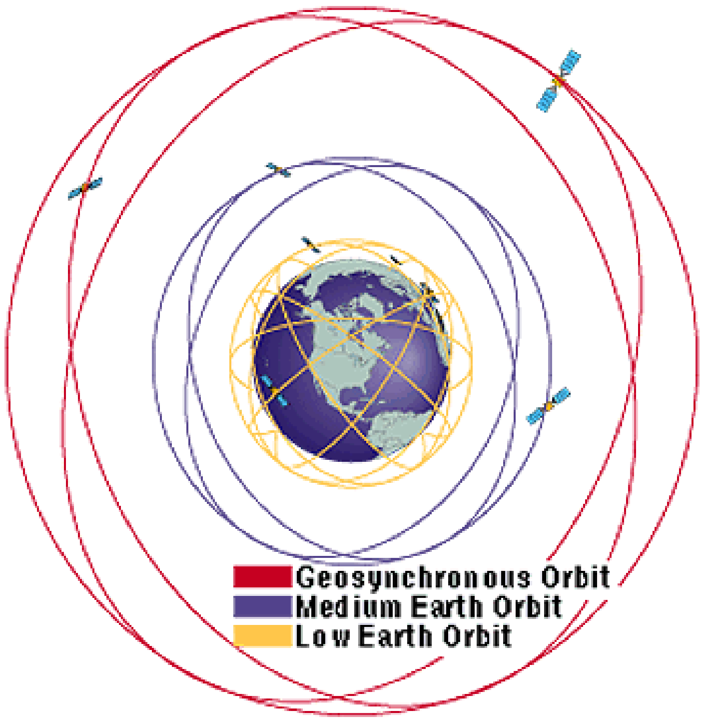
- Based on Eccentricity
  - Circular with centre at the earth’s centre
  - Elliptical with one foci at earth’s centre



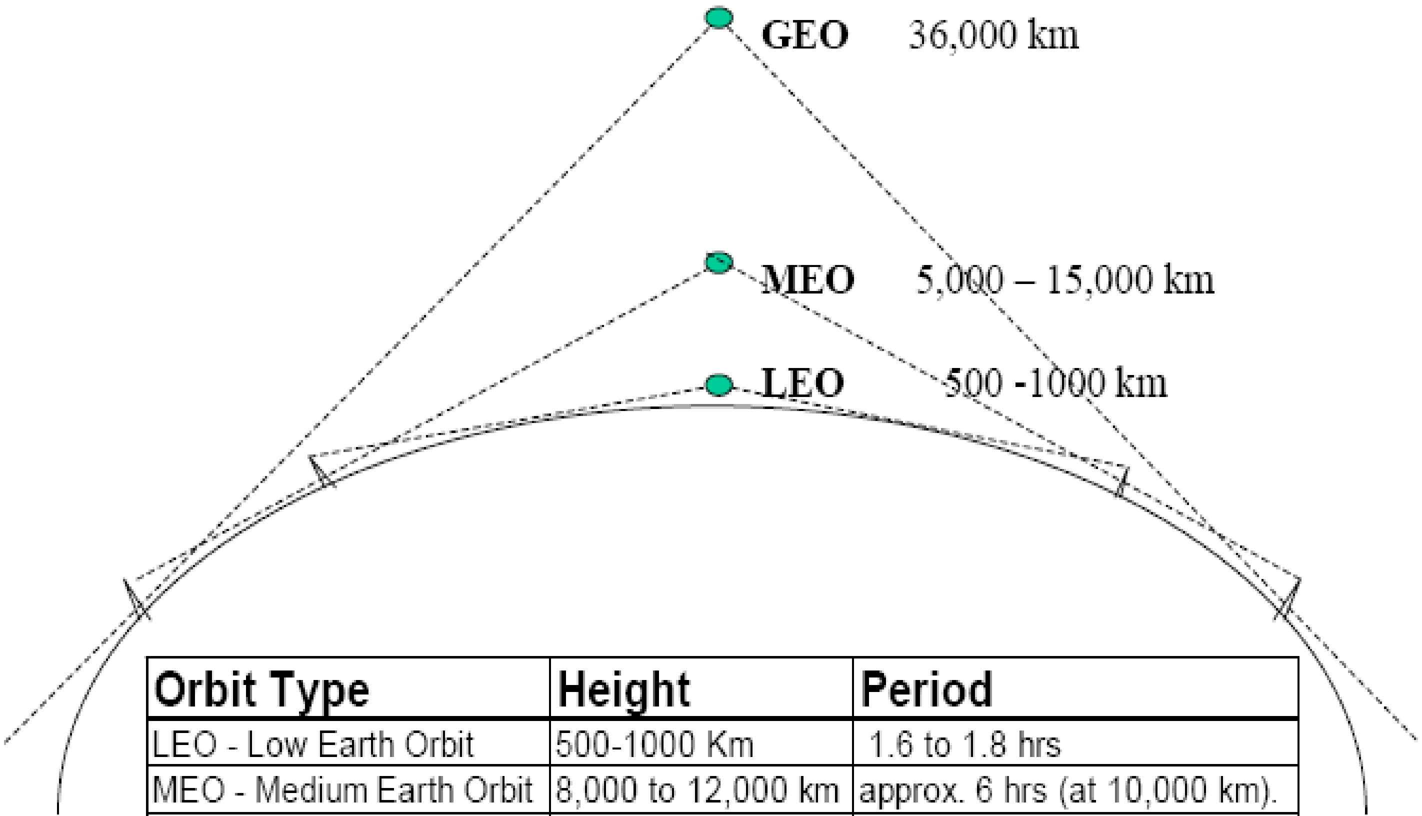


Types of Satellite based Networks

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



Satellite Orbits – Another perspective



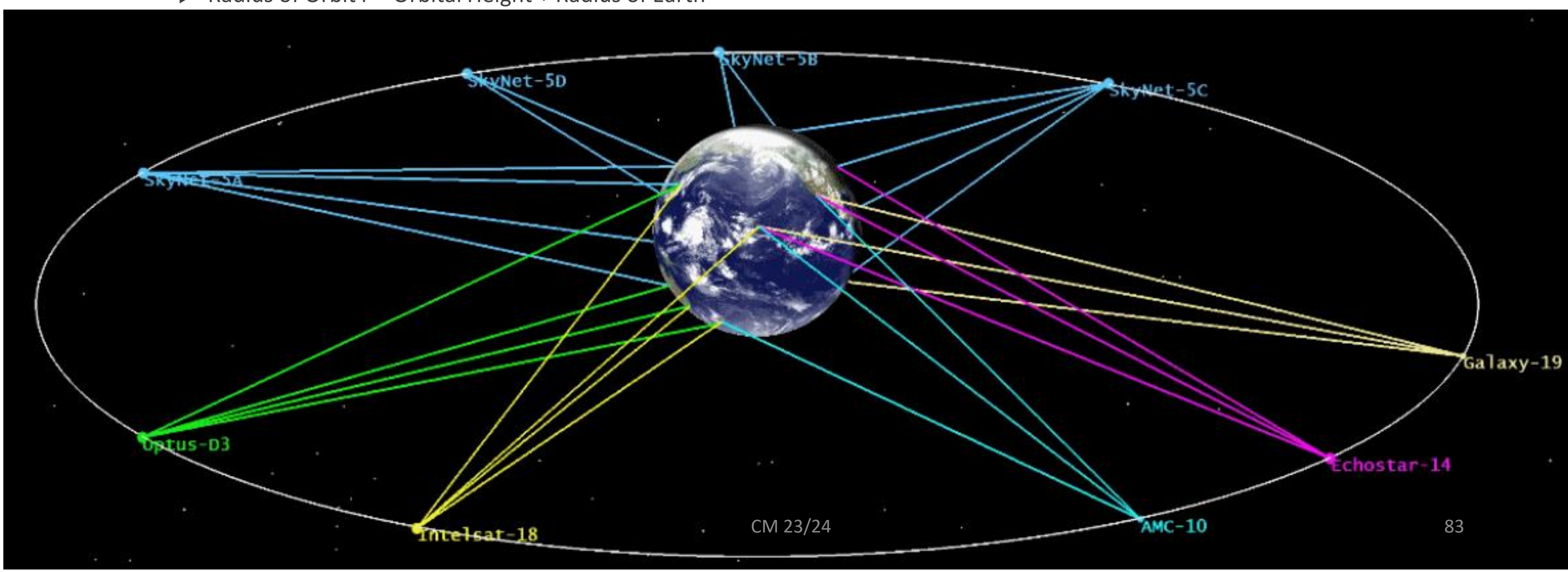
Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

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



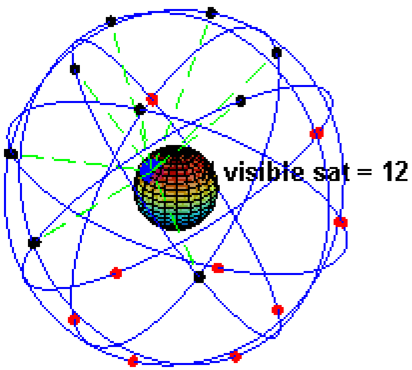
GEO Satellites

- 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

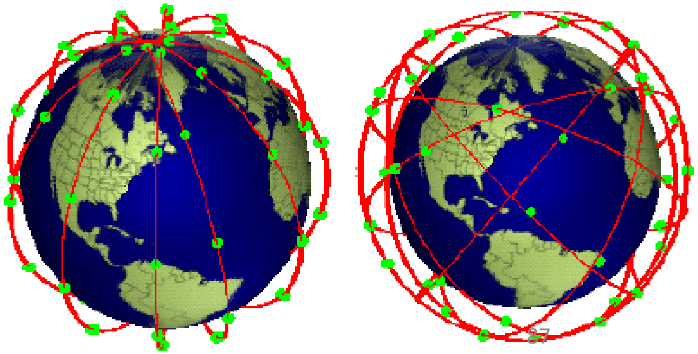
MEO Example: GPS



- 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 bet 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

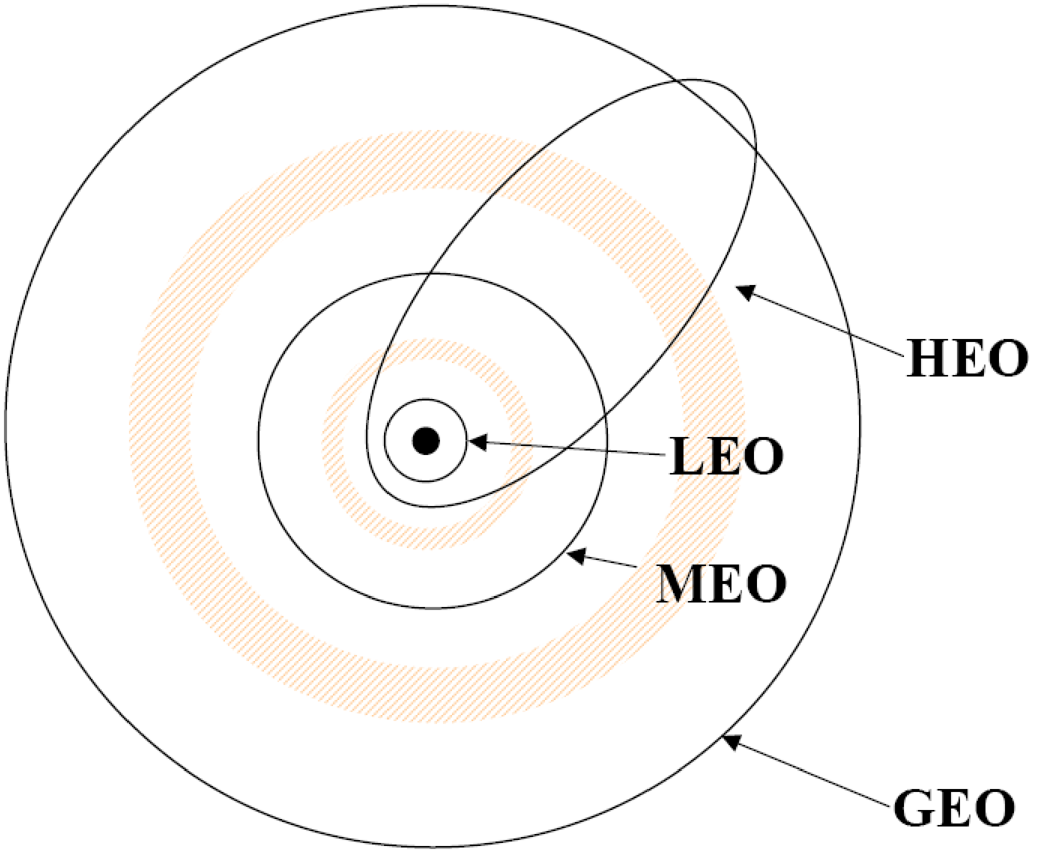


LEO Satellites

- 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

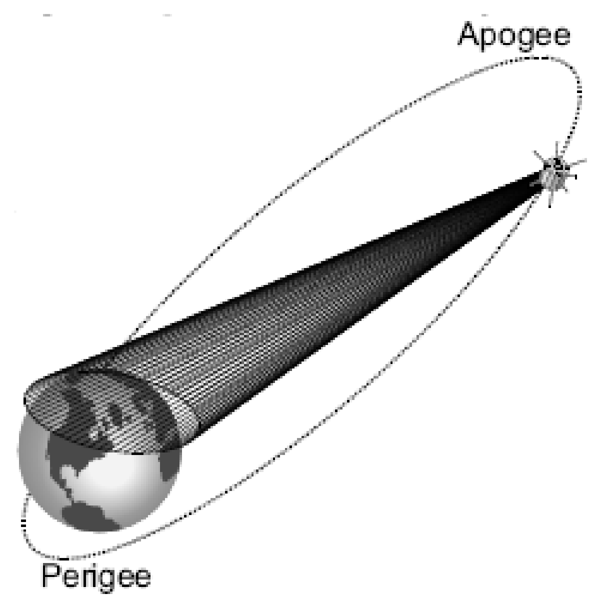
NGSO - Non Geostationary Orbits

- Orbit should avoid Van Allen radiation belts:
  - Region of charged particles that can cause damage to satellite
  - Occur at
    - ~2000-4000 km and
    - ~13000-25000 km



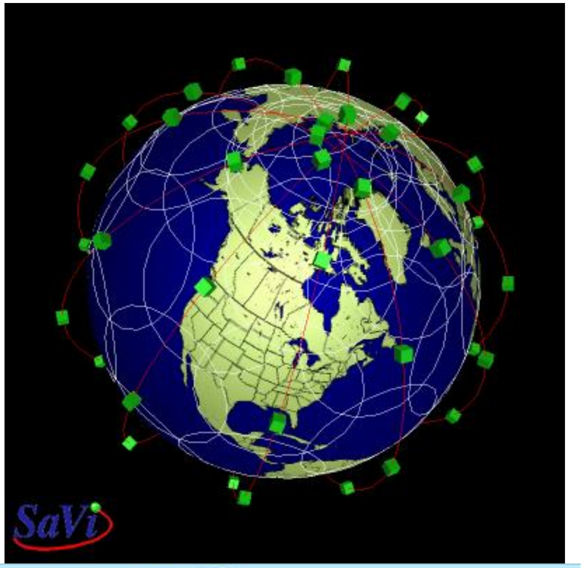
HEO - Highly Elliptical Orbits

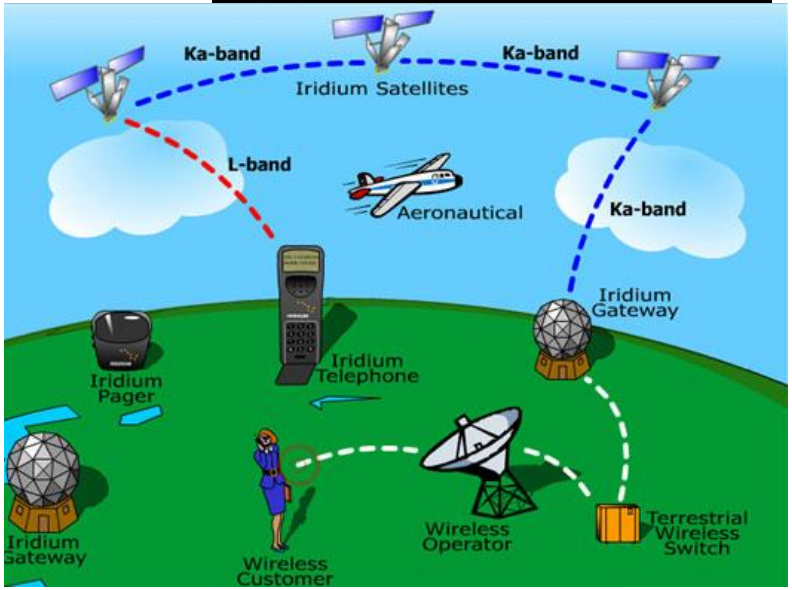
- HEOs ($i = 63.4°$) are suitable to provide coverage at high latitudes (including North Pole in the northern hemisphere)
- Depending on selected orbit (e.g. Molniya, Tundra, etc.) two or three satellites are sufficient for continuous time coverage of the service area.
- All traffic must be periodically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



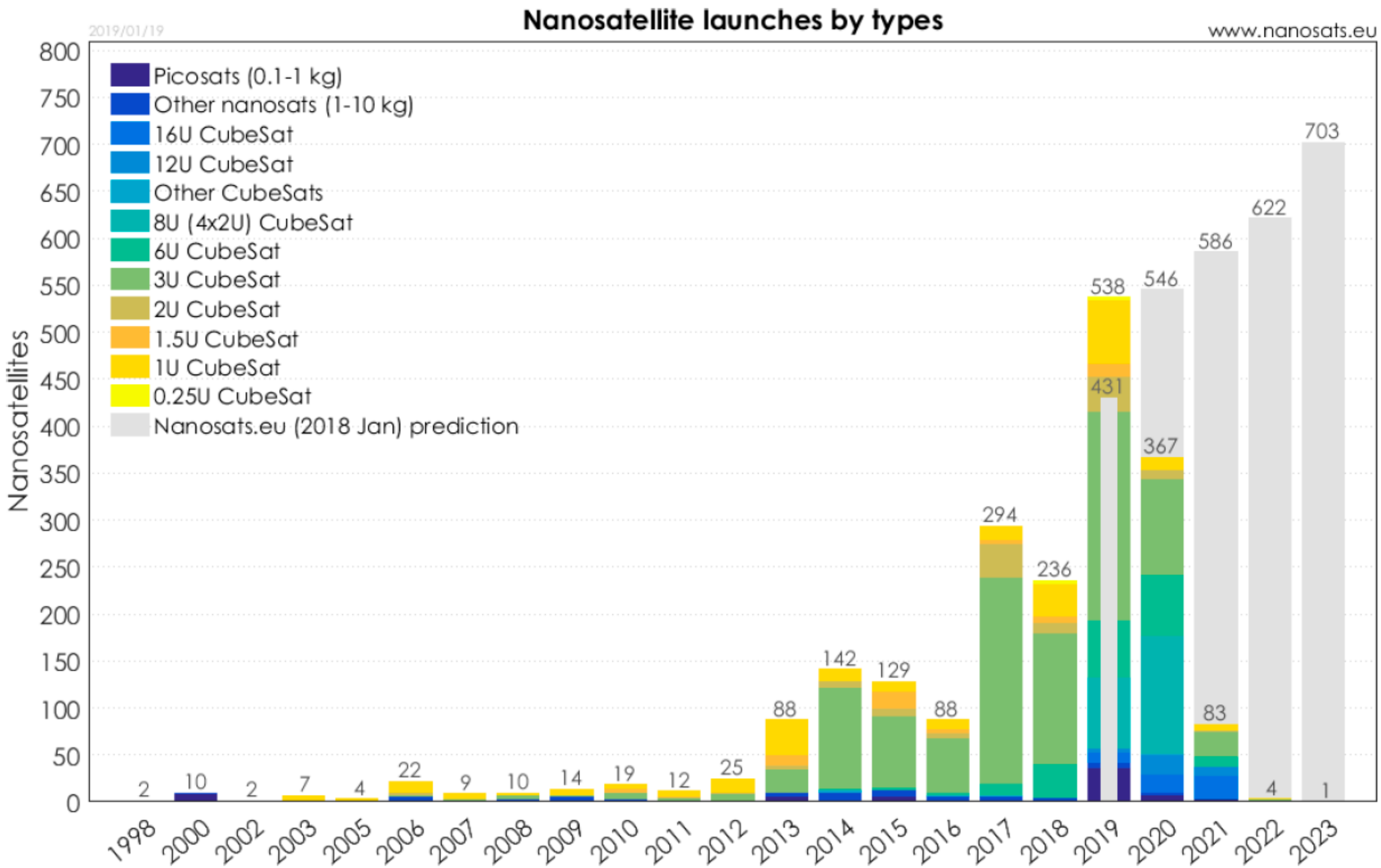
Iridium

- 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 bankrupcy
  - 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).

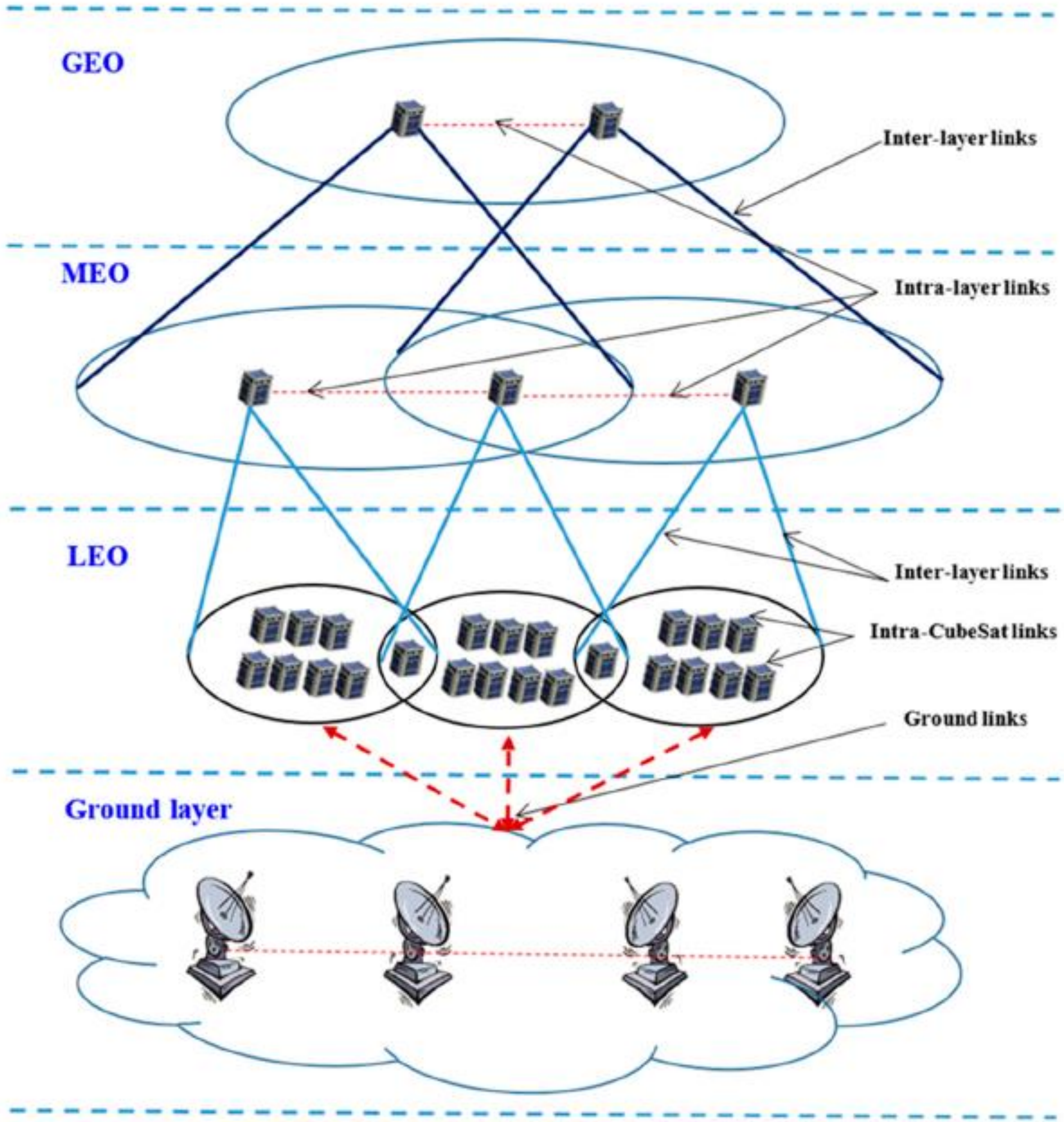




The cubesat explosion



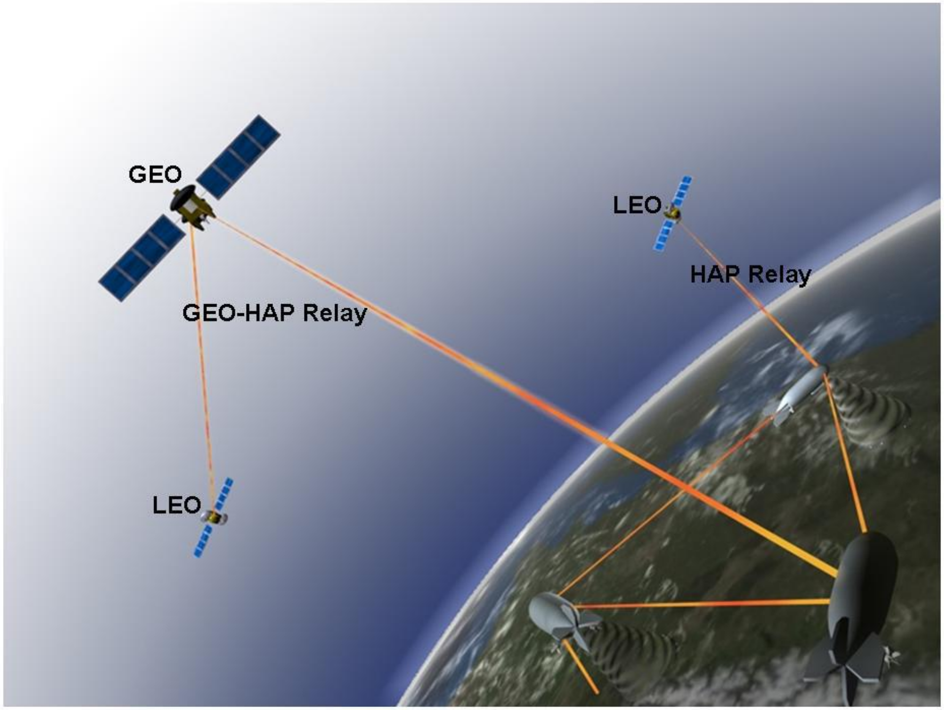
Challenges	Implications
Intermittent connectivity	- Satellites on this orbit are characterized by scheduled predictable/semi-predictable intermittent connectivity, whether for a satellite to ground links or inter-satellite links. - There are no contemporary paths present for satellite and ground station communication or cross-link communication.
Orbital period	- LEO satellite orbital velocity ~= 7800 m/s, based on the satellite altitude orbital period of about 90–110 minu for 160–1200 km altitudes respectively. - Limited encounter time between satellites which in turns bounds data transfer rate.
Inter-CubeSat links	- Transmission range between two satellites, approximately 5–200 km. - The transmission range of inter-CubeSats is bound by cross-link antenna transmission power. - Limited antenna size and capability compared with the conventional satellites. - Limited antenna coverage compared with the conventional satellites.
Up/Downlinks with the ground station	- Transmission range between satellite and ground station, approximately 200–1200 km - The transmission range of CubeSats is bounded by the downlink antenna transmit power. - Satellite revisit time Limited antenna size and capability
Altitude and inclination ranges	- Orbit altitude rang is 200–1200 km above the Earth and orbit inclination ranges 0°–180°.
Natural drag	- Common de-orbiting behaviour leads to changes in orbital height and hence meeting time between CubeSats will also change over time. - Orbiting at lower altitudes increases the drag process. - The drag upsurges with increasing solar activity (sunspots).
High failure rate	- Space radiation effects on electronic components, particularly Commercial-off-the Shelf (COTS) components. - Impossibility of recovery under failure.
Energy	- Solar cells limited space available on the small size of the CubeSat body. - Small storage batteries. - High power consumption of up/downlinks and cross-links.
Topology density	- Satellite dissemination and encounter times.
CubeSat stability on orbit	- There is no space on the CubeSats for advanced stability control devices. - Antenna directionality and steering ability.
Data rate	- A single CubeSat has limited data rate - 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.


GEO
Inter-layer links
MEO
Intra-layer links
LEO
Inter-layer links
Intra-CubeSat links
Ground links
Ground layer

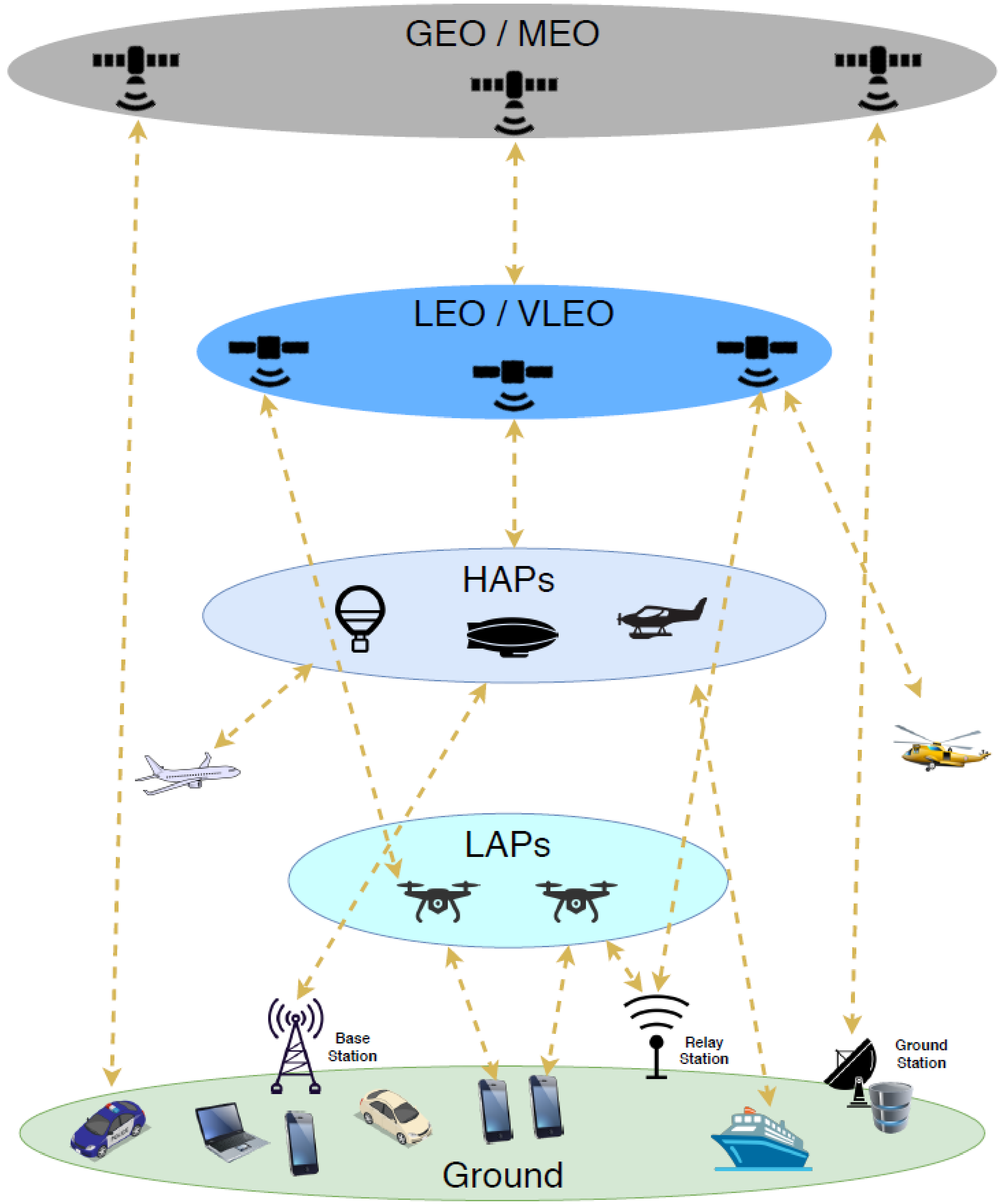
High Altitude Platforms (HAPs)

- 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.

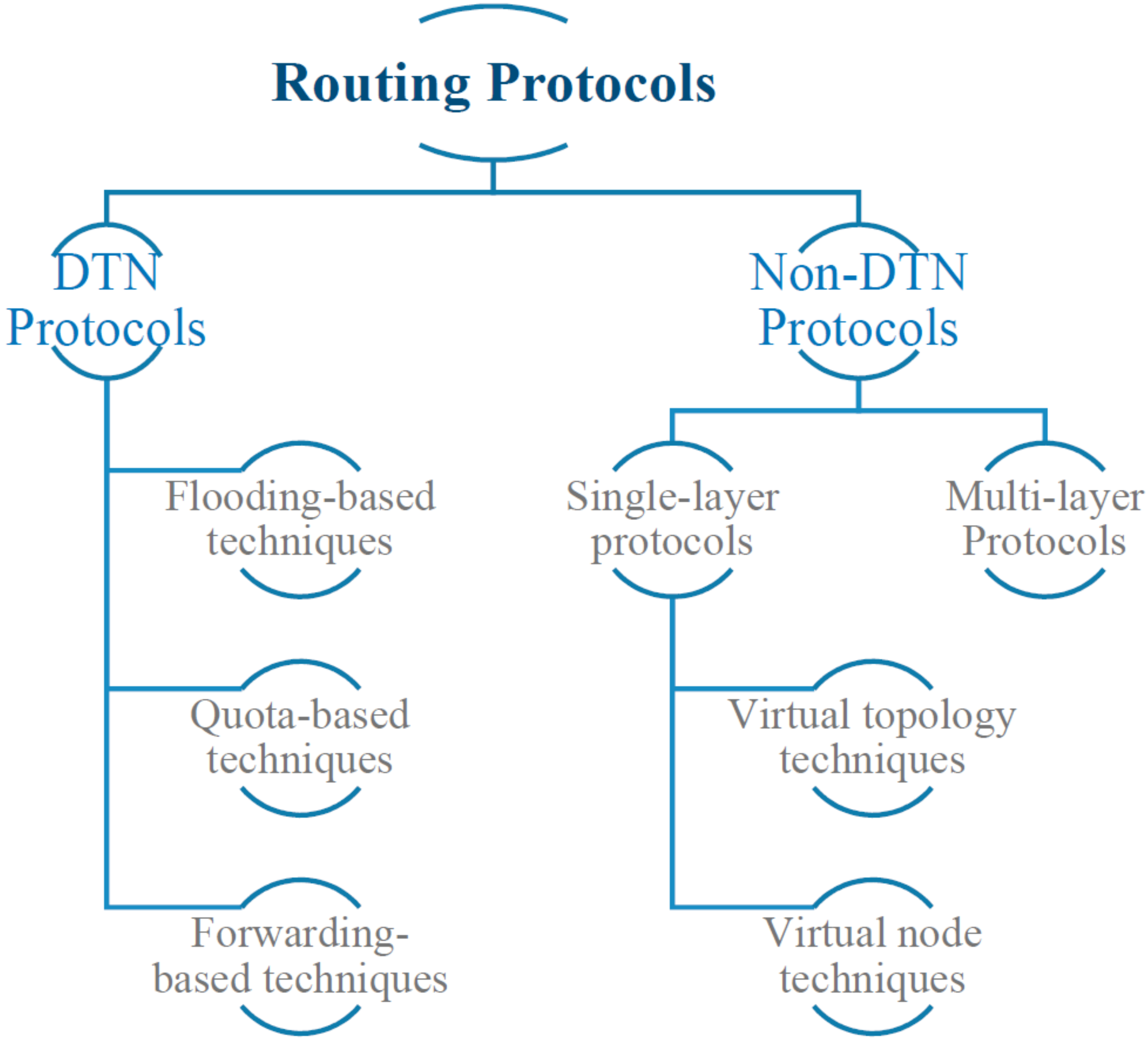

GEO / MEO
LEO / VLEO
HAPs
LAPs
Base Station
Relay Station
Ground Station
Ground

Satellites - Overview

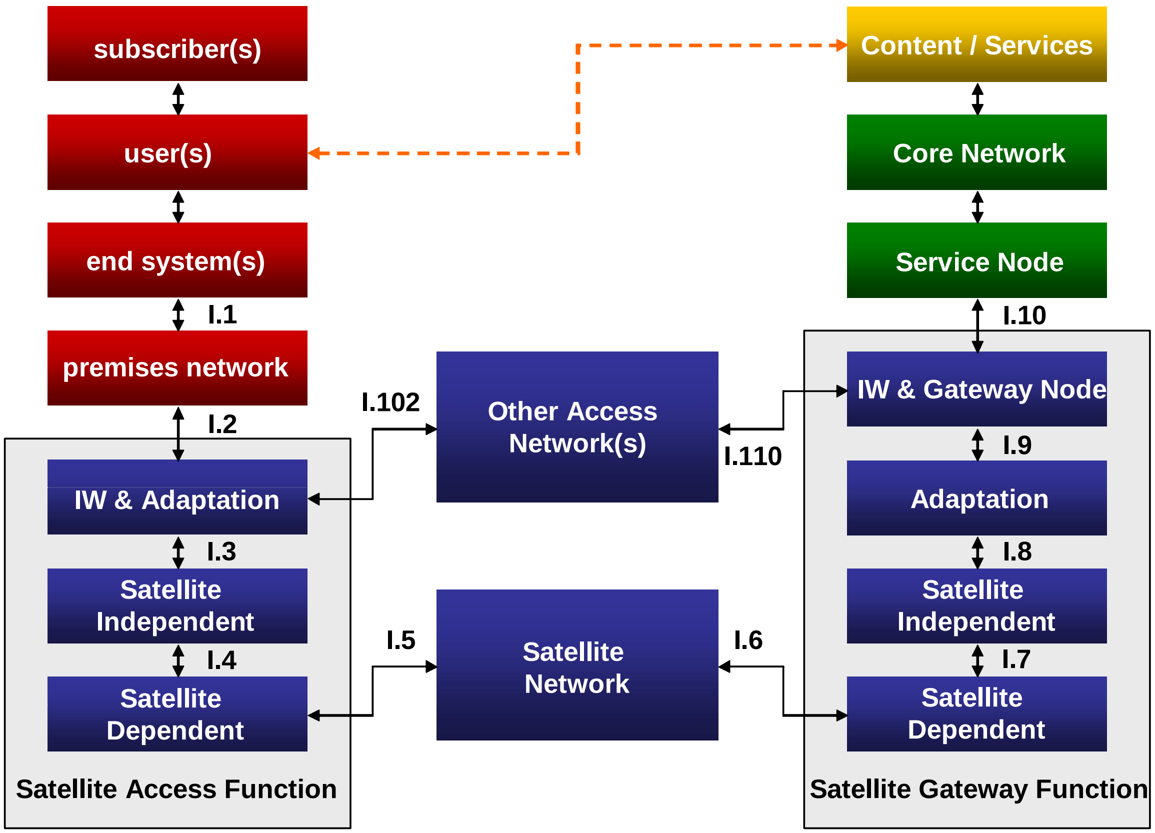
- GEOs have good broadcasting capability, but long propagation delay.
- LEOs offer low latency, low terminal power requirements.
- Inter-satellite links and on-board processing for increased performance and better utilization of satellites
  - From flying mirrors to intelligent routers on sky.
- Major 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

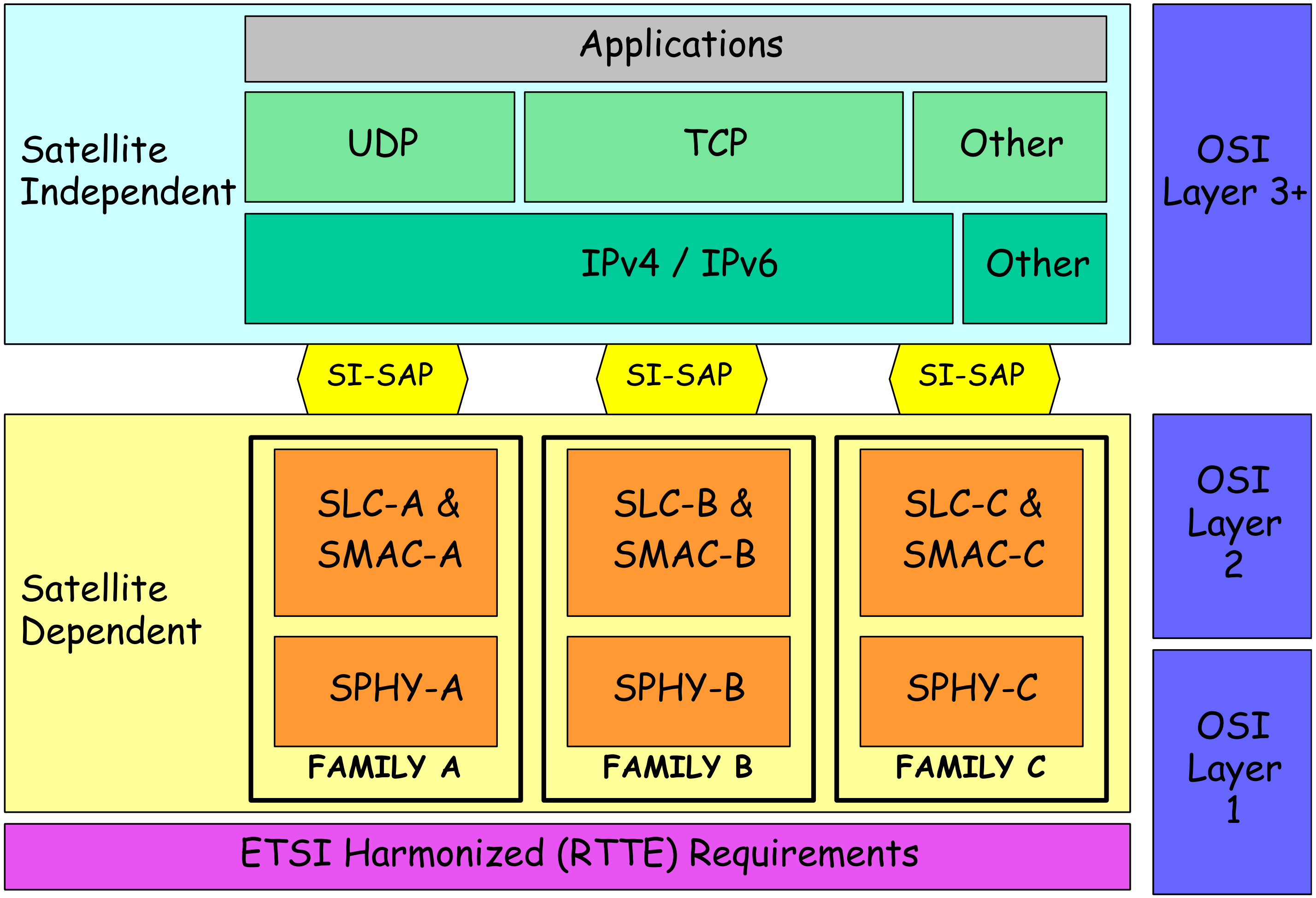
- One solution: inter satellite links (ISL)
  - reduced number of gateways needed
  - forward connections or data packets within the satellite network as long as possible
  - only one uplink and one downlink per direction needed for the connection of two mobile phones
- Problems:
  - more complex focusing 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


Routing Protocols
DTN Protocols
Non-DTN Protocols
Flooding-based techniques
Quota-based techniques
Forwarding-based techniques
Single-layer protocols
Multi-layer Protocols
Virtual topology techniques
Virtual node techniques

Reference model for satellite access

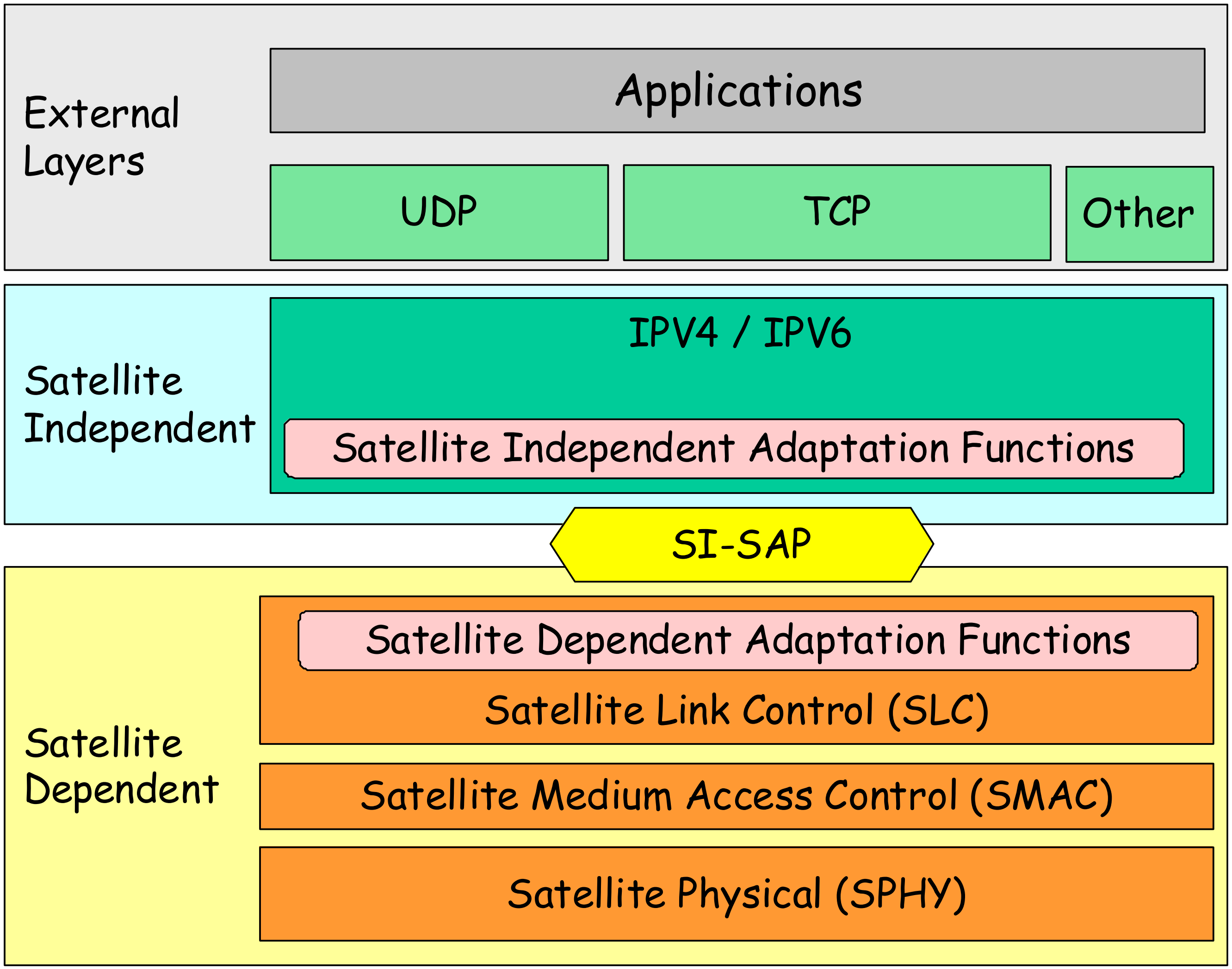


Protocol architecture



RTTE – Radio and Telecommunications Terminal Equipment Directive

Protocol architecture



IP interworking