



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

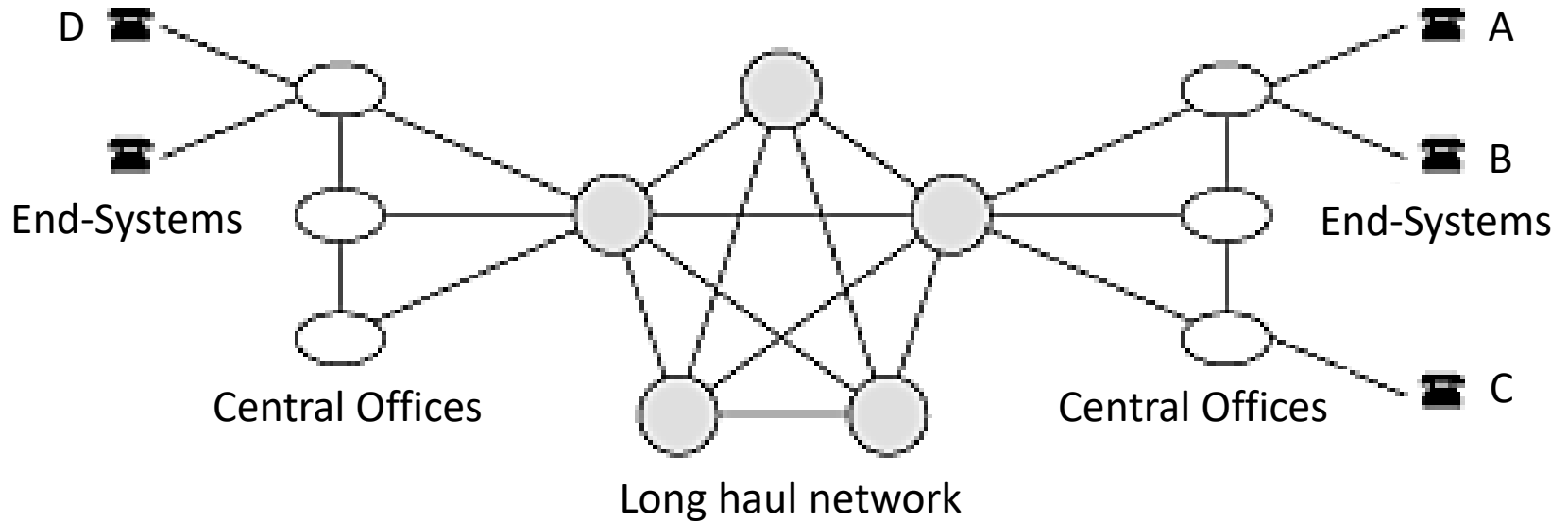


The communication network

Before mobile Communications, there where Fixed Communications



Telephone System

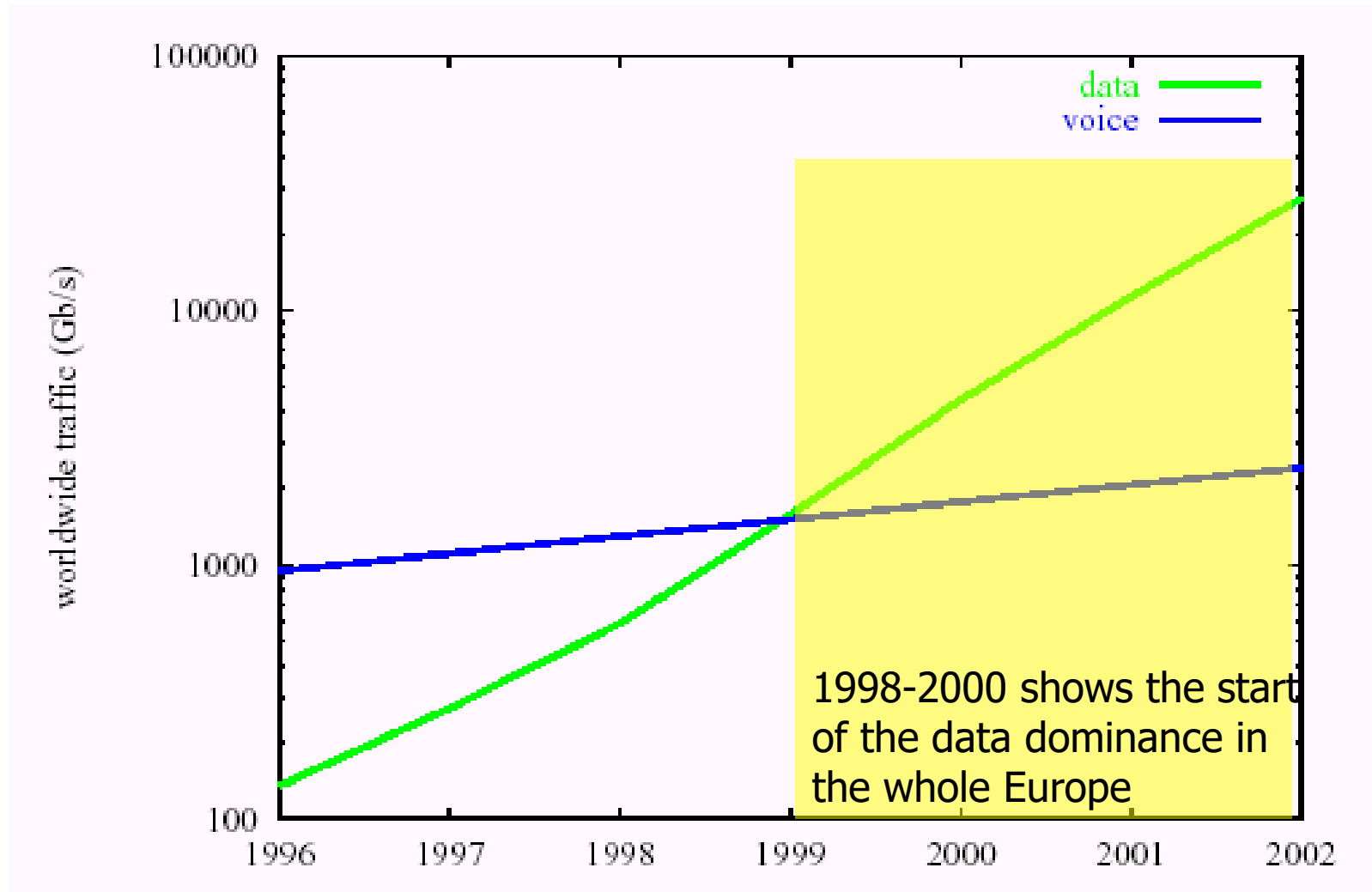


- Uses switched circuits (virtuals...)
- Access via low bandwidth circuits
- “out-of-band” call establishment using signaling system based in packets (SS7)
- Channels between switching exchanges carry multiple calls
 - Multiplexing (analogue or digital)





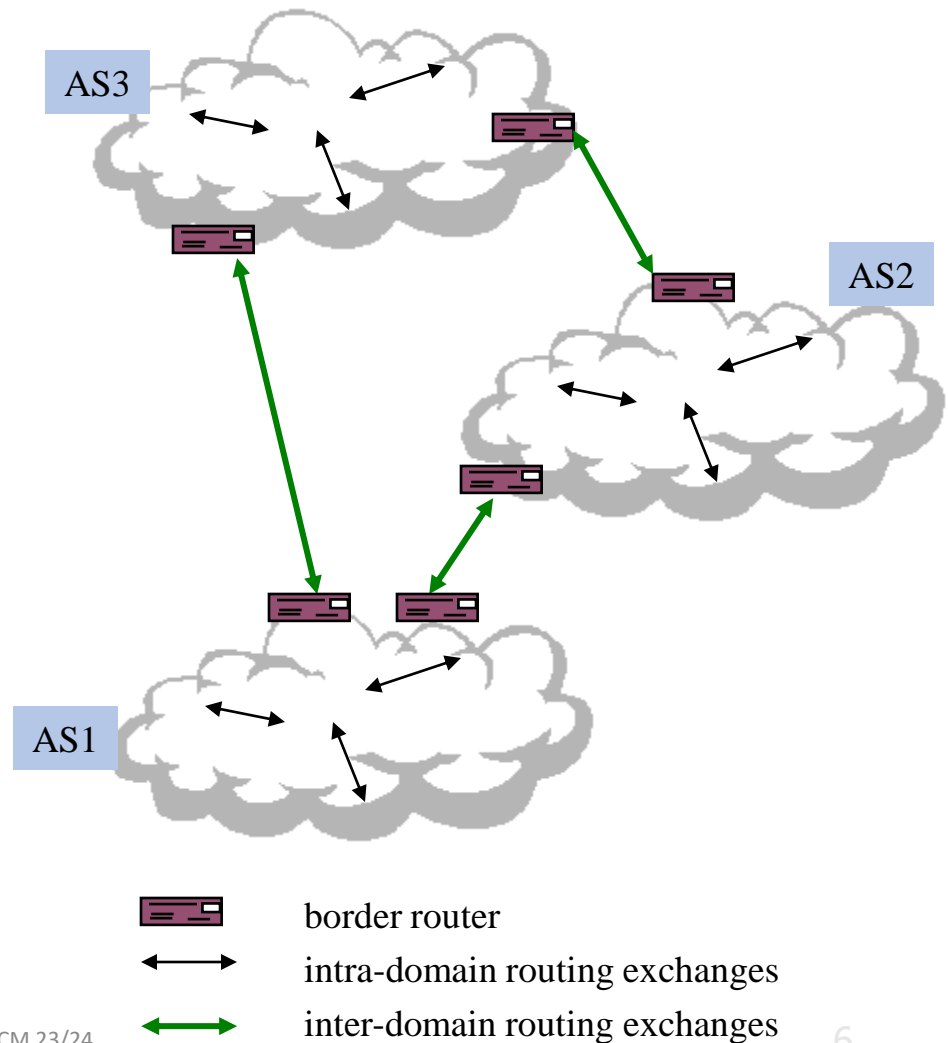
Evolution: Voice vs Data





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



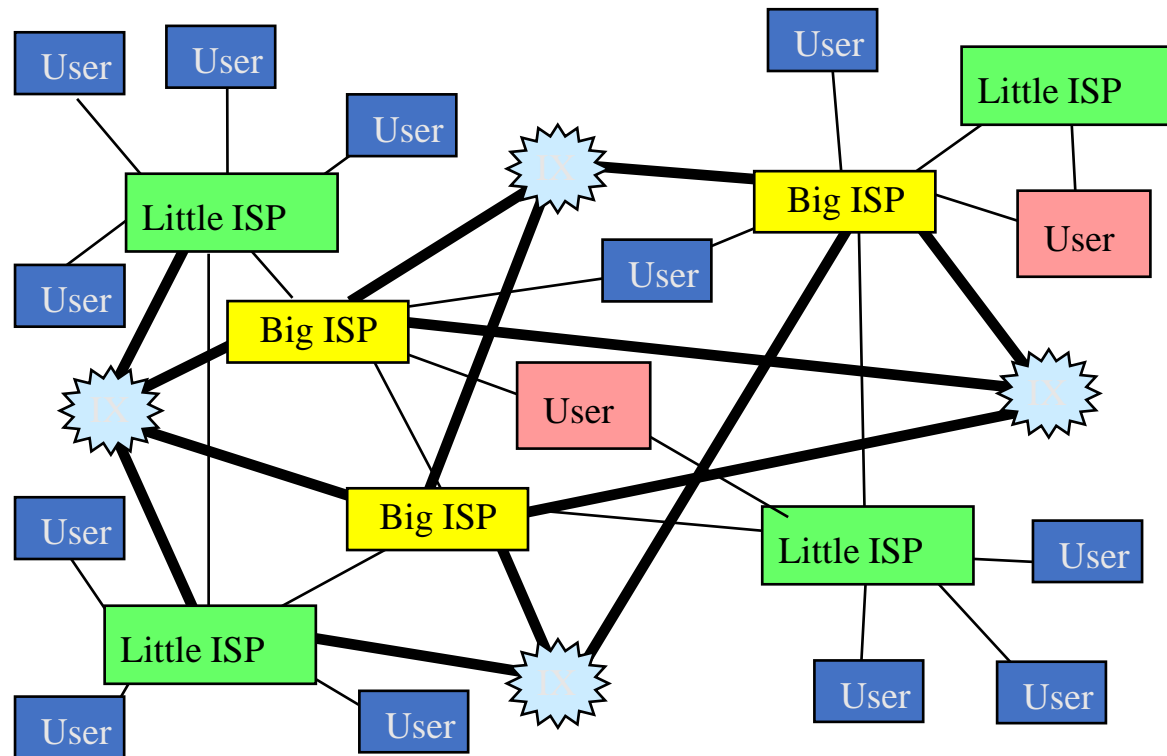


Internet: currently

- 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



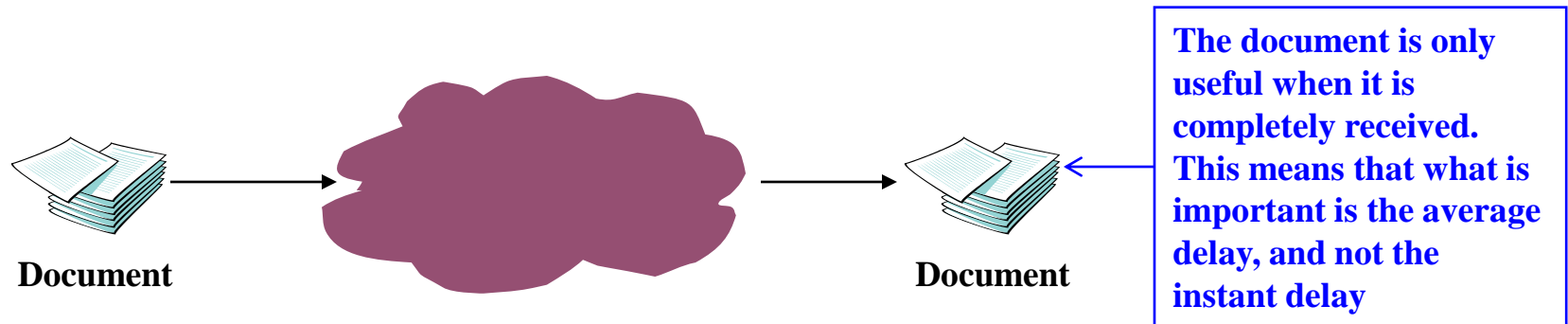
Transport service (operator/ISP) vs applications

- 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

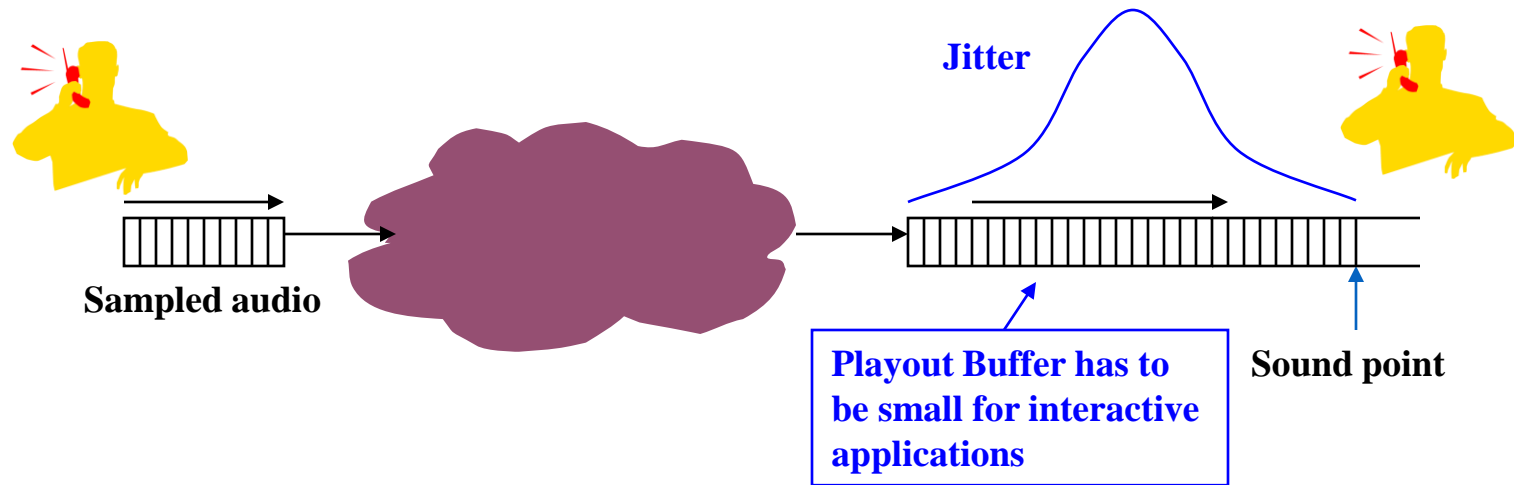


- Elastic applications

- 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

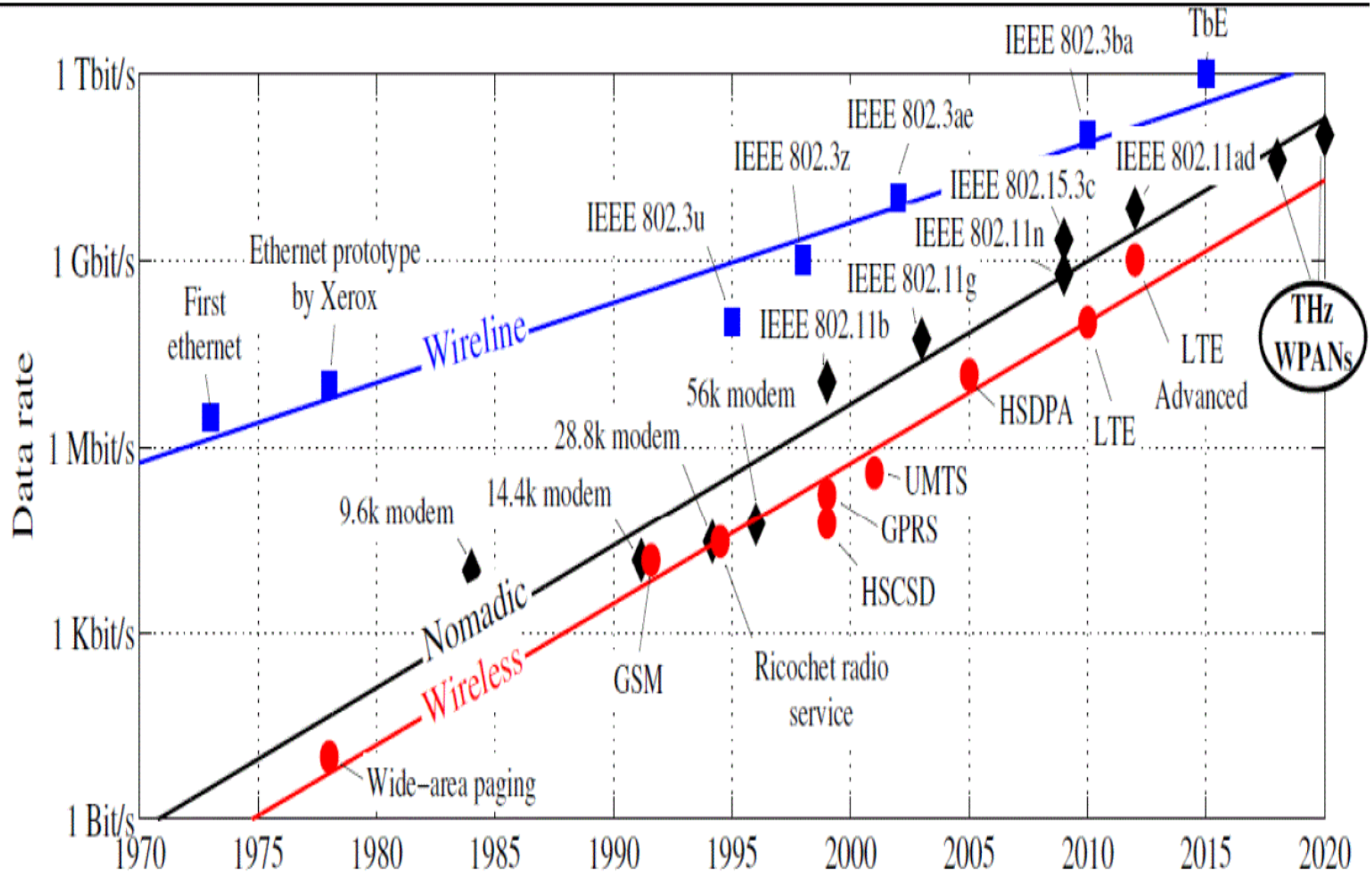


The Mobile Network

Economical and societal motivations



Edholm's Law

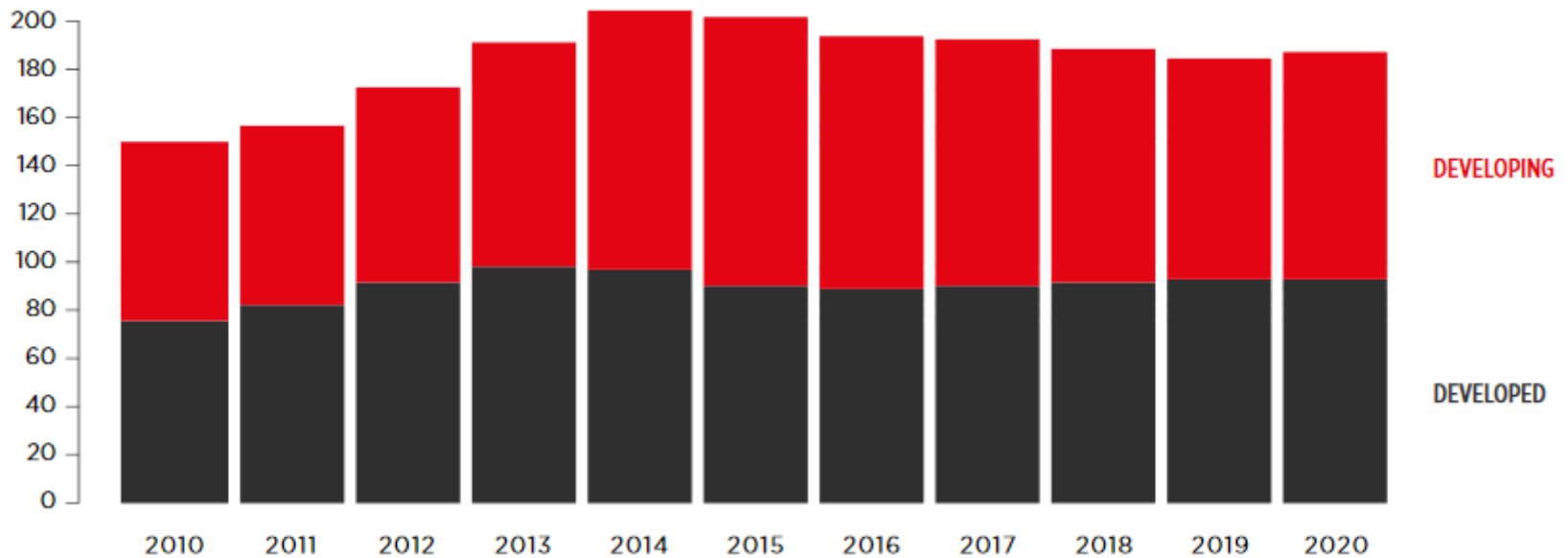




Cost of investment in telecom

Global mobile operator capex

(\$ billion)

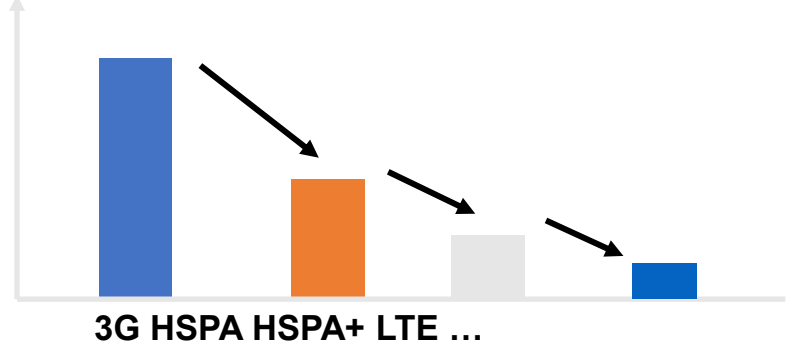




Motivations for technologies

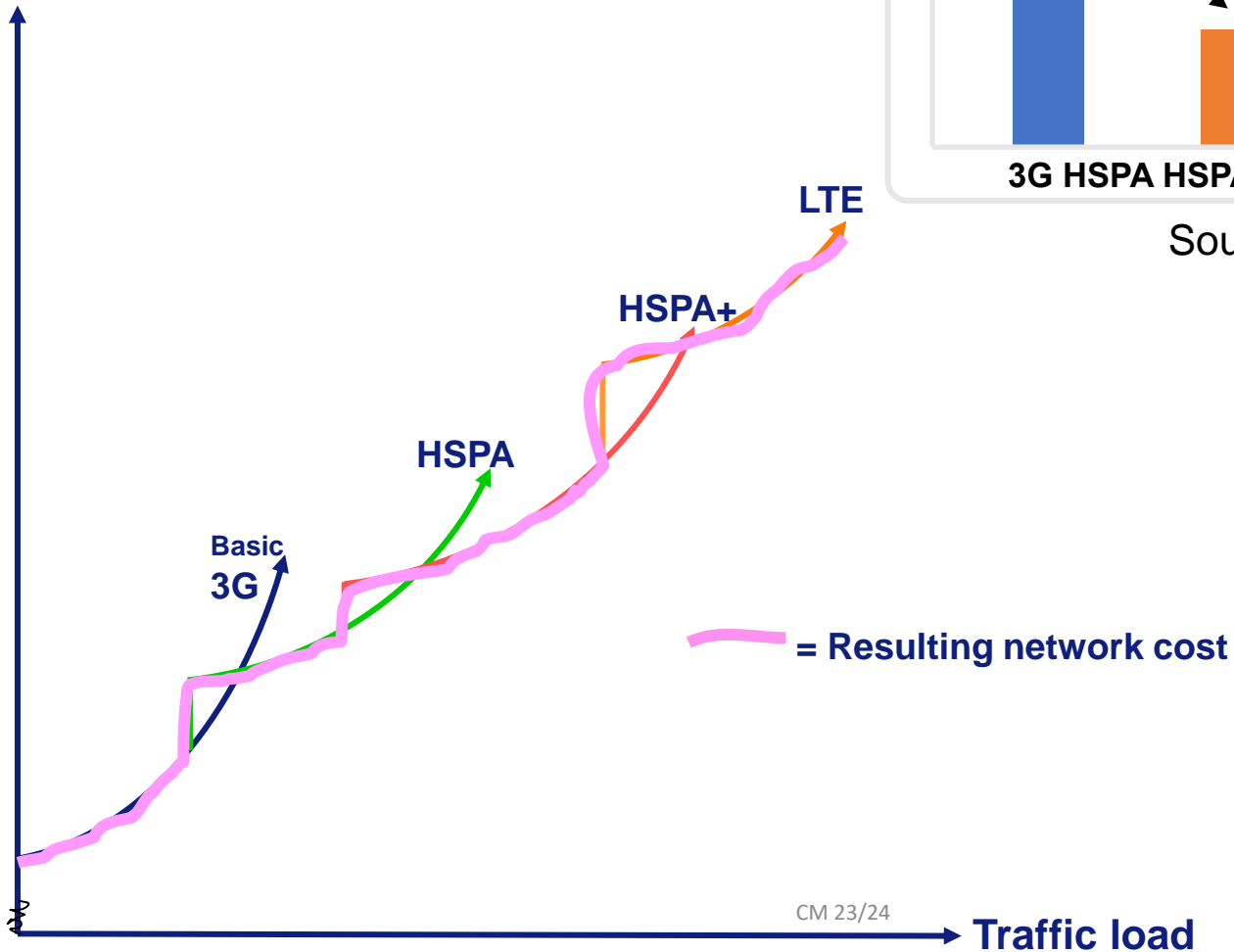
Lower production cost per bit

Cost per Mbyte



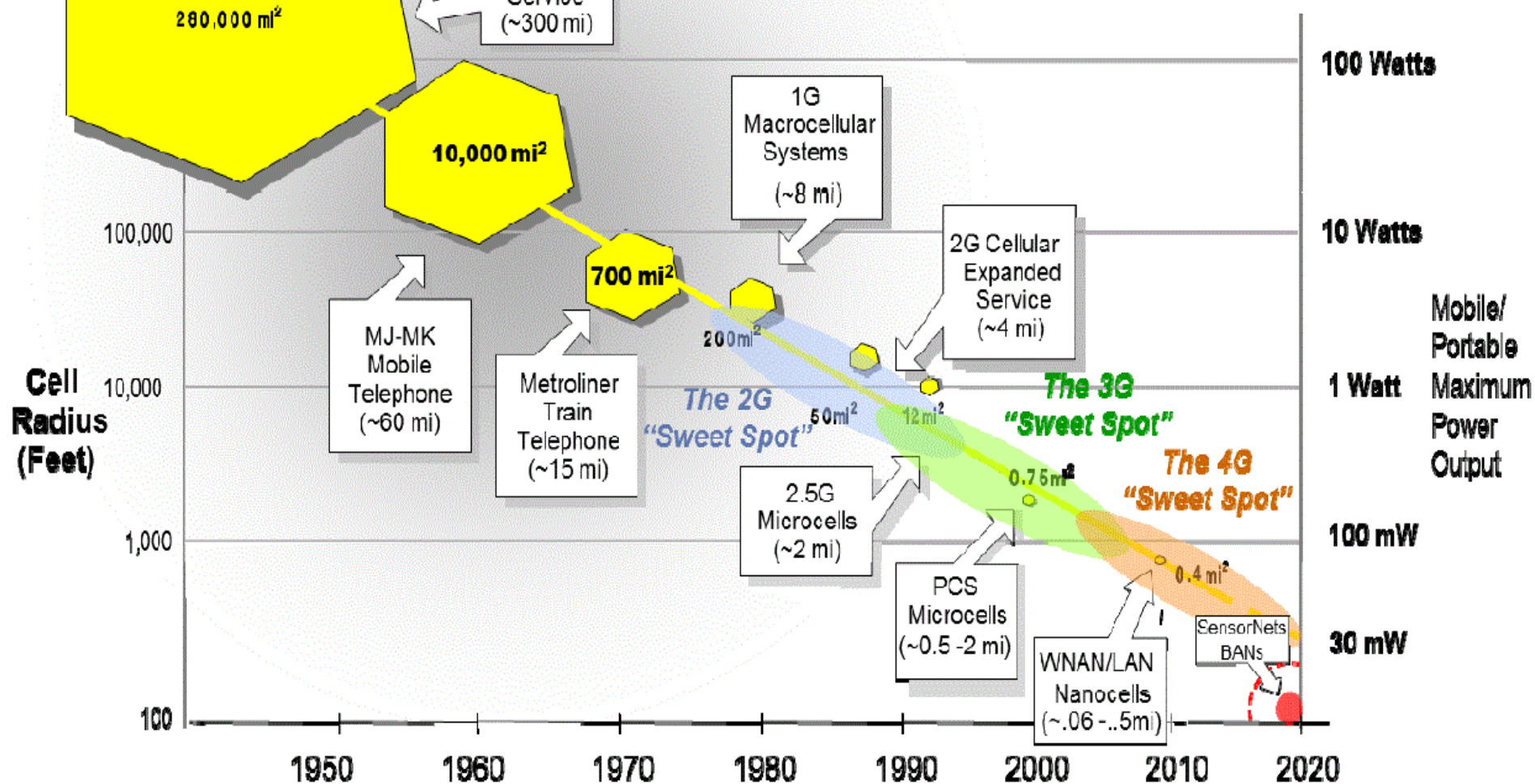
Source: NSN

Network cost





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





Dramatic Traffic Growth Fueled by Video

Global Mobile Data Traffic Growth
2011 to 2016



Gopher, FTP

1993-1995

WWW

1995-2000

P2P

2000-2013

Video
Content

2013-2025

Video
Communication

Dominant
Traffic Type

2025+



The things that surround us





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

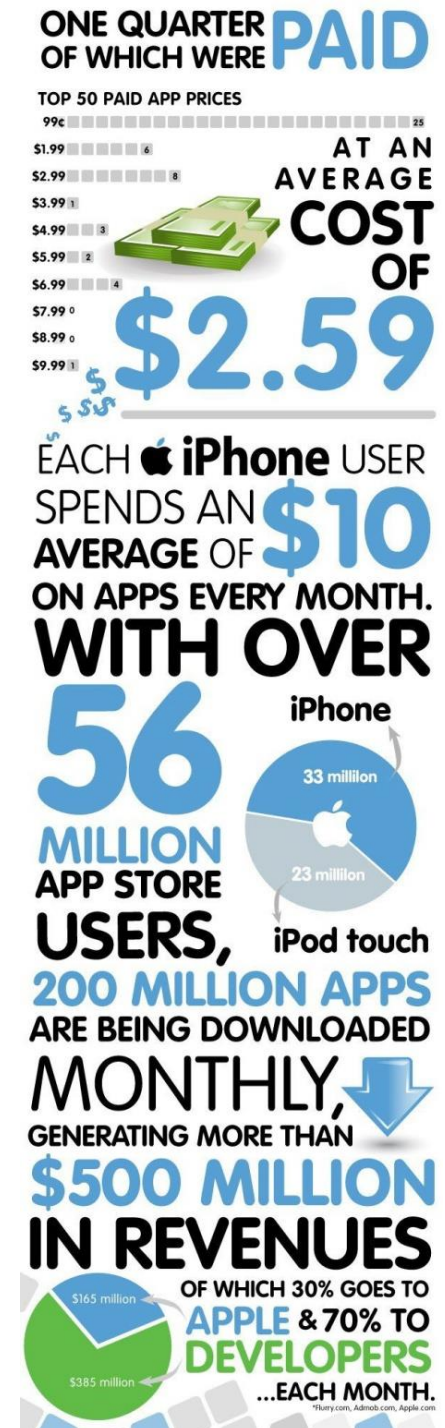




The market turned to SERVICES (+/- 2016)

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

Source: GigaOM



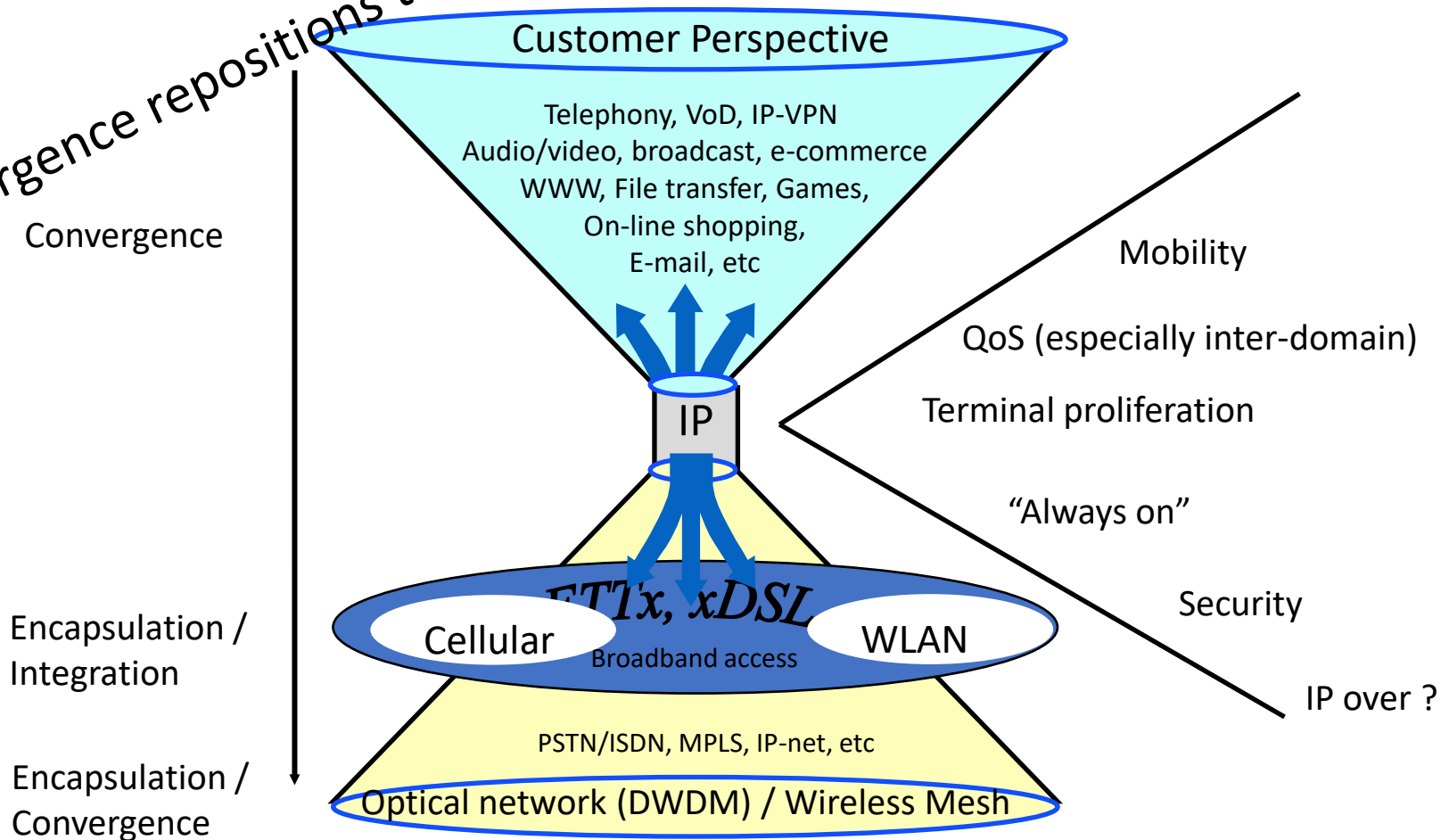


User behaviour and trends

- 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 ecosystem!





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

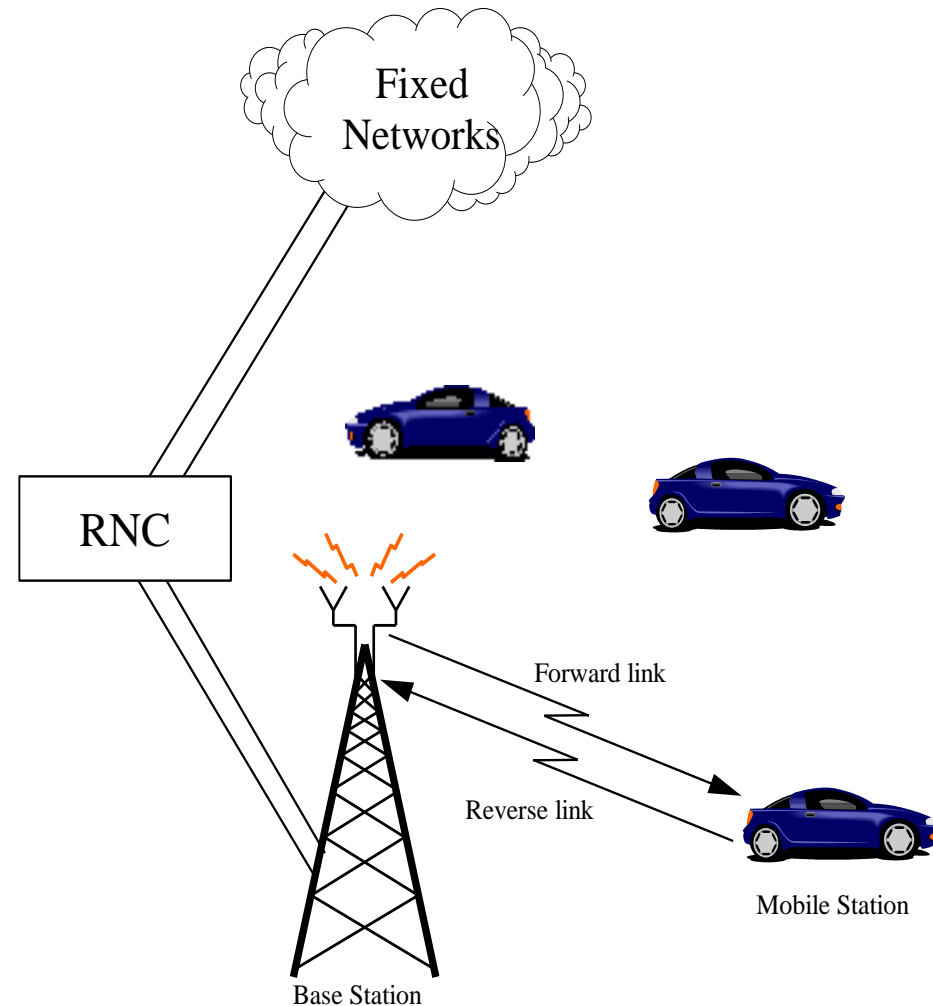
Generic technical aspects and challenges



Wireless Systems

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- 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



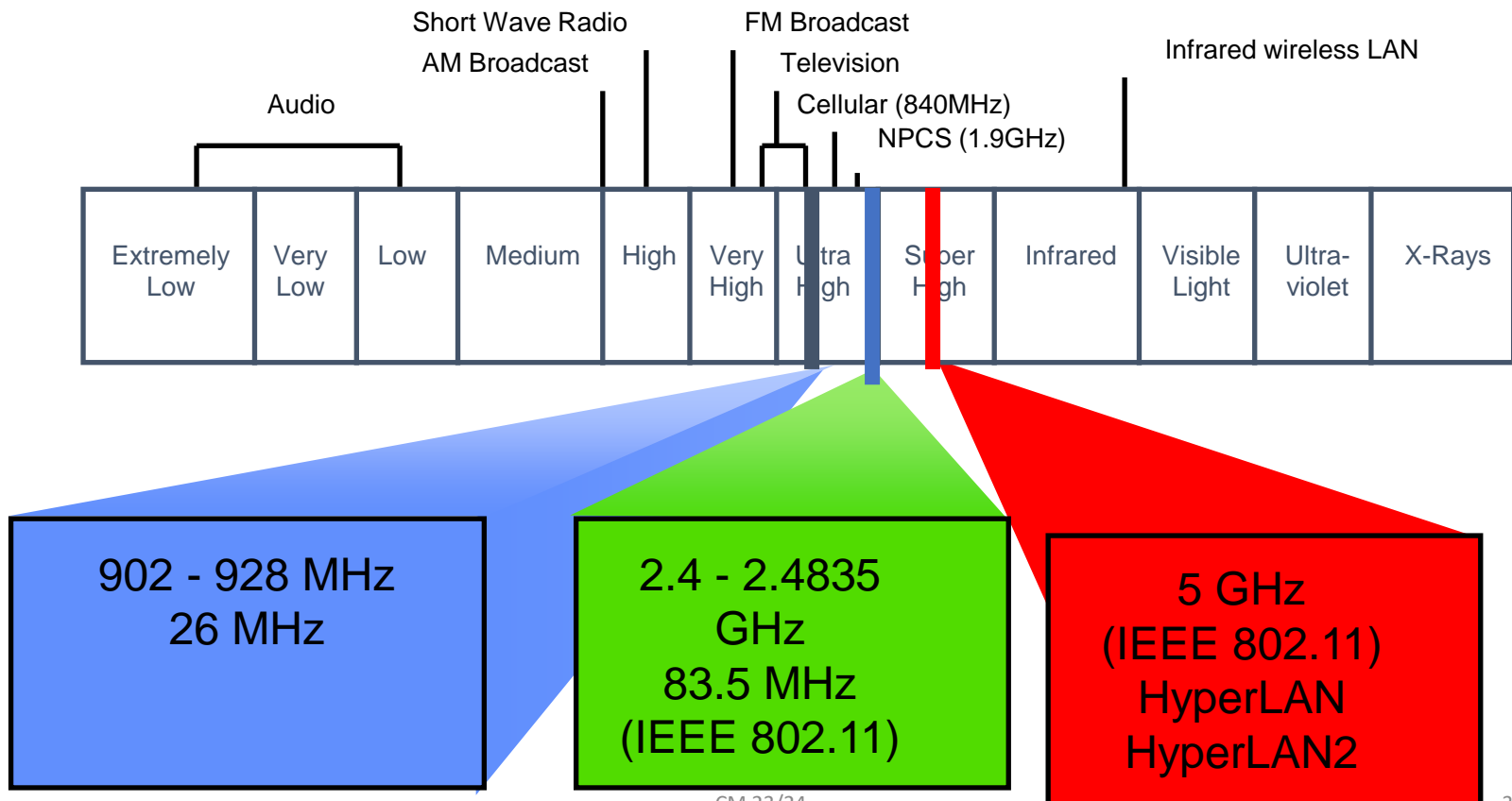
General Frequency Ranges

- 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, 3×10^{11} to 2×10^{14} Hz
 - Useful in local point-to-point multipoint applications within confined areas



Frequency Bands

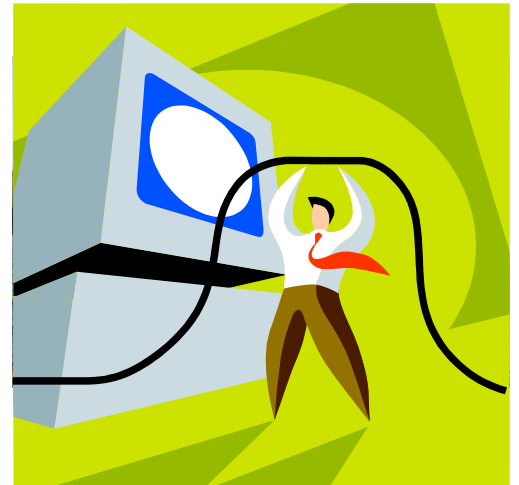
- Industrial, Scientific, and Medical (ISM) bands
- Unlicensed, 22 MHz channel bandwidth





Physical Layer

Problems we face





Classifications of Transmission Media

- 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?

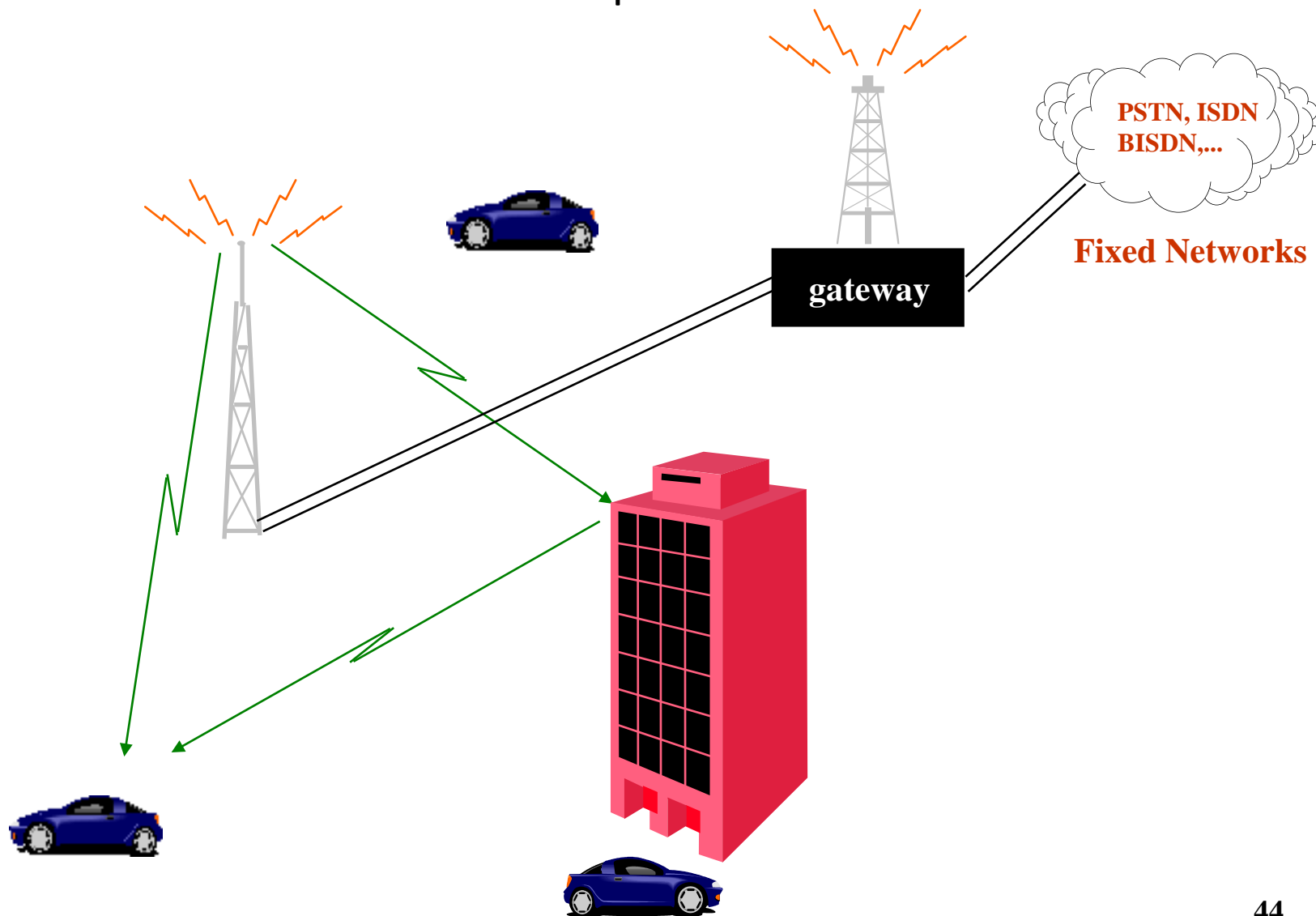
There are no wires!

Causes problems in many areas:

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



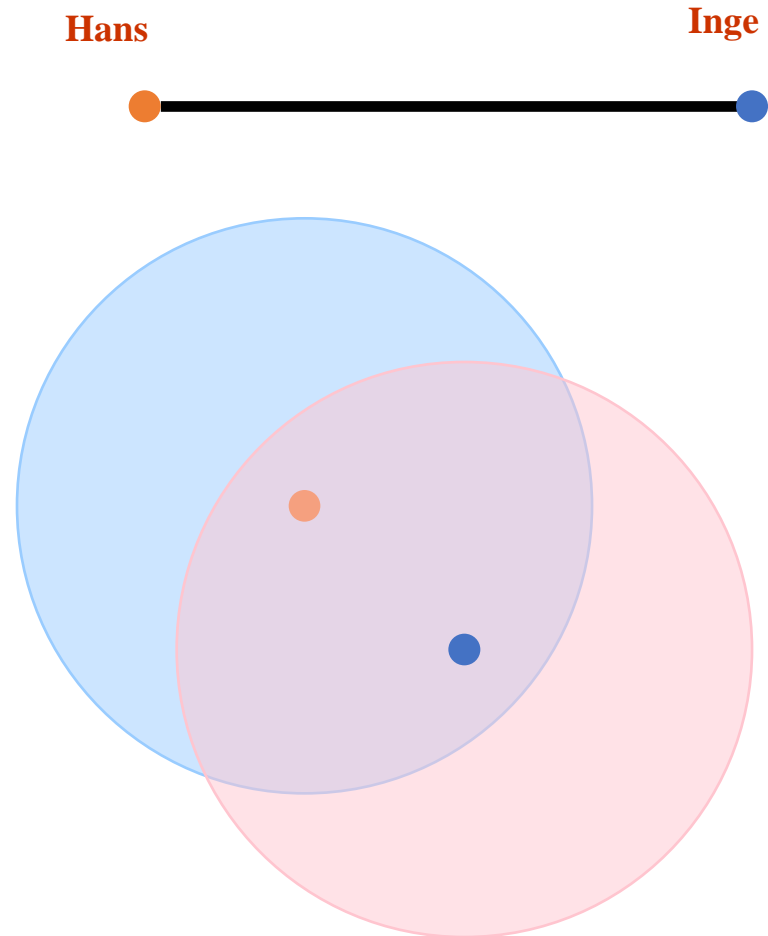
Radio Transmission Impairments





Communication based on Broadcasting

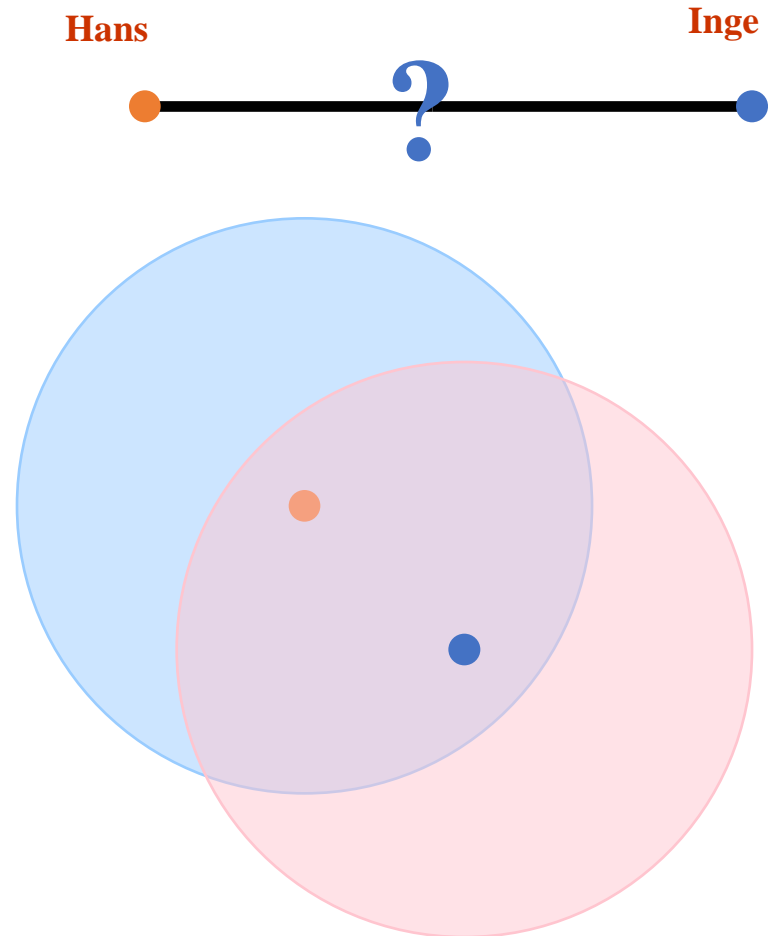
- Wired communication is usually point-to-point.
 - Broadcast is hard to scale
- Wireless communication is inherently broadcast.
 - Well, usually
- Of course: it does allow nodes to move





Mobility

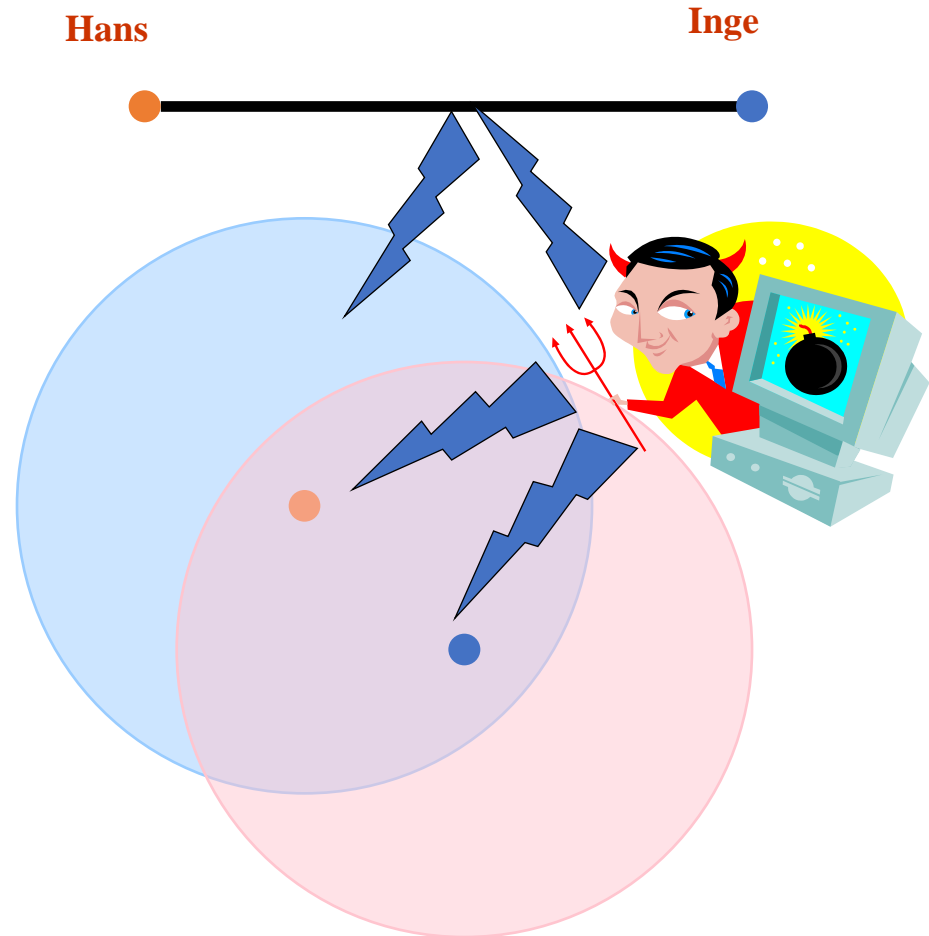
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Wireless is very Sensitive to Noise ...

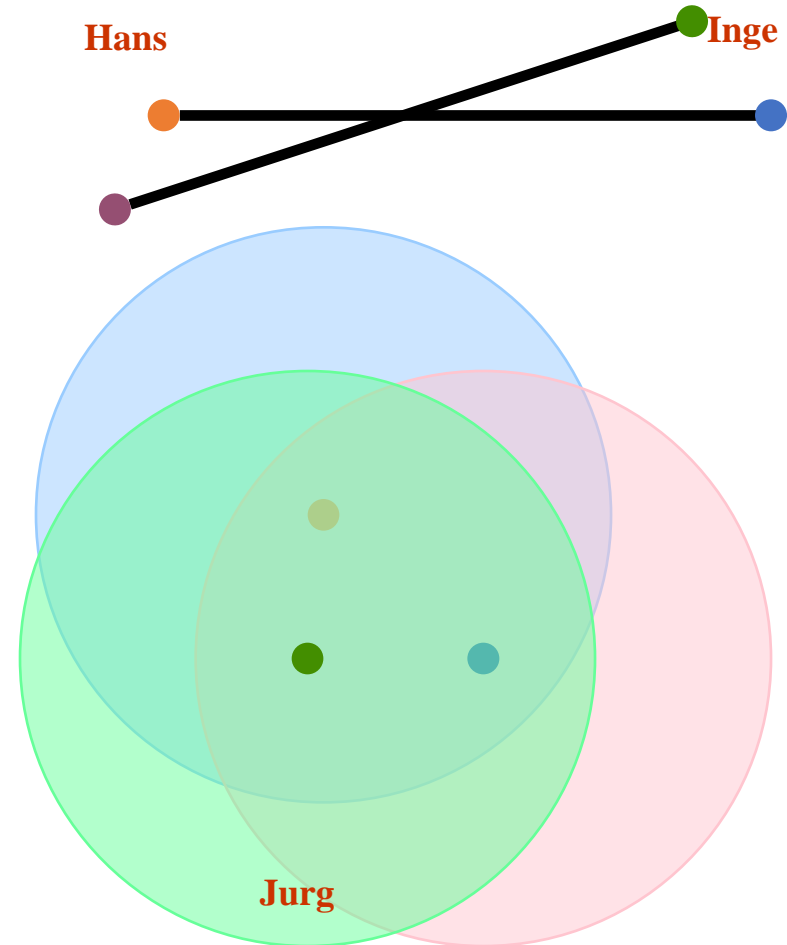
- Noise is naturally present in the environment from many sources.
- Interference can be from other users or from malicious sources.
- Impacts the throughput users can achieve.





... and Interference

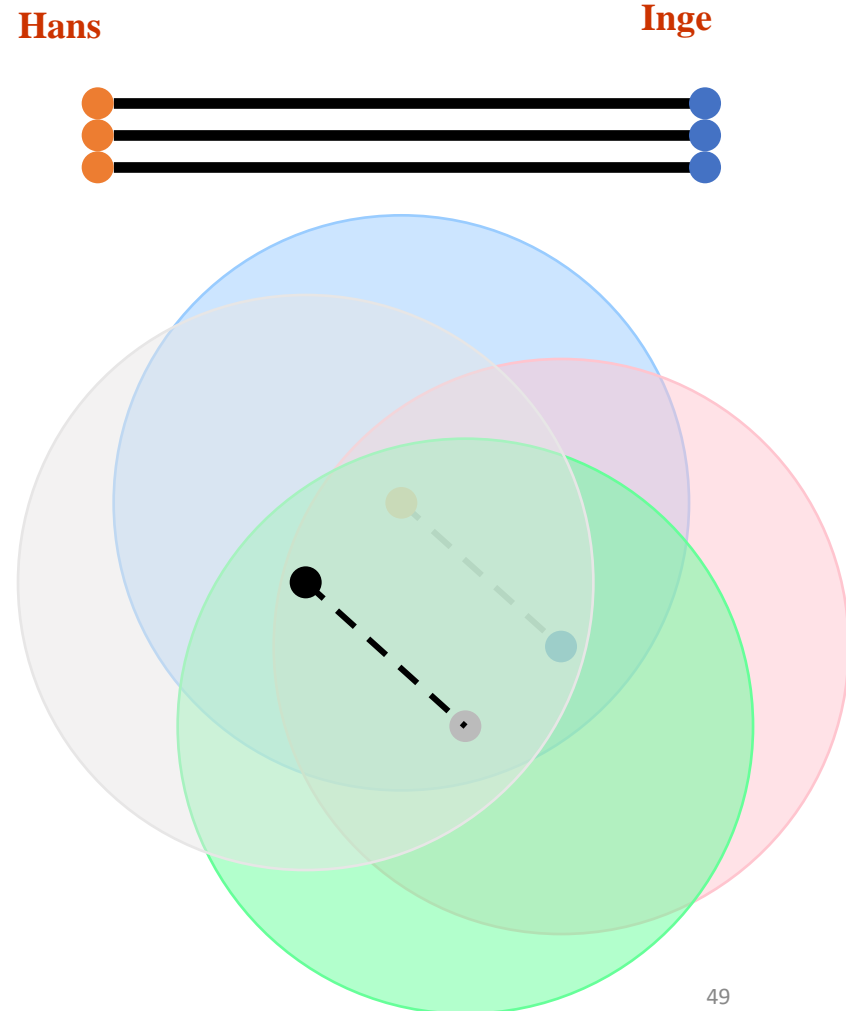
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How Do We Increase Network Capacity?

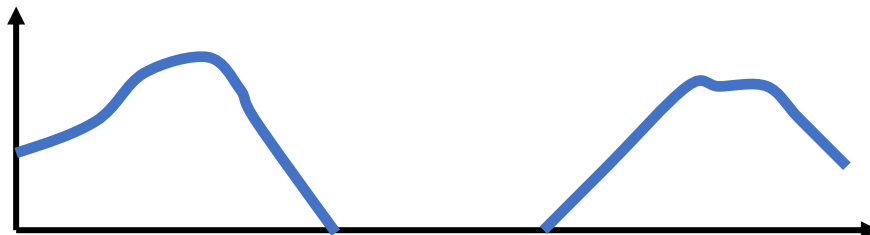
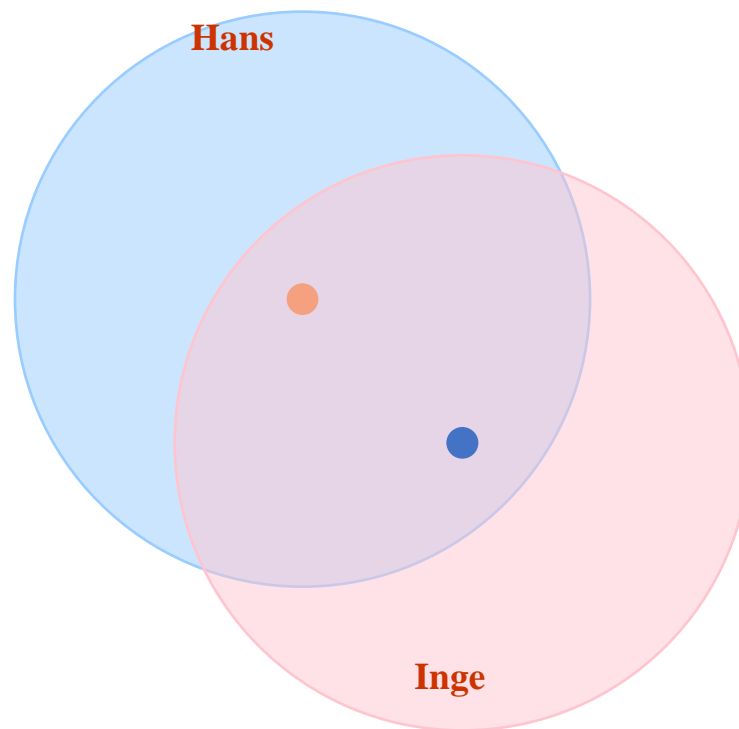
- Easy to do in wired networks: simply add wires.
 - Fiber is especially attractive
- Adding wireless “links” increases interference.
 - Frequency reuse can help ... subject to spatial limitations
 - Or use different spaces ... subject to frequency limitations
- The capacity of the wireless network is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





Mobility Affects the Link Throughput

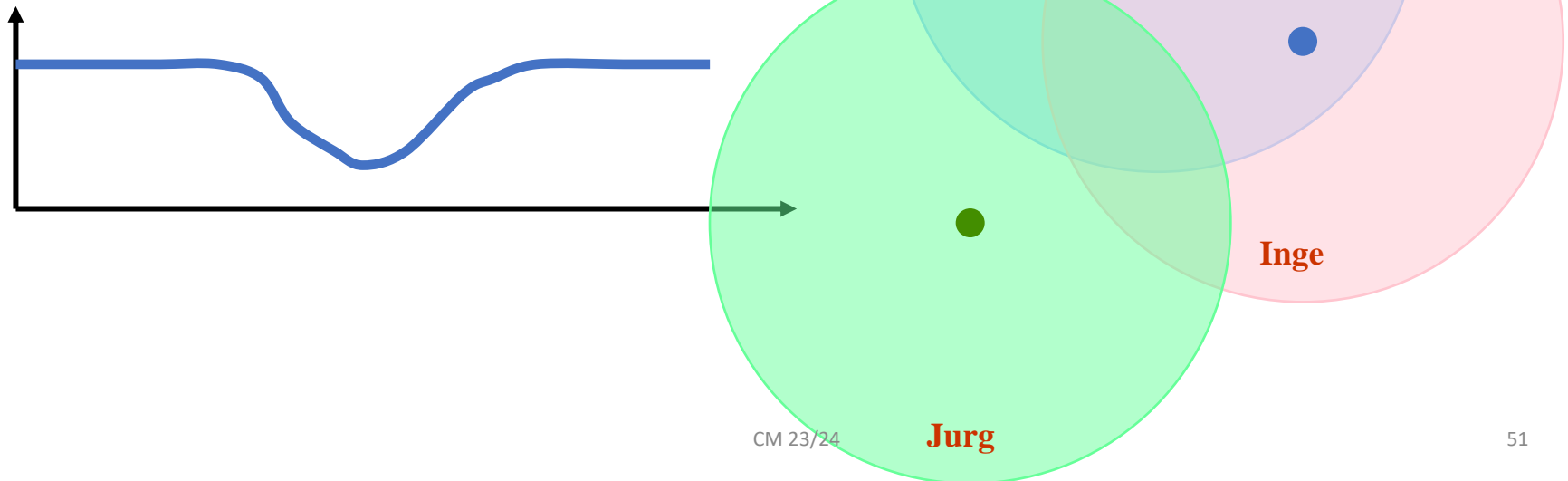
- Quality of the transmission depends on distance and other factors.
- Affects the throughput mobile users achieve.
- Worst case is periods with no connectivity!





Mobility is an Issue even for Stationary Users

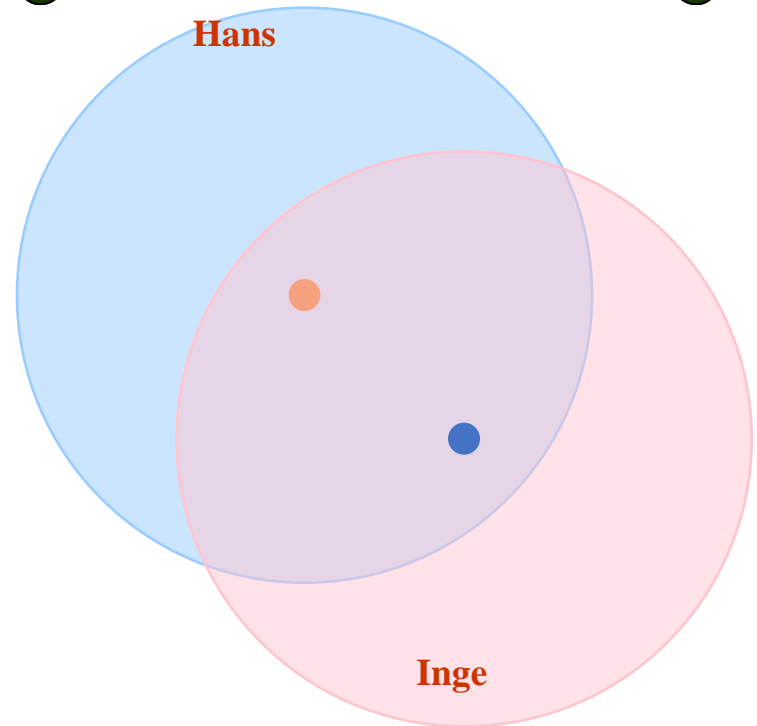
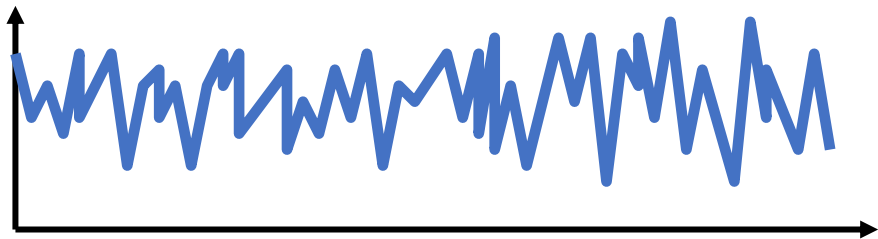
- Mobile people and devices affect the transmission channel of stationary nodes.





And It Gets Worse ...

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



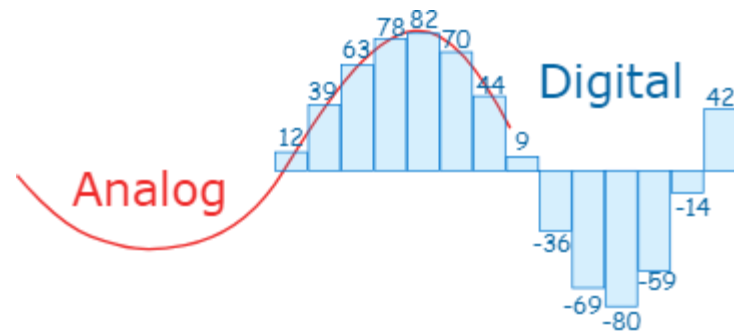


The Mobile Network

Basic principles of wireless signal properties



Time-Domain View

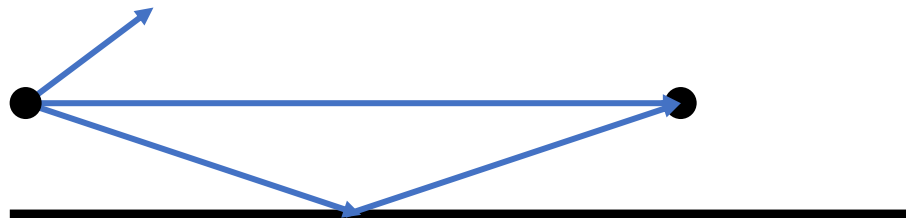
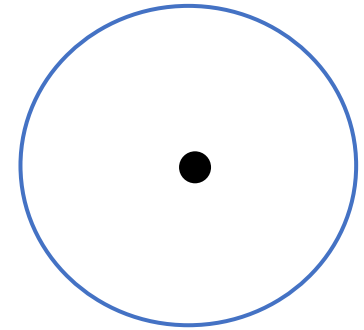


- Can be used to represent both an analog and a digital signal.
- Analog signal - signal intensity varies in a smooth fashion over time
 - No breaks or discontinuities in the signal
 - E.g. voice signal traveling over traditional phone line
- Digital signal - signal intensity maintains a constant level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

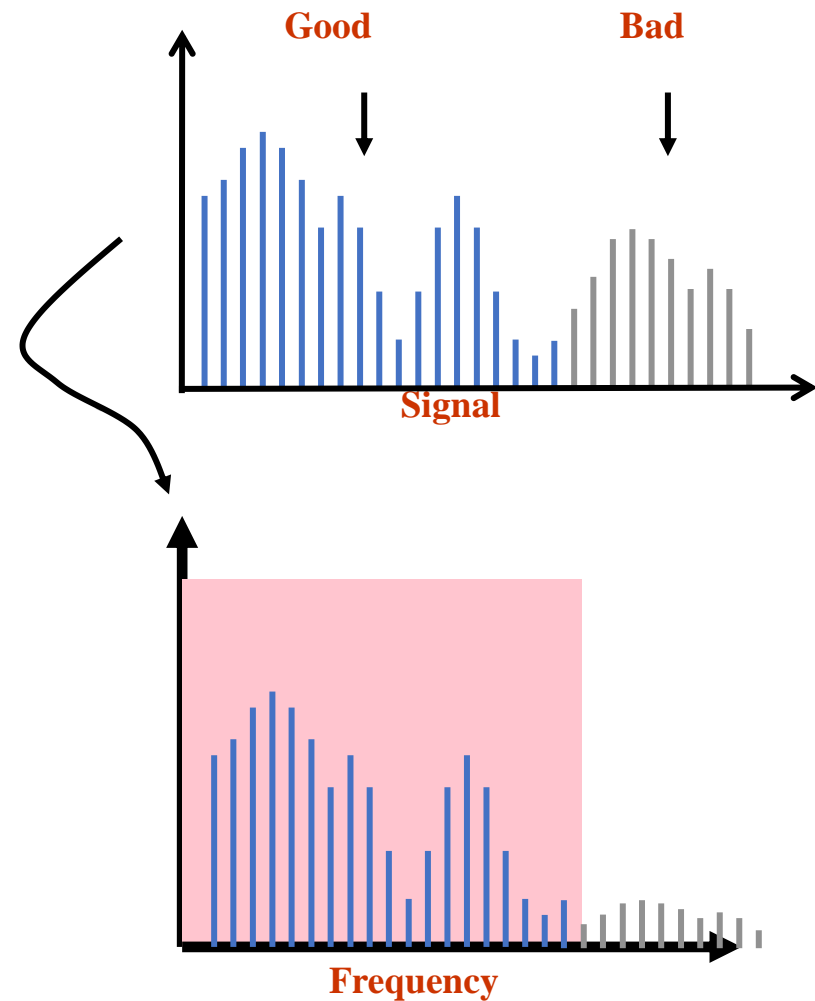
- Both are real in some way
- Think of it as energy that radiates from an antenna and is picked up by another antenna.
 - Helps explain properties such as attenuation
- Can also view it as a “ray” that propagates between two points.
 - Helps explain properties such as reflection and multipath





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

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- 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

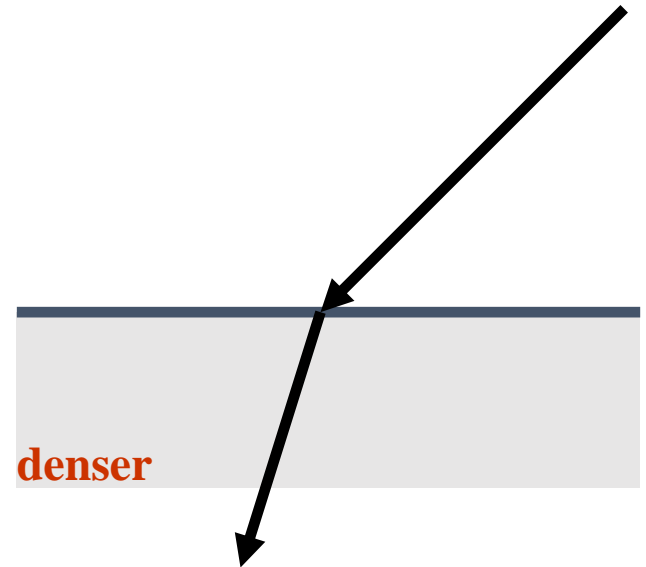
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- Attenuation in free space: signal gets weaker as it travels over longer distances
 - Radio signal spreads out – free space loss
 - Refraction and absorption in the atmosphere
 - Frequency dependent!
- Obstacles can weaken signal through absorption 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**



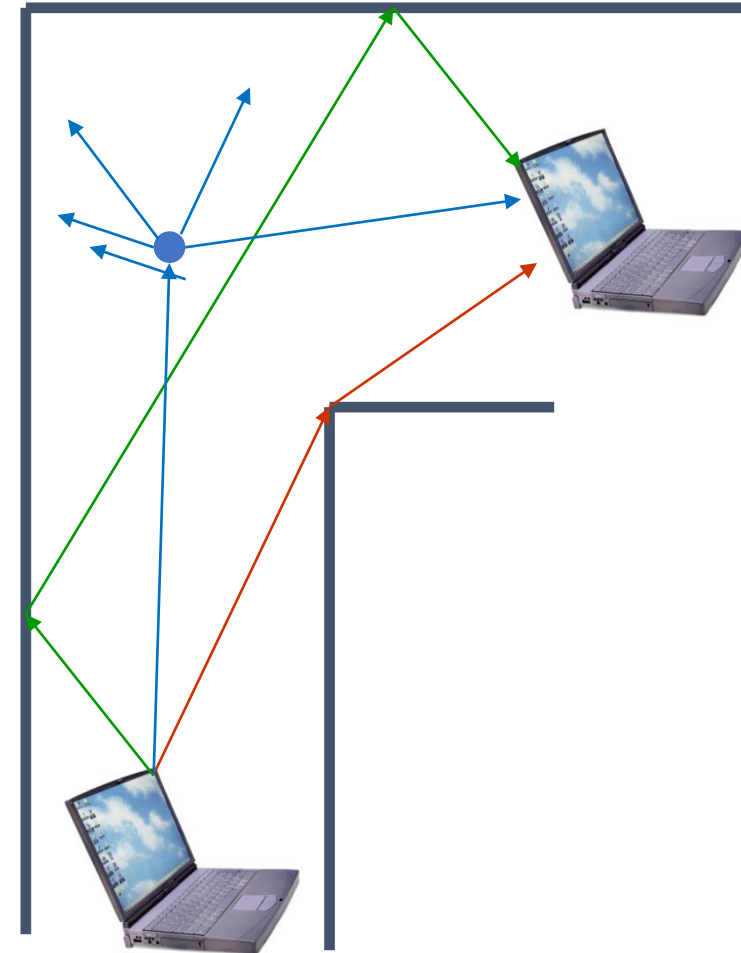
Other LOS Factors

- 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

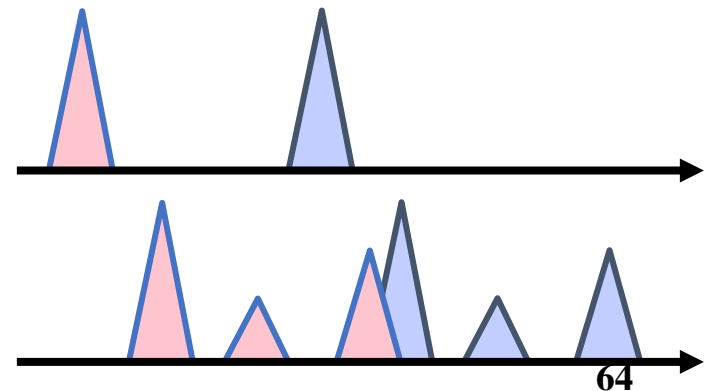
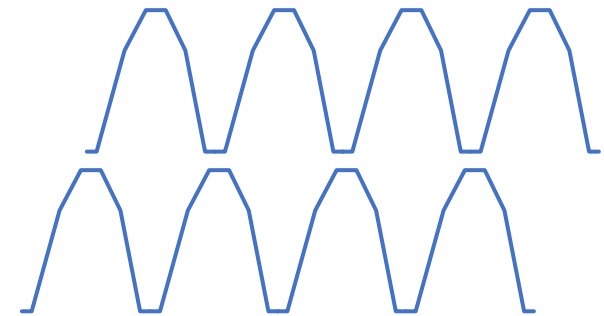
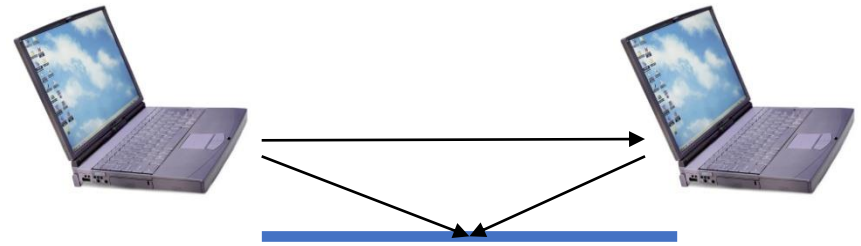
- Besides line of sight, signal can reach receiver in three other “indirect” ways.
- **Reflection**: signal is reflected from a large object.
- **Diffraction**: signal is scattered by the edge of a large object – “bends”.
- **Scattering**: signal is scattered by an object that is small relative to the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

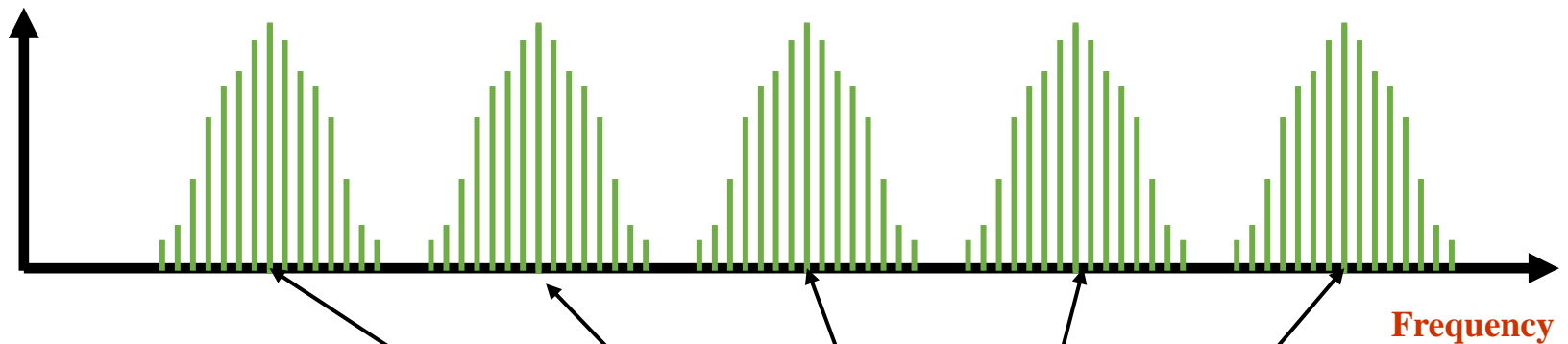
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- Protects digital data by introducing redundancy in the transmitted data.
 - Error detection codes: can identify certain types of errors
 - Error correction codes: can fix certain types of errors
- **Block codes** provide Forward Error Correction (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

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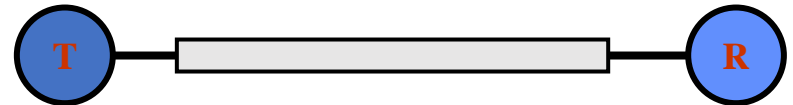
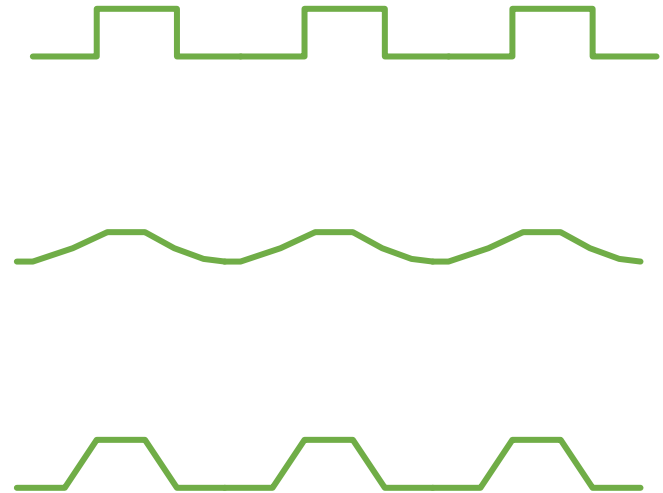


**Different users use
Different carrier frequencies**



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

- 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

CM 23/24



Satellite networks