Arquitecturas de Comunicações

Engenharia de Computadores e Telemática
4º ano, 1º semestre, 2021/2022

Outcomes

- Understand the historic pressures that created the current telecommunications infrastructure
- Discuss the liberalization of the phone network, the data dominance, and the apperance of mobile communications
- Understand the trend towards a digitized converged network

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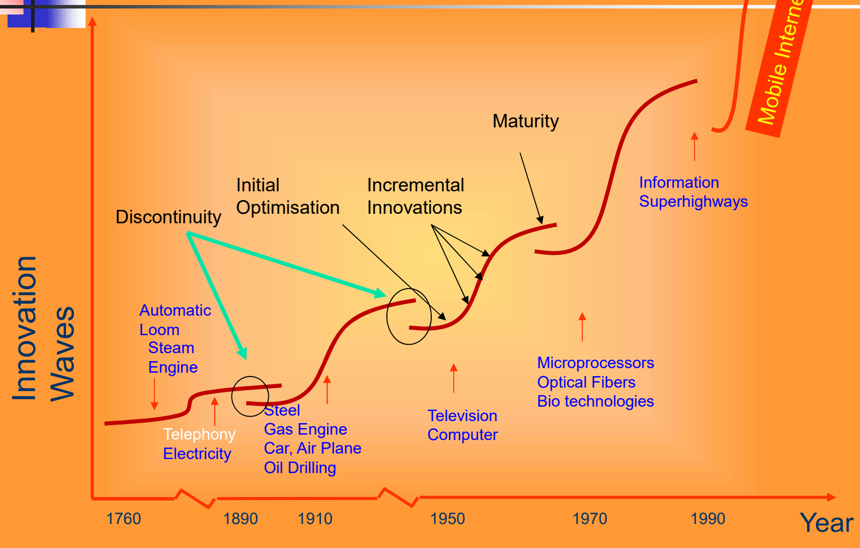
The communication network

Trends and history

Technological Revolutions



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Trends in communications

- Current telecommunication industry has been the result of different trends in the last 30 years:
  - The saturation of the telephone market, at the end of the 80ies → *The phone network*
  - The coming of age of the data world, in the early 90ies → *The Internet*
  - The pervasiveness of mobility, in the mid 90ies → *Mobility: voice and data*

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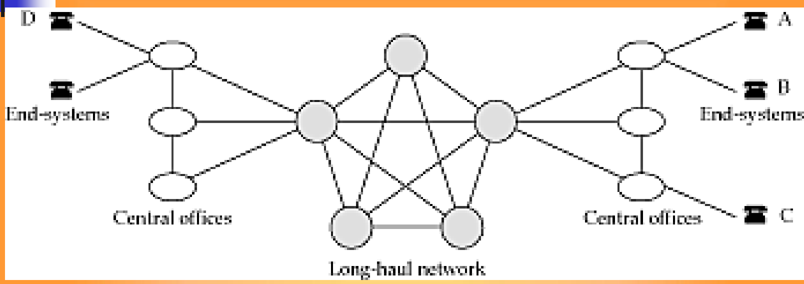
The communication network

The phone network

Telephone System



- Uses switched circuits (virtuals...)
- Access via low bandwidth circuits
- "out-of-band" call establishment using signalling system based in packets (SS7 – Signalling System 7)
- Channels between switching exchanges carry multiple calls
  - Multiplexing (analogue or digital)

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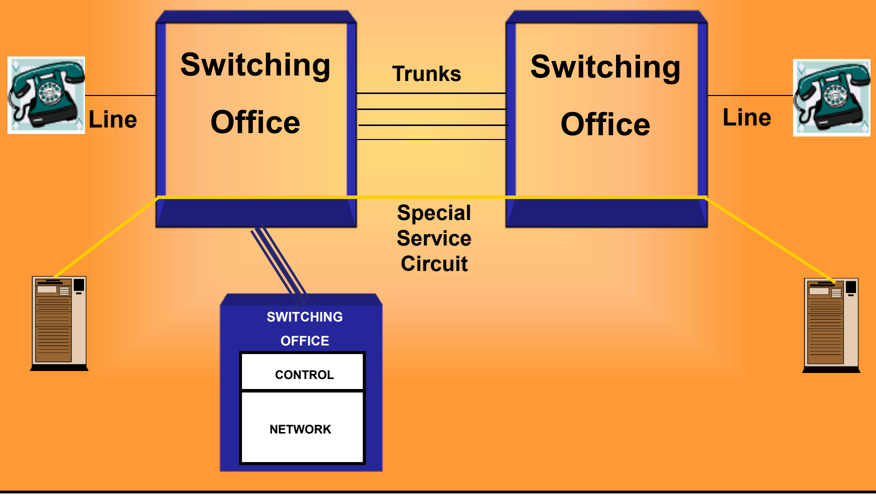
Public Switched Telephone Network (PSTN)

Major Components of the Public Switched Telephone Network (PSTN):

- Switching Offices
- Transmission facilities
- Customer Premise Equipment (CPE)

Transmission Facilities in Switching Offices

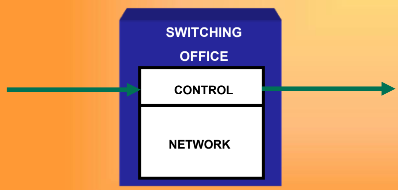


Essential part in circuit-switching is the:

SIGNALING

Signaling

Signaling is the generation, transmission, and reception of information needed to direct and control the setup and disconnect of a call.



Signaling

- In-band signaling
  - The communication (setup and teardown phases) is performed by human operators and finished in the same circuit for both signaling and voice communication.
- Out-of-band signaling
  - Use the digital signals to create a connection between the caller and the called parties.
  - A portion of the voice channel bandwidth is used for signaling.

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Signaling Systems Today

- Signaling system's tasks nowadays
  - Providing dial tone, ring tone, and busy tone
  - Transferring telephone numbers between offices
  - Maintaining and monitoring the call
  - Keeping billing information
  - Maintaining and monitoring the status of the telephone network equipment
  - Providing other functions such as caller ID, voice mail, and so on

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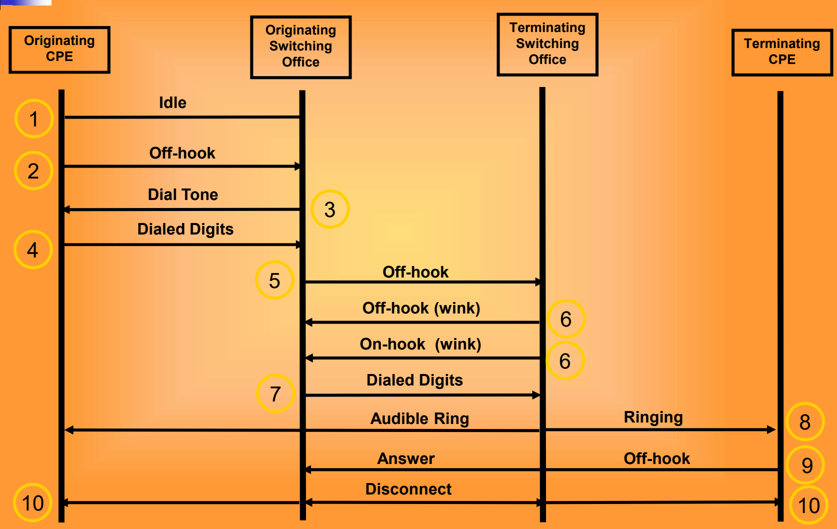
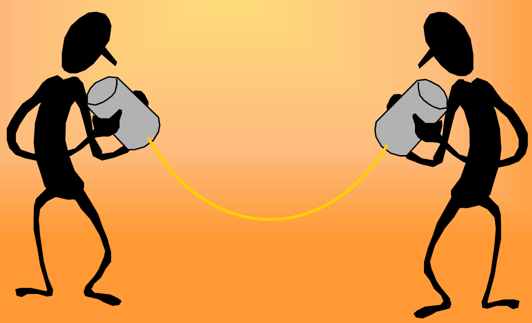
Signaling

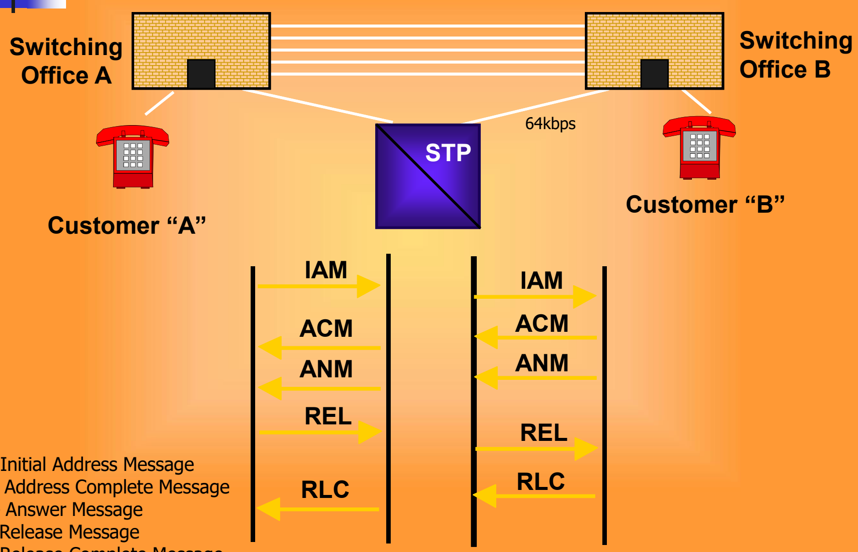


Common Channel Signaling (CCS)

Common Channel Signaling (CCS) is a signaling method that uses a separate dedicated channel to send and receive signaling information for a group of trunks or facilities by means of labeled messages.



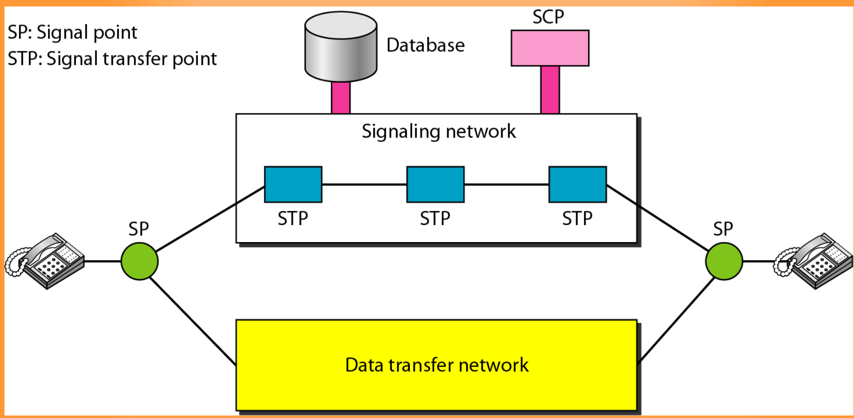
SS7



IAM – Initial Address Message
ACM – Address Complete Message
ANM – Answer Message
REL – Release Message
RLC – Release Complete Message

Data transfer and signaling networks

SCP: service control point



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SS7

The SS7 network and protocol are used for:

- Basic call setup, management, and tear down
- Wireless services
  - personal communications services (PCS), wireless roaming, and mobile subscriber authentication
- Local number portability (LNP)
- Toll-free and toll wireline services
- Enhanced call features
  - such as call forwarding, calling party name/number display, and three-way calling
- Efficient and secure worldwide telecommunications
- SMS (Short Message Service)

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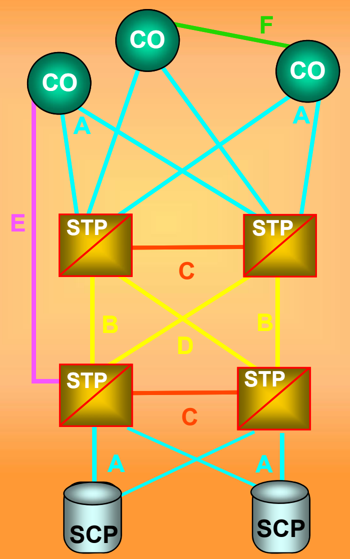
Signaling System 7 (SS7) LINKS



CO – central office

Layers in SS7

Upper layers	TCAP	TUP	ISUP
		SCCP	
Network layer	MTP level 3		
Data link layer	MTP level 2		
Physical layer	MTP level 1		

MTP: Message transfer part
SCCP: Signaling connection control point
TCAP: Transaction capabilities application port
TUP: Telephone user port
ISUP: ISDN user port

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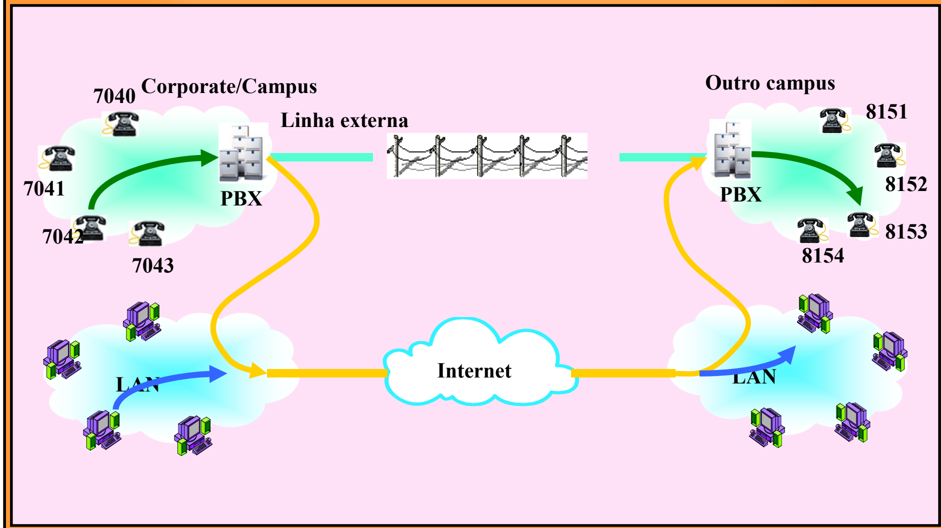
IP Telephony: when the PBX was replaced



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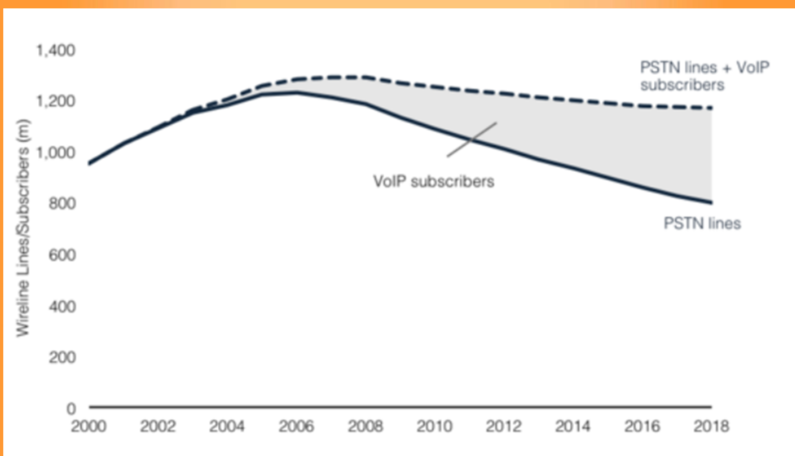
Voice is changing its profile as well

- VoIP on the rise, even in terms of formal subscriptions



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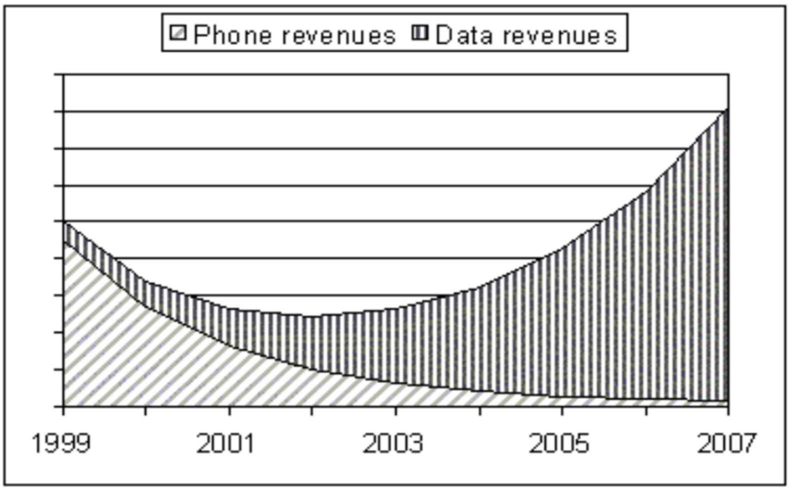
Evolution (@time): profits voice vs data



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The communication network

The Internet

Data Communications

- With increasing digitalization of all media, EVERYTHING is data communications
- We live in a Global Village
  - Supported by the Internet

<u>*Global computer network*</u>

  - A *comunity of communities*
  - The "*information highway*"
  - Also known as Cyberspace

Influence books:
- The third wave, Alvin Toffler
- Neuromancer, William Gibson

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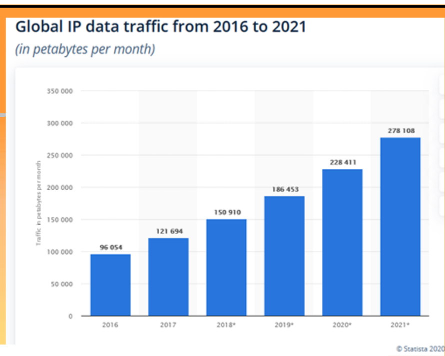
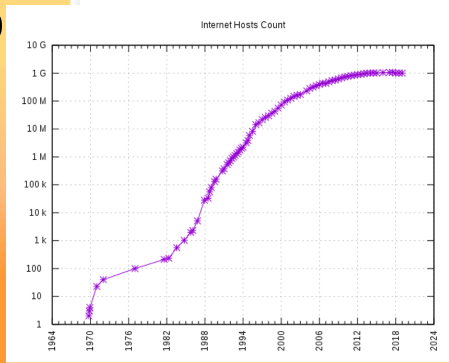
Global IP Traffic

- Total internet traffic has exploded
  - 1992, total traffic = 3TB month
  - 2014, total traffic = 450 EB month
  - 2020, total traffic = 220PB month





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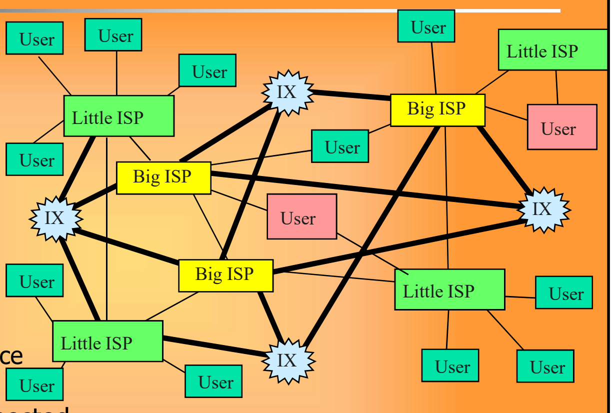
Internet: history

- In the beginning:
  - Internet: R&D network
  - Homogeneous user community, with values and joint understanding
- Now:
  - Internet is comercial!
  - Internet used for
    - Both work and diversion
    - By people with very different values (if existing...)
- "Comercial" Internet
  - 1989 – First commercial ISPs (UUNet and PSI)
  - NSFNet blocked of commercial usage, but creating follow-up commercial service providers
  - In Europe, delay due to discussion on OSI acceptance
    - First ISP comercial (EUNet) only in 1991
  - In Pacific, problems also associated with OSI...
    - First ISP comercial (IIJ) in Japão in 1992

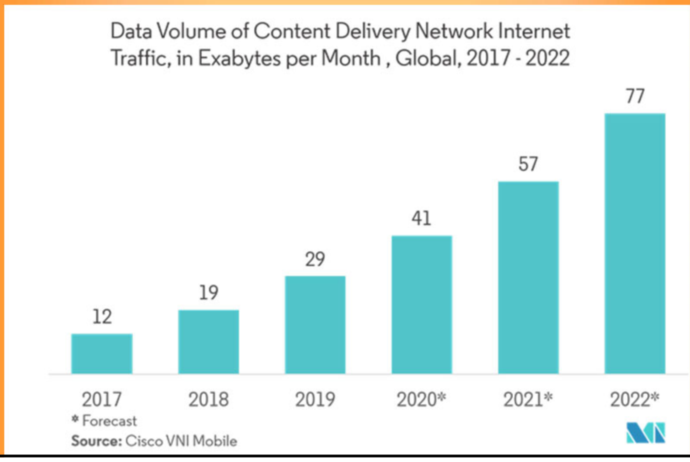
Real structure



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

The impact of CDNs

- Changes in traffic topology are being brought about by the increasing role of Content Delivery Networks (CDNs) in data delivery.
- CDNs will carry 72 percent of total Internet traffic by 2022



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The Applications in the Internet

"Data vs voice": packet swithcing vs circuit switching

Packet switching solves everything?

- Great for burst information
  - Resource sharing
  - No cal 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

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Transport service (operador/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.

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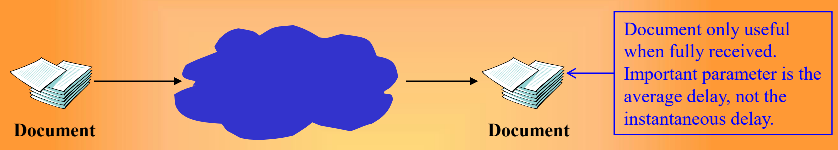
Elastic operations



- 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 (*generally, between reasonable values*)
    - Best effort works…

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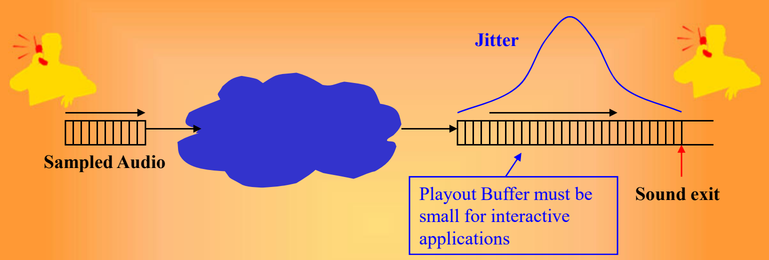
Inelastic applications



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

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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 mseg
Streamed audio/video	supports	See above	yes, poucos segs
Interactive gaming	supports	Some Kbps	yes, 100's mseg
Finance applications	lossless	elastic	Yes and no

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Interactive flows, real-time

- Audio-Video Flows
  - streaming audio/video
  - Use buffering at receiver
- Interactive real-time:
  - Buffering in receiver very limited
  - Delay <200ms
  - jitter <200ms
  - Keep low losses
- Loss impact:
  - depends on aplication, media, and user
- Áudio:
  - Humans tolerate "bad" audio for conversation
  - Humans require "good" audio for entertainment
- Vídeo:
  - Humans tolerate "low" video quality for business
  - Humans enjoy "good" video quality for entertainment
- Synchronizing audio/video:
  - Different flows?

Audio

QoS Requirements

- Delay < 400ms:
  - Including jitter
- Low losses are preferable:
  - some coding systems are tolerant to low losses
- Data rates:
  - Voice ≤ 64Kb/s
  - "good" music ≥ 128Kb/s

- Time-domain sampling
- Example – coded voice:
  - Coded 64Kb/s PCM
  - Sampling 8-bit
  - 8000 samples/sec
  - 40ms "time slices" for audio
  - 320 bytes (audio) per packet
  - 48 bytes overhead (20 bytes IP header) (8 bytes UDP header) (20 bytes RTP header)
  - 73.6Kb/s

Voice coders taxonomy

- Voide coders
  - Wave coders
    - Time domain: PCM, ADPCM
    - Frequency domain: e.g. Sub-band coder, Adaptive transformer coders
  - Source coders
    - Linear Predictive coder
    - Vocoder

- Vocoders:
  - Analyze voice, extract parameters, transmit model parameters
    - Voice synthesized by parametric models
  - LPC-10: 2.4 kbps
- Wave coders: try to preserve the wave format, not voice specific.
  - PCM 64 kbps, ADPCM 32 kpbs, CVSDM 32 kbps
- Hybrid: Try to combine the best of both… Eg: CELP

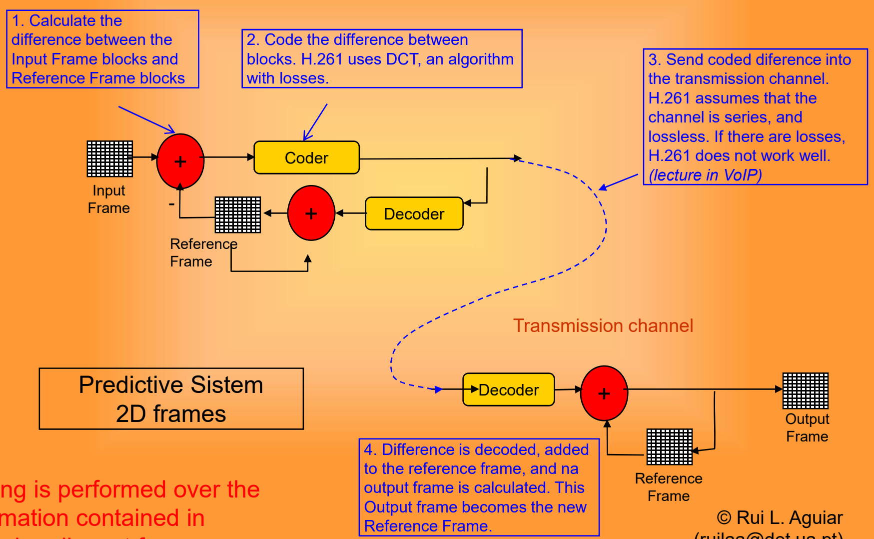
Vídeo

QoS Requirements

- Delay < 400ms:
  - including jitter
  - Equal to audio
  - Allows synchronization of flows
- Data rate – depends of:
  - Frame size
  - Color depth
  - frame rate
  - coding

- Usually processing on frequency domain:
  - discrete cosine transform (DCT) very common
- Losses need to be low

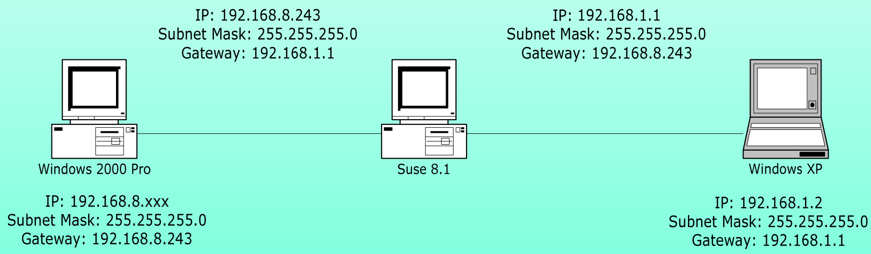
Example Standard H.261



Coding is performed over the information contained in multiple adjacent frames

Aplicações testadas

Esquema e configuração



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Chamada de voz

- Aplicação inelástica adaptativa
- Corre sobre o protocolo UDP, o que não nos dá garantias de que os pacotes sejam entregues nem que cheguem ordenadamente
- O NetMetting usa o protocolo G.723.1 para áudio o qual é resistente a perdas

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Testes realizados para uma chamada de voz

- Sem alterações
- Com perda de 10% de pacotes
- Com perda de 30% de pacotes
- Largura de banda limitada a 1.5 KB
- Largura de banda limitada a 1 KB
- Reordenamento de pacotes

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Sessão de Videoconferência

- Aplicação inelástica adaptativa
- Neste caso o NetMeeting utiliza o protocolo de vídeo H.263, que é sensível a perdas e duplicação de pacotes
- O protocolo de transporte de dados utilizado é o RTP que corre sobre UDP

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Testes realizados para uma sessão de videoconferência

- Com perdas de 1% de pacotes

- Com perdas de 5% de pacotes

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Videoconferência (cont)

- Duplicação de 1% de pacotes

- Duplicação de 10% de pacotes

- Não tolera reordenamento

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Transmissão de áudio gravado

- Aplicação inelástica interactiva porque permite pausas e reposicionamento
- Pode correr sobre TCP ou UDP
- Largura de banda mínima é igual a taxa de codificação

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Testes realizados para transmissão de áudio gravado

- Música com bitrate de 128 Kbps
  - Sem alterações
- 5% de perdas
- 15% de perdas
- Atraso de 200 ms
- Largura de banda limitada a 10 KB
- A duplicação não gera alterações

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Transferência de ficheiros

- Aplicação elástica
- Corre sobre TCP, o que garante a entrega de todos os pacotes e a sua ordenação

- Tamanho do ficheiro 66.1 Mbits
- Tempo de transferência (aprox.) 2 minutos, com L.B. de 900 KB/s

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Testes realizados para transferência de ficheiros

Atraso (ms)	%Perdas	%Duplic	L.B. média (B/s)	Tempo Tx.(min)
50	-----	-----	150 000	12
100	----	-----	50 000	36
-----	5	-----	150 000	12
-----	15	-----	1 500	Nunca +
-----	-----	10	900 000	2
-----	-----	50	790 000	5

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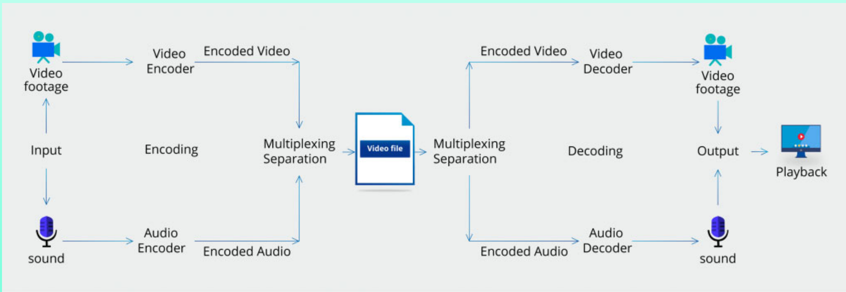
Study of video transmission with different codecs over a non-ideal network

Daniel Bastos, Marco Fernandes, Renato Afonso, Bruno Brandão
MAP-Tele program - 2019/2020

The codecs



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The codecs

H.264

It's a digital video compression standard that uses half the space of MPEG-2 to deliver the same quality video, being defined as a **block-oriented**, **compensation-based video compression**

Div3

Is based on the Microsoft MPEG-4 version 3. Microsoft had locked its own codec so that it could no longer be used to encode AVI's as it could **only encode** in Microsoft's **proprietary** format. Div3 has two versions: a

Mpeg 4

Includes compression of AV data for web and CD distribution, voice (telephone, videophone) and broadcast television applications. Is **efficient** across a variety of bit-rates ranging

Wmv 2

Consists on a series of **video codecs** and their corresponding video coding formats developed by **Microsoft**. It is part of the Windows Media framework.

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Methodology

MAP tele

- **Simulation part:**
  - Simulation in GNS3;
  - Uses Ubuntu VMs with different IPv4 address;
  - The VM in the middle configured in bridge mode;
  - Now the sender can communicate with the receiver;

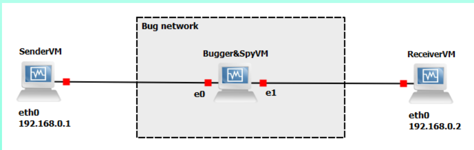


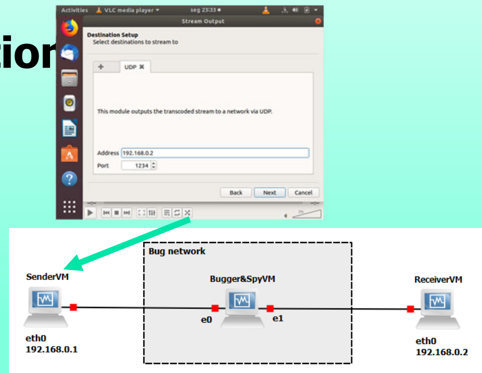
Diagram of the simulation setup deployed, capable of video streaming and network traffic shaping

5

Methodology

MAP tele

- **Simulation part:**



6

Methodology

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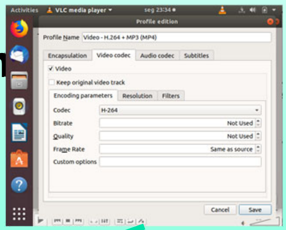
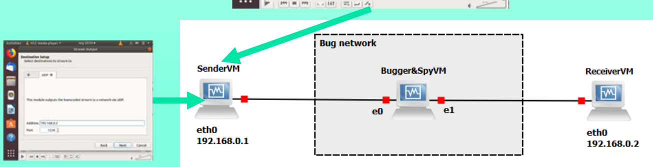
MAP tele

- **Simulation part:**





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Methodology

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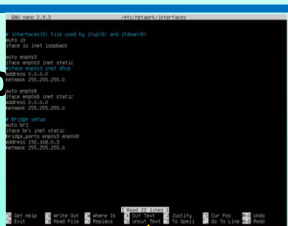
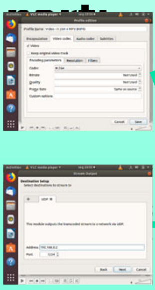
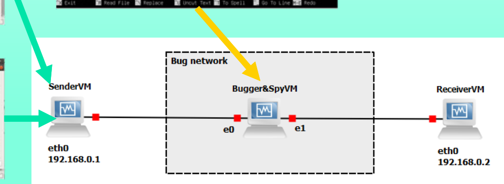
MAP tele

- **Simulatio**







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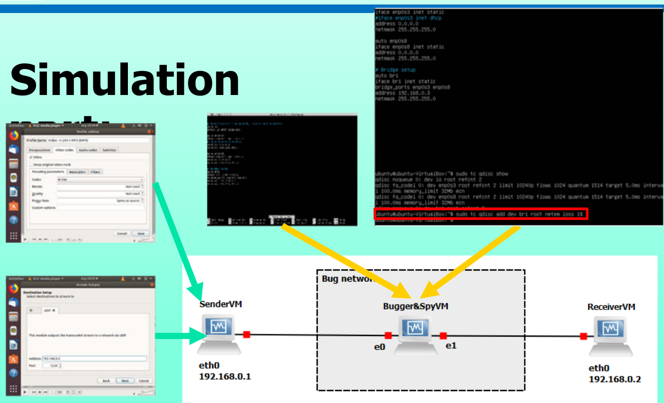
Methodology

- **Simulation**



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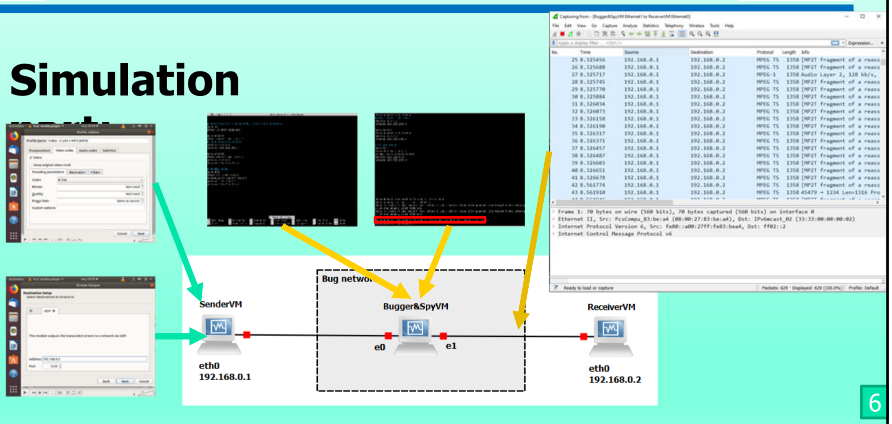
Methodology

- **Simulation**



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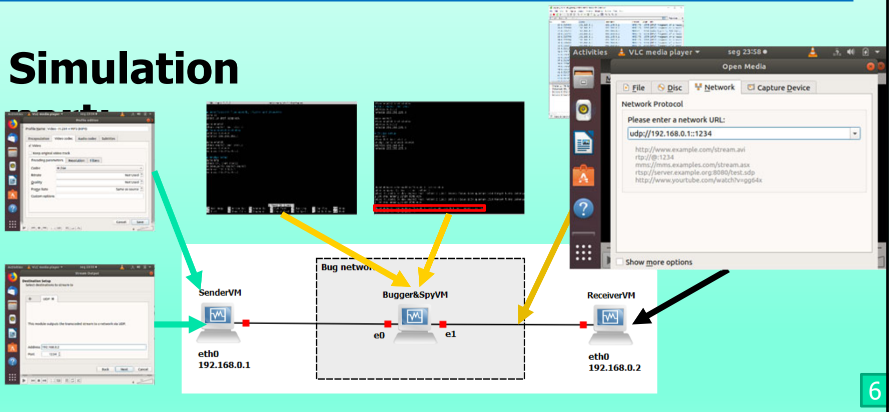
Methodology

- **Simulation**



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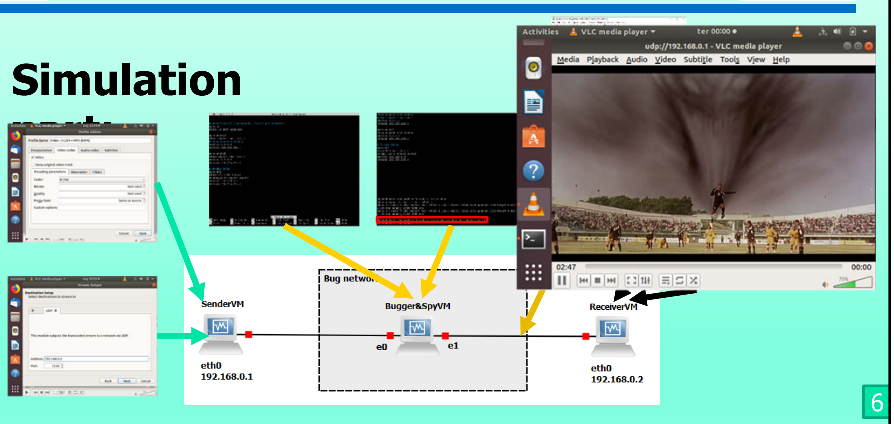
Methodology

- **Simulation**



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Methodology

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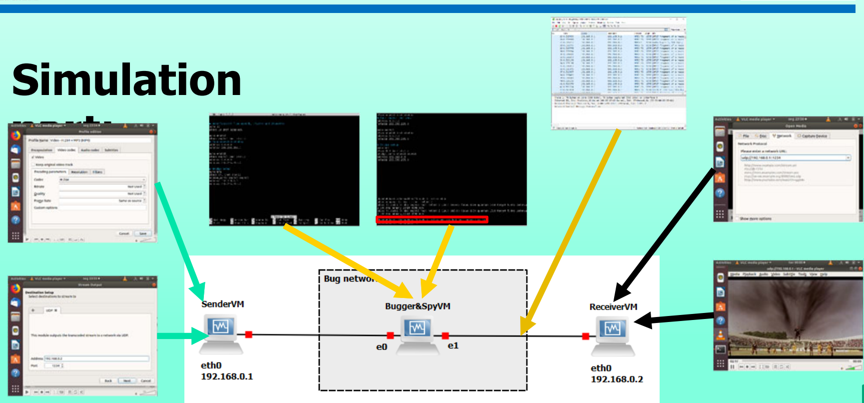
MAP tele

- **Simulation**



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Methodology

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MAP tele

- **Experimental part:**
  - Multiple codecs will be used in the transmission to test their robustness to network bottlenecks;
  - Configure different static IPv4 addresses in each PC;
  - Verify connection between terminals (ping);

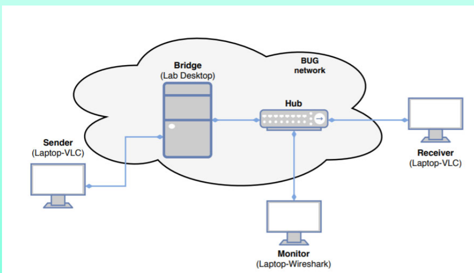

Diagram of the experimental setup deployed, capable of video streaming and network traffic shaping

7

Video Quality metrics

Some state-of-the-art tools:

- NTIA/vqm
  - Developed by ITS (Institute for Telecommunication Sciences, US)
  - Implemented in Matlab, compiled versions of different software packages available
  - Metrics: PSNR, VFD (Variable Frame Delay)
- VQMT: Video Quality Measurement Tool (EPFL)
  - Fast implementations of objective metrics: SSIM, PSNR, MS-SSIM, …
  - Implemented in OpenCV (C++)
- Netflix/VMAF
  - Video Multimethod Assessment Fusion (VMAF)
  - Perceptual video quality assessment algorithm
  - Most sophisticated, but also most complex
- google/rtc-video-quality
  - Compare (Real-Time) Video Codec Performance
  - Metrics: SSIM, AvgPSNR
  - *(Not an official Google product)*

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Video Quality metrics

- A simplified frame by frame analysis approach of the different received videos was chosen.
- The chosen video quality metrics were calculated by using some already built-in functions of **Matlab's Image Processing Toolbox**, thus reducing the complexity of application of the typical video quality measurement tools

- ✓ **MSE**: Mean-Squared Error between two given frames
- ✓ **PSNR**: Peak Signal-to-Noise Ratio, can be obtained from the MSE of two given frames and the dynamic range that the video pixels can have,
- ✓ **SSIM**: Structural Similarity index and takes into account different aspects of a frame and its reference frame to calculate a quality index.
- ✓ These metrics are considered as **full-reference** metrics.

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Video Quality metrics

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MAP tele

Methodology

- Consider two sequences of frames:
  - Video received for "ideal" network conditions
  - Video received for given network impairment
- Analyze and compute metrics for each frame of the distorted video for a given network problem
  - Which frame should be considered as the reference frame?
  - Our solution: The frame of the "ideal" received video that is closer to the to be evaluated frame of the distorted video, in terms of MSE
  - Search task to choose best frame pairings was too big, so some adjustments were employed to simplify it, such as evaluating the frame continuity.
- Same approach of calculating these metrics employed for all test cases, for both **simulated** and **experimental** realizations of the system.

The test results that were included on the report are next shown:

- ✓ Delay 5 ms and 2000 ms
- ✓ Packet loss 0.1% and 1%
- ✓ Packet duplication 0.5%
- ✓ Packet reordering 0.5%

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Results: simulation

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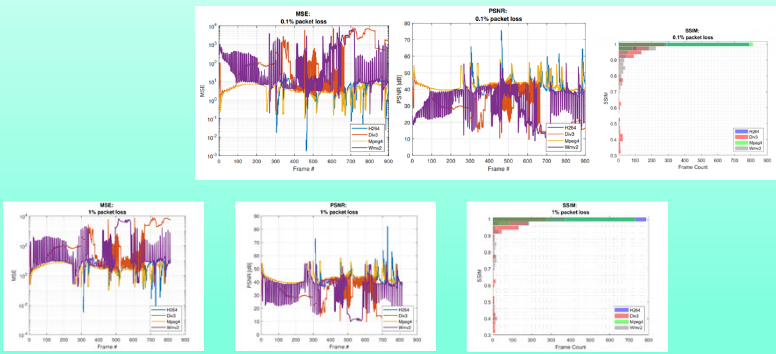
MAP tele



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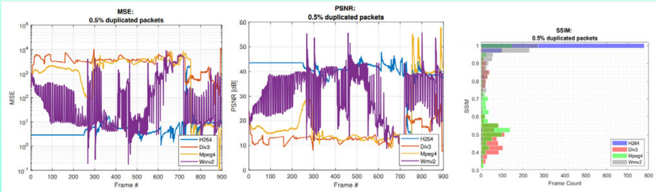
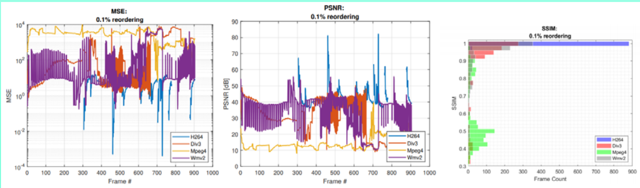
Results: simulation





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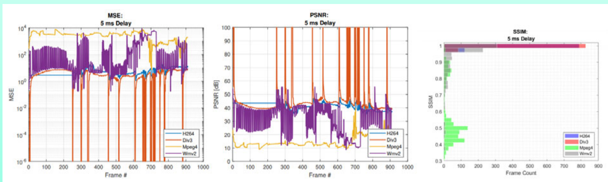
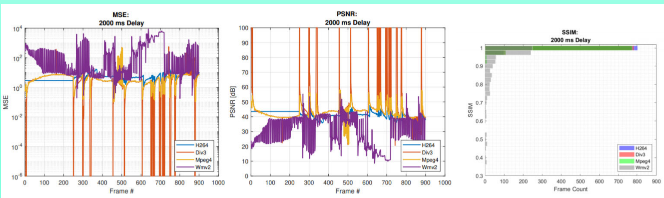
Results: simulation





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Results: experimental

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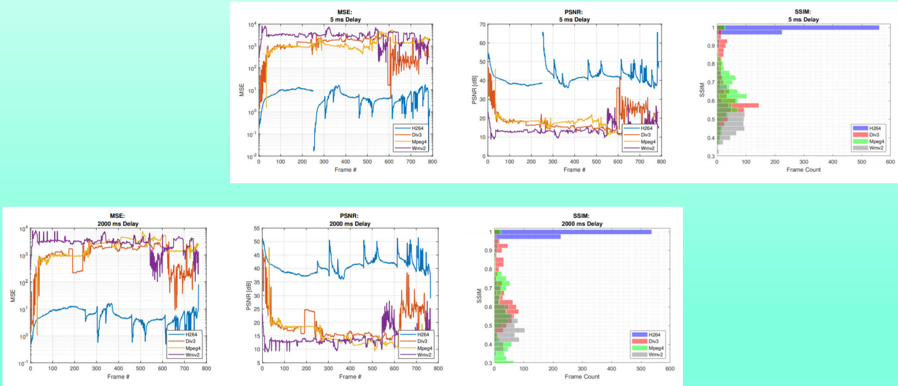
MAP tele



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Results: experimental

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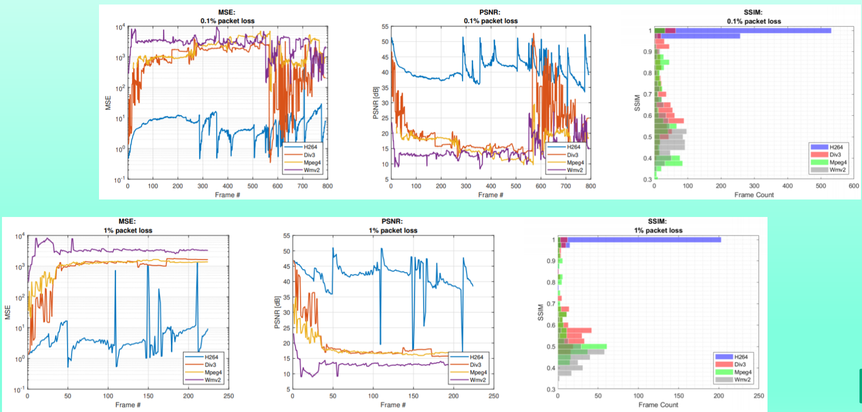
MAP tele



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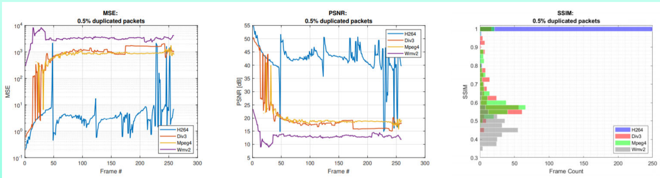
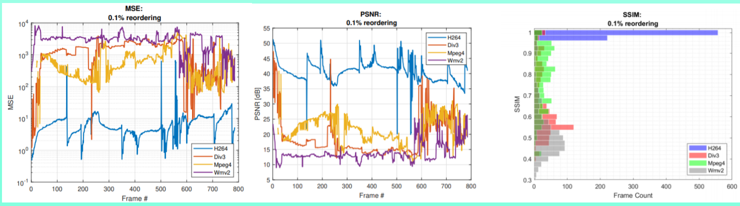
Results: experimental





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Conclusion

- Resilience of **codecs** H264, Div3, Wmv2 and MPEG4 to different impairments;
- **Delay**, **packet loss**, **duplication** and **reordering** were implemented in simulation and in a laboratorial scenario;
- **Video quality metrics** were applied/implemented in MATLAB;
- The obtained results showed an expected **difference** between a **simulation** environment and a **real-case** scenario;
- The codec **H264** was the **more robust;**
- This higher tolerance to network problems explain the reason behind the usage of this codec by most world-class stream environments.

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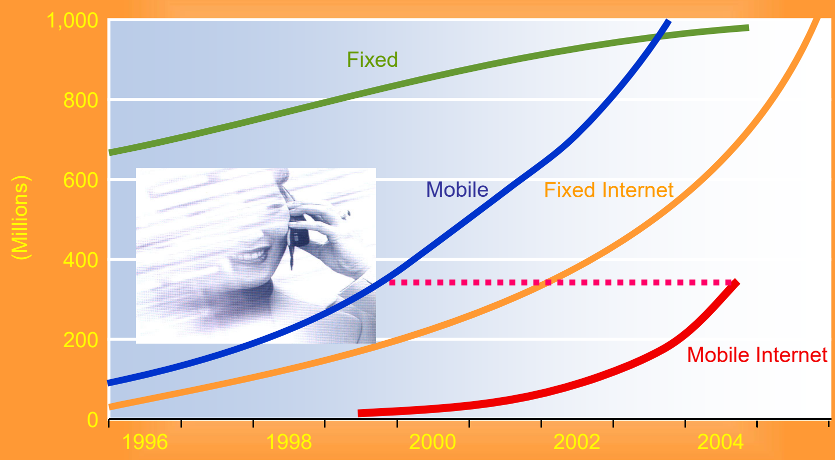
The communication network

Mobility: voice and data

The Rush to a Billion!



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Mobile environment issues

- Mobile Networks limitations
  - Heterogeneity of multiple independent networks
  - Frequent connection dropouts
  - Limited Bandwidth
- Mobility impose limitations
  - No mobility notion at systems and applications
  - Issues with route maintenance in routers
- Mobile device limitations
  - Small battery lifetime
  - Limited capabilities

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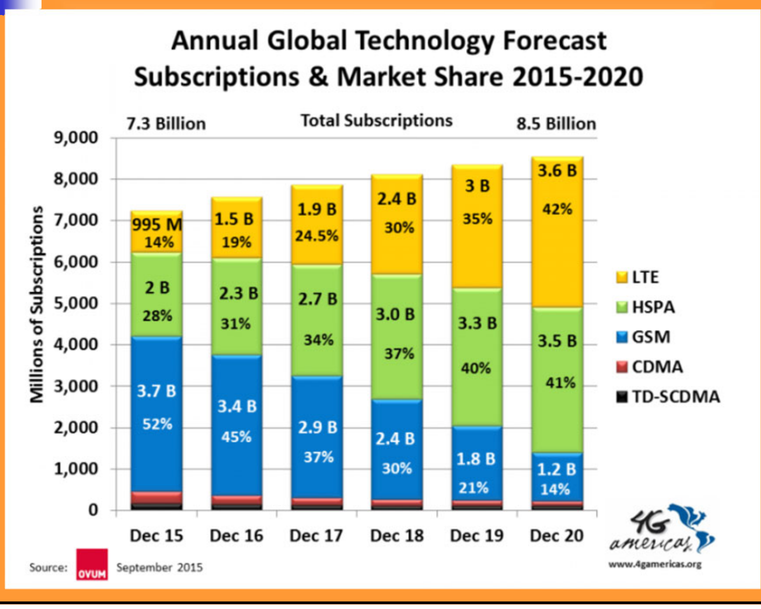
Mobile Technology Evolution



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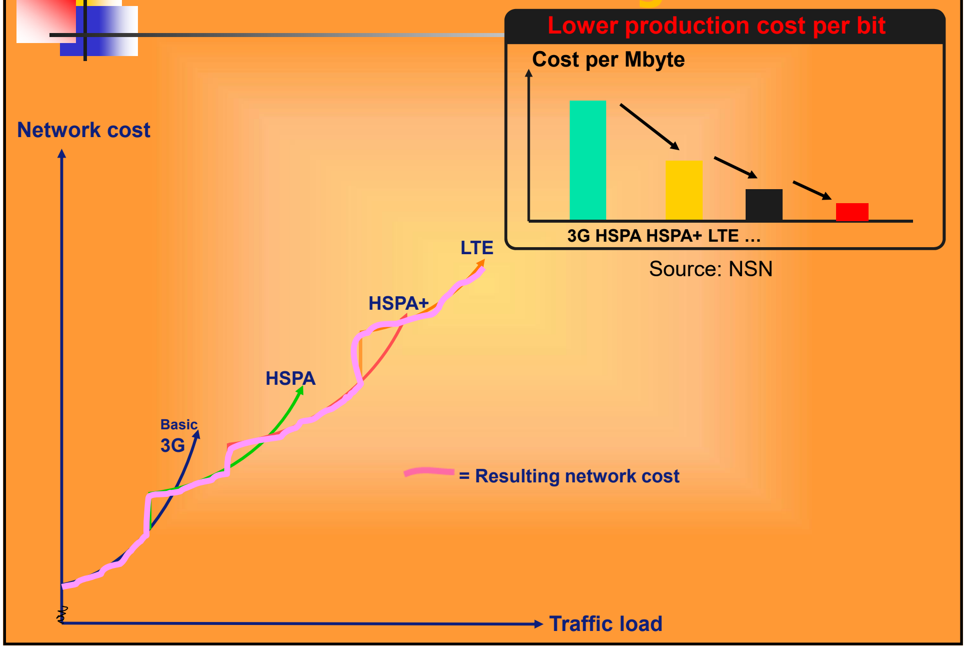
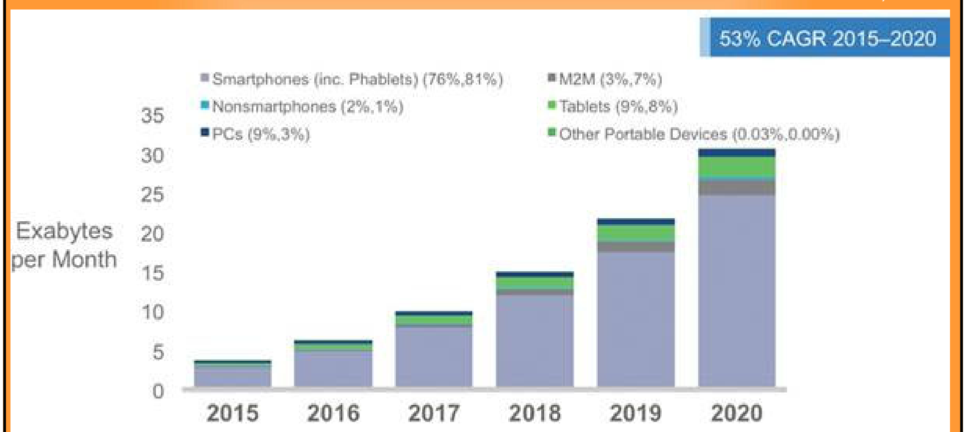
Motivations for technologies



Global Mobile Growth by Device type

Source: Cisco VNI Mobile, 2016

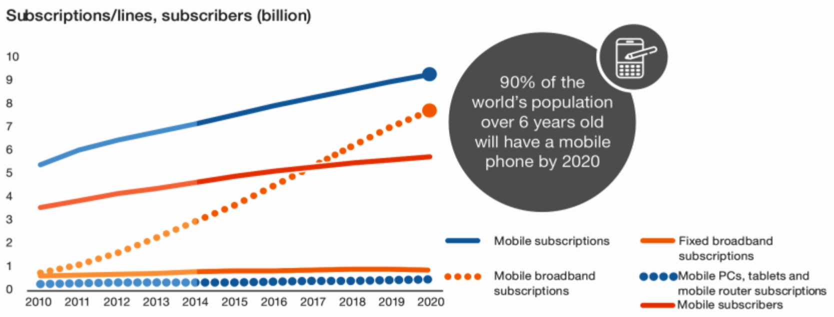


Figures in parentheses refer to 2015, 2020 device share.
What is the dominating traffic?

But it is all mobile…

Mobile Broadband

- Mobile broadband subscriptions will reach 7.7 billion globally by 2020.



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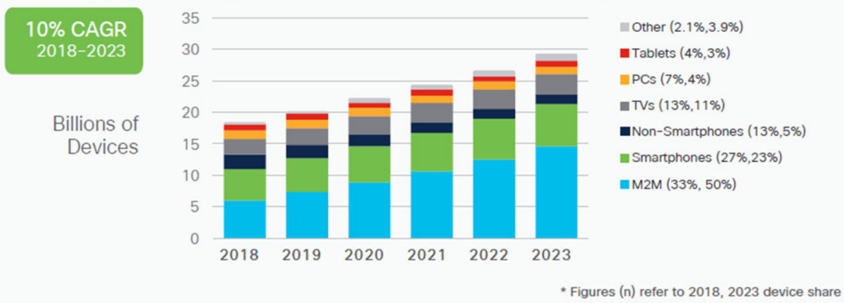
And now, also…

- M2M devices increasingly dominant
- "regular" PCs are becoming increasingly a minority
- IoT is a dominant trend



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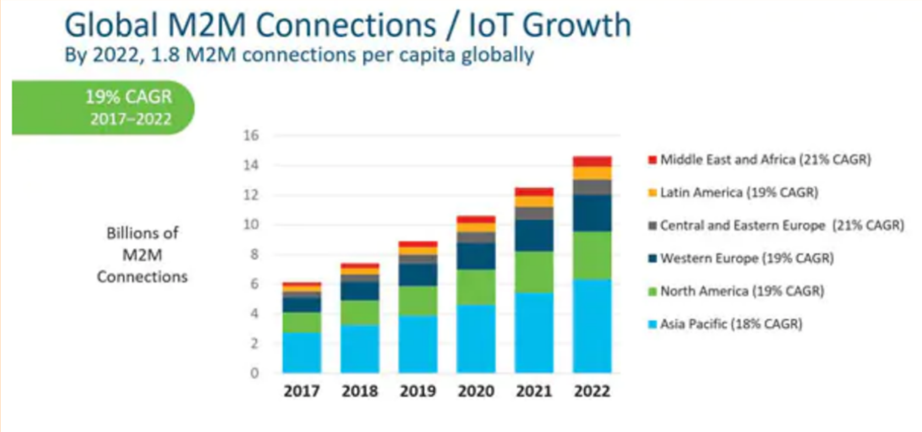
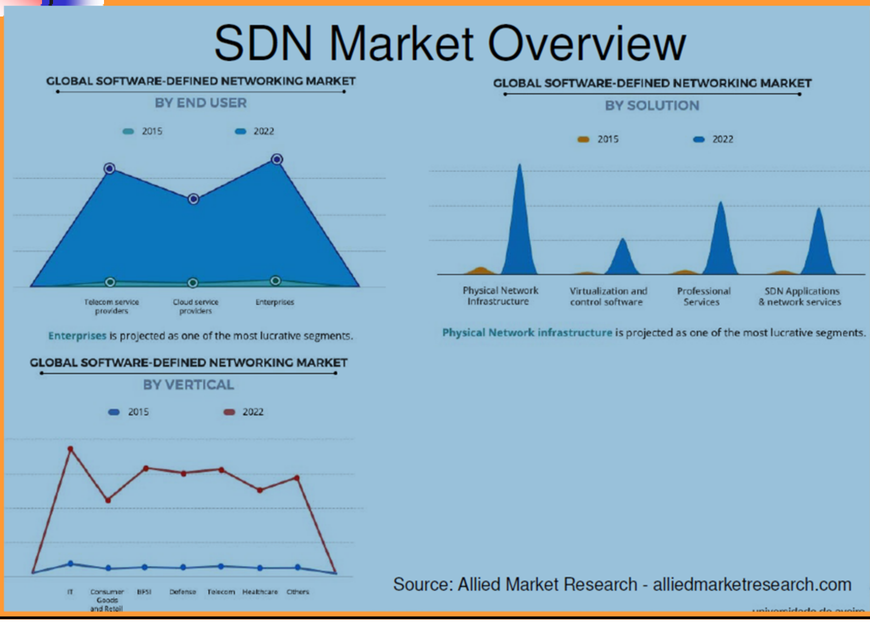
M2M developments

- IoT is increasing 20% per year, and devices are changing their formats.



The network will need to be adaptable to all types of services



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What changed

- Voice was very profitable
- Design of networks for voice allowed the design for peak traffic (95% of peak)
  - Voice is very predictable

  Voice systems were easy to build and very profitable to operate.
- Initially, data used only the “margin” of the voice network
  - Data was a small part of traffic
  - Very profitable as well in the beginning, as it was charged at voice costs, paid by big companies, and did not have special infrastructure

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Trends: the Internet era

- Internet appeared
  - Public networks transport mosly data
  - Low entry cost in market
  - Huge growth in the data traffic
- Market liberalization impacts:
  - New operators
  - Huge competition in the profitable markets
    - Mobile service
    - Internation services
  - Competition in the data market

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Trends: the Internet crisis

- Internet Growth
  - Data rose fast to become 70% of traffic...
  - ... But only 2% of the profit of the traditional operators
  - Very low margins, not easy to invest to expand the network
  - Liberalization helped consumer, but hard on infrastructure
- Huge pressure to reduce the transmission cost, merging all traffic into the same optimized transport infrastructure
  - This has been a old trend in telecommunication networks (ISDN, BISDN, ATM, MPLS,...)

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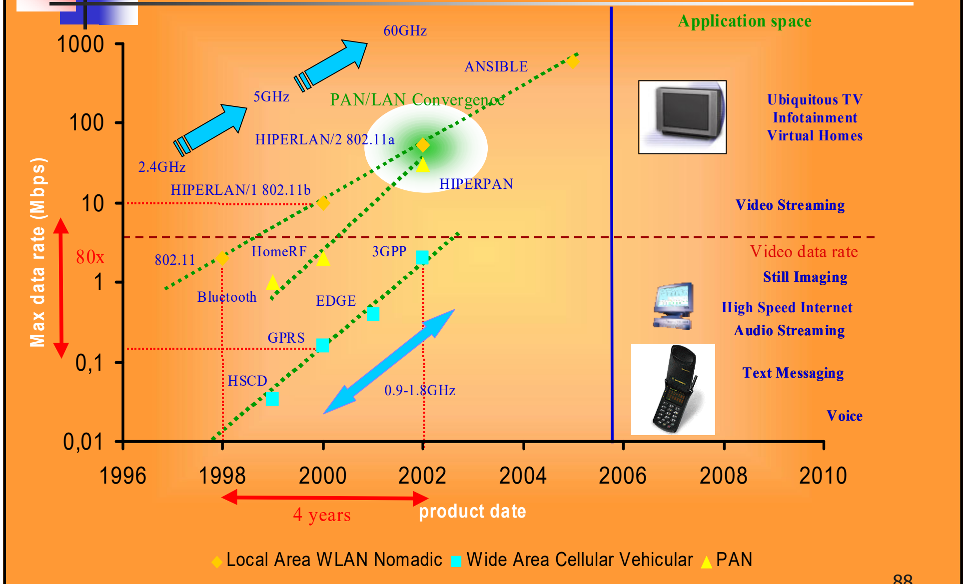
Convergence scenario: celular is catch all



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Source: Marc de Courville, Motorola, May00 IEEE 802.15 Plenary Meeting http://grouper.ieee.org/groups/802/15/pub/2000/Mar00/00128r0P802-15_TG3-OFDM-HIPERPAN.ppt

Trends: the single network

- Mobile networks took over as major communication infrastructure
  - Initially as voice networks, now as data networks
- Reference system for the development of new applications
  - The app economy
  - New web interface designs
  - Novel applications (location) and systems (sensors)

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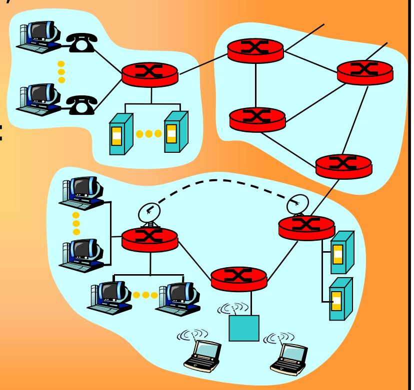
The communication network

What is then a network

Networks: service vision

- Distributed communications infrastructure supporting applications, also potentially distributed
  - WWW, email, games, e-commerce, databases, voting
- Communications services supporting:
  - Connection-oriented
  - Connection-less
- Service platforms for millions of devices: *hosts, end-systems*
  - Pc's, workstations, servers
  - PDA's, phones, fridges...



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Network structure

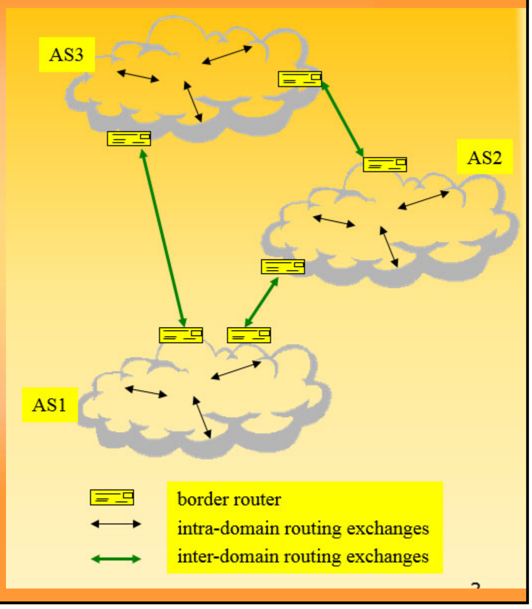
- Administrative borders define:
  - Autonomous systems(AS)
    - **Intradomain routing**
    - Internal policies
    - Different metrics can be used on different domains

    (connectivity protocols in Internet: RIPv2, OSPFv2)
  - Interconnection of ASs
    - **Interdomain routing**

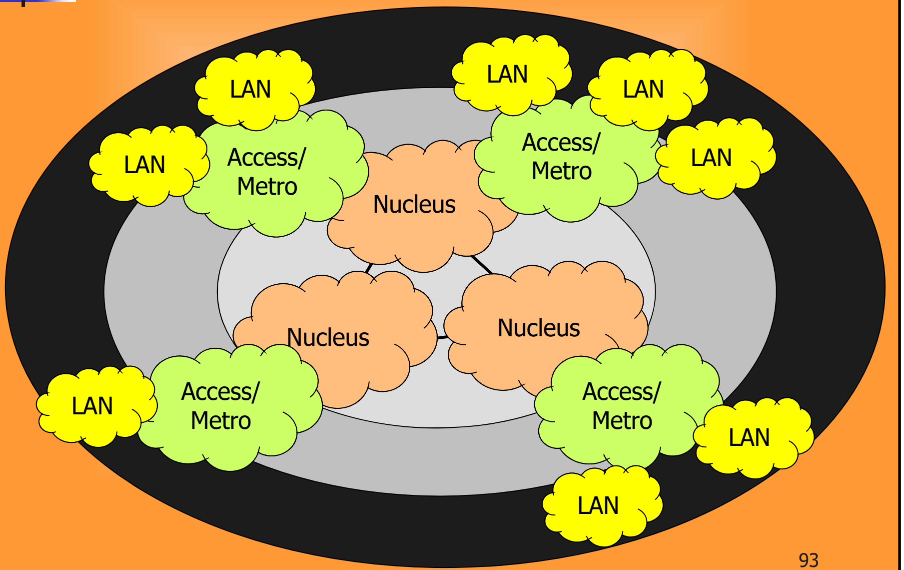
    (Connectivity information protocols in Internet: BGP)

NOTE: this structure is for ALL NETWORKS

- But details presented are for ISPs.



Network architecture



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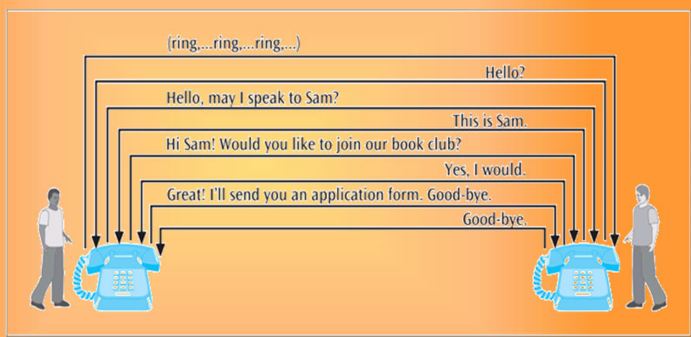
Connection-oriented versus Connectionless



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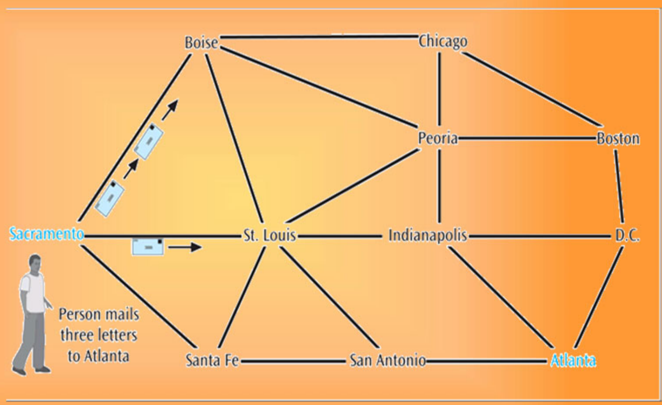
Connection-oriented versus Connectionless



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Connection-oriented versus Connectionless

- A connection-oriented application can operate over both a circuit switched network or a packet switched network.
- A connectionless application can also operate over both a circuit switched network or a packet switched network but a packet switched network may be more efficient.

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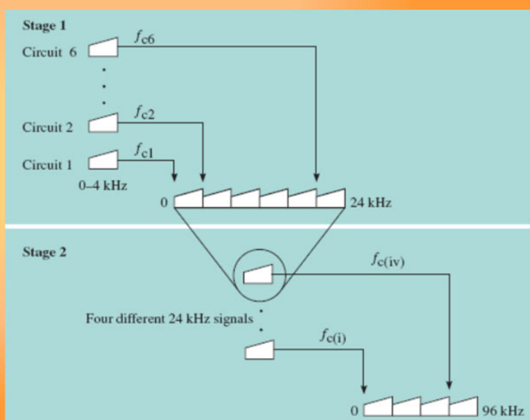
The bits must go on

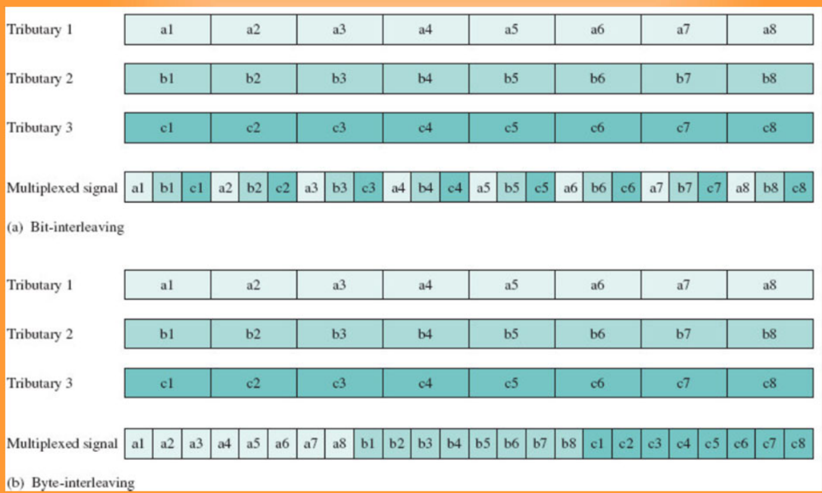
MULTIPLEXING AND TRANSMISSION

History of Multiplexing

- Synchronous digital hierarchy (SDH) is a world-wide standard for digital communication network.
- Two other systems were before it:
  - the plesiochronous digital hierarchy (PDH) and
  - frequency division multiplexing (FDM).
- ***Frequency division multiplexing*** (FDM):
  - a number of signals share a medium that has a much larger bandwidth.
  - Support of many stages

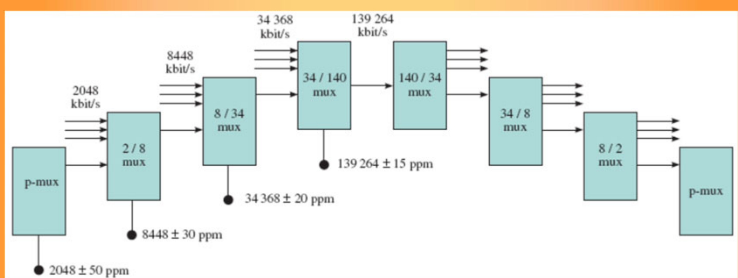


Time Division Multiplexing (two ways)



Plesiochronous Digital Hierarchy

- PDH basic data transfer rate is 2048 Kbps
- It is broken in
  - 30 x 64Kbps
  - 2 x 64Kbps (synchronization and signaling)
- The exact frequency of the 2Mpbs is controlled by a clock with some percentage +/- %0.005
- Justification or Stuffing
  - Extra bits that are need to reconstruct correctly



SONET / SDH

- What is SONET / SDH?
  - **S**ynchronous **O**ptical **Net**work – ANSI (US)
  - **S**ynchronous **D**igital **H**ierarchy –ITU-T Europe
  - Similar and compatible
  - A standard to be used for fibre optics
  - Recommendation for FOTS equipment
    - Fibre Optic Transmission Systems
  - Can carry incompatible DS-0, DS1 (Asyn)

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SONET / SDH

- What is SONET / SDH?
  - Single reference clock
    - synchronize transmissions
  - Predictability
  - Powerful frame – Transmission envelope
    - Multiplex channels
  - Multiplexed transport mechanism
    - Optical based Carrier System
  - Self healing ring topology
  - Consolidate and segregate traffic from different end-points
  - Extensive integrated OAM&P
  - Backward compatibility

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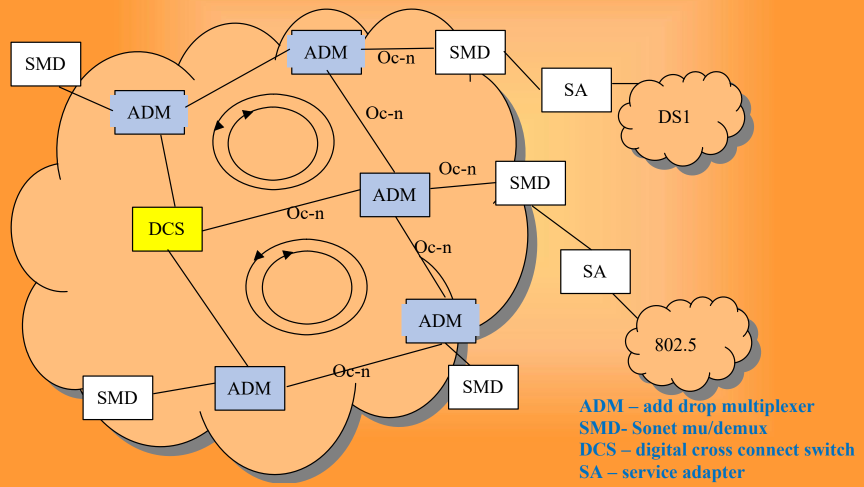
SONET / SDH topology



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SONET structure

- Signal Hierarchy
  - STS – Synchronous Transport Signals
    - support a certain base data rate- 51.84Mbps
    - STS 1 – STS 192 – different hierarchies
  - Corresponding carrier System
    - Optical Carrier – OC-1, OC-3, OC-12, OC-48
  - SDH – STM – Synchronous Transport Module
    - STM 1 = STS 3
- SONET/SDH is *channelized*.
  - STS-3 consists of 3 STS-1 streams, and each STS-1 consists of a number of DS-1 and E1 signals.
  - STS-12 consists of 12 STS-1 streams
- *Concatenated structures* (OC-3c, OC-12c, etc)
  - The frame of the STS-3 payload is filled with ATM cells or IP packets packed in PPP or HDLC frames.
  - Concatenated SONET/SDH links are commonly used to interconnect ATM switches and IP routers (Packets over SONET).

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The SONET/SDH hierarchy

Optical level	SONET level (electrical)	SDH level (electrical)	Data rate (Mbps)	Overhead rate (Mbps)	Payload rate (Mbps)
OC-1	STS-1	-	51.840	1.728	50.112
OC-3	**STS-3**	**STM-1**	**155.520**	**5.184**	**150.336**
OC-9	STS-9	STM-3	466.560	15.552	451.008
OC-12	**STS-12**	**STM-4**	**622.080**	**20.736**	**601.344**
OC-18	STS-18	STM-6	933.120	31.104	902.016
OC-24	STS-24	STM-8	1244.160	41.472	1202.688
Oc-36	STS-36	STM-12	1866.240	62.208	1804.932
OC-48	**STS-48**	**STM-16**	**2488.320**	**82.944**	**2405.376**
OC-96	STS-96	STM-32	4976.640	165.888	4810.752
OC-192	**STS-192**	**STM-64**	**9953.280**	**331.776**	**9621.504**
OC-768	**STS-768**	**STM-256**	**39813.120**	**1327.104**	**38486.016**
OC-N	STS-N	STM-N/3	N*51.840	N*1.728	N*50.112

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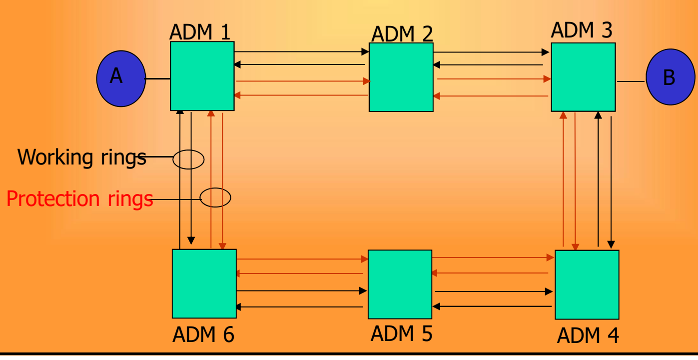
SONET/SDH protection

- Features (Four-fiber bidirectional line switched ring)
  - Two working rings and two protection rings.
    - The two working rings transmit in opposite directions, and each is protected by a protection ring which transmits in the same direction.
  - Advantage: it can suffer multiple failures and still function.
    - Deployed by long-distance telephone companies in regional and national rings.



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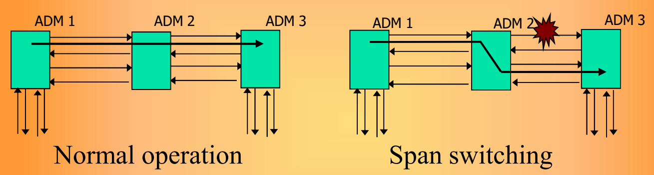
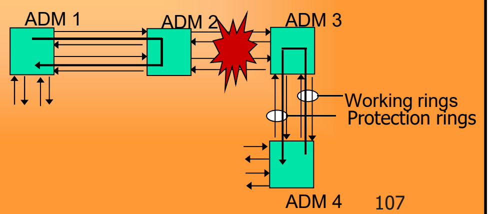
Self-healing operation

- *span switching:* If a working fiber fails, the working traffic will be transferred over its protection ring.



- *ring switching*: the working and protection fibers are part of the same bundle of fibers. When the bundle is cut the traffic will be switched to the protection fibers.



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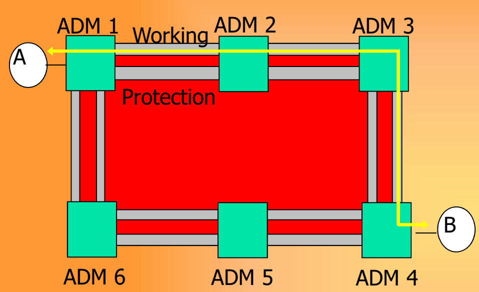
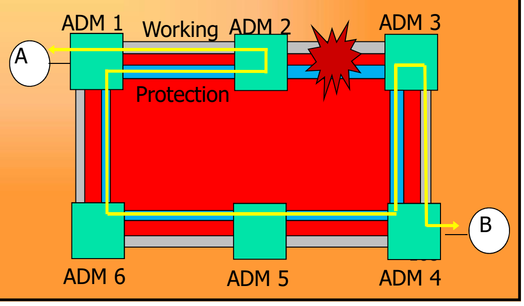
Ring switching: Rerouting a connection



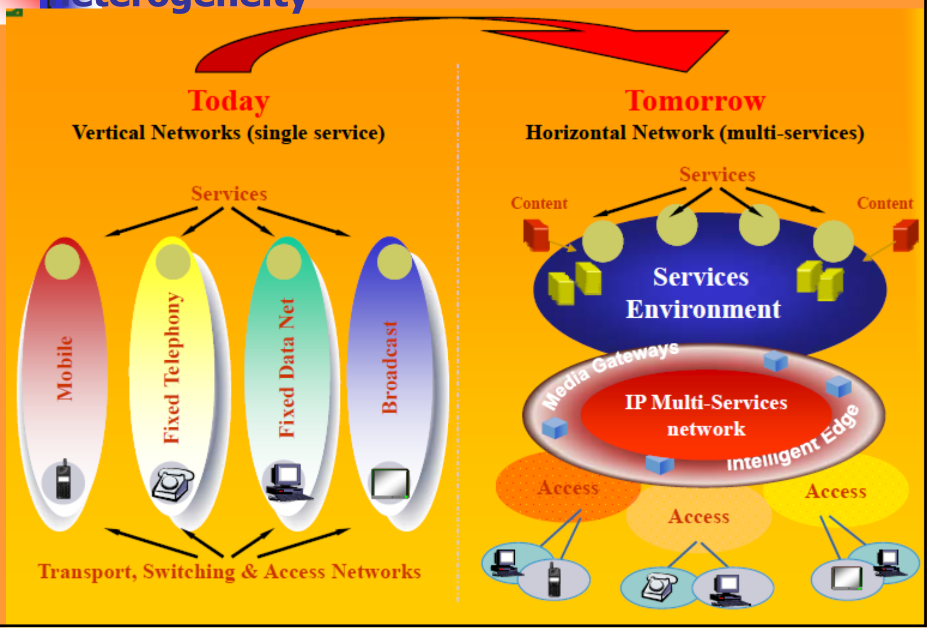
Times ~100ms



Moving from the Telecom into the data business, operators developed:

CONVERGED NETWORKS

The opportunity provided by network heterogeneity



Converged IP Telephony Architecture