SAPIENZA
UNIVERSITÀ DI ROMA

Network Infrastructures

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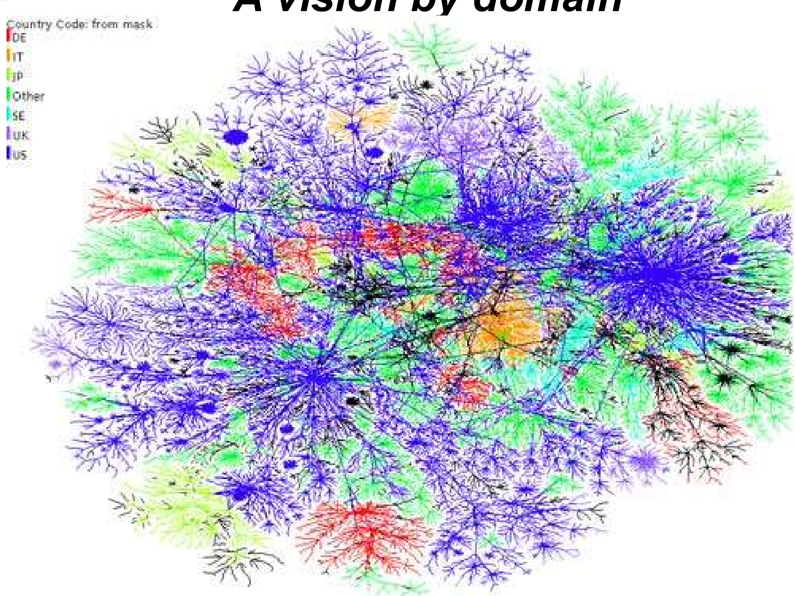
Review on
Data Networking and the Internet

Inter-Networks: Networks of Networks

- What is it ?
  - "Connect many disparate physical networks and make them function as a coordinated unit … " - Douglas Comer
  - Many => scale
  - Disparate => heterogeneity
- Result: Universal connectivity!
  - The inter-network looks like one large switch,
  - User interface is sub-network independent

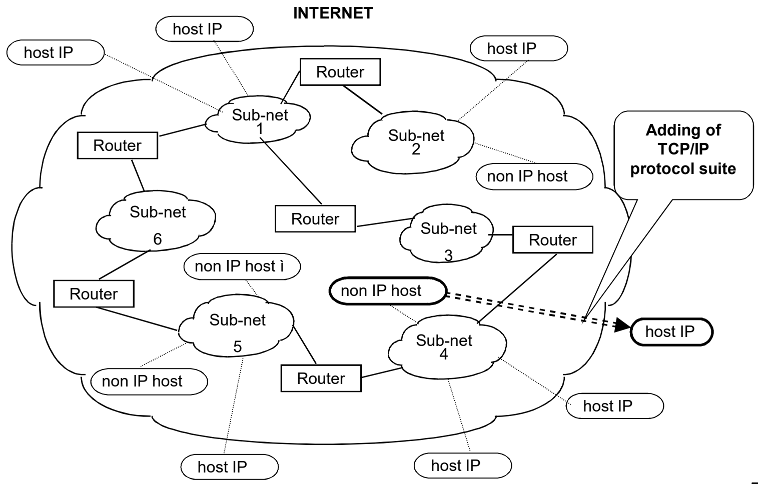
3

The Internet:
A vision by domain



4

Inter-Networks: *Networks of Networks*



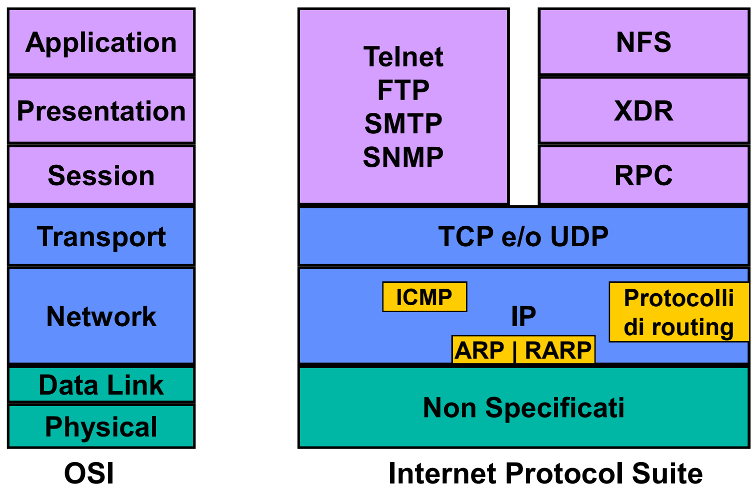
5

Inter-Networks: Networks of Networks

- Internetworking involves two fundamental problems: heterogeneity and scale
- Concepts:
  - Translation, overlays, address & name resolution, fragmentation: to handle heterogeneity
  - Hierarchical addressing, routing, naming, address allocation, congestion control: to handle scaling

6

Internet protocol suite



7

IP: Internet Protocol

- Layer 3 protocol
- Defines
  - Packet format
  - Address format
  - Data (named datagram) forwarding procedures
- Best-effort service
  - connectionless
  - unrealiable
  - With no QoS guarantess
- Specified in RFC 791 (november 1981)

8

IP protocol

- Connectionless delivery
  - Stateless approach
    - » No state information on datagram kept in routers
    - » No connection concept at IP layer
  - Each datagram routed independently
    - » Two packets with the same source and destination can follow two different paths
    - » In practice, most packets follow a fixed route, unless
      - Link faiulure
      - Parallel links among routers
- No QoS guarantees
  - All packets treated fairly
  - Extensions to the traditional IP QoS model

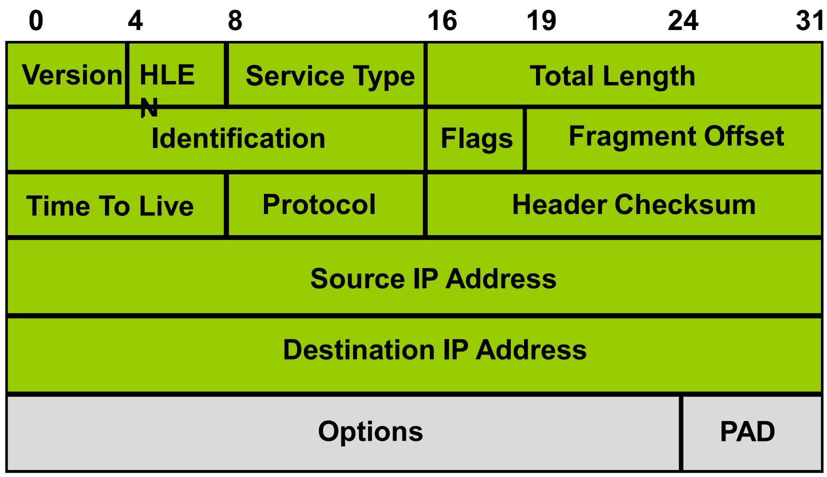
9

IP protocol: unreliable delivery

- In case of:
  - Failure (ex. out of service router, link failure)
    - » Datagram dropped end error message sent to the source
  - Buffer shortage
    - » Datagram dropped (no error message sent, since the datagram cannot be stored)
  - Checksum error (error control only over the header!)
    - » Datagram dropped
    - » No error message sent, since address may be wrong

10

IP packet header

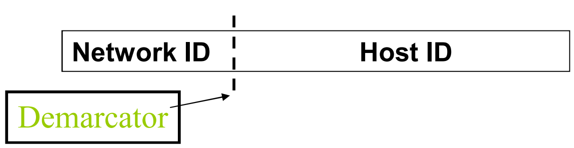


Standard size: 20 byte

11

Scalable Forwarding, Structured Addresses

- Address has structure which aids the forwarding process.
- Address assignment is done such that nodes which can be reached without resorting to L3 forwarding have the same prefix (network ID)



12

Scalable Forwarding, Structured Addresses

- A simple comparison of network ID of destination and current network (broadcast domain) identifies whether the destination is “directly” connected
  - I.e. Reachable through L2 forwarding only
- Within L3 forwarding, further structure can aid hierarchical organization of routing domains (because routing algorithms have other scalability issues)

13

Internet Routing Drivers

- Technology and economic aspects:
  - Internet built out of cheap, unreliable components as an overlay on top of leased telephone infrastructure for WAN transport.
    - » Cheaper components => fail more often => topology changes often => needs dynamic routing
  - Components (including end-systems) had computation capabilities.
    - » Distributed algorithms can be implemented
  - Cheap overlaid inter-networks => several entities could afford to leverage their existing (heterogeneous) LANs and leased lines to build inter-networks.
    - » Led to multiple administrative “clouds” which needed to inter-connect for global communication.

14

Internet Routing Model

- 2 key features:
  - Dynamic routing
  - Intra- and Inter-AS routing, AS = locus of admin control
- Internet organized as "autonomous systems" (AS).
  - AS is internally connected
- Interior Gateway Protocols (IGPs) within AS.
  - Eg: RIP, OSPF, HELLO
- Exterior Gateway Protocols (EGPs) for AS to AS routing.
  - Eg: EGP, BGP-4

15

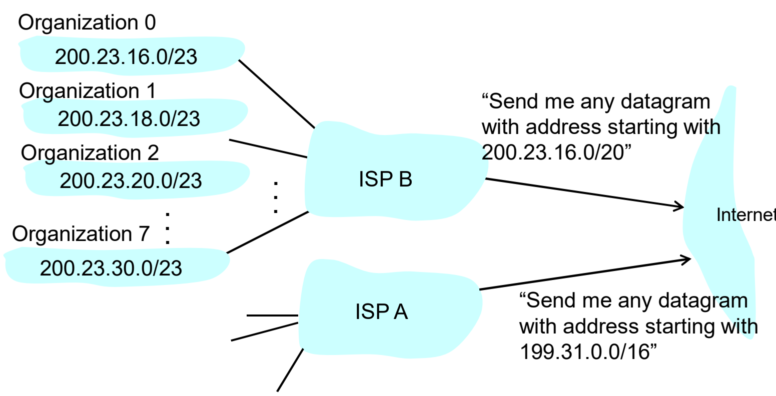
Hierarchical routing

- Ideal (conceptually simpler) case
  - All routers are identical
  - Flat network, no hierarchy
- Not useable in practice
  - Scalability: with 100 million of destination :
    - » All destinations in a single routing rable?
    - » Routing info exchange would require too much bandwidth
  - Administrative autonomy
    - » Internet = network of networks
    - » Each network administrator is willing to control rotuing functions within its domain

16

Hierarchical routing: route aggregation

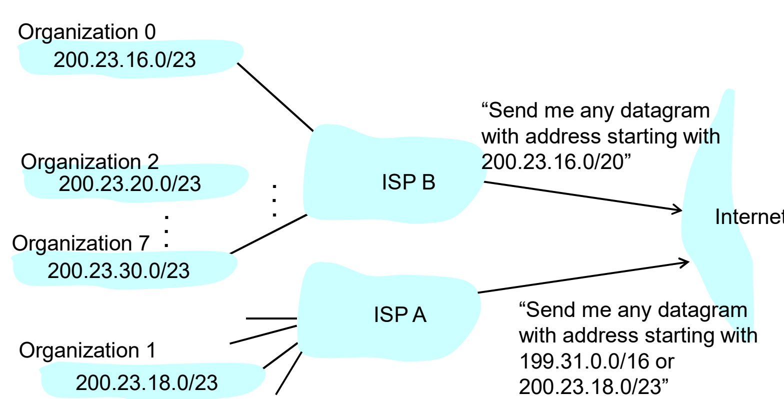
- Hierarchical addressing permits more efficient announcements of routing infos



17

Hierarchical routing: route aggregation

- If ISP A has a more specific path to Organization 1



18

Hierarchical routing

- Router aggregated in Autonomous System (AS)
  - Networks with complex structure (many subnets and routers) but with the same administrative authority
  - Router within the same AS use the same routing protocol
  - Intra-AS routing protocols: (IGP: Interior Gateway Protocol)
    - » Routers belonging to different AS may use different IGP protocols

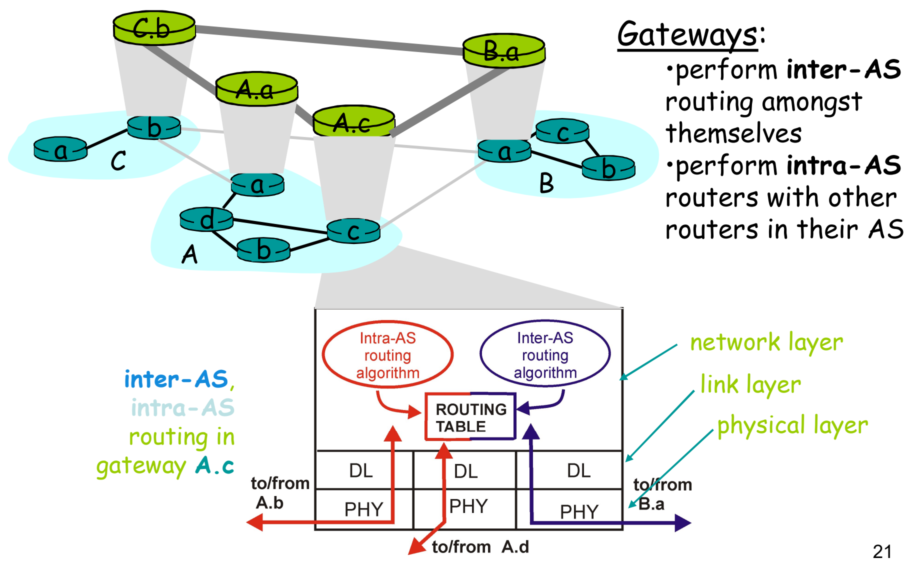
19

Hierarchical routing

- In each AS there exist “gateway” routers
  - Responsible to route to destinations external to the AS
  - Run intra-AS routing protocols with all other AS routers
  - Run also inter-AS routing protocols (EGP: Exterior Gateway Protocol)
- We can identify an internal routing (IGP) and an external routing (EGP)

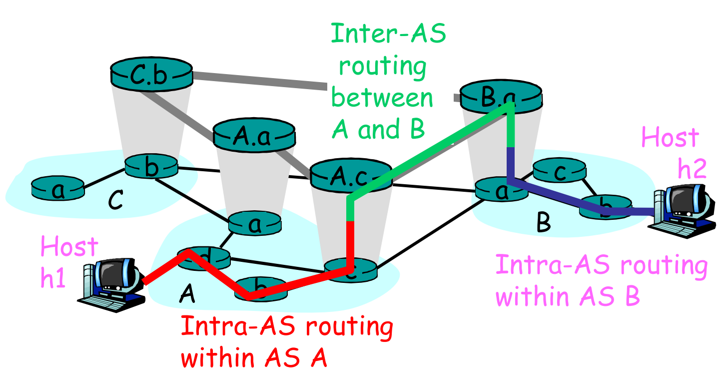
20

Intra-AS and Inter-AS routing



21

Intra-AS and Inter-AS routing



22

Requirements for Intra-AS Routing

- Should scale for the size of an AS.
  - Low end: 10s of routers (small enterprise)
  - High end: 1000s of routers (large ISP)
- Different requirements on routing convergence after topology changes
  - Low end: can tolerate some connectivity disruptions
  - High end: fast convergence essential to business (making money on transport)
- Operational/Admin/Management (OAM) Complexity
  - Low end: simple, self-configuring
  - High end: Self-configuring, but operator hooks for control
- Traffic engineering capabilities: high end only

23

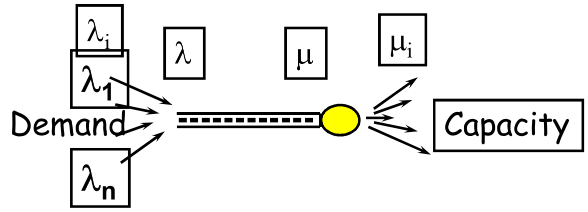
Requirements for Inter-AS Routing

- Should scale for the size of the global Internet.
  - Focus on reachability, not optimality
  - Use address aggregation techniques to minimize core routing table sizes and associated control traffic
  - At the same time, it should allow flexibility in topological structure (eg: don't restrict to trees etc)
- Allow policy-based routing between autonomous systems
  - Policy refers to arbitrary preference among a menu of available options (based upon options' attributes)
  - In the case of routing, options include advertised AS-level routes to address prefixes
  - Extensible to meet the demands for newer policies.

24

The Congestion Problem

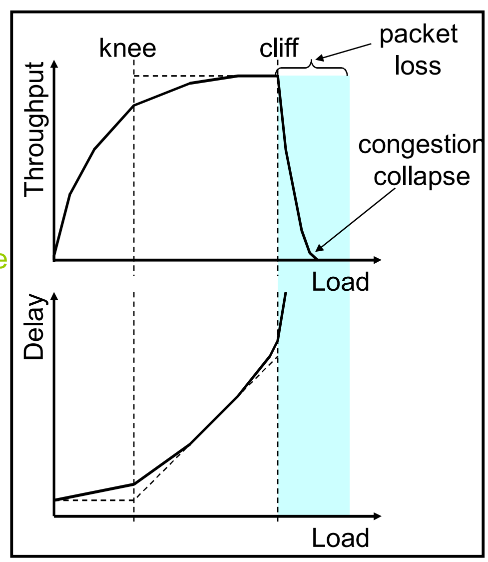
- ***Problem: demand outstrips available capacity***
- If information about λ_i, λ and μ is known in a central location where control of λ_i or μ can be effected with zero time delays,
  - the congestion problem is solved!
- Unfortunately, we have incomplete info, require a distributed solution with time-varying time-delays



25

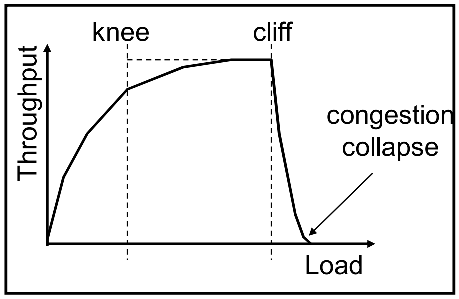
Congestion: A Close-up View

- knee – point after which
  - throughput increases very slowly
  - delay increases fast
- cliff – point after which
  - throughput starts to decrease very fast to zero (congestion collapse)
  - delay approaches infinity
- Note (in an M/M/1 queue)
  - delay = 1/(1 – utilization)



Congestion Control vs. Congestion Avoidance

- Congestion control goal
  - stay left of cliff
- Congestion avoidance goal
  - stay left of knee
- Right of cliff:
  - Congestion collapse



27

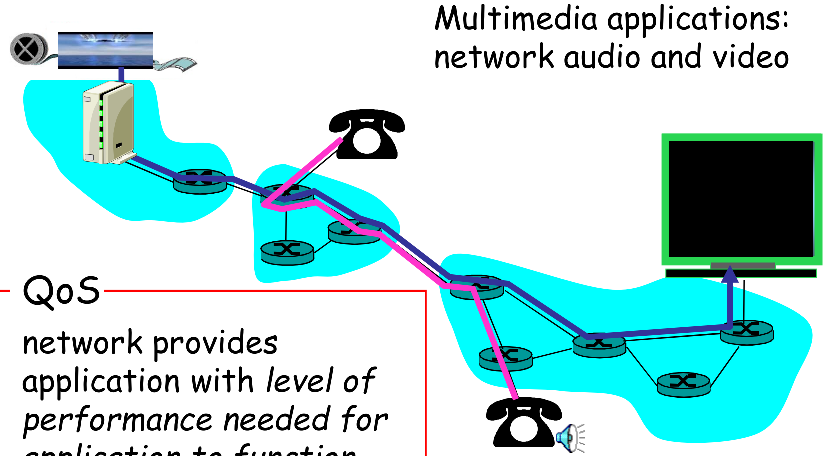
Goals of Congestion Control

- To guarantee stable operation of packet networks
  - Sub-goal: avoid congestion collapse
- To keep networks working in an efficient status
  - Eg: high throughput, low loss, low delay, and high utilization
- To provide fair allocations of network bandwidth among competing flows in steady state
  - For some value of "fair" ☺

28

Quality of Service: What is it?

Multimedia applications: network audio and video



QoS
network provides application with *level of performance needed for application to function.*

29

QoS Challenges

- TCP/UDP/IP suite provides best-effort, no guarantees on expectation or variance of packet delay
- Streaming applications delay of 5 to 10 seconds is typical and has been acceptable, but performance deteriorate if links are congested (transoceanic)
- Real-Time Interactive requirements on delay and its jitter have been satisfied by over-provisioning (providing plenty of bandwidth), what will happen when the load increases?...

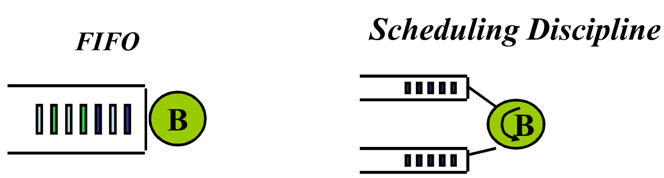
30

QoS Challenges

- Most router implementations use only First-Come-First-Serve (FCFS or FIFO) packet processing and transmission scheduling
- To mitigate impact of "best-effort" protocols, we can:
  - Use UDP to avoid TCP and its slow-start phase…
  - Buffer content at client and control playback to remedy jitter
  - Adapt compression level to available bandwidth

31

Fundamental QoS Problems



- In a FIFO service discipline, the performance assigned to one flow is *convoluted* with the arrivals of packets from all other flows!
  - Cant get QoS with a "free-for-all"
  - Need to use new scheduling disciplines which provide "*isolation*" of performance from arrival rates of background traffic

32

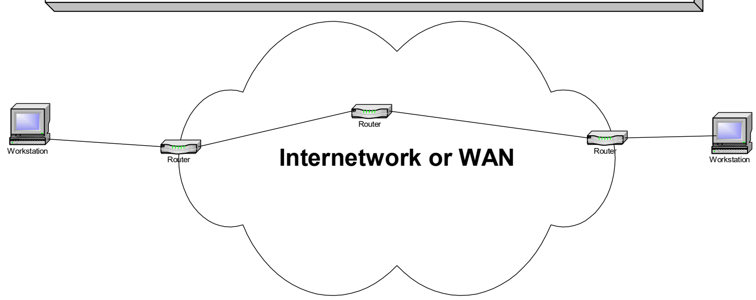
Solution Approaches in IP Networks

- Just add more bandwidth and enhance caching capabilities (over-provisioning)!
- Need major change of the protocols :
  - Incorporate resource reservation (bandwidth, processing, buffering), and new scheduling policies
  - Set up service level agreements with applications, monitor and enforce the agreements, charge accordingly
- Need moderate changes (“Differentiated Services”):
  - Use two traffic classes for all packets and differentiate service accordingly
  - Charge based on class of packets
  - Network capacity is provided to ensure first class packets incur no significant delay at routers

33

QoS Big Picture: Control/Data Planes

Control Plane: Signaling + Admission Control or SLA (Contracting) + Provisioning/Traffic Engineering



Data Plane: Traffic conditioning (shaping, policing, marking etc) + Traffic Classification + Scheduling, Buffer management

34

Internet transport layer

- Two alternative protocols: TCP e UDP
- Different service models:
  - TCP is connection oriented, reliable, it provides flow and congestion control, it is stateful, it supports only unicast traffic
  - UDP is connectionless, unreliable, stateless, it supports multicast traffic
- Common characteristics:
  - Multiplexing and demultiplexing of application processes through the port mechanism
  - Error detection over header and dati (optional in UDP)

35

Mux/demux: ports

- Final destination of data is not the host but an application process running in the host
- Interface between application processes and the network architecture is named port
  - Integer number over 16 bit
  - There is an association between ports and processes
    - » Public server process are statically associated to well-know ports, with an identifier smaller than 1024 (e.g.: 80 for WWW, 25 for email)
    - » Client processes use ports dynamically assigned by the operating system, with an identifier larger than 1024
      - – Each client process on a given host has a unique port number within that host

36

UDP: User Datagram Protocol

- Connectionless transport protocol
- No delivery guarantee
- Two main functions:
  - Application process multiplexing through port abstraction
  - checksum (optional) to verify data integrity
- Applications using UDP should solve (if interested)
  - Reliability issues
    - » Data loss, data duplication
  - Sequence control
  - Flow and congestion control
- Standardized in RFC 768

37

UDP: packet format

0 4 8 16 19 24 31

UDP Source Port	**UDP Destination Port**
UDP Message Length	**UDP Checksum**
DATA	

38

UDP: applicability

- UDP is useful when:
  - Operating in local area, a reliable network (NFS)
  - All application data are contained in a single packet, so that there is no need to open a connection for a single packet (DNS)
  - Full reliability is not fundamental (some intercative video/audio service)
  - A fast protocol is needed
    - » Connection opening overhead avoided
    - » Retransmission mechanisms to ensure reliability cannot be used due to strict timing constraints
  - Application manages retransission mechanisms (DNS)
  - Need to send data at constant rate or at a rate independent from the network (some interactive video-audio services)

39

TCP protocol

- TCP (Transmission Control Protocol) is
  - Connection oriented
  - Reliable (through retransmission)
    - » Correct and in-order delivery of stream of data
  - Flow control
  - Congestion control
- Used by applications requiring reliability
  - telnet (remote terminal)
  - ftp (file transfer protocol)
  - smtp (simple mail transfer protocol)
  - http (hypertext transfer protocol)

40

TCP

- Multiplexing/demultiplexing through ports
- Connection opened between two TCP entities (service similar to a virtual circuit)
  - bidirectional (full duplex)
  - With error and sequence control
- It is more complex than UDP, it requires more CPU and memory, state information (port numbers, window size, etc) must be kept in each host for each TCP connection

41

TCP

- TCP freely segments and reassembles data:
  - Manages byte stream generated by application protocols; unstructured data at TCP level
  - A FIFO buffer byte oriented is the interface between TCP and application processes
- Window protocol to ensure reliability
- Flow control and congestion control operates on the transmitter window size
  - Flow control executed by the TCP receiver exploiting the window field in the TCP header
  - Congestion control autonomously executed by the TCP transmitter

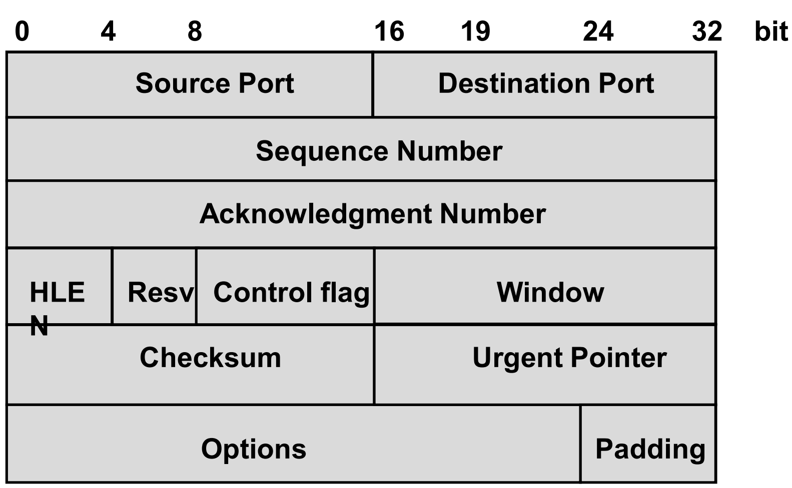
42

TCP: connection identification

- A TCP connection is identified uniquely by:
  - Source and destination IP addresses (layering principle violation)
  - Source and destination port numbers
  - Example: TCP connection identifed by porta 15320 on host with IP address 130.192.24.5 and port 80 on host with IP address 193.45.3.10
- Note that TCP and UDP use port numbers are independent

43

TCP: header



44

RTP

- Real-Time Transport Protocol is an Internet protocol standard to manage real-time transmission of multimedia data
- RTP is commonly used in Internet telephony applications.
- RTP combines its data transport with a control protocol (RTCP), which makes it possible to monitor data delivery for large multicast
- RTP runs on top of UDP

45

RTP

- RTP includes:
  - a **sequence number**, which is used to detect lost packets;
  - **payload identification**, which describes the specific media encoding so that it can be changed if it has to adapt to a variation in bandwidth;
  - **frame indication**, which marks the beginning and end of each frame;
  - **source identification**, which identifies the originator of the frame;
  - **intramedia synchronization**, which uses timestamps to detect different delay jitter within a single stream and compensate for it

46

RTPC

- RTPC includes:
  - **quality of service** (QoS) feedback, which includes the numbers of lost packets, round-trip time, and jitter, so that the sources can adjust their data rates accordingly;
  - **session control**, which uses the RTCP BYE packet to allow participants to indicate that they are leaving a session;
  - **identification**, which includes a participant's name, e-mail address, and telephone number for the information of other participants;
  - **intermedia synchronization**, which enables the synchronization of separately transmitted audio and video streams.

47