INF 5071 – Performance in Distributed Systems

Further Protocols with/-out QoS support

5/10 - 2007

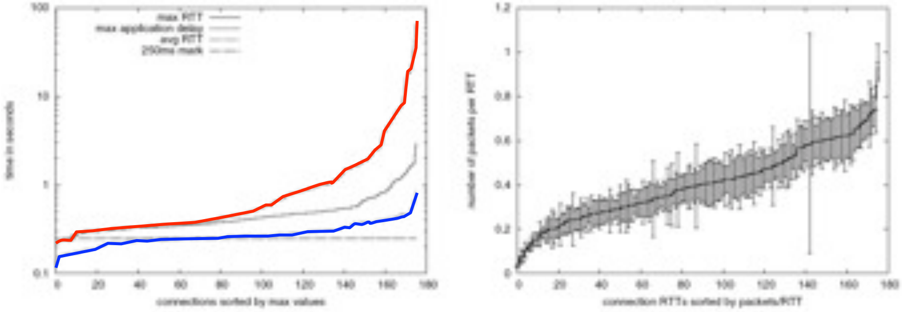
Interactive applications

Interactive applications

- Main examples today:
  - Multiplayer games
  - Audio streams
    - Audio conferencing, IP telephony
  - Signaling
    - RTSP for video stream control, SIP for 3G telephone dialing, ...
- Others
  - Remote surgery
  - Robot control
  - Sensing
    - Sensing voice, temperatures, movement, light, ...
  - Bank transactions
  - ...

Thin Streams

- Transport protocols being developed for throughput-bound applications
- BUT, there exists several **low-rate, time-dependent** applications
- Anarchy Online MMORPG Case Study



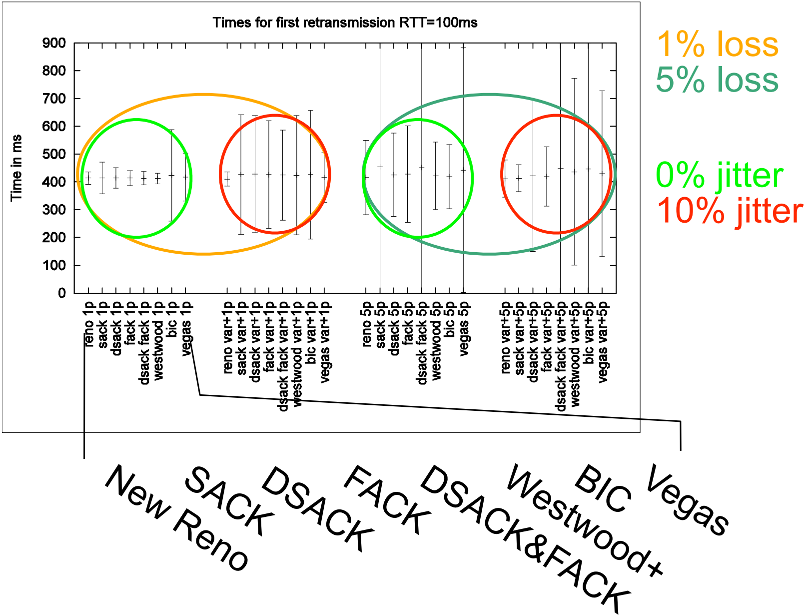
(a) RTT versus maximum application delay

(b) Packets per RTT with standard deviation

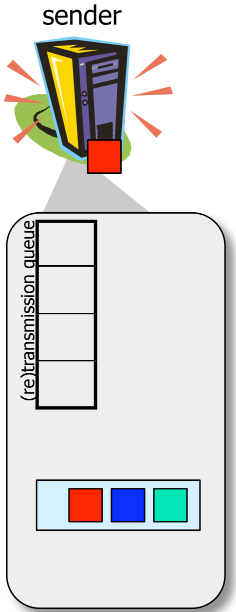
- average delay: **~250 ms**
- max delay: **67 seconds (6 retransmissions)**
- packets per second: **< 4 (less then one per RTT)**
- average packet size: **~120 bytes**
- average bandwidth requirement: **~4 Kbps**

TCP 1st retransmission

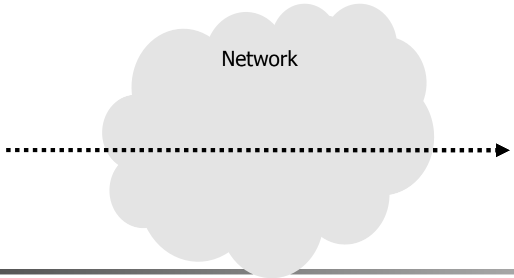
Times of first retransmission, RTT=100 ms

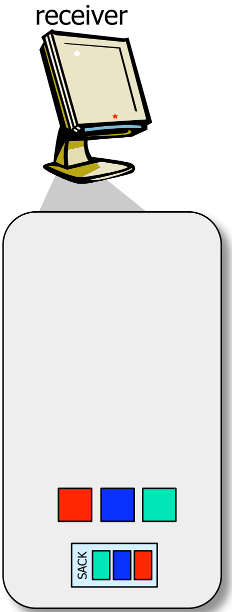


Stream Control Transmission Protocol



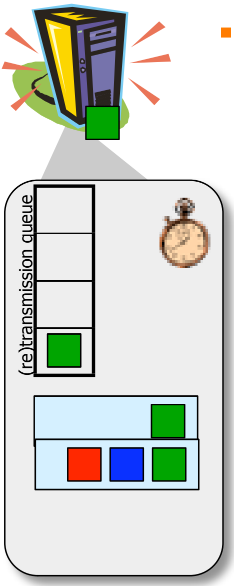
- **SCTP** should support signaling
  - acknowledged error-free transfers
  - data fragmentation according to MTU size
  - packet boundary maintenance
  - sequenced delivery within multiple streams
  - bundling
  - partial reliability
  - …
  - supposed to address low latencies
    "require response between 500 – 1200 ms" … or
    "initiation of error procedures" [rfc 2719]



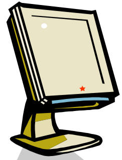


Retransmission by Time-Out

sender



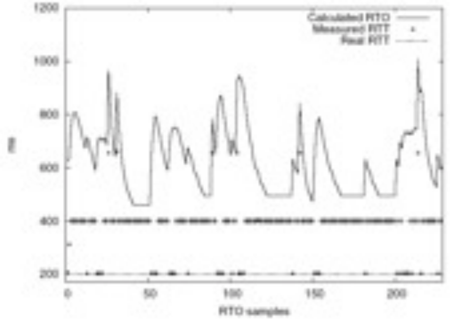
receiver



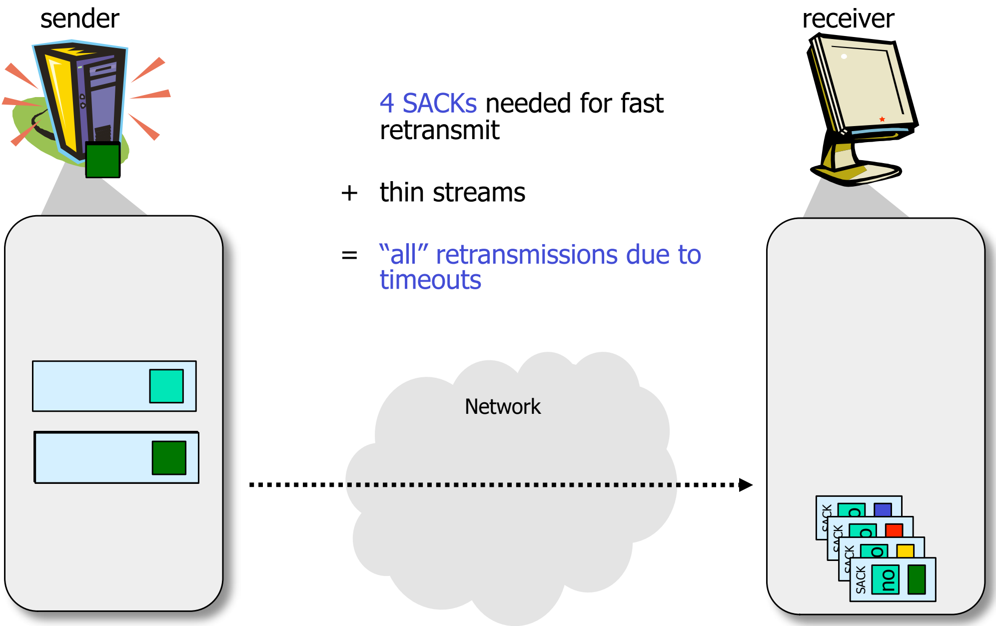
- Timeout is dependent on
  - minRTO = 1000 ms
  - estimated RTT based on SACKs
    - BUT SACKs are delayed
      - one ACK for two packets
      - 200 ms timer
    - influences estimated RTT, especially for thin streams

retransmission of packet with **green** chunks due to timeout

Network



Retransmission by Fast Retransmit

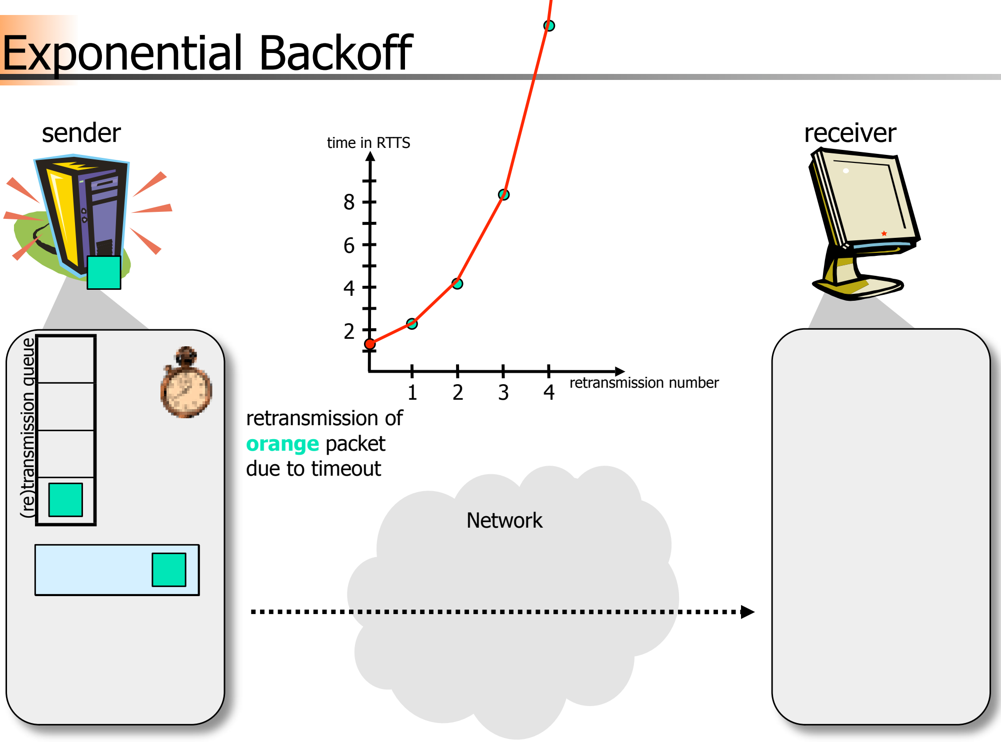


4 SACKs needed for fast retransmit

\+ thin streams

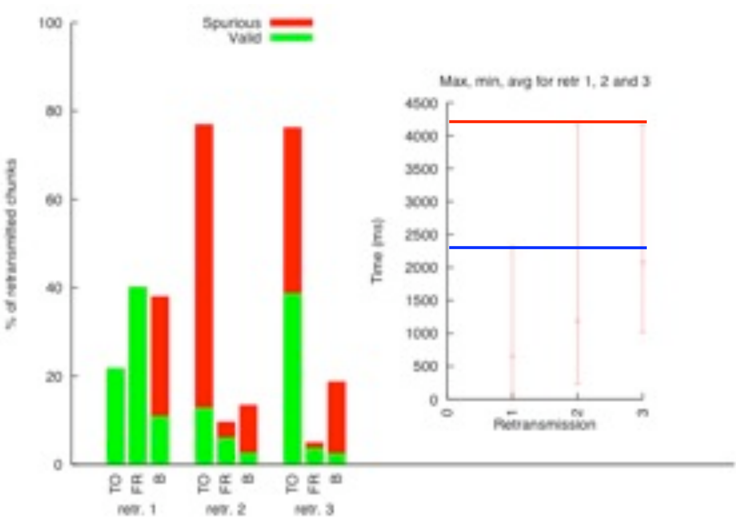
= "all" retransmissions due to timeouts

Exponential Backoff



lksctp performance

Lksctp: RTT100, INT250

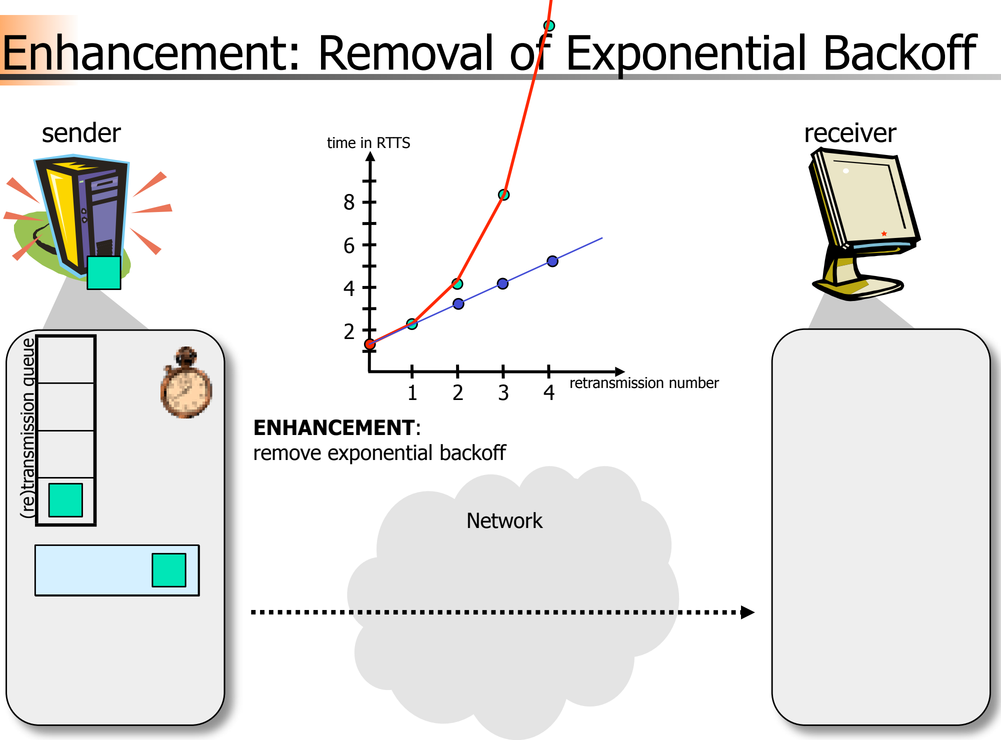


Improvement idea

- Figure out when a stream suffers
  - When it is a "Thin Stream"
  - Whenever so few packets are in-flight that a fast retransmit can not be triggered
  - Then the sender can only wait until RTO (retransmission timeout) and perform a timeout retransmission

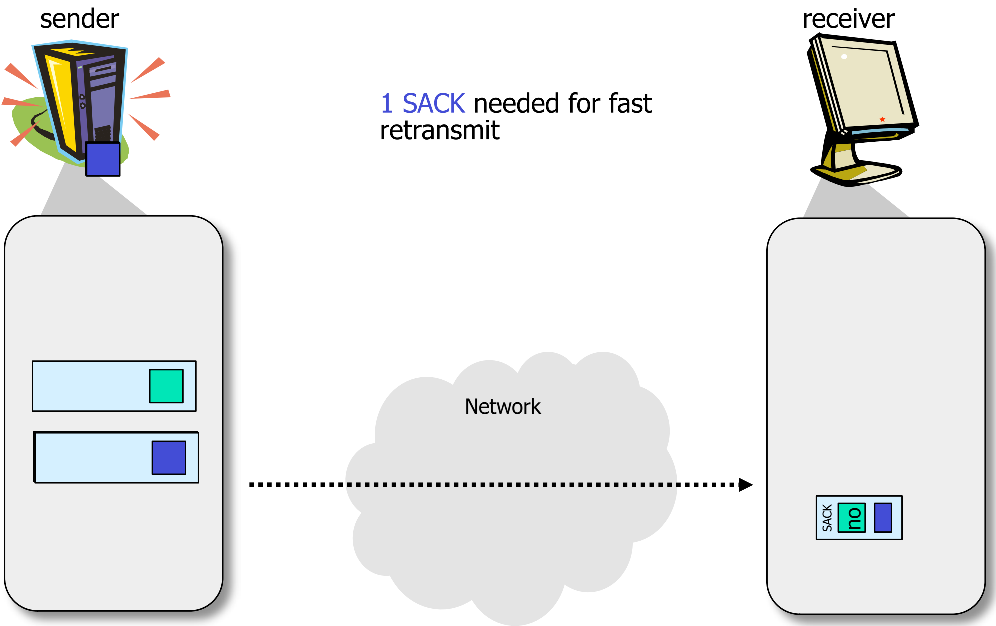
- Then switch on changes
  - No exponential backoff
  - Faster retransmit
  - Minimum retransmission timeout

Enhancement: Removal of Exponential Backoff



ENHANCEMENT:
remove exponential backoff

Retransmission by Faster Retransmit

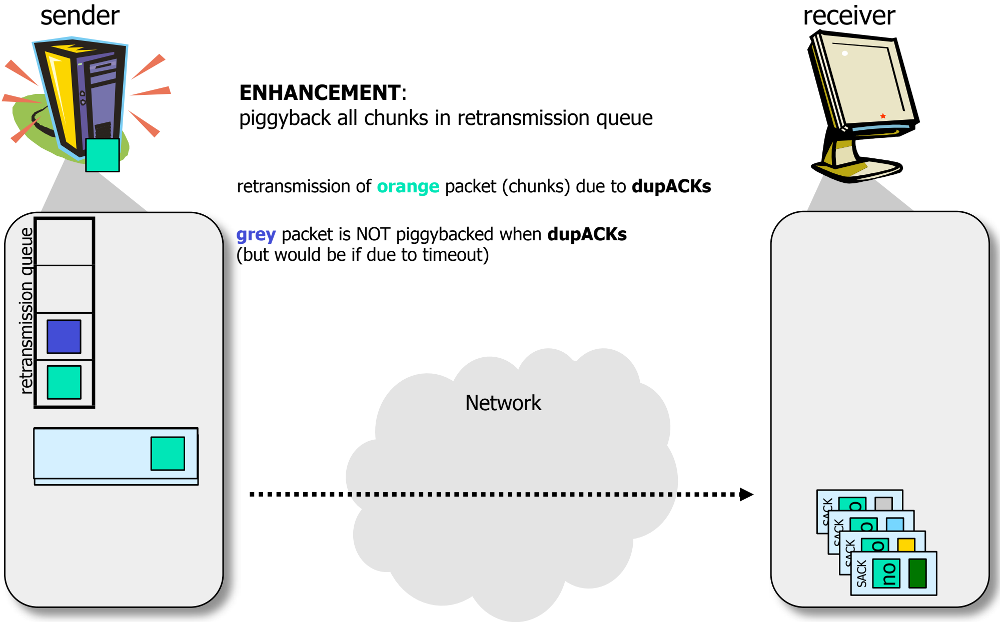


Enhancement: Fast Retransmit Bundling

ENHANCEMENT:
piggyback all chunks in retransmission queue

retransmission of **orange** packet (chunks) due to **dupACKs**

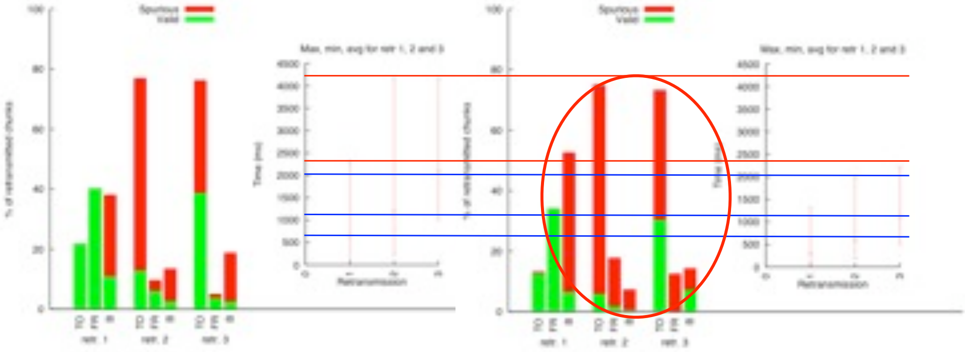
grey packet is NOT piggybacked when **dupACKs**
(but would be if due to timeout)



lksctp performance

RTT100, INT250

2.6.16 lksctp | All modifications

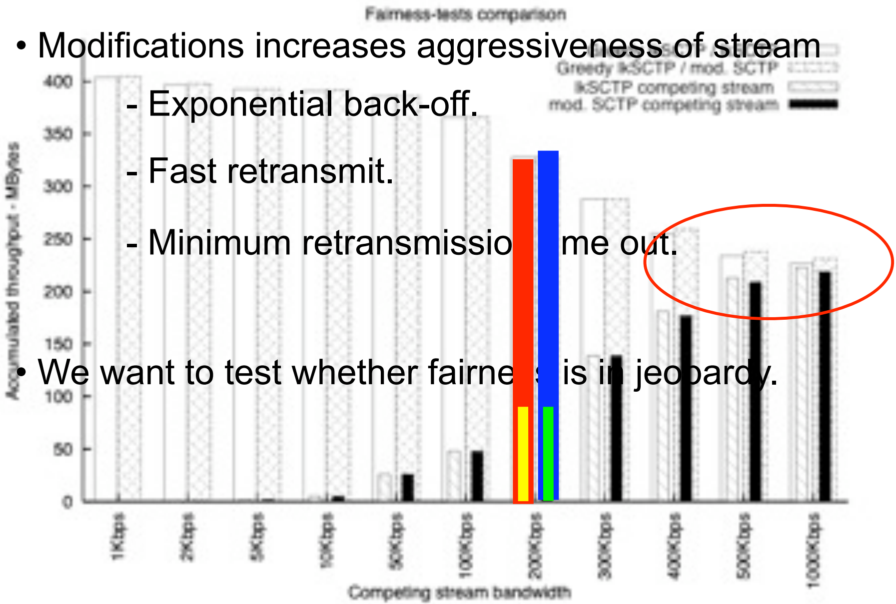


- ☺ Large reduction in maximum and average latency
- ☹ An increase in spurious retransmissions

  -Tolerable due to the low datarate.

Fairness considerations and tests

- Modifications increases aggressiveness of stream
    - Exponential back-off.
    - Fast retransmit.
    - Minimum retransmission time out.
- We want to test whether fairness is in jeopardy.



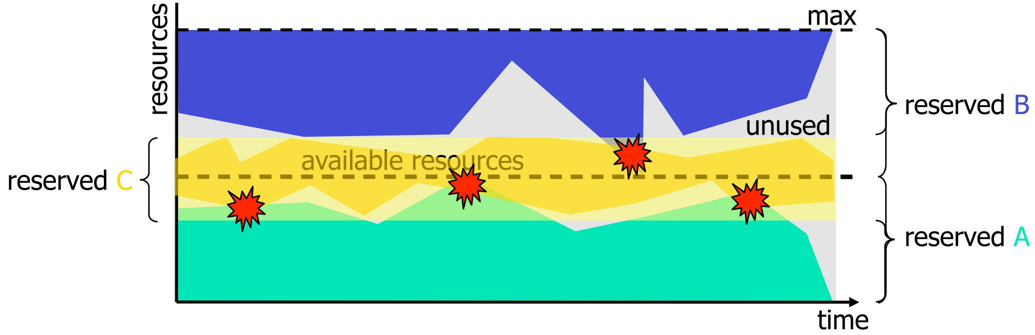
Quality-of-Service

Overview

- Quality-of-Service
- Per-packet QoS
  - IP
- Per-flow QoS
  - Resource reservation
- QoS Aggregates
  - DiffServ, MPLS
  - The basic idea of Network Calculus

Quality–of–Service (QoS)

- Different semantics or classes of QoS:
  - determines reliability of offered service
  - utilization of resources



Quality–of–Service (QoS)

- **Best effort QoS:**
  - system tries its best to give a good performance
  - no QoS calculation (could be called no effort QoS)

  ☺ simple – do nothing

  ☹ QoS may be violated → unreliable service

- **Deterministic guaranteed QoS:**
  - hard bounds
  - QoS calculation based on upper bounds (worst case)
  - premium better name!!??

  ☺ QoS is satisfied even in the worst case → high reliability

  ☹ over-reservation of resources → poor utilization and unnecessary service rejects

  ☹ QoS values may be less than calculated hard upper bound

Quality–of–Service (QoS)

- Statistical guaranteed QoS:
  - QoS values are statistical expressions (served with some probability)
  - QoS calculation based on average (or some other statistic or stochastic value)

  ☺ resource capabilities can be statistically multiplexed → more granted requests

  ☹ QoS may be temporarily violated → service not always 100 % reliable

- Predictive QoS:
  - weak bounds
  - QoS calculation based previous behavior of imposed workload

Quality–of–Service

- Applicability: QoS support
  - A dream of early network researchers
    (lots of research topics)
  - Guarantees that distributed systems work as promised

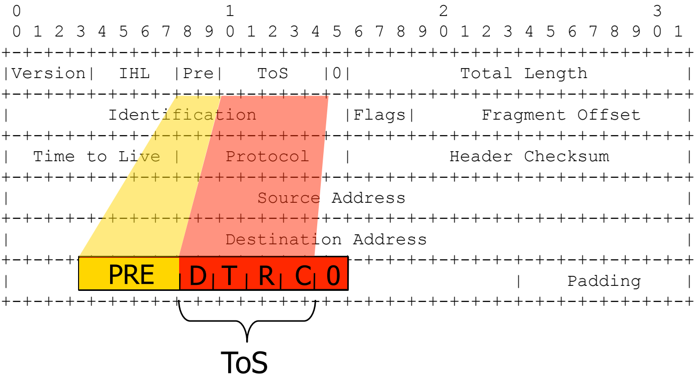
- QoS doesn’t exist?
  - IP doesn’t support QoS
  - Equality is the Internet’s mantra
    (do you listen to the net neutrality debate?)
  - Violates Internet philosophy
    (shunned by the gurus)

- QoS requirement
  - Companies and end-users demand guarantees
  - What’s being done?

Per-packet QoS

Internet Protocol version 4 (IPv4)

[RFC1349]



ToS

- Type of Service
  - D – minimize delay
  - T – maximize throughput
  - R – maximize reliability
  - C – minimize cost

PRE

- Precedence Field
  - Priority of the packet

Internet Protocol version 4 (IPv4)

[RFC2474]

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |    DSCP    |0 0|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 0  0                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Class selector codepoints of the form xxx000

DSCP

- Differentiated Services Codepoint
  - xxxxx0 reserved for standardization
  - xxxx11 reserved for local use
  - xxxx01 open for local use, may be standardized later

Internet Protocol version 6 (IPv6)

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Source Address                        +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                      Destination Address                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Traffic class
  - Interpret like IPv4's DS field

Per-flow QoS

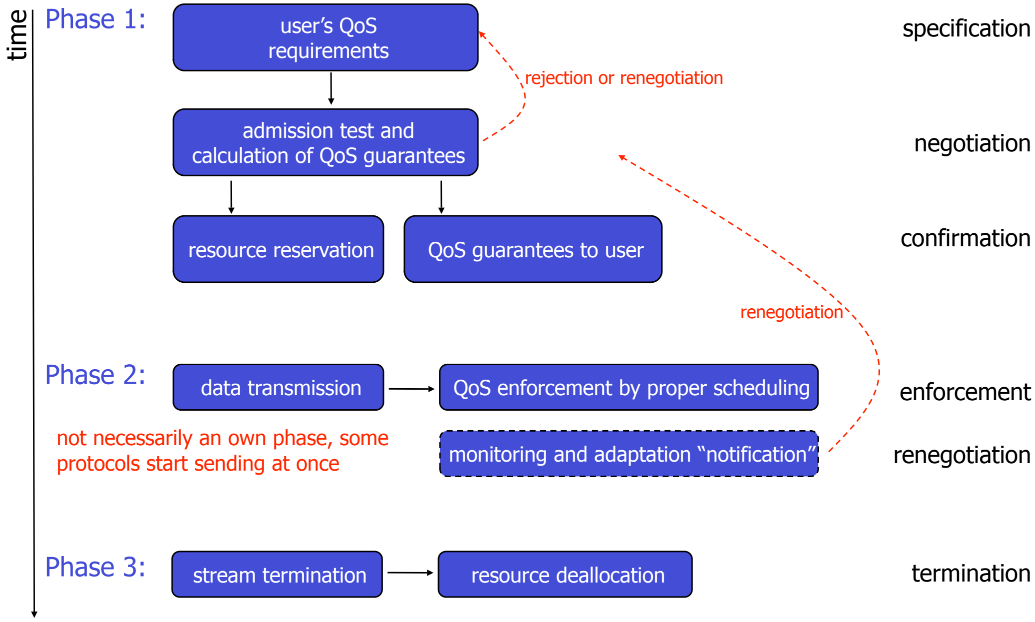
Resource Reservation

Resource Reservation

- Reservation is fundamental for reliable enforcement of QoS guarantees
  - per-resource data structure (information about all usage)
  - QoS calculations and resource scheduling may be done based on the resource usage pattern

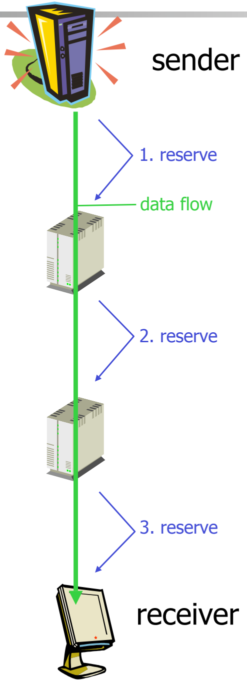
  - reservation protocols
    - negotiate desired QoS
    - transfer information about resource requirements and usage
    - between the end-systems and all intermediate systems
  - reservation operation
    - calculate necessary amount of resources based on the QoS specifications
    - reserve resources according to the calculation (or reject request)
  - resource scheduling
    - enforce resource usage with respect to resource administration decisions

Resource Management Phases



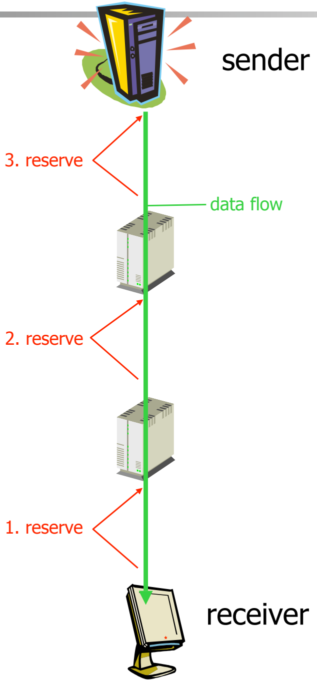
Reservation Directions

- Sender oriented:
  - sender (initiates reservation)
    - must know target addresses (participants)
    - in-scalable
    - good security



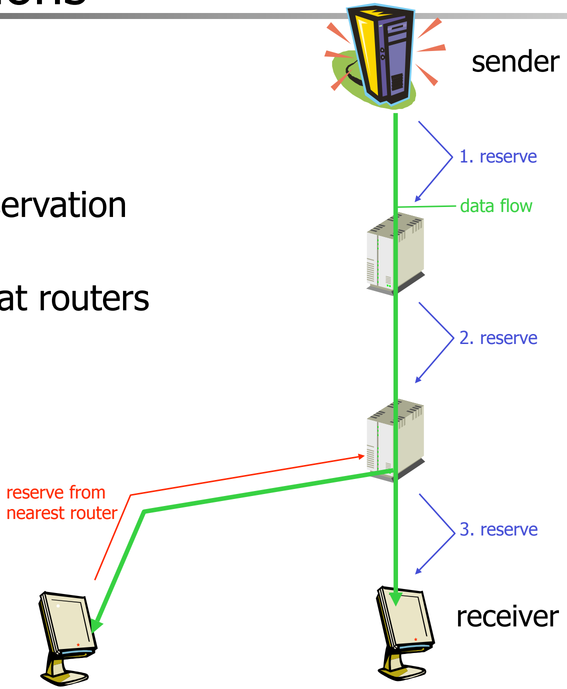
Reservation Directions

- Receiver oriented:
  - receiver (initiates reservation)
    - needs advertisement before reservation
    - must know “flow” addresses
  - sender
    - need not to know receivers
    - more scalable
    - in-secure



Reservation Directions

- Combination?
  - start sender oriented reservation
  - additional receivers join at routers (receiver based)



Per-flow QoS

Integrated Services

Integrated Services (IntServ)

- Framework by IETF to provide individualized QoS guarantees to individual application sessions

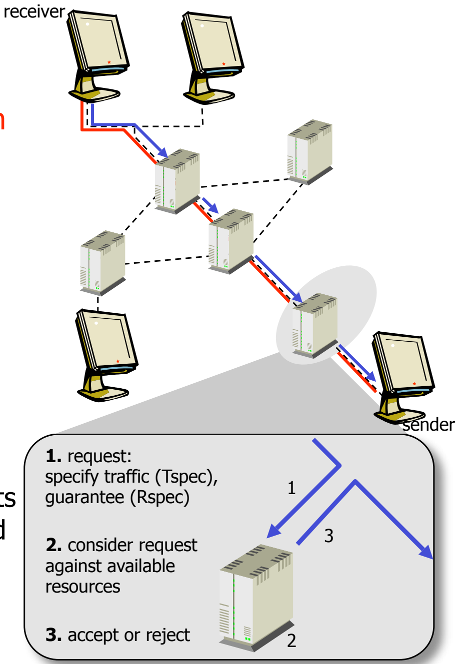
- Goals:
  - efficient Internet support for applications which require service guarantees
  - fulfill demands of multipoint, real-time applications (like video conferences)
  - do not introduce new data transfer protocols

- In the Internet, it is based on IP (v4 or v6) and RSVP
  - RSVP – Resource reSerVation Protocol

- Two key features
  - reserved resources – the routers need to know what resources are available (both free and reserved)
  - call setup (admission call) – reserve resources on the whole path from source to destination

Integrated Services (IntServ)

- Admission call:
  - traffic characterization and specification
    - one must specify the traffic one will transmit on the network (Tspec)
    - one must specify the requested QoS (Rspec – reservation specification)
  - signaling for setup
    - send the Tspec and Rspec to all routers
  - per-element admission test
    - each router checks whether the requests specified in the R/Tspecs can be fulfilled
    - if YES, accept; reject otherwise



Integrated Services (IntServ)

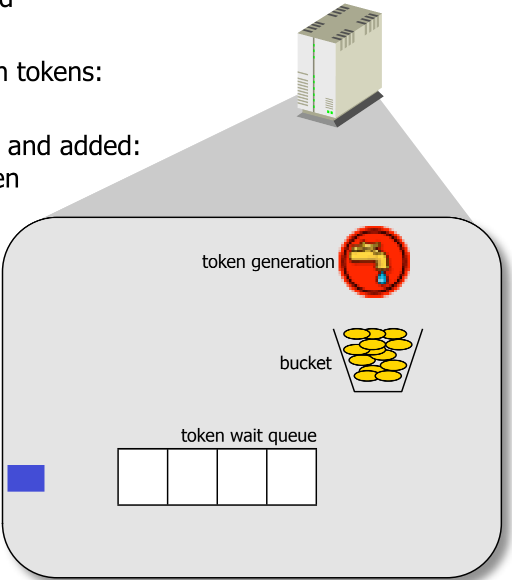
- IntServ introduces two new services enhancing the Internet's traditional best effort:

  - guaranteed service
    - guaranteed bounds on delay and bandwidth
    - for applications with real-time requirements

  - controlled-load service
    - "a QoS closely to the QoS the same flow would receive from an unloaded network element" [RFC 2212], i.e.,
      similar to best-effort in networks with limited load
    - no quantified guarantees,
      but packets should arrive with "a very high percentage"
    - for applications that can adapt to moderate losses, e.g.,
      real-time multimedia applications

Integrated Services (IntServ)

- Both service classes use token bucket to police a packet flow:
  - packets need a token to be forwarded
  - each router has a b-sized bucket with tokens:
    if bucket is empty, one must wait
  - new tokens are generated at a rate r and added:
    if bucket is full (little traffic), the token
    is deleted
  - the token generation rate r serves
    to limit the long term average rate
  - the bucket size b serves to limit the
    maximum burst size



Integrated Services (IntServ)

- Today implemented
  - in every router
  - for every operating system
    (its signaling protocol RSVP is even switched on by default in Windows!)

- … and not used

- Arguments
  - too much overhead
  - too large memory requirements
  - too inflexible
  - “net neutrality” argument
  - no commercial model

QoS Aggregates

Protocols

Differentiated Services (DiffServ)

- IntServ and RSVP provide a framework for per-flow QoS, but they …
  - … give complex routers
    - much information to handle
  - … have scalability problems
    - set up and maintain per-flow state information
    - periodically PATH and RESV messages overhead
  - … specify only a predefined set of services
    - new applications may require other flexible services

⇨ DiffServ [RFC 2475] tries to be both scalable and flexible

Differentiated Services (DiffServ)

- ISPs favor DiffServ
- Basic idea
  - multicast is not necessary

  - make the core network simple - support to many users
  - implement more complex control operations at the edge
  - aggregation of flows –
    reservations for a group of flows, not per flow

  ⇨ thus, avoid scalability problems on routers with many flows

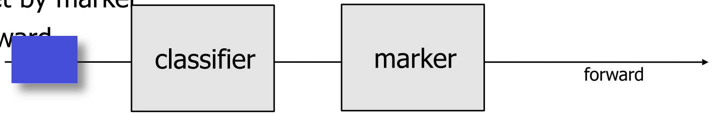
  - do not specify services or service classes
  - instead, provide the functional components on which services can be built

  ⇨ thus, support flexible services

Differentiated Services (DiffServ)

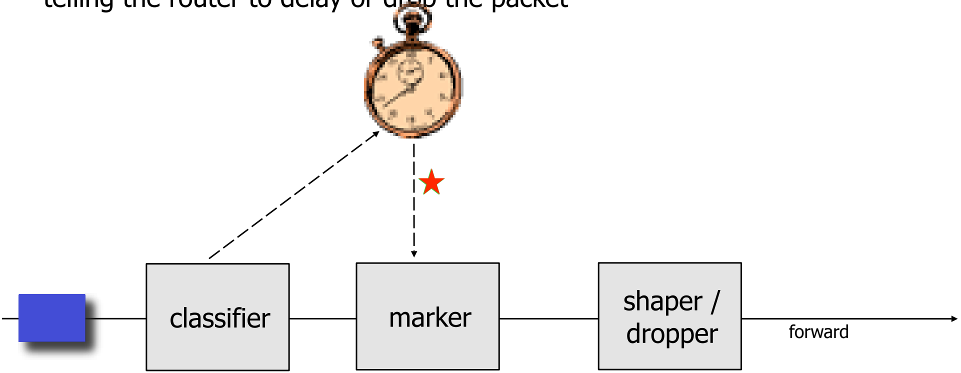
- Two set of functional elements:
  - edge functions: packet classification and traffic conditioning
  - core function: packet forwarding

- At the edge routers, the packets are tagged with a DS-mark (differentiated service mark)
  - uses the type of service field (IPv4) or the traffic class field (IPv6)
  - different service classes (DS-marks) receive different service
  - subsequent routers treat the packet according to the DS-mark
  - classification:
    - incoming packet is classified (and steered to the appropriate marker function) using the header fields
    - the DS-mark is set by marker
    - once marked, forward



Differentiated Services (DiffServ)

- Note, however, that there are no “rules” for classification – it is up to the network provider
- A metric function may be used to limit the packet rate:
  - the traffic profile may define rate and maximum bursts
  - if packets arrive too fast, the metric function assigns another marker function telling the router to delay or drop the packet

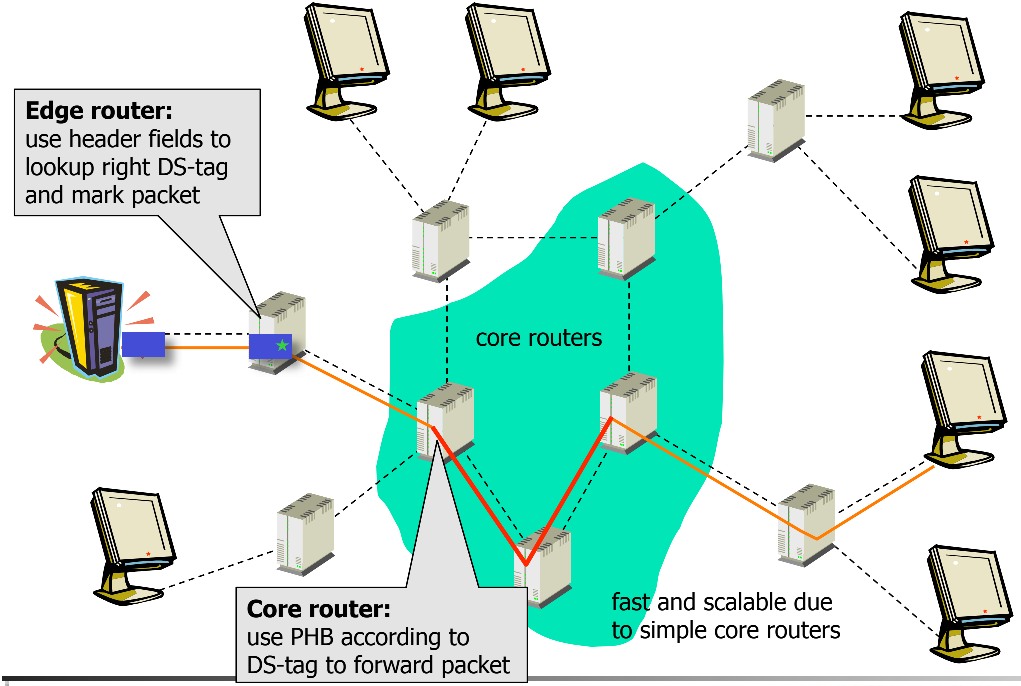


Differentiated Services (DiffServ)

- In core routers,
  DS-marked packets are forwarded
  according to their per-hop behavior (PHB)
  associated with the DS-tag
  - the PHB determines how the router resources are used and shared among the competing service classes
  - the PHB should be based on the DS-tag only
    - no other state in the router
  - traffic aggregation
    - packets with same DS-tag are treated equally
    - regardless of original source or final destination

  - a PHB can result in different service classes receiving different performance
  - performance differences must be observable and measurable to be able to monitor the system performance
  - no specific mechanism for achieving these behaviors are specified

Differentiated Services (DiffServ)



Differentiated Services (DiffServ)

- Currently, two PHBs are under active discussion
  - expedited forwarding [RFC 3246]
    - specifies a minimum departure rate of a class, i.e., a guaranteed bandwidth
    - the guarantee is independent of other classes, i.e., enough resources must be available regardless of competing traffic
  - assured forwarding [RFC 2597]
    - divide traffic into four classes
    - each class is guaranteed a minimum amount of resources
    - each class are further partitioned into one of three "drop" categories (if congestion occur, the router drops packets based on "drop" value)

Multiprotocol Label Switching (MPLS)

- Multiprotocol Label Switching
  - Separate path determination from hop-by-hop forwarding
  - Forwarding is based on labels
  - Path is determined by choosing labels

- Distribution of labels
  - On application-demand
    - LDP – label distribution protocol
  - By traffic engineering decision
    - RSVP-TE – traffic engineering extensions to RSVP

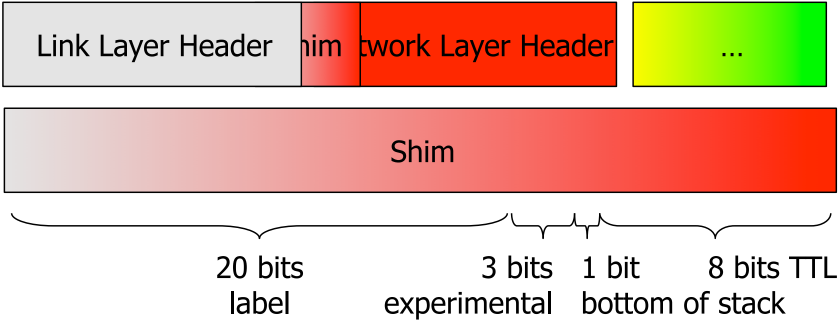
Multiprotocol Label Switching (MPLS)

- MPLS works above **multiple** link layer **protocols**
- Carrying the **label**
  - Over ATM
    - Virtual path identifier or Virtual channel identifier
    - Maybe shim
  - Frame Relay
    - data link connection identifier (DLCI)
    - Maybe shim
  - Ethernet, TokenRing, …
    - Shim

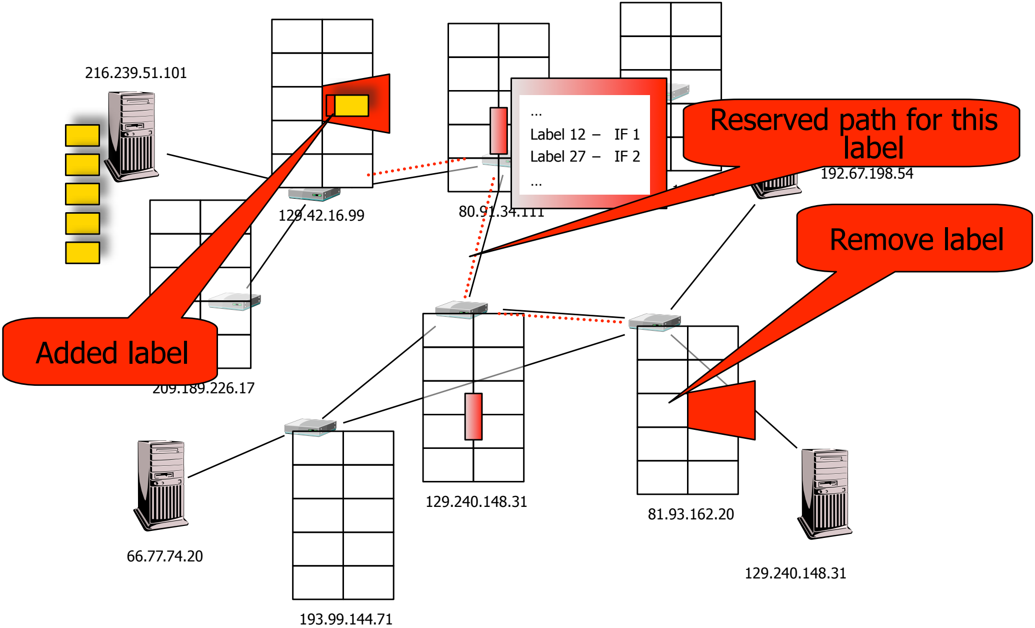
- Shim?

Multiprotocol Label Switching (MPLS)

- Shim: the label itself

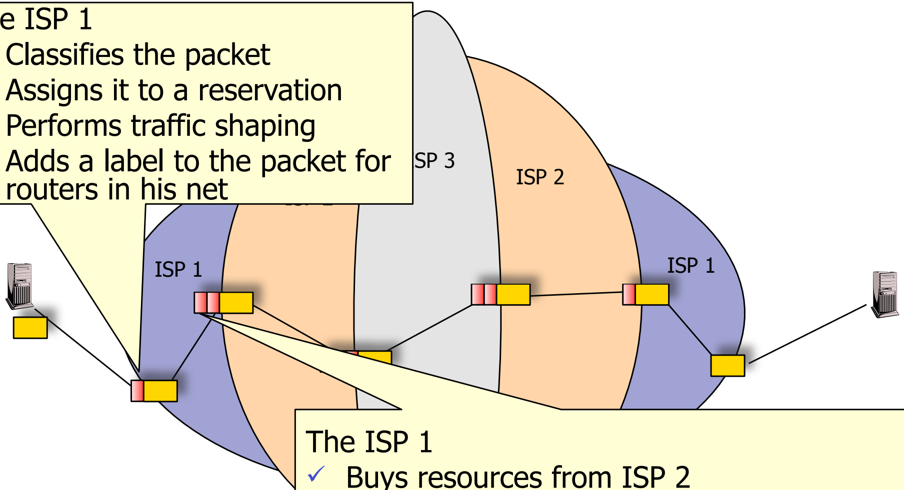


Routing using MPLS



MPLS Label Stack

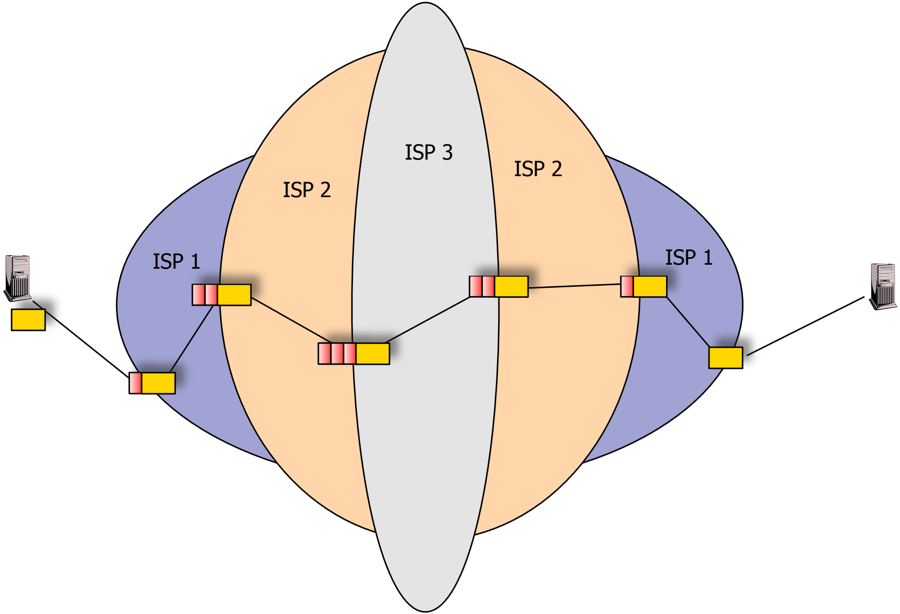
The ISP 1
- ✓ Classifies the packet
- ✓ Assigns it to a reservation
- ✓ Performs traffic shaping
- ✓ Adds a label to the packet for routers in his net



The ISP 1
- ✓ Buys resources from ISP 2

The ISP 2
- ✓ Repeats classifying, assignment, shaping
- ✓ Adds a label for the routers in his net
- ✓ He **pushes a label on the label stack**

MPLS Label Stack

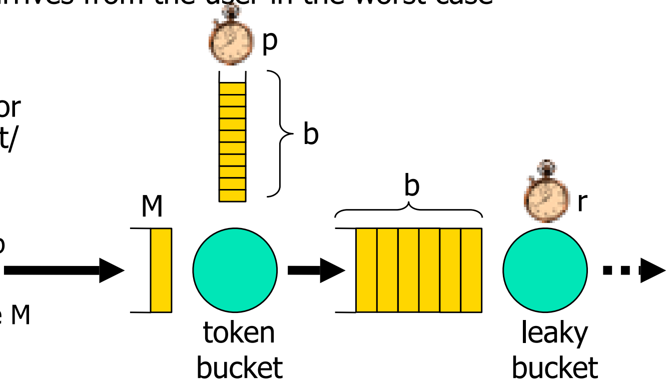


QoS Aggregates

Network Calculus

Using Network Calculus

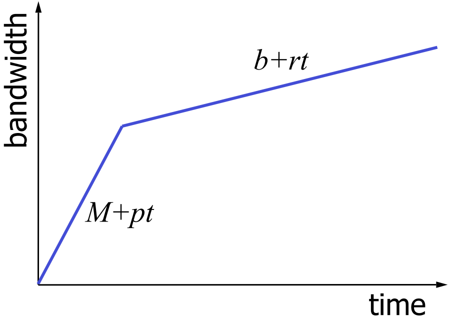
- Guaranteed Service
  - An assured level of bandwidth
  - A firm end-to-end delay bound
  - No queuing loss for data flows that conform to a TSpec
- TSpec – traffic specification
  - Describes how traffic arrives from the user in the worst case

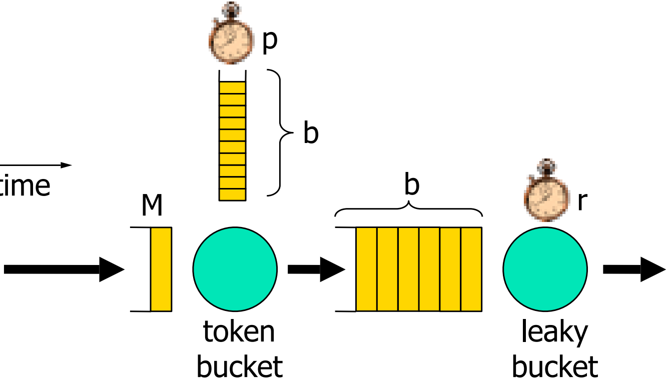


- Double token bucket (or combined token bucket/ leaky bucket)
  - Token bucket rate r
  - Token bucket depth b
  - Peak rate p
  - Maximum packet size M

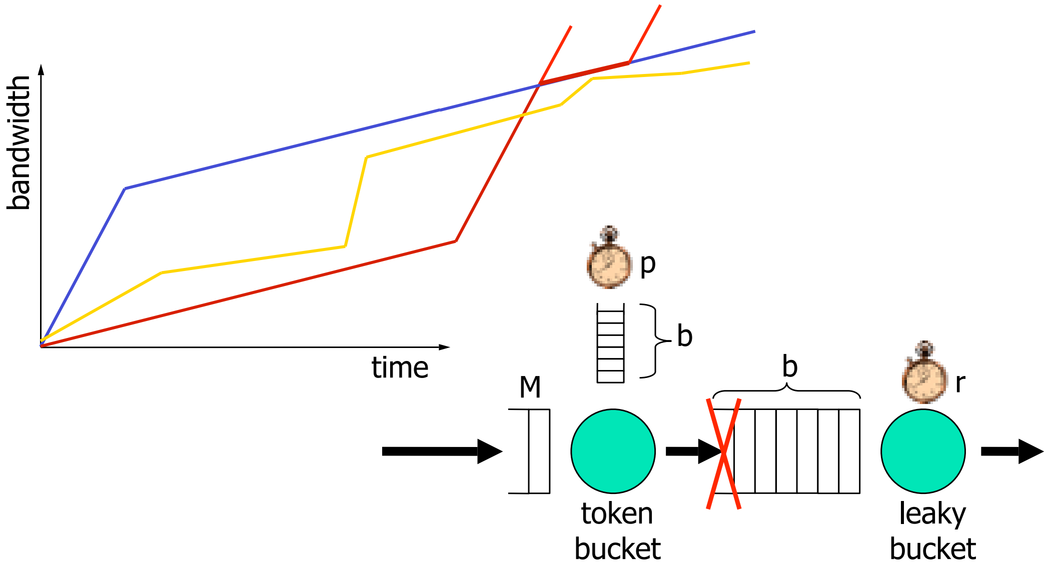
Using Network Calculus

arrival curve: $$a(t) = \begin{cases} M + pt & t < \dfrac{b-M}{p-r} \\ b + rt & t \geq \dfrac{b-M}{p-r} \end{cases}$$





Using Network Calculus



Using Network Calculus

- Service curve
  - The network's promise
  - Based on a "fluid model"

Service curve: $c(t) = R(t - V)^{+}$

Service rate: $R \geq r$ (validity condition)

Deviations: $V \approx D$ (router's delay)

$$R \geq p \geq r \qquad d_{\max} = \frac{M}{R} + D$$

$$p \geq R > r \qquad d_{\max} = \frac{(b - M)(p - R)}{R(p - r)} + \frac{M}{R} + D$$

Delays in the network

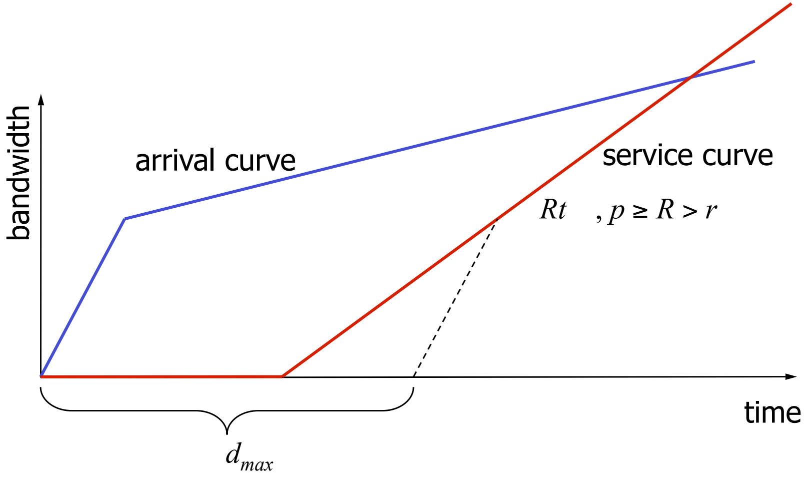
But: delay d_{max} is usually part of the user-network negotiation

Required service rate dependent on requested d_{max}

$$R \geq p \geq r \qquad R = \frac{M}{d_{\max} - D}$$

$$p \geq R > r \qquad R = \frac{p\dfrac{b - M}{p - r} + M}{d_{\max} + \dfrac{b - M}{p - r} - D}$$

Using Network Calculus



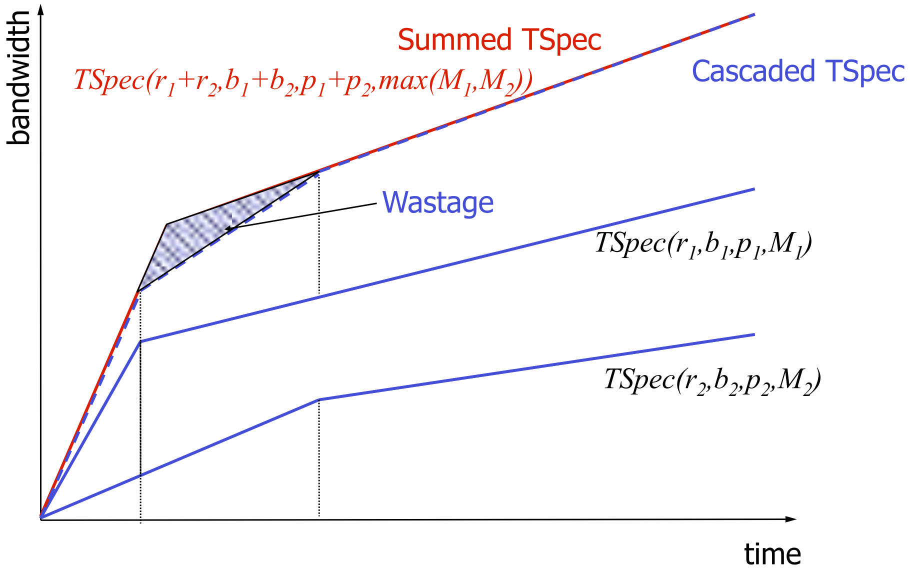
Using Network Calculus

- Using network calculus to scale

- Aggregation
  - Less state in routers
    - One state for the aggregate
  - Share buffers in routers
    - Buffer size in routers depends on the TSpec's rates
  - Use scheduling to exploit differences in d_{max}
    - Schedule flows with low delay requirements first

Using Network Calculus

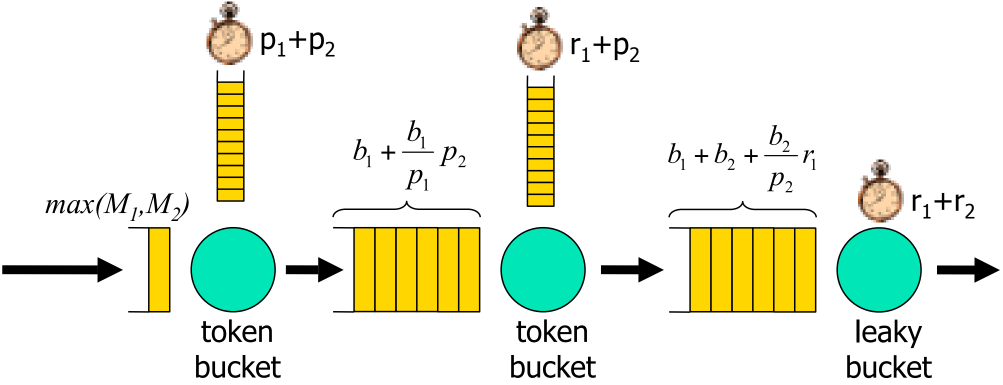
Aggregation



Using Network Calculus

Aggregation

Cascaded TSpec: n+1 token buckets



Summary

Directions of Network QoS

[Liebeherr]

- Old-style QoS is dead
  - ATM,
    IntServ,
    DiffServ,
    Service overlays didn't take hold
  - Causes?
    - No business case
    - Bothed standardization
    - Naïve implementations
    - No need
- Future QoS
  - Look for fundamental insights
  - Develop design principles
  - Develop analytical tools
    - Network calculus

[Crowcroft,Hand,Mortier,Roscoe,Warfield]

- Old-style QoS is dead
  - X.25 too little, too early
  - ATM too much, too late
  - IntServ too much, too early
  - DiffServ too little, too late
  - IP QoS not there
  - MPLS too isolated
- QoS through overlays can't work
- Future QoS
  - Single bit differentiation
  - Edge-based admission control
  - Micropayment

Directi

[Liebeherr ... er,Roscoe,Warfield]

- Old-style Q ... is dead
  - ATM, ... e, too early
  - IntServ, ... ch, too late
  - DiffServ, ... much, too early
  - Service o ... little, too late
  - hold ... here
  - ... lated
  - Causes?
    - No bu
    - Bothe
    - Naïve
    - No ne
- ... overlays can't
- Future Qo
  - ... ferentiation
  - Look for ... admission control
  - Develop ... nt
  - Develop
    - Netw

- Companies do provide QoS
  - AT&T
    - MPLS
  - Equant
    - MPLS
  - Cable and Wireless
    - ATM
    - MPLS
  - TeliaSonera
    - SDH
    - WDM
    - ATM
  - Nortel
    - MPLS
    - SONET/SDH
    - WDM

Summary

- Timely access to resources is important for multimedia application to guarantee QoS – reservation might be necessary

- Many protocols have tried to introduce QoS into the Internet, but no protocol has yet won the battle...
  - often NOT only technological problems, e.g.,
    - scalability
    - flexibility
    - ...
  - but also economical and legacy reasons, e.g.,
    - IP rules – everything must use IP to be useful
    - several administrative domains (how to make ISPs agree)
    - router manufacturers will not take the high costs (in amount of resources) for per-flow reservations
    - pricing
    - ...

Summary

- What does it means for performance in distributed applications?
  - QoS protocols
    - either not present
    - or used for traffic multiplexes

⇒ Applications must adapt to bandwidth competition

- either to generic competing traffic
- or to traffic within a multiplex

⇒ End-to-end QoS can be statistically guaranteed

- Overprovisioning in access networks
- Network calculus in long-distance networks