Quality of Service (QoS)

Outline

- Quality of Service
- Integrated Services (RSVP)
- Differentiated Services

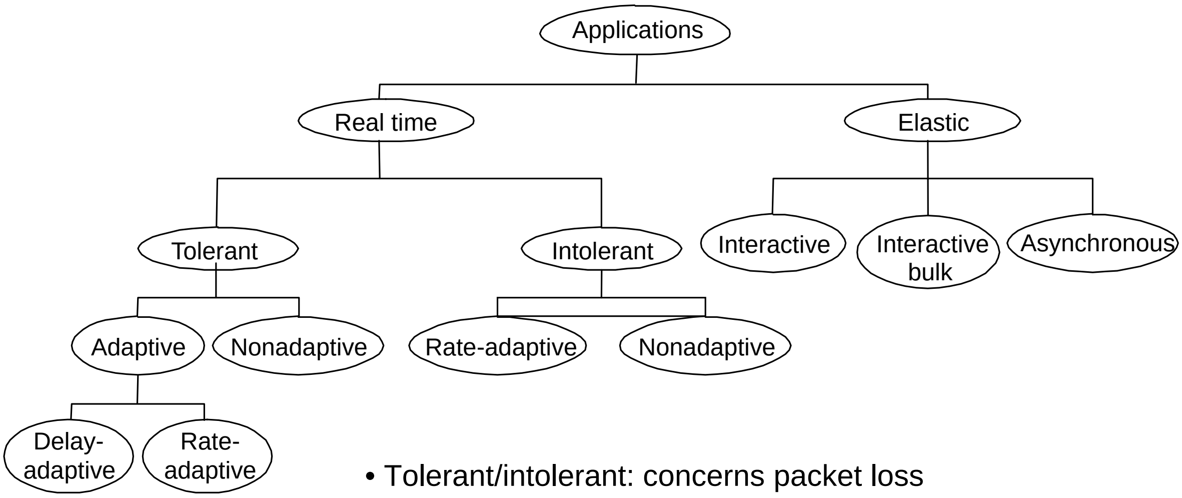
Need for QoS

- Basic assumption: bandwidth is **scarce** also in the future
  - if we can install enough capacity that network can never be overloaded, everyone gets premium service all the time ⇒ best effort service is enough
  - if bandwidth is scarce, mechanisms are needed to control/isolate different traffic types (need a new service model to support QoS)
- Need to understand requirements from different (new) applications
  - traditional data does not (necessarily) need QoS
  - **multimedia** has different/varying requirements on the network
    - need for high-bandwidth links (improved coding helps)
    - **timeliness** of delivery, called real-time application
      - ex. voice, video, industrial control
  - multimedia needs assurance from the network that data arrives on time
  - if bandwidth is scarce, data and multimedia traffic interfere with each other
- Current state of Internet
  - best-effort model: makes no guarantees, leaves cleanup operation to edges
- QoS network = network that can provide different levels of service

Application requirements

- Roughly, two types: real-time and non-real-time
- Non-real-time:
  - “traditional data”
  - applications like Telnet, FTP, email, web browsing
  - relies on lossless delivery (through retransmissions)
  - can work without guarantees of timely delivery of data
  - also called **elastic:** applications adjust to available capacity (TCP)
  - since applications are elastic, no need for QoS (just add more capacity)
- Real-time:
  - telephone, video conference, streaming audio/video
  - requires “deliver on time” assurances
    - large delay prohibits for example phone conversation
    - variations in delay can be smoothened by using application level buffers, but overall delay increases
  - may also need assurances regarding bandwidth (throughput) and loss
  - assurance must come from inside the network ⇒ need QoS mechanisms

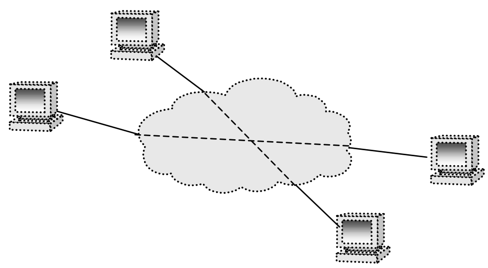
Taxonomy of applications

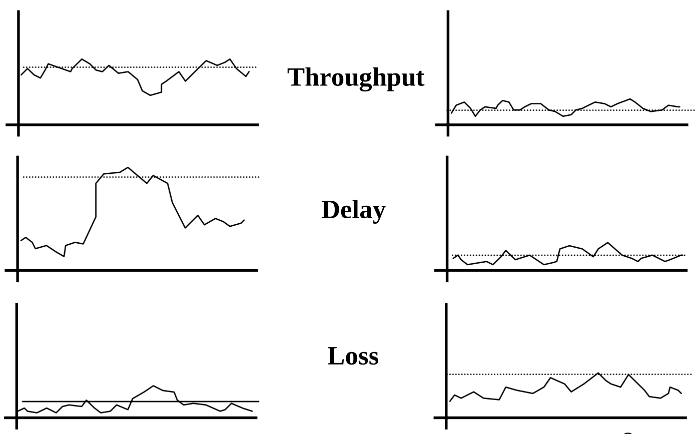


- Tolerant/intolerant: concerns packet loss
- Adaptive/nonadaptive: concerns delay variations
- Delay adaptive: application can adjust amount of buffering
- Rate adaptive: e.g., audio codec can change its bit rate

Internet QoS

- By adding Quality of Service (QoS), we are aiming to provide service differentiation to users
  - with respect to bandwidth, delay and loss characteristics
- Differentiation can be based on different criteria
  - Usage
  - Money
  - Status





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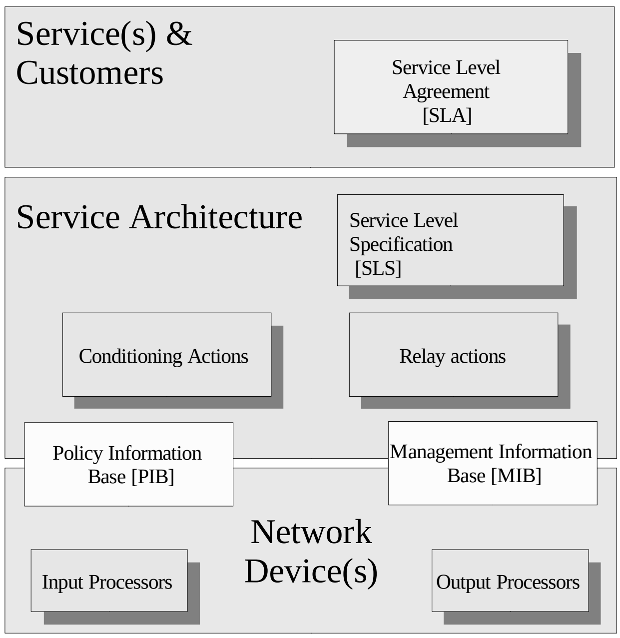
Terminology

- **Connection**: a dynamically formed reservation of network resources for a period of time.
  - Connection requires a state to be formed inside the network
  - State is a filter defining packets which belong into particular connection and required reservation attributes
- **Flow**: formed from arbitrary packets which fall within predefined filter and temporal behaviour.
  - Packets from one source to the same destination arrive to the investigation point with interarrival time less than t seconds.
  - Local knowledge, no state stored for particular flow
- **Aggregate**: a group of flows which have same forwarding characteristics and share link resources.
- **Class**: a group of connections which share same forwarding characteristics.

Approaches to QoS support

- A complete QoS architecture comprises several layers
  - here we look at basic mechanisms in the “lower layers” (no customer/user relation)
- Fine-grained approach
  - provide QoS to individual applications or flows
  - Integrated Services, RSVP (ATM)
- Coarse-grained approach
  - provide QoS to large classes of data or aggregated traffic
  - Differentiated Services



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Elements of Integrated Services

- Different functional components of the IntServ architecture
  - Service classes
  - Flowspecs
  - Admission control
  - Reservation protocol
  - Packet classifying and scheduling

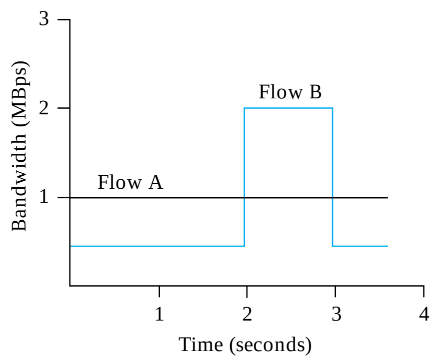
- $\Rightarrow$ Main question: does it scale?

Integrated Services (cont.)

- Service classes
  - guaranteed service:
    - for delay intolerant application, packets never arrive late
    - maximum delay guaranteed
  - controlled load:
    - for adaptive applications that run well if network is not heavily loaded
    - emulate lightly loaded network, even though the network as a whole may be heavily loaded, i.e., use queuing mechanisms to isolate controlled load traffic
    - use admission control to limit controlled load traffic
- Mechanisms
  - telling the network about service requirements, characterizing the data (flowspec) , admission control (can we provide requested service to given data) , signaling / resource reservation (network routers exchange information), packet scheduling (actions of routers to meet the requirements)

Flowspecs

- Two parts: TSpec and RSpec
  - TSpec: flow's traffic characteristics, information about bandwidth used by the flow
  - RSpec: service requested from network (ex. request for controlled load, or delay bound)
- Token bucket: describes the bandwidth characteristics of a source
  - parameters: token rate r and a bucket depth B
  - idea: To send a byte, you need a token. To send packet of length n, you need n tokens. At start no tokens, tokens accumulate at rate r - but never more than B tokens. Whenever you have enough tokens you can spend them in sending data.
  - figure: two flows with the same mean, but different token bucket

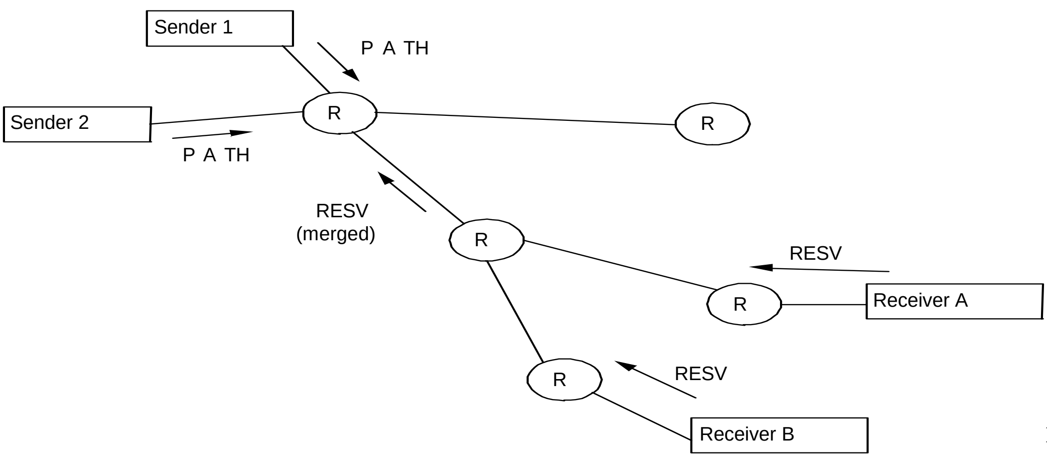


Admission and reservation

- Admission control
  - per flow decision to admit a new flow or not
  - given TSpec and RSpec decide if desired service can be provided with available resources - a difficult task
  - if a new flow is admitted, old flows may not get worse service than what it has requested earlier
  - different from policing = function applied on per-packet basis to make sure that flow conforms to TSpec
- Resource Reservation Protocol (RSVP)
  - key assumption: should not detract from the robustness of today's Internet where routers may crash, links may go down but the end-to-end connectivity survives
  - uses a soft state in routers - soft state need not be explicitly deleted, it times out if not refreshed periodically (30 s refreshment period in IntServ)
  - aims to support also multicast

Path reservation

- Receiver-oriented approach - receiver needs to know sender's TSpec and the path
- Sender sends a message with TSpec to receiver, gets reverse path as a bonus: source transmits PATH, receiver responds with RESV
- If link fails, routing creates a new PATH message and receiver sends RESV along new path, reservations on old path time out and are released $\Rightarrow$ adaptation to changes in topology



Packet classification and scheduling

- Packet classification: associate each packet with appropriate reservation
  - mapping from flow-specific information in the packet header to a single class identifier that determines how the packet is handled in the queue
- Packet scheduling: manage packets in the queues to that they get the service that has been requested
  - not a trivial task...

Scalability problem of Integrated Services

- Integrated services and RSVP enhance best-effort service model, but ISPs find that it is not the right model
- Violates the fundamental design goal of IP: scalability
  - as Internet grows, routers just need to keep up (move bits faster and deal with larger routing tables)
  - with RSVP every flow through router may have a reservation
  - ex. 2.5 Gbps full of 64-Kbps audio streams $\Rightarrow$ $2.5 \times 10^9 / 64 \times 10^3 = 39\ 000$ flows
  - each reservation needs a state that is stored in memory and refreshed periodically
- Need for a solution that does not require so much “per-flow” work

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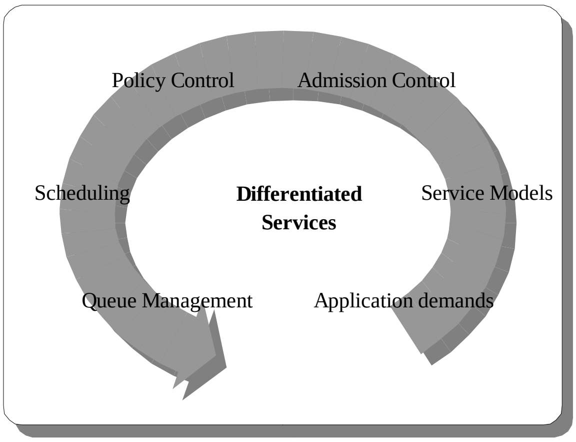
Differentiated Services overview

- Physically, nothing more than Best Effort (well, sort of …)
- Logically, number of parallel Best Effort networks
- Packet is destined to one of the parallel networks
  - Packet per packet processed quality of service
  - Connectionless architecture is still preserved
- Each parallel network uses same routing topology (not neccesarily)



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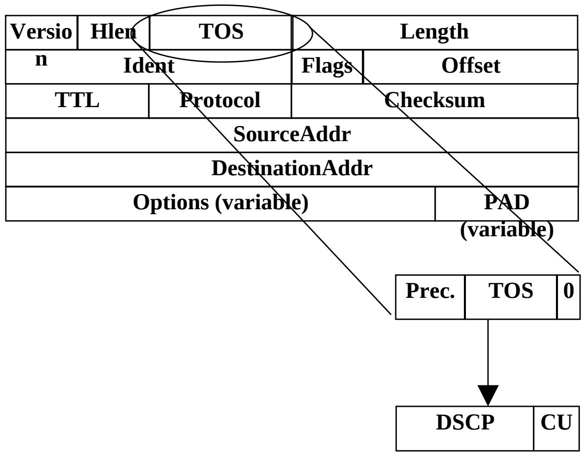
Differentiated Services overview (cont)

- Identification of which parallel best effort network packet is destined, is coded in each packet
  - IPv4 ToS field is reformatted
  - 6 bits reserved for indicating traffic classes, DSCP (Differentiated Services Code Points) bits
- Questions:
  - Who sets the premium bit, and under what circumstances?
  - What does the router do differently when it sees a packet with the bit set?



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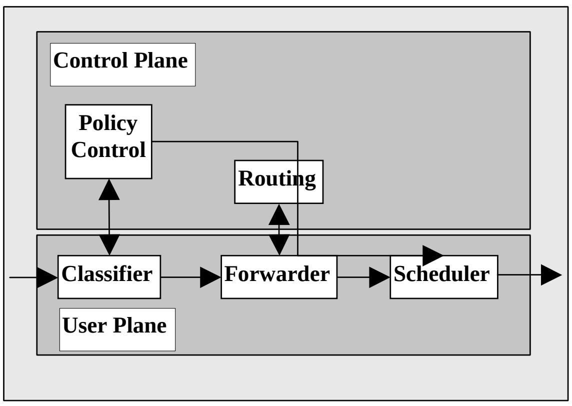
DiffServ router

- Packets are forwarded based on the destination address and class information (DSCP of the packet)
  - scheduling and queueing is done based on the class information
- DiffServ router has two additional elements in datapath compared to basic Best Effort router:
  - Traffic conditioner (TC) (Classifier in figure)
  - Per hop behavior (PHB) (Scheduler in figure)
- Control plane of DiffServ router has one extra element, i.e., policy controller, which is responsible for internal management and configuration of TC and PHB



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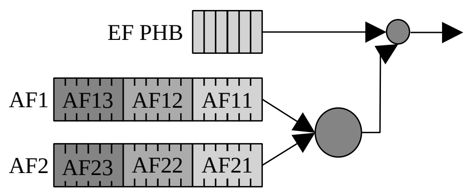
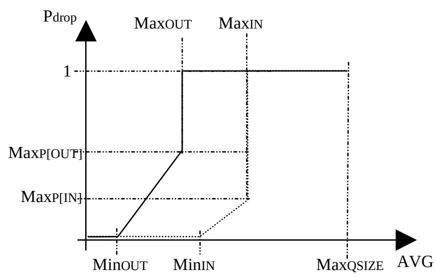
DiffServ conditioner

- Traffic Conditioner consists of
  - Classifiers
    - responsible for logical separation of packet streams
    - inspects DSCP bits from packets
  - Meters
    - responsible for rate metering of logical streams
    - done by using for example token buckets
  - Markers
    - responsible for actions based on metering results and predefined thresholds
    - non-conformant packets may be dropped or marked

DiffServ PHB

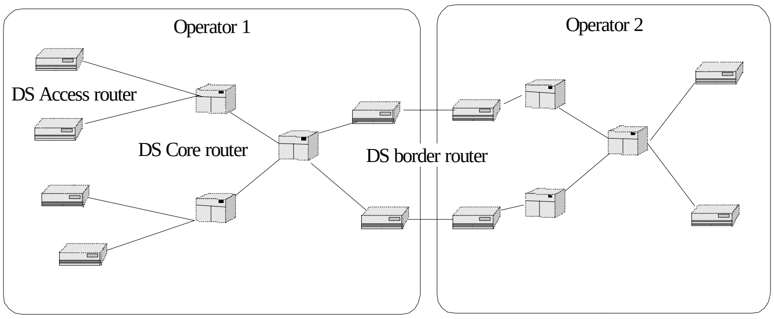
- PHB = Per Hop Behavior
- PHB is a block containing queue management methods required to implement desired service (locally)
  - queues
  - queue space management algorithms
  - schedulers
- PHB defines forwarding actions in a router - no end-to-end specification





DiffServ network

- Workload in DiffServ is divided between two inherently different types of routers
  - edge routes
  - core routers
- Edge routers are on the domain edge and interface
  - customers
  - other ISPs
- Edge routers are responsible for conditioning actions which eventually determine logical network where packet is to be forwarded
  - edge routers set DSCP bits based on service contracts (SLAs) and traffic metering



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DiffServ network (cont)

- Logical network offering differentiated service is a concatenation of PHBs which interact together.
- These logical networks have target service called per domain behavior (PDB).
- Target service is a loose definition for the goal of the logical network when it is provisioned and configured in an appropriate way.
- Edge router chooses PDB for each packet which comes from the customer.
  - marks packet with DSCP of PHB used to implement PDB
- 2 PHBs have been standardized
  - EF: Expedited Forwarding
  - AF: Assured Forwarding
    - actually collection of 4 different classes

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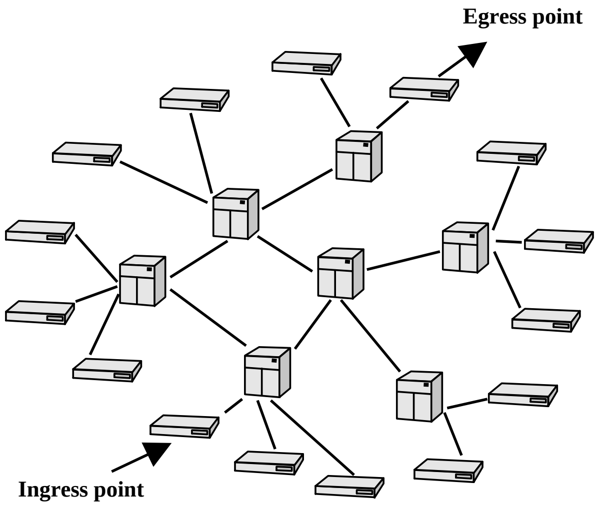
DiffServ network (cont)

- Service decision in edge router can be based on:
  - metering result
    - rate based
    - token buckets
  - predefined set of filters
    - IP address i.e. customer
    - TCP/UDP port, i.e., application
  - user request
    - precoded DSCP
    - RSVP signaling
- Core routers do nothing but forwarding of packets based on the extra information in DSCP field of packets
- Requires
  - Classifier to detect DSCP fields
  - PHB to implement forwarding behaviors

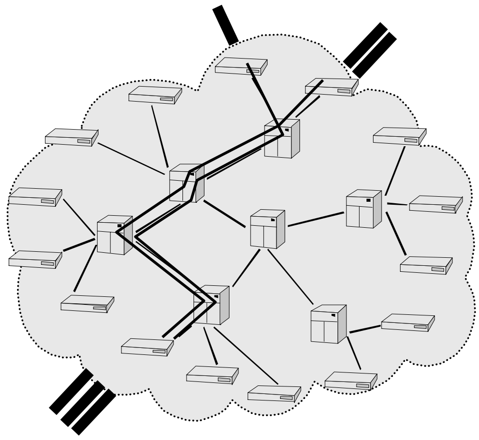
Expedited Forwarding (EF) [RFC2598]

- Leased line emulation
  - from destined ingress point to destined egress point
  - end-to-end service with
    - low loss
    - low latency
    - low jitter
  - “premium service”



EF

- Service commitment is only assured (not guaranteed)
  - resources inside EF class are shared
    - amount of other EF traffic influences the observed delay, jitter and loss
  - path is freely chosen
    - strict delay constraint can not be held as the delay of paths are inherently different
  - no reservation is done
    - provisioning is in the key role



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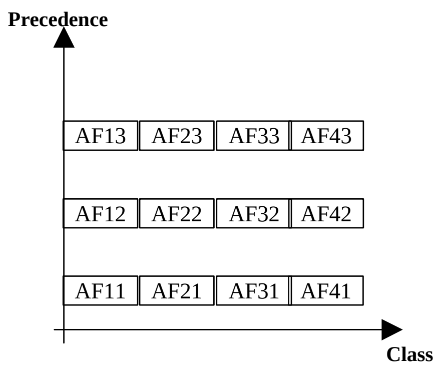
Assured Forwarding (AF) [RFC2597]

- Four independent service classes
  - all packets of a flow are destined to one of the classes
  - no association of service level between the classes
- Three precedences in each class
  - flow can have packets with different precedences (priorities)
  - order of packets in a flow is not allowed to change
    - precedence can not be used to scheduling decissions inside the class
    - precedence used to give, e.g., drop priorities



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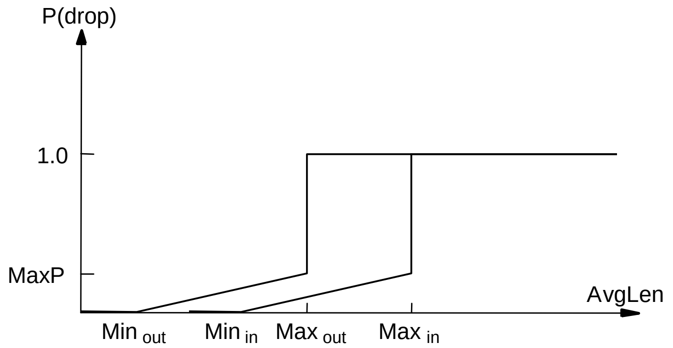
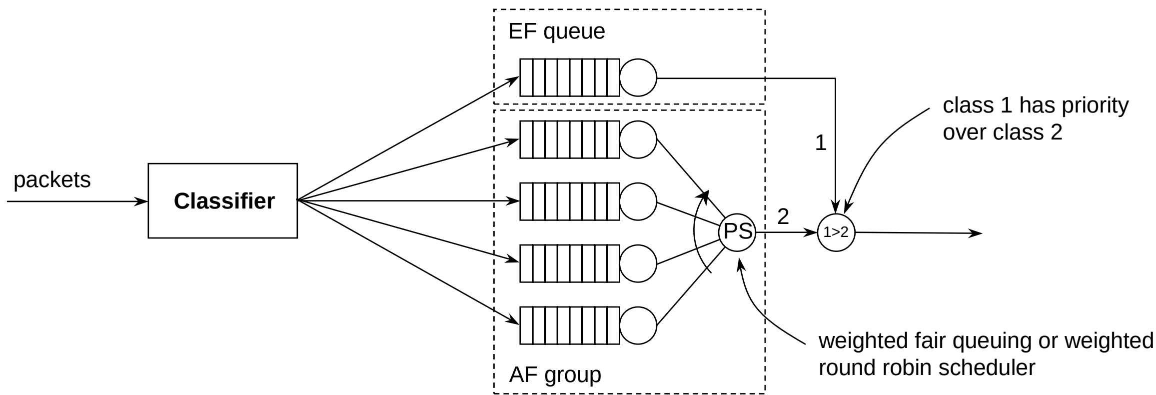
Implementing DiffServ PHBs: RIO

- One possible SIMPLIFIED implementation idea: assume two classes of traffic - “in” and “out”
- Business idea:
  - customer has contracted capacity of X bps, but sends packets with rate Y bps
  - if Y > X, some packets are marked out of profile
  - start to drop “out” packets first if there is congestion
- Two parallel RED algorithms for “in” and “out” packets = RIO
  - more than 2 classes = WRED algorithm

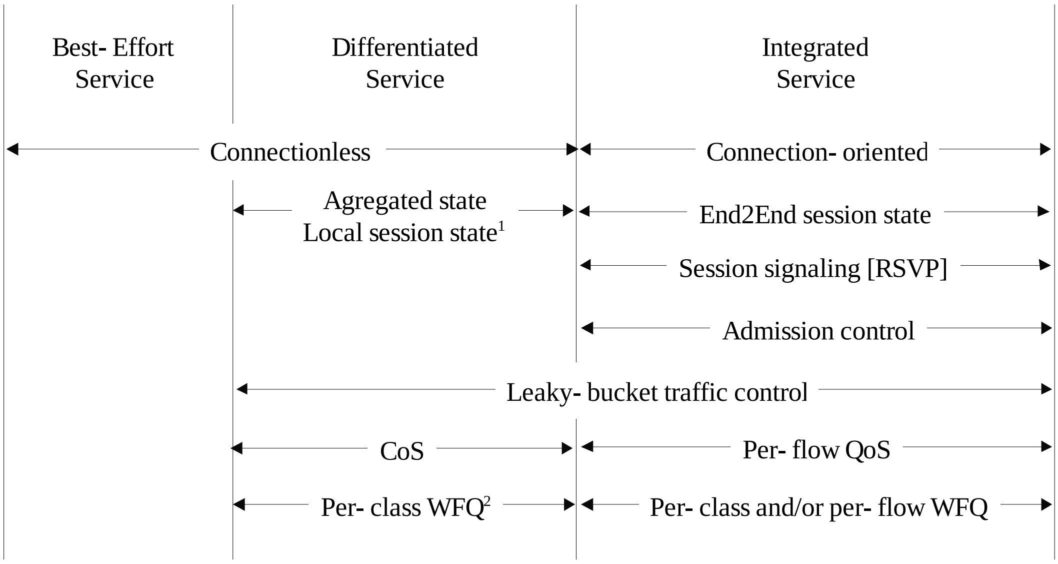


Implementing DiffServ PHBs: more advanced...

- EF packets have absolute priority over AF packets
  - if too much EF traffic, may starve AF queue(s)
  - could be fair queuing, as well
- AF groups separated with fair queuing
  - for each group, to implement drop precedences (3), we could have WRED with 3 classes (instead of 2 as in the previous slide)



Comparison



[1] Border routers may keep track individual sessions if required by policing or multifield classification.
[2] Scheduling depends on per hop behavior [PHB]. Minimum requirement is FIFO with multilevel RED.

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Remarks about Differentiated Services

- The idea of DiffServ is to combine individual flows into aggregates and to provide differentiated services inside the network (i.e., forwarding and discarding) to those.
- Under what conditions does it follow that when you serve an aggregate in a certain way, each individual flow in the aggregate gets some specific service?
  - need fair algorithms
  - open research problem
  - note: if you charge a customer (flow) for a better service, you need to provide that…
- Knowledge of the **offered flow** and careful setting of parameters are important in DiffServ
  - wrong parameters ⇒ your “premium” service is actually worse than your “best-effort” ⇒ careful network planning and provisioning are essential
- How to make sure that system can not be manipulated?