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# Quality of Service In Data Networks: Problems, Solutions, and Issues

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These slides are available at

<http://www.cis.ohio-state.edu/~jain/talks/qos9906.html>



ATM QoS and Issues

Integrated services/RSVP and Issues

Differentiated Services and Issues

QoS using MPLS

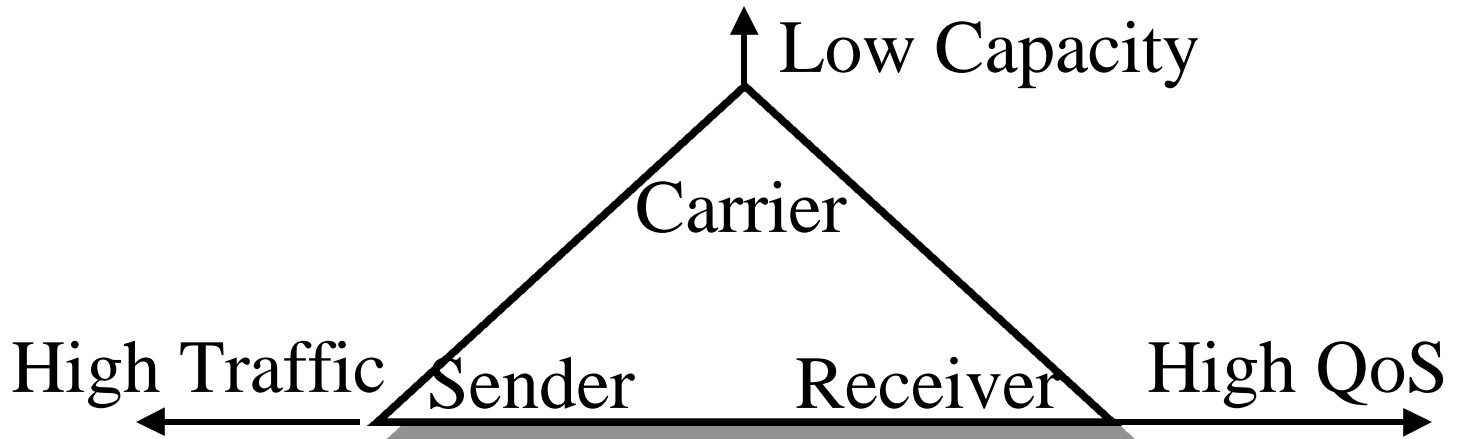
End-to-end QoS

This is an update to the May'98 talk

<http://www.cis.ohio-state.edu/~jain/talks/ipqos.htm>

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# QoS Triangle



Senders want to send traffic any time with high load and high burstiness

Receivers expect low delay and high throughput

Since links are expensive, providers want to minimize the infrastructure

If one of the three gives in  $\Rightarrow$  no problem

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# What is QoS?

Predictable Quality: Throughput, Delay, Loss, Delay jitter, Error rate

Opposite of best effort = Random quality

Mechanisms:

- Capacity Planning
- Classification, Queueing, Scheduling, buffer management
- QoS based path determination, Route pinning
- Shaping, policing, admission control
- Signaling

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# ATM Service Categories

**CBR**: Throughput, delay, delay variation

**rt-VBR**: Throughput, delay, delay variation

**nrt-VBR**: Throughput

**UBR**: No Guarantees

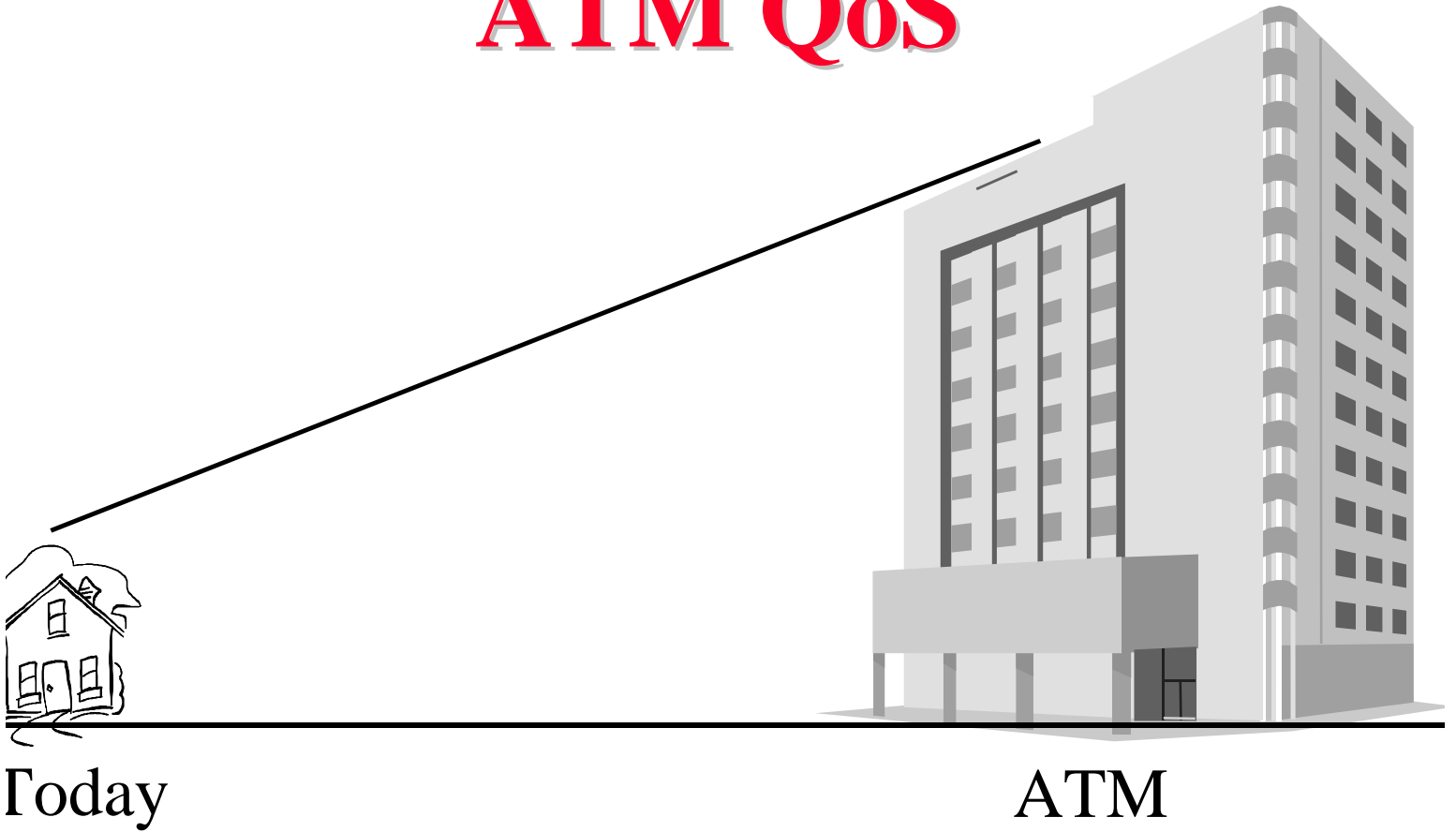
**GFR**: Minimum Throughput

**ABR**: Minimum Throughput. Very low loss.  
Feedback.

ATM also has QoS-based routing (PNNI)

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# ATM QoS



Too much too soon

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# ATM QoS: Issues

Can't easily aggregate QoS:  $VP = \Sigma VCs$

Can't easily specify QoS: What is the CDV required for a movie?

signaling too complex  $\Rightarrow$  Need Lightweight Signaling

Need Heterogeneous Point-to-Multipoint:

Variegated VCs

Need QoS Renegotiation

Need Group Address

Need priority or weight among VCs to map DiffServ and 802.1D

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# Integrated Services

Best Effort Service: Like UBR.

Controlled-Load Service: Performance as good as in an unloaded datagram network. No quantitative assurances. Like nrt-VBR or UBR w MCR

Guaranteed Service: rt-VBR

- Firm bound on data throughput and delay.
- Delay jitter or average delay not guaranteed or minimized.
- Every element along the path must provide delay bound.
- Is not always implementable, e.g., Shared Ethernet
- Like CBR or rt-VBR

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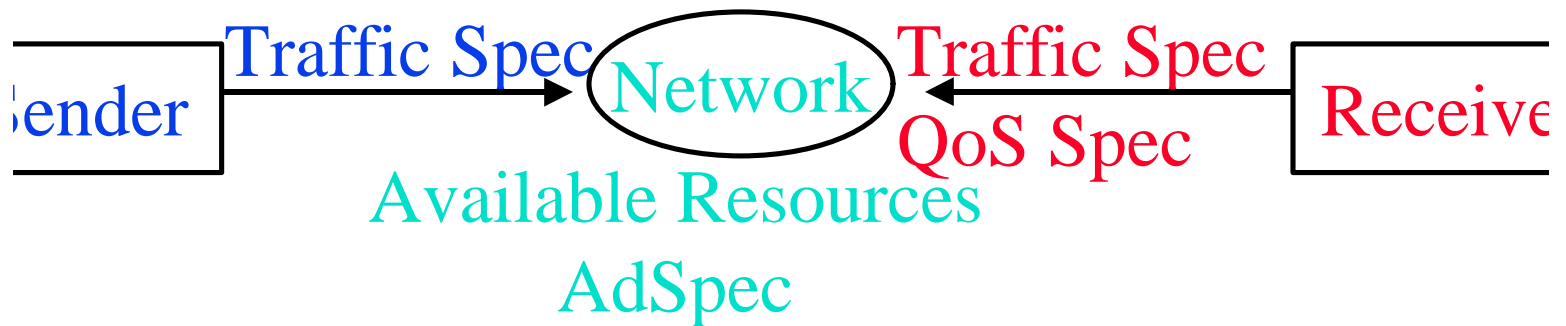
# RSVP

Resource ReSerVation Protocol

Internet signaling protocol

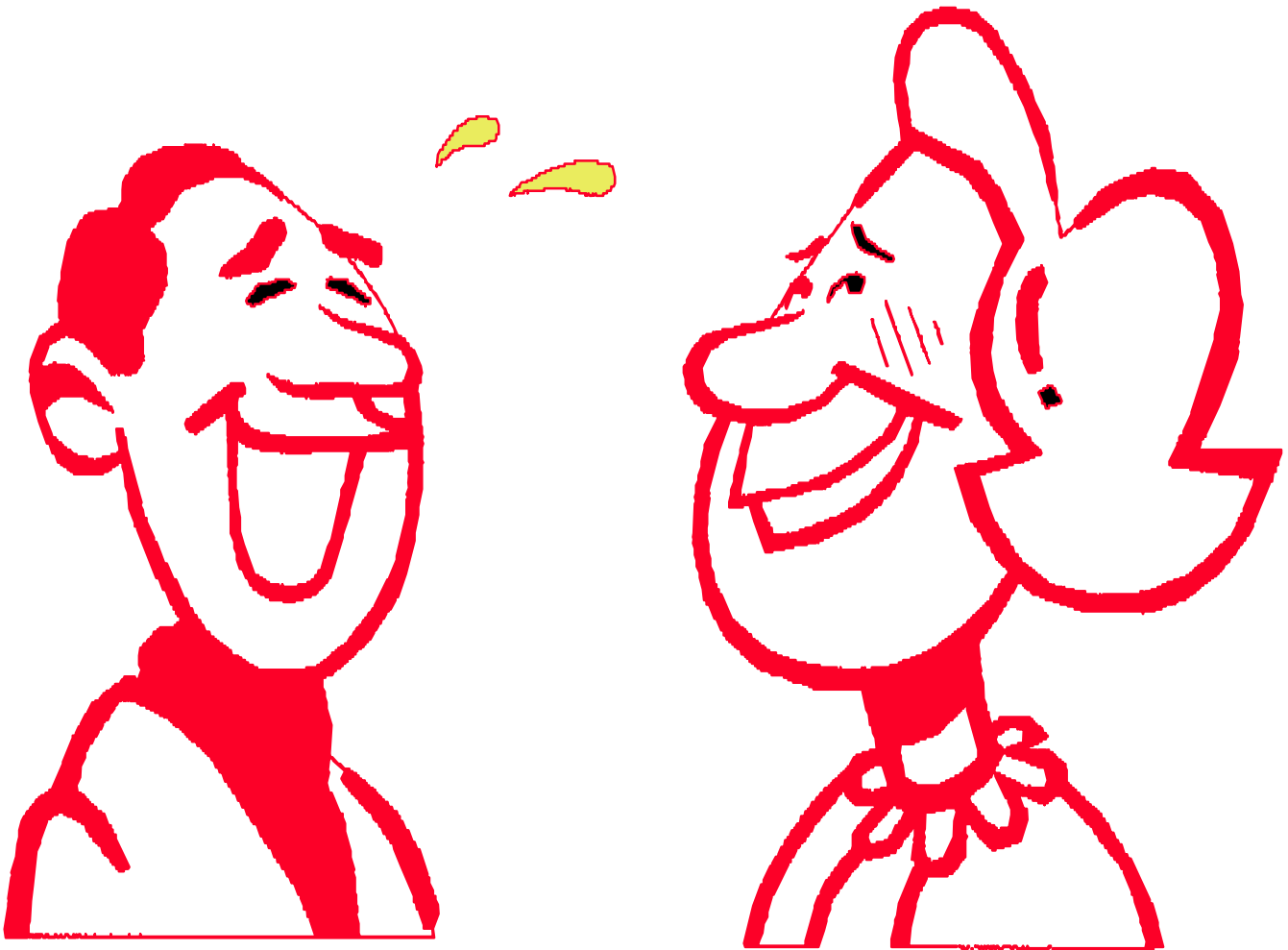
Carries resource reservation requests through the network including traffic specs, QoS specs, network resource availability

sets up reservations at each hop



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# Before



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# After



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# problems with RSVP and Integrated Services

Complexity in routers: packet classification,  
scheduling

scalable in number of receivers per flow but

Per-Flow State:  $O(n)$   $\Rightarrow$  Not scalable with # of flow

Number of flows in the backbone may be large.

$\Rightarrow$  Suitable for small private networks

Need a concept of “Virtual Paths” or aggregated flow  
groups for the backbone

Need policy controls: Who can make reservations?

Support for accounting and security.

$\Rightarrow$  RSVP admission policy (rap) working group.

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## Problems (Cont)

Receiver Based:

Need sender control/notifications in some cases.

Which receiver pays for shared part of the tree?

Soft State: Need route/path pinning (stability).

Limit number of changes during a session.

RSVP does not have negotiation and backtracking

Throughput and delay guarantees require support of

lower layers. Shared Ethernet  $\Rightarrow$  IP can't do GS or

CLS. Need switched full-duplex LANs.

Can't easily do RSVP on ATM either

Most of these arguments also apply to integrated

services.  
Ohio State University

Raj .

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# Differentiated Services

Ver	Hdr Len	Precedence	ToS	Unused	Tot Len
4b	4b	3b	4b	1b	16b

Pv4: 3-bit precedence + 4-bit ToS

DSPF and integrated IS-IS can compute paths for each ToS

Many vendors use IP precedence bits but the service varies  $\Rightarrow$  Need a standard  $\Rightarrow$  Differentiated Services

Diffserv working group formed February 1998

Charter: Define ds byte (IPv4 ToS field)

Mail Archive: <http://www-nrg.ee.lbl.gov/diff-serv-arch/>

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# DiffServ Concepts

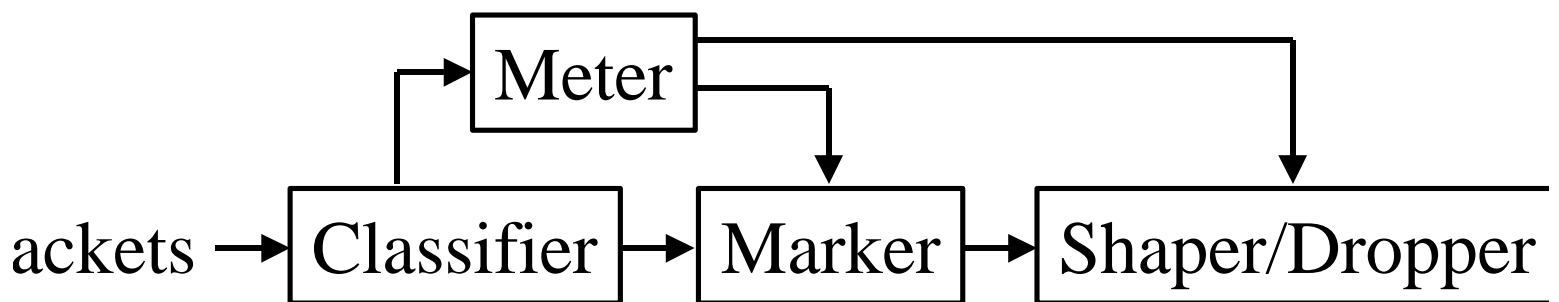
Micro-flow = A single application-to-application flow  
Traffic Conditioners: Meters (token bucket), Marker (tag), Shapers (delay), Droppers (drop)

Behavior Aggregate (BA) Classifier:

Based on DS byte only

Multi-field (MF) Classifiers:

Based on IP addresses, ports, DS-byte, etc..



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# Diff-Serv Concepts (Cont)

Service: Offered by the protocol layer

- Application: Mail, FTP, WWW, Video,...
- Transport: Delivery, Express Delivery,...  
Best effort, controlled load, guaranteed service
- DS group will not develop services  
They will standardize “Per-Hop Behaviors”

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# Per-hop Behaviors



Externally Observable Forwarding Behavior

$x\%$  of link bandwidth

Minimum  $x\%$  and fair share of excess bandwidth

Priority relative to other PHBs

PHB Groups: Related PHBs. PHBs in the group share common constraints, e.g., loss priority, relative delay

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# Expedited Forwarding

Also known as “Premium Service”

Virtual leased line

Similar to CBR

Guaranteed minimum service rate

Policed: Arrival rate  $<$  Minimum Service Rate

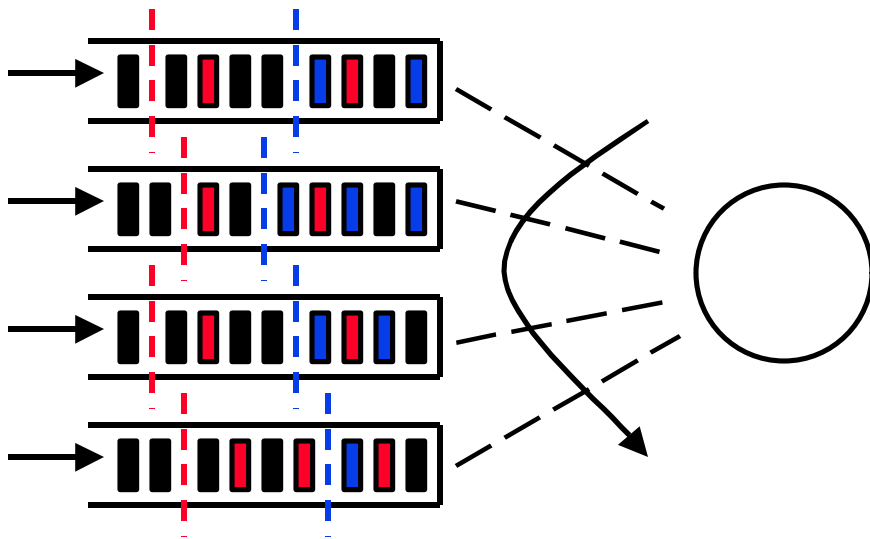
Not affected by other data PHBs

⇒ Highest data priority (if priority queueing)

Code point: 101 110

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# Assured Forwarding



PHB Group

Four Classes: No particular ordering

Three drop preference per class

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# Assured Forwarding (Cont)

DS nodes SHOULD implement all 4 classes and MUST accept all 3 drop preferences. Can implement 2 drop preferences.

Similar to nrt-VBR/ABR/GFR

Code Points:

Drop Prec.	Class 1	Class 2	Class 3	Class 4
Low	010 000	011 000	100 000	101 000
Medium	010 010	011 010	100 010	101 010
High	010 100	011 100	100 100	101 100

Avoids 11x000 (used for network control)

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# AF Simulation Results

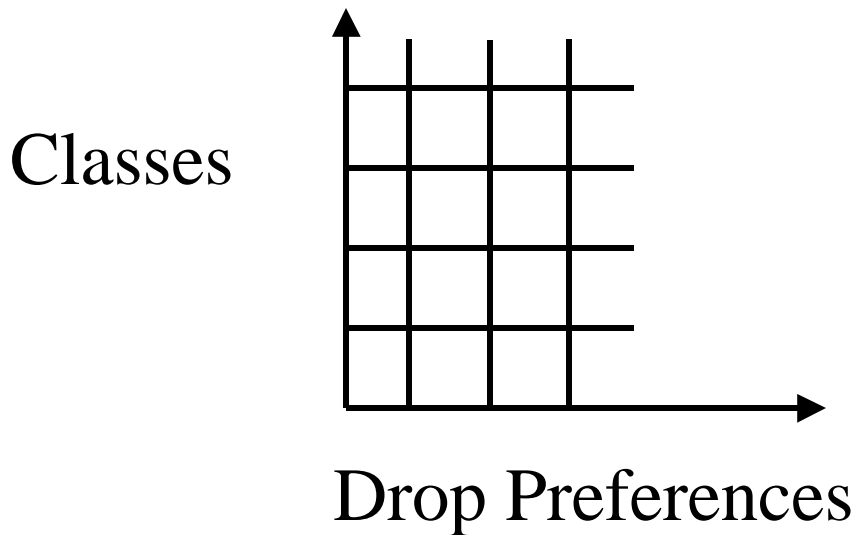
W/O DPs, TCP is punished for good behaviour  
Fairness is also poor.

Three DPs give the same perf for TCP as two DPs  
Reason: TCP does not distinguish between loss of  
packets of different drop precedences

Reference: M. Goyal, et al, "Effect of Number of Drop  
Precedences in Assured Forwarding," IETF draft-goyal-dpstdy-00.txt, March 1999, <http://www.cis.ohio-state.edu/~jain/ietf/dpstdy.htm>

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# On Drop Preferences



We have two dimensions of control

- Classes = Queues

- Drop Preferences = Right to enter the queue

Classes  $\Rightarrow$  Directly controls bandwidth allocation

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# Drop Preferences (Cont)

DPs  $\Rightarrow$  Controls buffer allocation

$\Rightarrow$  Indirectly affects bandwidth allocation

- Depends upon the arrival pattern

  - $\Rightarrow$  Random  $\Rightarrow$  Not Reliable

Given a limited number of PHB's, it is better to have more classes than more DPs

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# Problems with DiffServ

per-hop  $\Rightarrow$  Need at every hop

One non-DiffServ hop can spoil all QoS

End-to-end  $\neq \Sigma$  per-Hop

Designing end-to-end services with weighted guarantees at individual hops is difficult.

Only EF will work.

Designed for static Service Level Agreements (SLA)

Both the network topology and traffic are highly dynamic.

Multicast  $\Rightarrow$  Difficult to provision

Dynamic multicast membership  $\Rightarrow$  Dynamic SLAs?

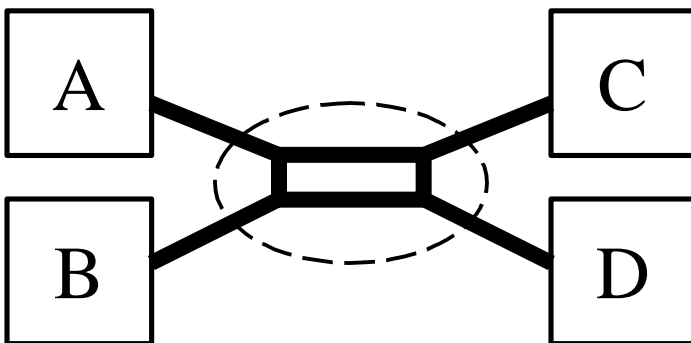
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# DiffServ Problems (Cont)

DiffServ is unidirectional  $\Rightarrow$  No receiver control  
Modified DS field  $\Rightarrow$  Theft and Denial of service.  
Ingress node should ensure.

How to ensure resource availability inside the network?

QoS is for the aggregate not per-destination.  
Multi-campus enterprises need inter-campus QoS.



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# DiffServ Problems (Cont)

QoS is for the aggregate not micro-flows.

Not intended/useful for end users. Only ISPs.

- Large number of short flows are better handled by aggregates.
- Long flows (voice and video sessions) need per-flow guarantees.
- High-bandwidth flows (1 Mbps video) need per-flow guarantees.

All IETF approaches are open loop control  $\Rightarrow$  Drop

Closed loop control  $\Rightarrow$  Wait at source

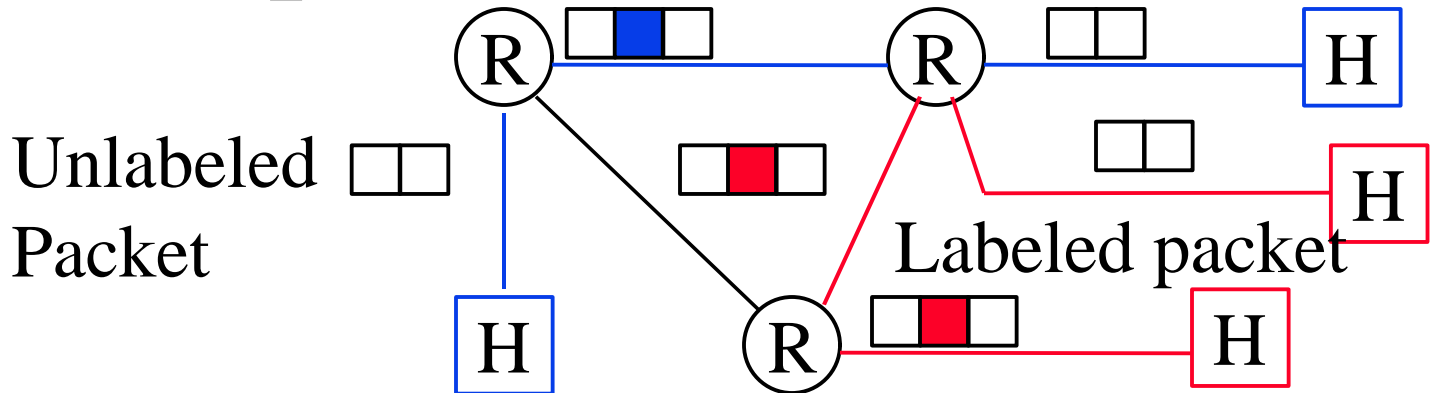
Data prefers waiting  $\Rightarrow$  Feedback

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# DiffServ Problems (Cont)

Guarantees  $\Rightarrow$  Stability of paths  
 $\Rightarrow$  Connections (hard or soft)  
Need route pinning or connections.

# Multiprotocol Label Switching



Entry “label switch router (LSR)” attaches a label to the packet based on the route

Other LSRs switch packets based on labels.

Do not need to look inside  $\Rightarrow$  Fast.

Labels have local significance

$\Rightarrow$  Different label at each hop (similar to VC #)

Exit LSR strips off the label

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# Traffic Engineering Using MPLS

Traffic Engineering = Performance Optimization  
= Efficient resource allocation, Path splitting  
⇒ Maximum throughput, Min delay, min loss  
⇒ Quality of service

In MPLS networks: “Traffic Trunks” = SVCs

Traffic trunks are routable entities like VCs

Multiple trunks can be used in parallel to the same ingress.

Each traffic trunk can have a set of associated characteristics, e.g., priority, preemption, policing, overbooking

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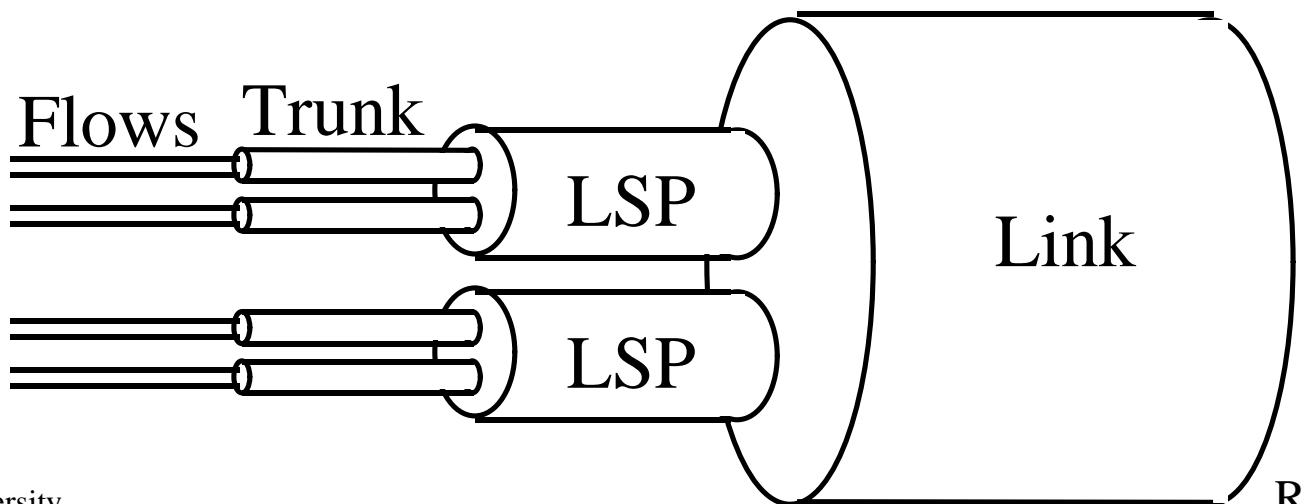
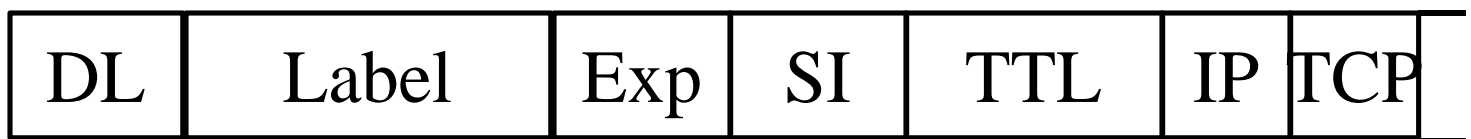
# Flows, Trunks, LSPs, and Links

Label Switched Path (LSP):

All packets with the same label

Trunk: Same Label+Exp

Flow: Same MPLS+IP+TCP headers



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# MPLS Simulation Results

Total network throughput improves significantly with proper traffic engineering

Congestion-unresponsive flows affect congestion-responsive flows

- Separate trunks for different types of flows

Trunks should be end-to-end

- Trunk + No Trunk = No Trunk

Reference: P. Bhaniramka, et al, “*QoS using Traffic Engineering over MPLS: An Analysis*,” IETF draft-bhani-mpls-te-anal-00.txt, March 1999, <http://www.cis.ohio-state.edu/~jain/teanal.htm>

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# Bandwidth Broker

Repository of policy database. Includes authentication

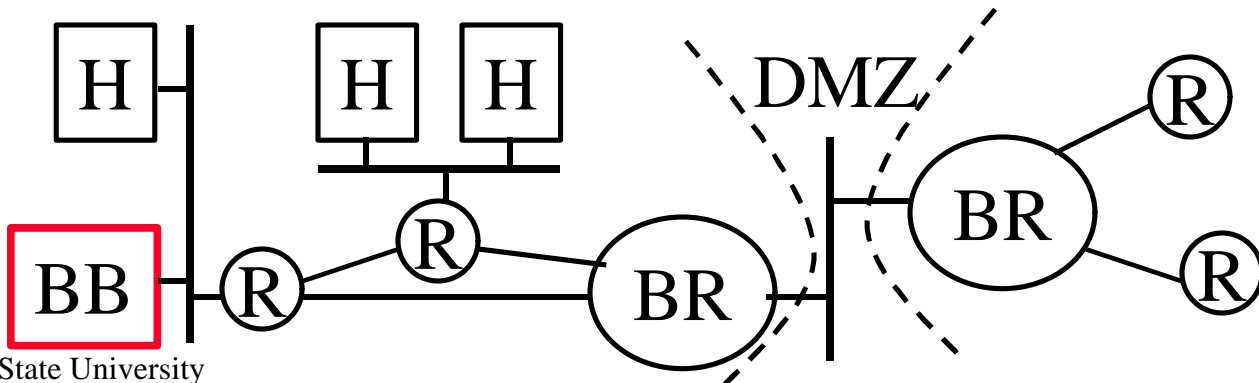
Users request bandwidth from BB

BB sends authorizations to leaf/border routers

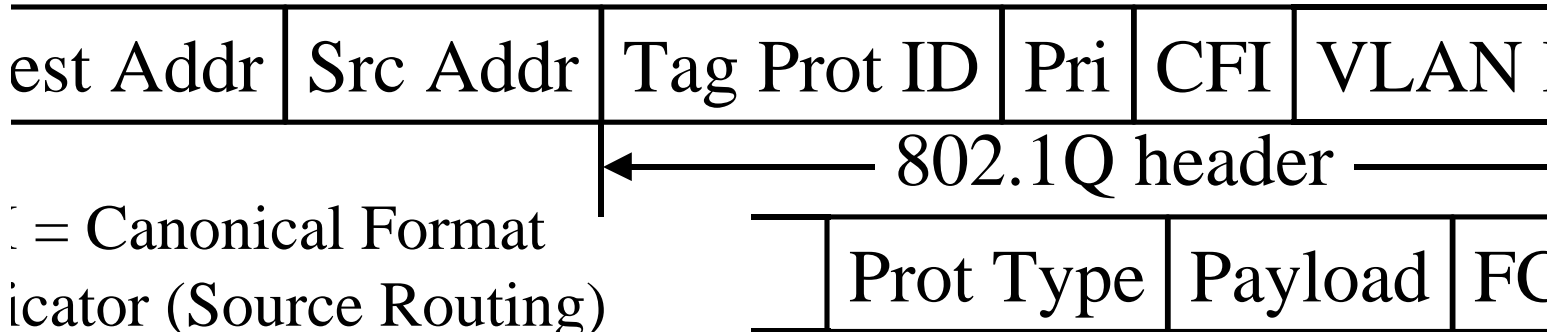
Tells what to mark.

Ideally, need to account for bandwidth usage along path

BB allocates only boundary or bottleneck



# IEEE 802.1D Model



**Up to eight priorities:** Strict.

0 Background

1 Spare

2 Best Effort

3 Excellent Effort

4 Control load

5 Video (Less than 100 ms latency and jitter)

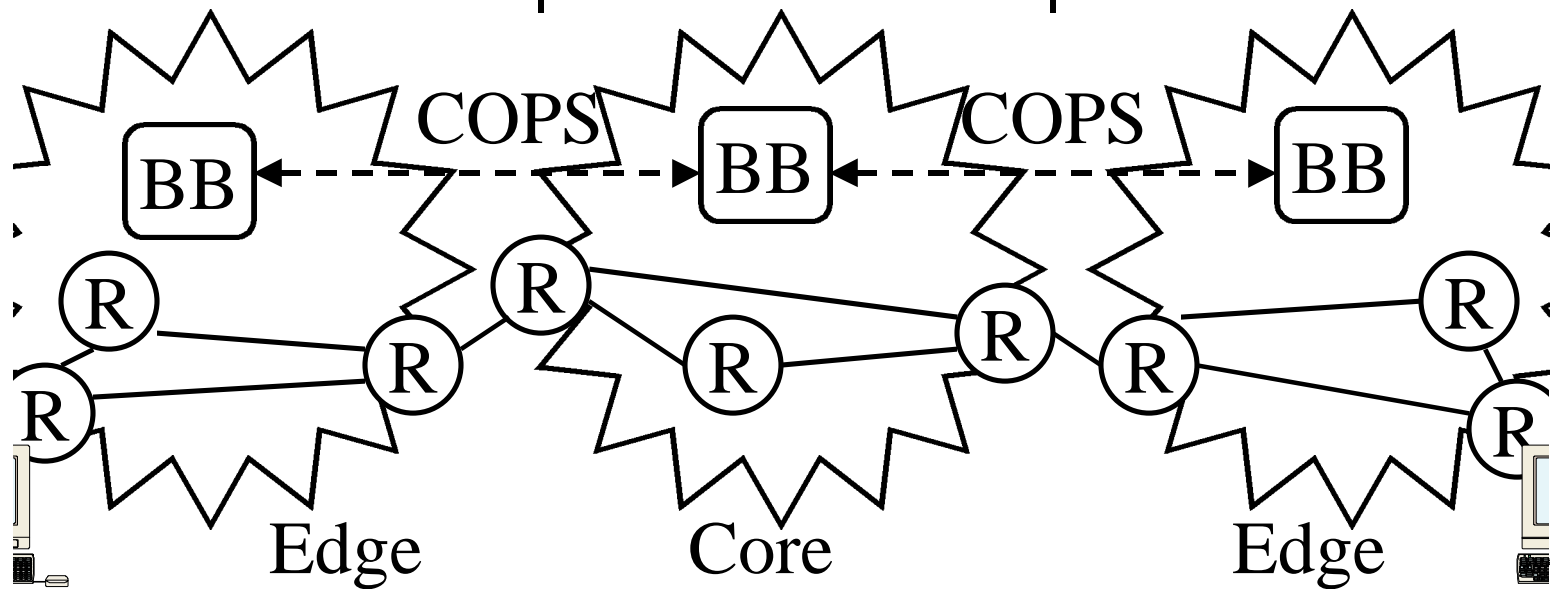
6 Voice (Less than 10 ms latency and jitter)

7 Network Control

# End-to-end View

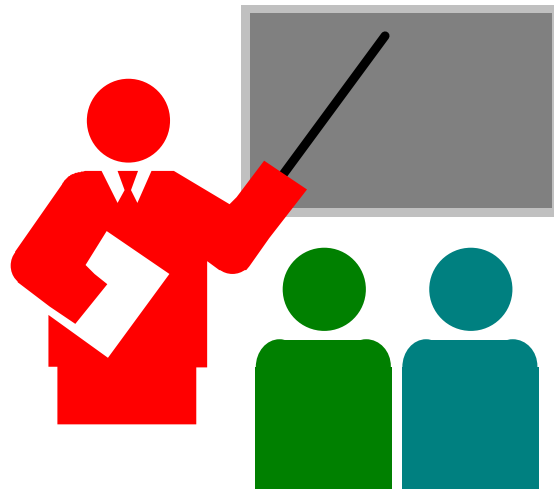
ATM/PPP backbone, Switched LANs/PPP in Stub  
IntServ/RSVP, 802.1D, MPLS in Stub networks  
DiffServ, ATM, MPLS in the core

Switched LANs/PPP | ATM/PPP | Switched LANs/P  
IntServ/RSVP, 802.1D, MPLS | DiffServ, ATM, MPLS | IntServ/RSVP, 802.1D, M



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# Summary



ATM: CBR, VBR, ABR, UBR, GFR

Integrated Services: GS = rtVBR, CLS = nrt-VBR

signaling protocol: RSVP

Differentiated Services will use the DS byte

MPLS allows traffic engineering and is most promising

802.1D allows priority

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# References

For a detailed list of references see:

[efs/ipqs\\_ref.htm](#)

Additional papers and presentations on QoS are at:

<http://www.cis.ohio-state.edu/~jain/>

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# Thank You!

