Quality of Service (QoS) in Data Networks

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These slides are available on-line at:

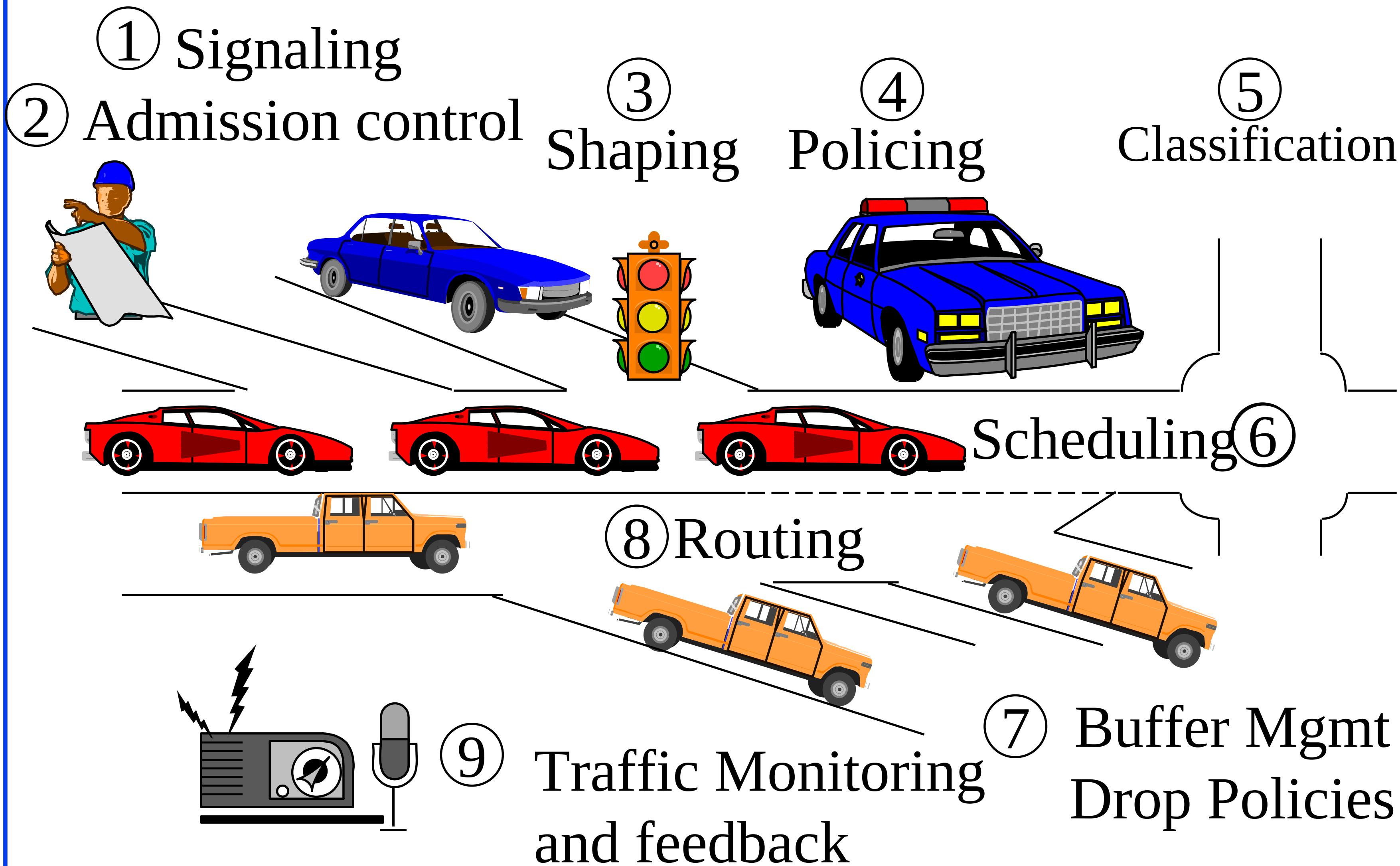
http://www.cse.wustl.edu/~jain/cse574-06/

- QoS Mechanisms
- ATM QoS
- Integrated services/RSVP
- Differentiated Services
- Multiprotocol Label Switching (MPLS)
- Comparison of different QoS approaches
- QoS over Wireless

Quality of Service

- **Service**: Movie, Song, Telephone Call, FTP
- **Quality of Service**: Picture quality, Color quality, sound quality,
- For network based services, service quality may depend upon:
  - Throughput – Min, max, average rate
  - Delay – Max delay, delay variation (Jitter)
  - Packet Loss Rate
  - Reliability – Links going up/down
- Each layer – PHY, MAC, IP, TCP, and application - has to have mechanisms to guarantee QoS

QoS Components

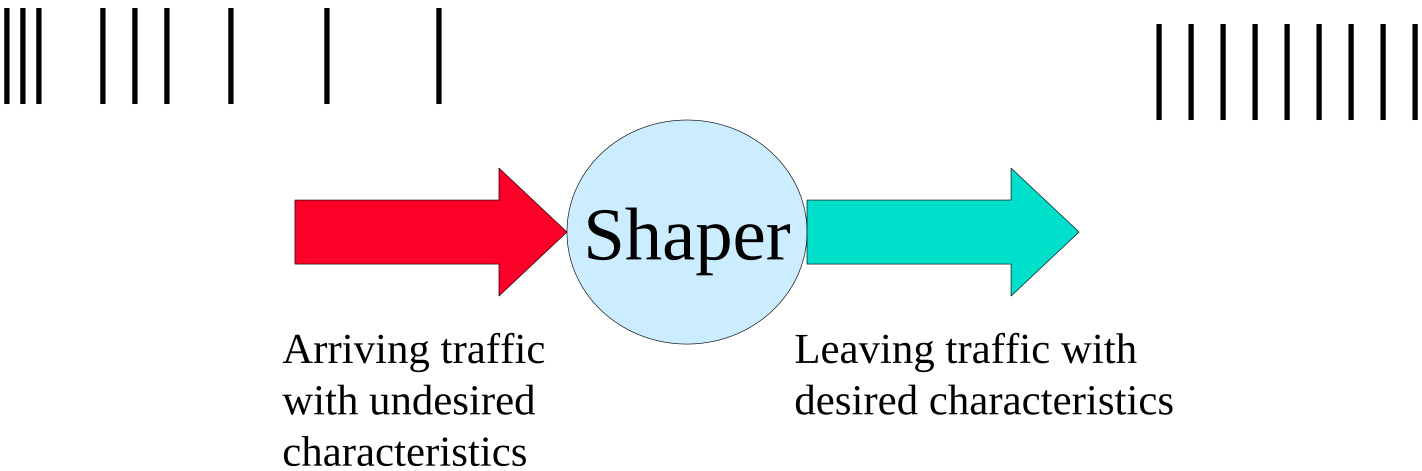


QoS Components

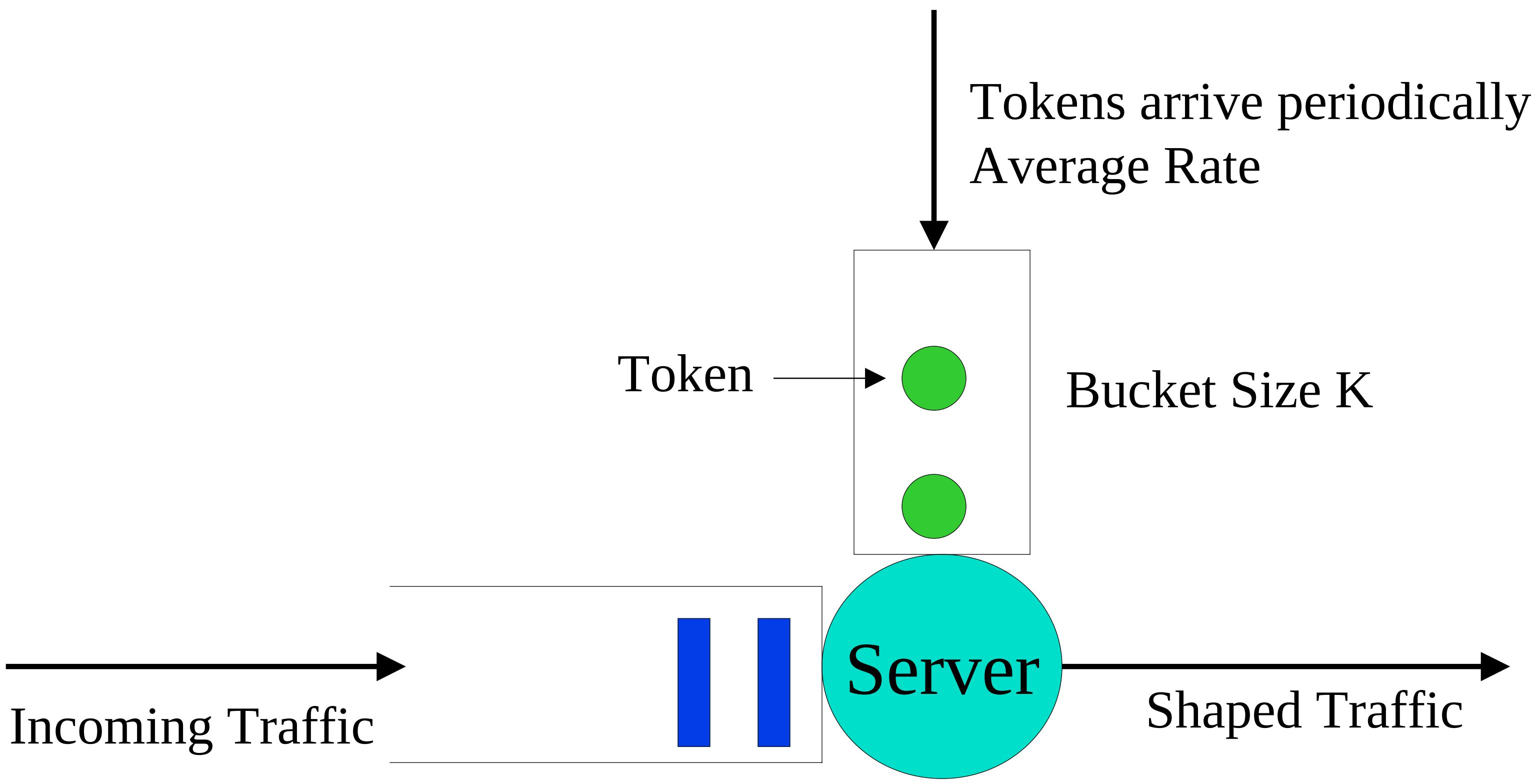
1. **Signaling**: Users need to tell/negotiate their QoS requirements with the network
2. **Admission Control**: Network can deny requests that it can not meet
3. **Shaping**: Traffic is smoothed out so that it is easier to handle
4. **Policing**: Ensuring that the users are sending at the rate they agreed to
5. **Marking/Classification**: Packets are classified based on the source, destination, TCP ports (application)
6. **Scheduling**: Different flows get appropriate treatment
7. **Drop Policies**: Low priority packets are dropped.
8. **Routing**: Packets are sent over paths that can meet the QoS
9. **Traffic Management**: Sources may be asked to reduce their rates to meet the loss rate and delay guarantees

Traffic Shaping

- Altering the traffic characteristics of a given flow is called traffic shaping
- The source must shape its traffic prior to sending it to network so it does not violate traffic contract

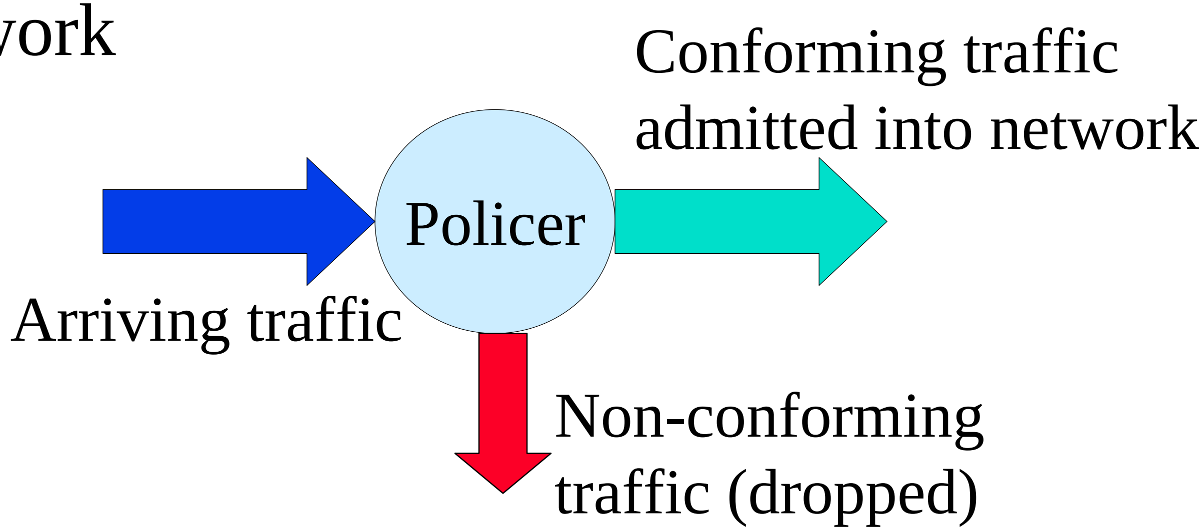


Token Bucket Shaper



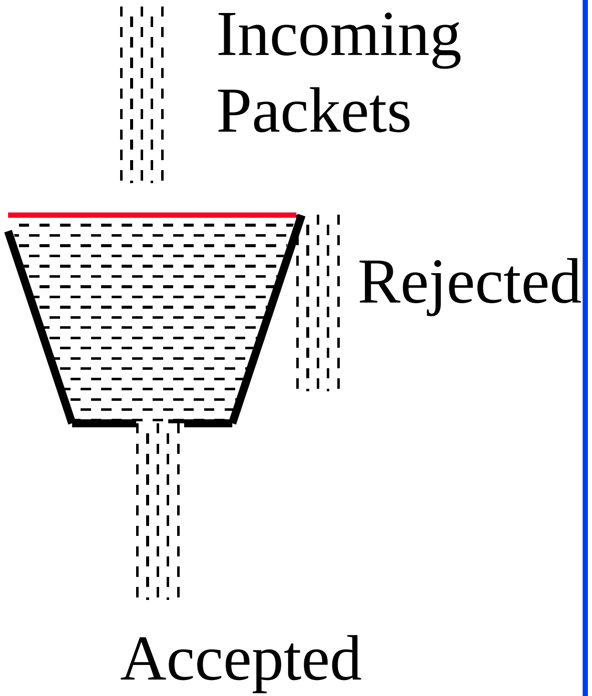
Traffic Policing

- Users violating the traffic contract can jeopardise the QoS of other connections
- The network must protect well behaving users against such traffic violations
- Policing functions are deployed at the edge (entry) of the network

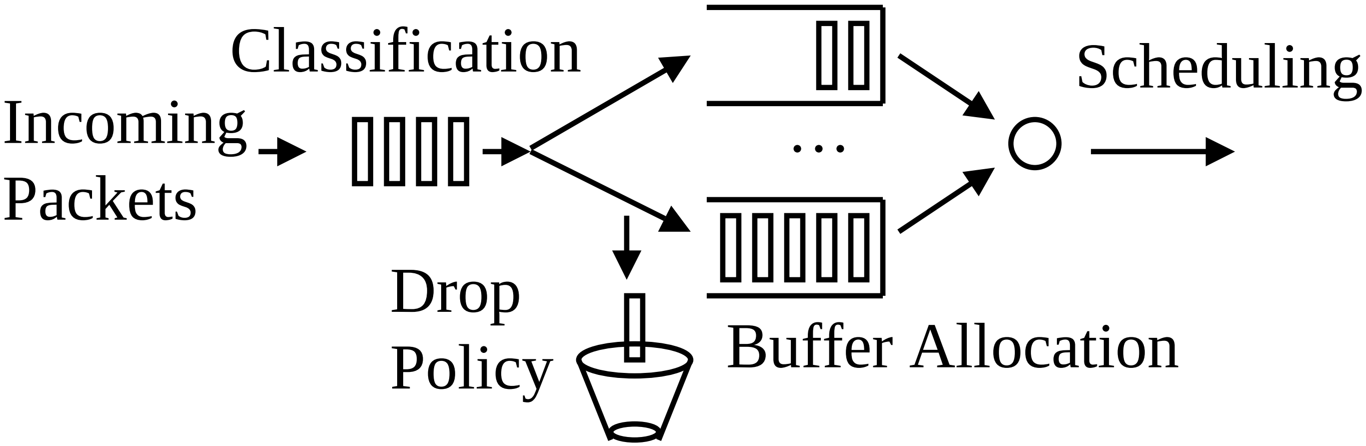


Peak Rate Policing with Leaky Bucket

- Enforces sustained rate and maximum burst size
- Requires only one counter
  - counter is decremented, to a minimum of zero, at the avg rate
  - counter is incremented by one, to a maximum of a limiting value, for each packet arrival
- An arriving packet is non-conforming if counter is at its limit

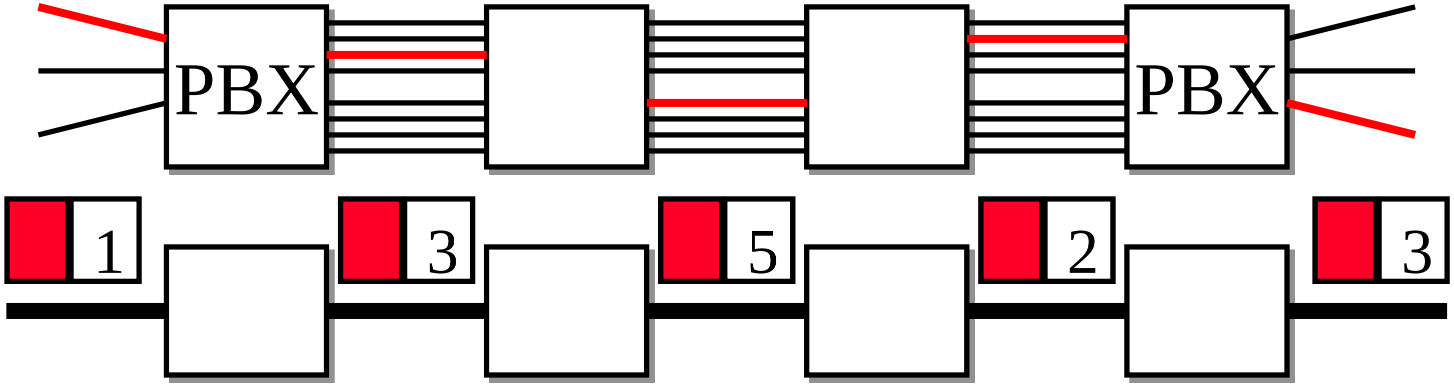


Queuing and Scheduling for QoS



- Packets from multiple flows are queued at a given transmission link
- To give different QoS, multiple queues may be used. Buffer allocation, scheduling, and drop policies for each queue are set to provide different QoS

ATM Networks



- ATM cells are fixed size: 48-byte payload + 5-byte header
- IP packets can be segmented into ATM cells at entry to ATM connection and reassembled at the end
- Each cell has a circuit number: Virtual Circuit Id (VCI)
- Circuit number determines the cell's queuing and forwarding
- Circuits have be set up before use
- Circuits are called Virtual Circuits (VCs)
- Multiple VCs can be grouped in to a "virtual path" (VP)

ATM Service Categories

- **Constant Bit Rate (CBR)**: Throughput, delay, delay variation guaranteed
- **Real-Time Variable Bit Rate (rt-VBR)**: Average Throughput, delay, delay variation guaranteed
- **Non-Real-Time Variable Bit Rate (nrt-VBR)**: Throughput guaranteed.
- **Unspecified Bit Rate (UBR)**: No Guarantees. Best Effort.
- **Available Bit Rate (ABR)**: Minimum Throughput. Very low loss. Feedback.
- **Guaranteed Frame Rate (GFR)**: Minimum Throughput. Frame based guarantee.
- ATM also has Rate shaping, Connection-Admission control (CAC), Policing, and QoS-based routing (PNNI).

Service Class and QoS Parameters

Service Class	Traffic Parameter	QoS Parameter
CBR	PCR	maxCTD, CDV, CLR
rt-VBR	PCR, SCR, MBS	maxCTD, CDV, CLR
nrt-VBR	PCR, SCR, MBS	CLR
ABR	PCR, MCR	CLR (network specific)
UBR	PCR	No QoS

CDV = Cell delay variation

CLR = Cell Loss Rate

CTD = Cell Transfer Delay

PCR = Peak Cell Rate

SCR = Sustained (avg) Cell Rate

MCR = Minimum Cell Rate

MBS = Maximum Burst Size

ATM QoS: Issues

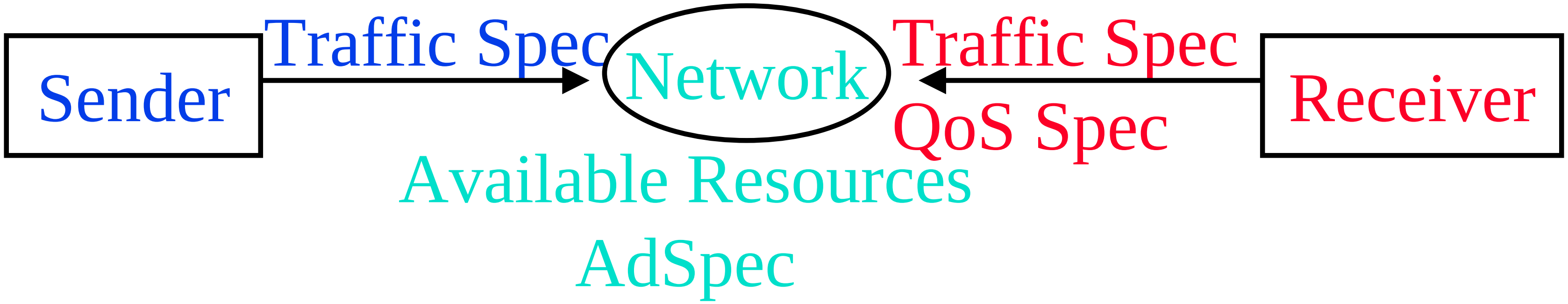
- Can't easily aggregate QoS: VP = Σ VCs
- Can't easily specify QoS: What is the CDV required for a movie?
- Signaling too complex ⇒ Need Lightweight Signaling
- Need Heterogeneous Point-to-Multipoint: Variegated VCs
- Need QoS Renegotiation
- Need Group Address
- Need priority or weight among VCs to map DiffServ and 802.1D

Integrated Services

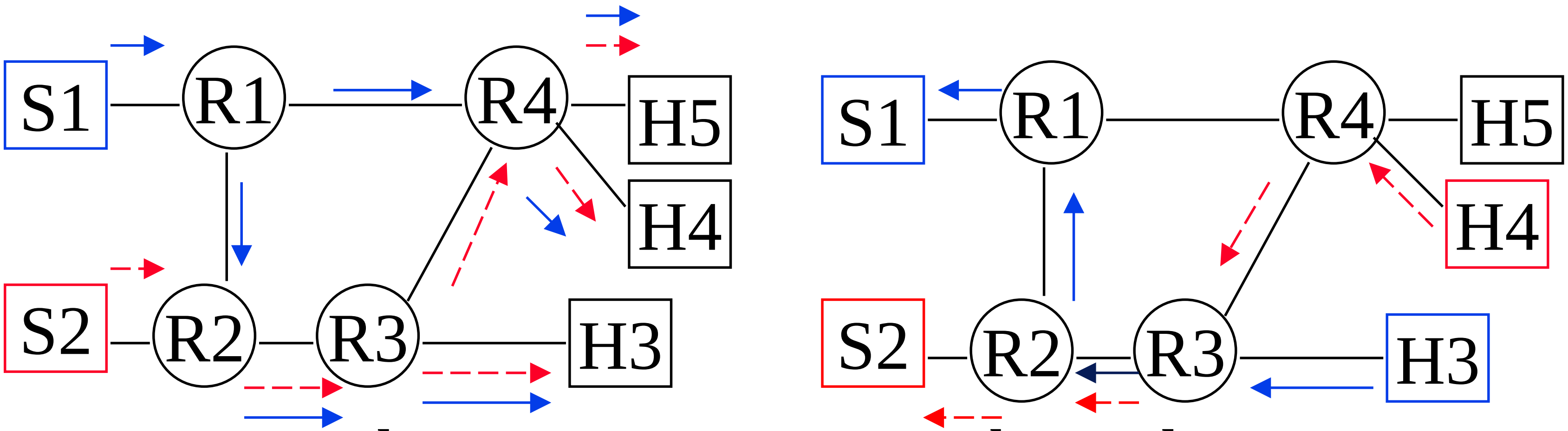
- **Best Effort Service**: Like UBR.
- **Controlled-Load Service**: Performance as good as in an unloaded datagram network. No quantitative assurances. Like nrt-VBR or UBR w minimum cell rate (MCR)
- **Guaranteed Service**: rt-VBR
  - Firm bound on data throughput and delay.
  - Delay jitter or average 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

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



RSVP Messages



- Sources send **PATH** messages to the multicast address. Contain traffic spec and has place for network to indicate available resources.
- Receivers send **ResV** messages in the reverse direction. Contain QoS spec.
- Similar requests from multiple receivers are merged.

RSVP and Integrated Services: Issues

- Complexity in routers: packet classification, scheduling
- Scalable in number of receivers per flow but Per-Flow State: O(n) $\Rightarrow$ Not scalable with # of flows. 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.

Issues (Cont)

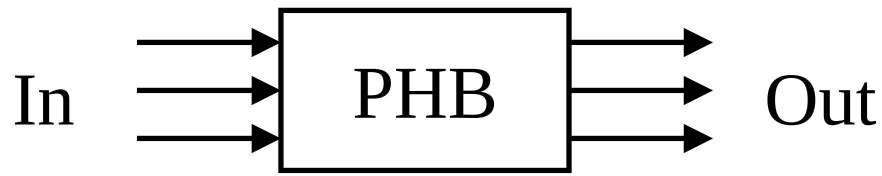
- **Receiver Based**:
  Need sender control/notifications in some cases.
  Which receiver pays for shared part of the tree?
- **Soft State**: Need route/path pinning (stability).
  Limit number of changes during a session.
- RSVP does not have negotiation and backtracking
- Throughput and delay guarantees require support of lower layers. Shared Ethernet ⇒ 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.

Differentiated Services

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

- IPv4: 3-bit precedence + 4-bit ToS
- OSPF and integrated IS-IS can compute paths for each ToS
- Many vendors use IP precedence bits but the service varies ⇒ Need a standard ⇒ Differentiated Services
- DS working group formed February 1998
- Only 6 of the 8 bits in ToS byte are used for DS
- DS code indicate per-hop behavior (PHB)

Per-hop Behaviors (PHBs)

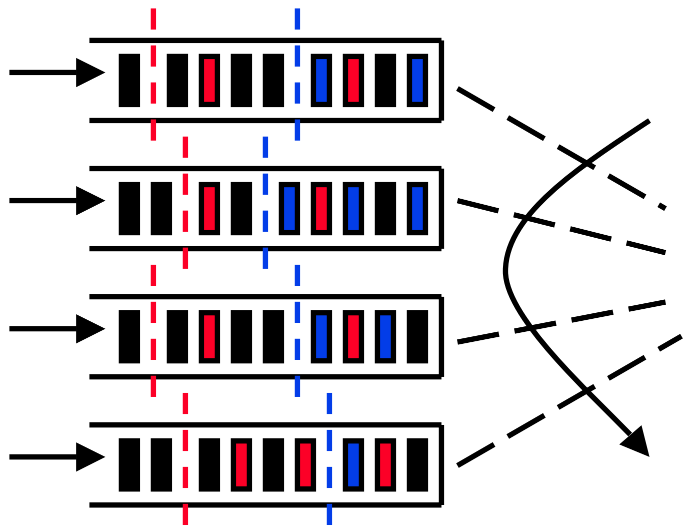


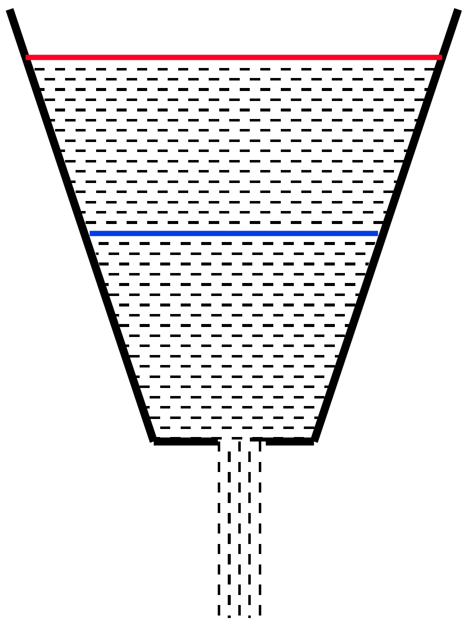
- Externally Observable Forwarding Behavior
- x% of link bandwidth
- Minimum x% and fair share of excess bandwidth
- Priority relative to other PHBs
- PHB Groups: Related PHBs. PHBs in the group share common constraints, e.g., loss priority, relative delay

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
  $\Rightarrow$ Highest data priority (if priority queueing)
- Code point: 101 110

Assured Forwarding





- PHB <u>Group</u>
- Four Classes: Decreasing weights in WFR/WFQ
- Three drop preference per class
  (one rate and two bucket sizes)

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

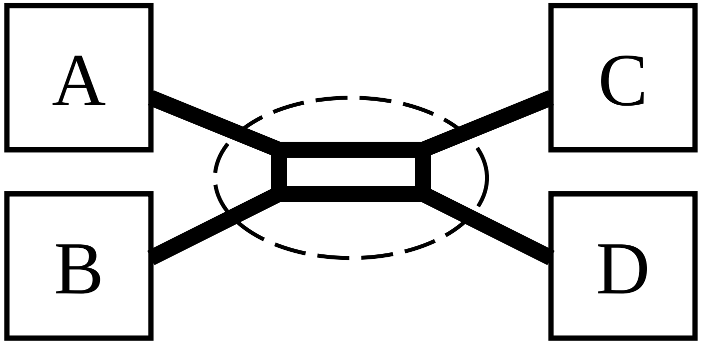
- Avoids 11x000 (used for network control)

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 (SLAs)
  Both the network topology and traffic are highly dynamic.
- Multicast $\Rightarrow$ Difficult to provision
  Dynamic multicast membership $\Rightarrow$ Dynamic SLAs?

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.



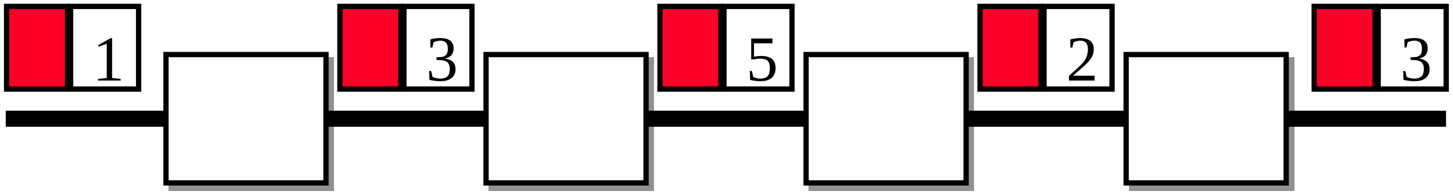
DiffServ Problems (Cont)

- 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

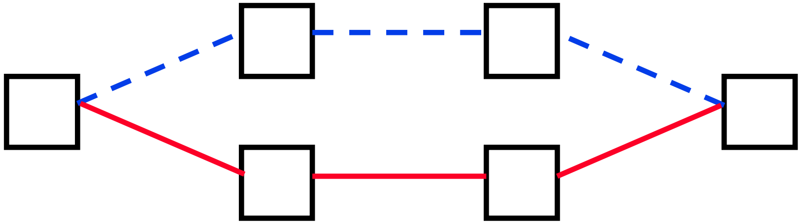
DiffServ Problems (Cont)

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

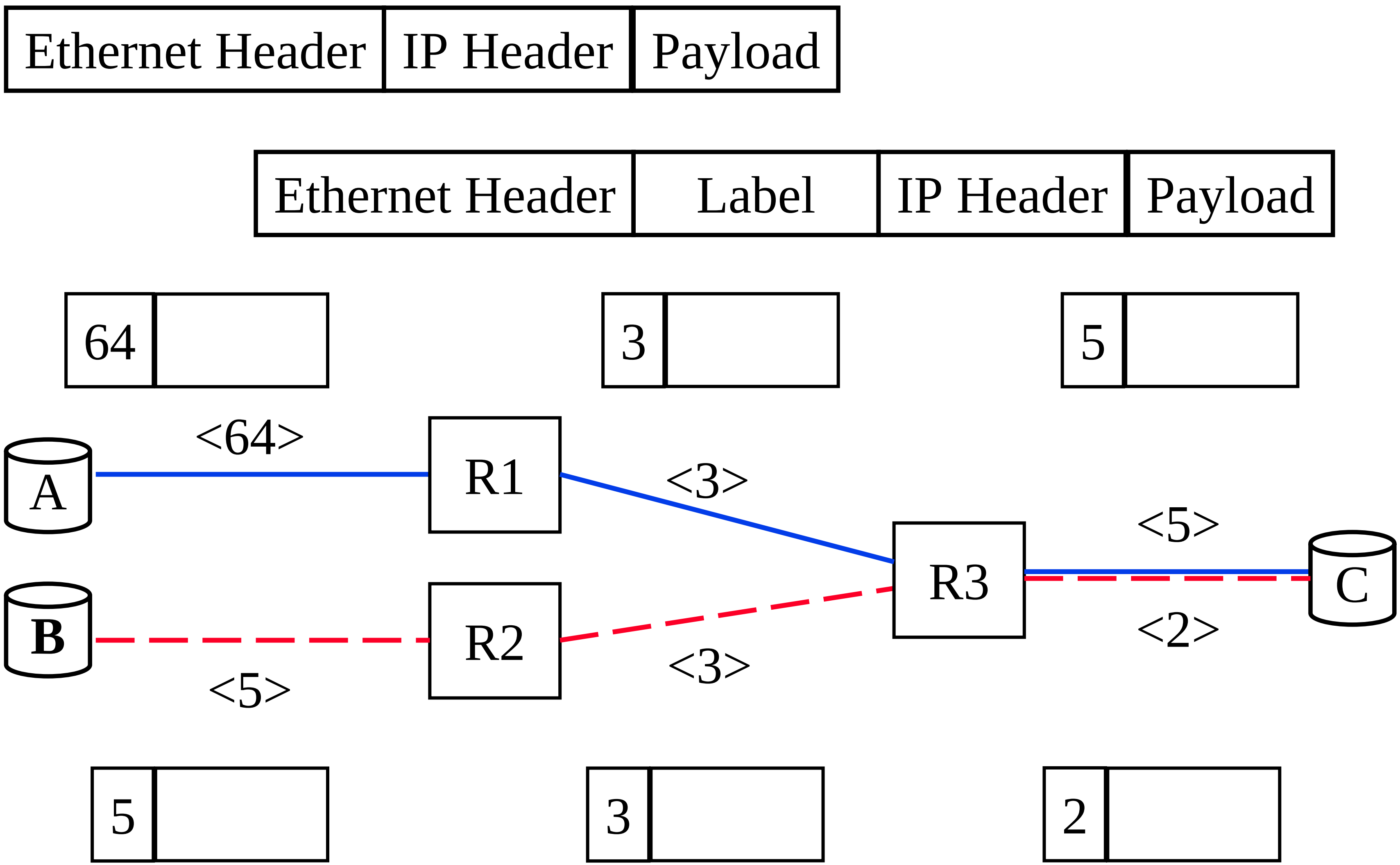
Multiprotocol Label Switching (MPLS)



- Allows virtual circuits in IP Networks (May 1996)
- Each packet has a virtual circuit number called ‘label’
- Label determines the packet’s queuing and forwarding
- Circuits are called Label Switched Paths (LSPs)
- LSP’s have to be set up before use
- Allows traffic engineering



Label Switching Example



Traffic Engineering Using MPLS

- Trunk paths are setup based on policies or specified resource availability.
- A traffic trunk can have alternate sets of paths in case of failure of the main path. Trunks can be rerouted.
- Multiple trunks can be used in parallel to the same egress.
- Some trunks may preempt other trunks. A trunk can be preemptor, non-preemptor, preemptable, or non-preemptable.
- Each trunk can have its own overbooking rate

IEEE 802.1D Model

Dest Addr	Src Addr	Tag Prot ID	Pri	CFI	VLAN ID

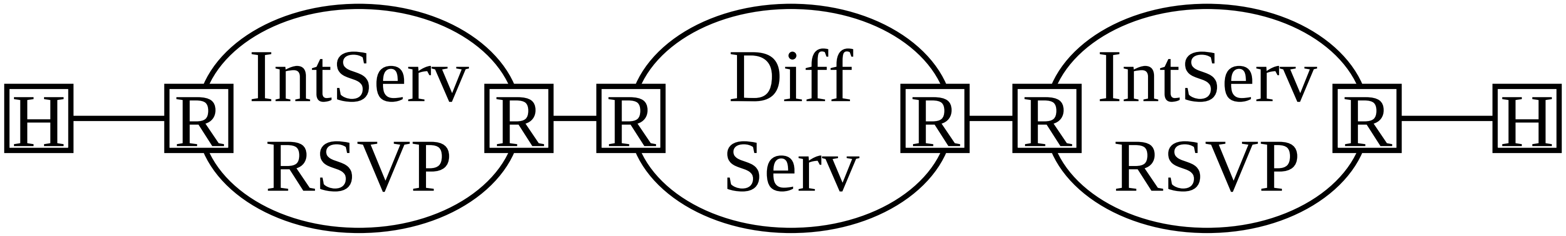
802.1Q header (Tag Prot ID, Pri, CFI, VLAN ID)

Prot Type	Payload	FCS

CFI = Canonical Format Indicator (Source Routing)

- **Up to eight priorities:** Strict.
  1 Background
  2 Spare
  0 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 QoS



- Hosts may mark DS byte or use RSVP signaling or both or none.
- Why hosts? 1. Encryption, 2. Hosts know the importance of info even if the header fields are same
- Routers may mark DS byte if necessary.
- Routers at the intserv diff-serv boundary accept/reject RSVP requests based on current load

QoS Debate

- Massive Bandwidth vs Managed Bandwidth
- Per-Flow vs Aggregate
- Quantitative vs Qualitative
- Absolute vs Relative
- End-to-end vs Per-hop
- Soft State vs Hard State
- Path based vs Access based
- Source-Controlled vs Receiver Controlled

Comparison of QoS Approaches

Issue	ATM	IntServ	DiffServ	MPLS	IEEE 802.1D
Massive Bandwidth vs Managed Bandwidth	Managed	Managed	Massive	Managed	Massive
Per-Flow vs Aggregate	Both	Per-flow	Aggregate	Both	Aggregate
Quantitative vs Qualitative	Quantitative	Quantitative+Qualitative	Mostly qualitative	Both	Qualitative
Absolute vs Relative	Absolute	Absolute	Mostly Relative	Absolute plus relative	Relative
End-to-end vs Per-hop	e-e	e-e	Per-hop	e-e	Per-hop
Soft State vs Hard State	Hard	Soft	None	Hard	Hard
Path based vs Access based	Path	Path	Access	Path	Access
Source-Controlled vs Receiver Controlled	Unicast Source, Multicast both	Receiver	Ingress	Both	Source

Radio Spectrum Management

- Fixed Channel Allocation: Divide the spectrum in to N bands: $N = i^2 + j^2 + ij$, e.g., N=7
- Dynamic Channel Allocation:
  - All channels in a central pool
  - Allocated to cells on a need basis
  - Adopts to changing traffic conditions
  - Complexity of management
- Hybrid Channel Allocation:
  - Some channels in central shared pool, some permanently assigned to cells
  - Shared channels assigned on demand

CAC: Blocking vs Dropping

- Rejecting new connections ⇒ Blocking
- No channel in new cell for a mobil user ⇒ Dropping
- Blocking preferred over dropping
- Prioritization:
  - Handoffs higher priority over new connections
  - Starves new connections at highway intersections
- Guard Channels:
  - Channels reserved for handoffs
  - New connections are not granted in guard channels
  - Can be dynamically adjusted depending upon the traffic in neighboring cells and predicted handoffs

Mean Opinion Score (MOS)

Rating	Quality	Distortion Level
5	Excellent	Imperceptible
4	Good	Just perceptible, but not annoying
3	Fair	Perceptible but slightly annoying
2	Poor	Annoying but not objectionable
1	Unsatisfactory	Very annoying and objectionable

Voice Codecs

Vocoder	Bit Rate (kbps)	MOS	Application
G.711	64	4.5	Fixed telephone systems
G.729	8	4	Mobile telephone, VOIP
G.723	5.3 or 6.8	3.8	Video Telephony, VOIP
GSM Half Rate	5.6	3.5	GSM/2.5G Networks
GSM EFR	12.2	4.0	GSM/2.5G
GSM	13.0	3.5	GSM networks
AMR	4.75-12.2	3.5-4.0	3G mobile networks

VOIP Quality Factors

A/D	Digitization Noise
Coder	Compression. Coding delay
RTP	Packetization delay
UDP/IP	Jitter due to multiplexing
Link Layer	Jitter due to ARQs
MAC	Media Sharing
PHY	Bit errors

- Mean Opinion Score (MOS): 4 is Toll quality. Cellular systems have a quality of about 3.4

Transmission Impairments

- Packet Loss:
  - Higher compression $\Rightarrow$ Less loss resilience
  - Higher interval of loss $\Rightarrow$ more perceptible $\Rightarrow$ Bursty losses are undesirable
  - In G.729, loss of voiced frames causes more degradation than unvoiced frames. Loss of voiced frames at unvoiced/voiced transition causes significant degradation.

Transmission Impairments (Cont)

- Delay:
  - One-way delay between 50ms and 150ms is acceptable
    150 ms to 400 ms is marginally acceptable
    over 400 ms is unacceptable
    (3G defines 400 ms as upper limit)
  - Propagation + Serialization (transmission) + PHY Channel coding (interleaving) + Media access delay (DIFS) + Bridge/router forwarding delay + queuing delay + packetization delay (application level) + algorithmic and look-ahead delay + decoding delay
- Header compression increases capacity by a factor of 2

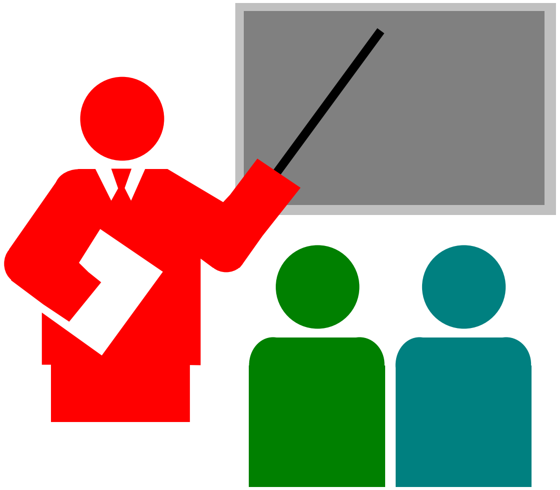
VOIP over 802.11

- PCF vs DCF: PCF (CBR) is better but does not exploit voice activity detection.
  Is not implemented in products.
- Need Forward error correction (FEC) and automatic repeat request (ARQ)
- Acceptable performance for a single channel on 11 Mbps link. Not necessarily at lower rates.
- High delay jitter $\Rightarrow$ High end-to-end delay (due to large play out buffer)
- EDCF priorities help significantly

Selective Packet Marking

- Speech property based Selective Packet Marking (SPB-Mark)
- Based on the observation that in G.729 coding, frames at unvoiced-to-voiced transition are important
- Two priorities
- Detect unvoiced-to-voiced transitions
- 10 to 20 frames at the beginning of transitions are protected. These frames are packed in packets at priority 1.
- Other frames are sent at priority 0
- Only priority 1 packets are retransmitted (ARQ'd) if lost. Priority 0 packets are not ARQ'd.

Summary



- QoS = Guaranteeing throughput, delay, jitter, loss
- ATM: CBR, rt-VBT, nrt-VBR, UBR, ABR, GFR
- Integrated Services: GS = rtVBR, CLS = nrt-VBR
- Signaling protocol: RSVP
- Differentiated Services uses the DS byte ⇒ PHBs
- MPLS allows traffic engineering
- VOIP over wireless ⇒ Codec based prioritization

Reading Assignment

- Read Sections 8.4, 0.1, 11.3, 11.4 of Dixit and Prasad
- Read Chapter 10 of Dixit and Prasad on VOIP over Wireless