Quality of Service for Multimedia over Next Generation Data Networks

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Outline of Talk

- Present state of the Internet.
- Characteristics of Multimedia
- QoS requirements for multimedia
- Asynchronous Transfer Mode networks
- Integrated Services
- Differentiated Services
- QoS mapping from Integrated Services to Differentiated Services

Existing Switching Technologies

- Circuit switching
  - Path set up before data transmission.
  - Good for high volume data transfer.
  - Strong QoS guarantees.
  - Example: Telephone network.
- Packet switching
  - Packet contains information about the destination
  - Good for bursty traffic.
  - QoS guarantee is hard to achieve.
  - Example: Internet.

Current Internet

- TCP/IP glues together all the computers in the Internet.
- TCP/IP was designed for
  - Terrestrial networks
  - Non-real time data services
- Internet routers treat all packets equally.
- TCP/IP does not
  - offer QoS to real time applications, or
  - perform well in long delay bandwidth networks.

QoS Parameters

- Bandwidth
- Delay (Latency)
- Jitter
- Loss

Multimedia

- Real time constraints.
- Interactive applications have low delay and jitter requirements.
- Large bandwidth requirement.
- Certain applications can tolerate some loss.

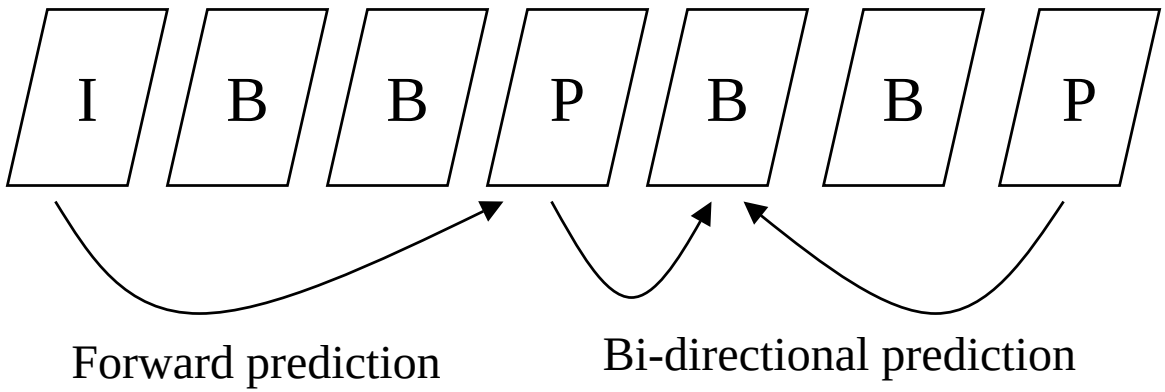
MPEG

- Coding standard to compress audio and video.
- Exploits the temporal and spatial redundancy in video.
- Types of frames:
  - Intracoded (I)
  - Bidirectional (B)
  - Predictive (P)
- I, B, P frames
  - BW usage typically 5:3:1(I:P:B)
- Compression makes the traffic stream bursty.
  - Difficult to manage traffic in the network.

MPEG (cont.)

- MPEG
  - Constant bit rate:
    - variable image quality
    - buffer at the output of the encoder
  - Variable bit rate:
    - constant image quality
    - output traffic is very bursty

MPEG Frames



Importance of MPEG frames

- I frames
  - Reference frame
  - Most important
  - Should not be dropped by the network
- P frames
  - Moderately important
- B frames
  - Least important

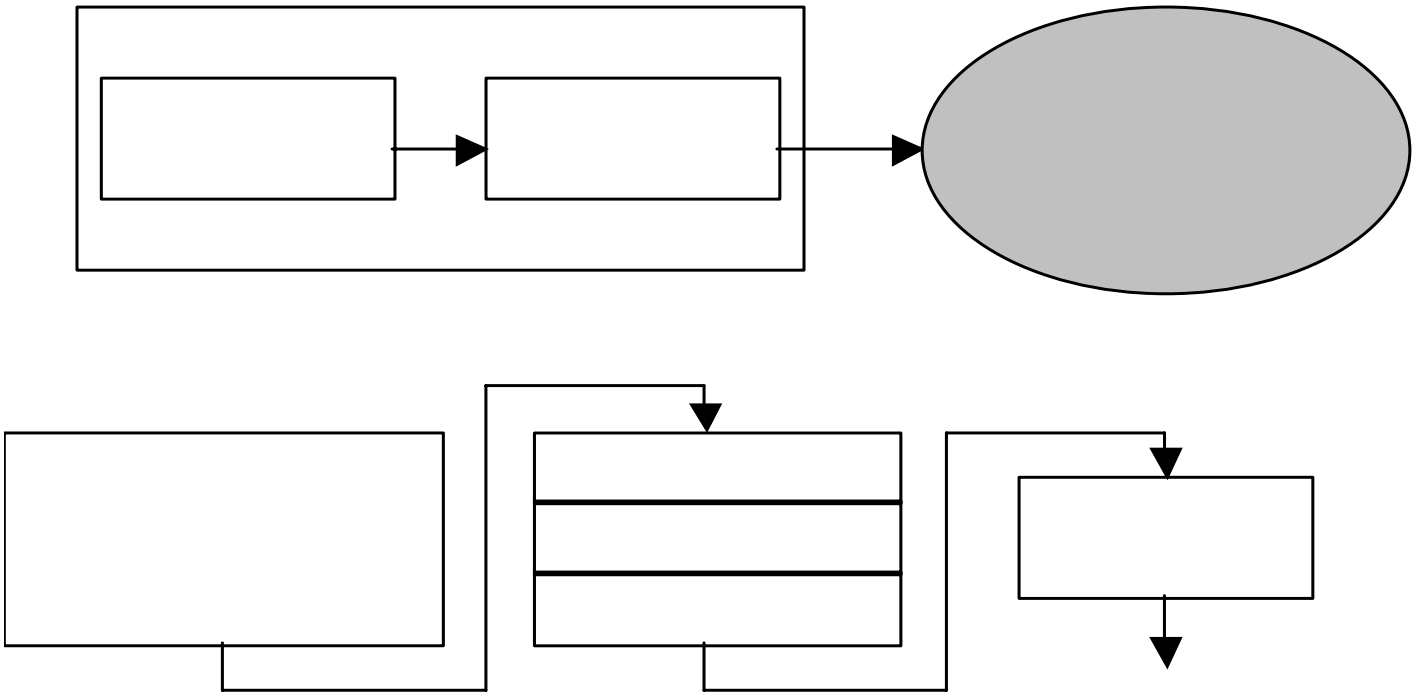
TCP

- *Reliable* transport mechanism.
  - May not be necessary for multimedia.
  - Retransmission of lost packets
- Ordered delivery.
  - Packets are reassembled and reordered at the destination.
- Strong congestion control mechanisms.
  - Throttles back the transmission rate the if network is congested.

RTP/UDP

- UDP/IP sends data without waiting for acknowledgement → unreliable protocol.
- No guarantee that all traffic will be received at the destination.
  - Lack of acknowledgement allows faster delivery of data to the destination.
- Real Time Protocol (RTP) defines how audio, video and data are to be encoded in a packet.

MPEG transmission over Internet



Packet format for RTP over UDP/IP

Elements to Provide QoS

- Resource reservation
  - Buffer: to control packet loss.
  - Bandwidth: to provide adequate bandwidth.
- Scheduling
  - To provide bounded delay and avoid starvation.
- Admission Control
  - To protect the QoS of connections already in place.
- Policing
  - To control misbehaving users.

Efforts to provide QoS in Internet

- Asynchronous Transfer Mode (ATM)
- Integrated Services (IS)
- Differentiated Services (DiffServ)
- Explicit Congestion Notification (ECN)
- Multiprotocol Label Switching (MPLS)

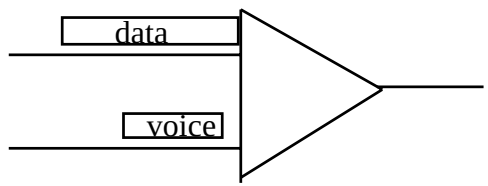
QoS
For Multimedia

End to End Delay

- Encoder delay
- Packetization delay – time to fill an IP packet
- Input delay – time to join together fragmented IP packets
- Queuing delay
- Switching delay – depends on technology
- Propagation delay – ~5 microsecond/km

Effect of packet size on delay

- Small packet size is good to guarantee low delay for multimedia traffic.
  - Used in ATM (48 bytes payload + 5 bytes header)
- Wastes lot of bandwidth to carry header bits.
- Increasing the packet size linearly increases the queuing delay of a packet.



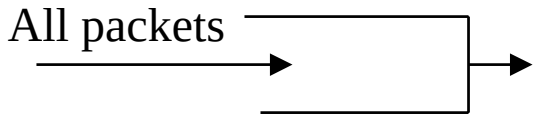
Queuing Disciplines

Queuing Disciplines

- First In First Out (FIFO)
- Priority Queuing (PQ)
- Class Based Queuing (CBQ)
- Weighted Fair Queuing (WFQ)

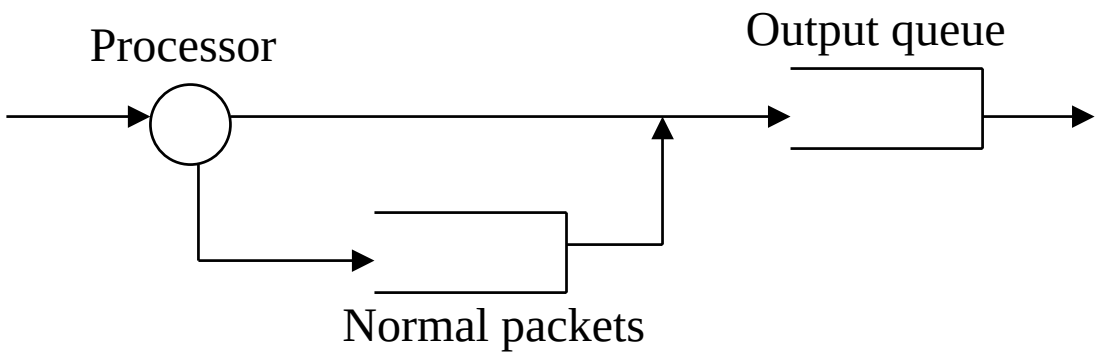
First In First Out (FIFO)

- Packets served on a first in first out fashion
  - Does not consider priority of packets
- Good enough for a queue having enough outgoing link bandwidth.
  - Applications will not notice much delay
- Problem arises when the buffer is getting full.
  - Packets are dropped.
- Discrimination of service can not be achieved.



Priority Queuing (PQ)

- Priority packets are given preference and put in the front of the queue.
- Lower priority packets are put in a packet buffer until there are no high priority packets.
- Advantages:
  - Possible to differentiate services and protocols (for example, TCP could be given preference over UDP)



Priority Queuing (contd.)

- Disadvantages
  - Packet reordering.
  - Increased computational burden on the router processor; more noticeable as the output link speed increases.
  - Resource denial: low priority traffic may suffer
    - buffer starvation and get dropped
    - high delay
  - Some higher level protocols may time out due to higher delay.
  - Does not scale well for high speed networks.

Class Based Queuing (CBQ)

- Several output queues.
- Each class queued in a different queue.
- Queues have different service priorities.

Class Based Queuing (cont.)

- Advantages
  - Avoids starvation.
  - Provides some delay bounds to low priority traffic.
  - A specific class can not hog the output link for too long.
  - Avoids resource denial.
  - No packet reordering within classes.
- Disadvantages
  - Increased computational burden on the router processor; more noticeable as the output link speed increases.
  - Does not scale well for high speed networks.

Weighted Fair Queuing (WFQ)

- Packets classified according to flows
- Low volume traffic given preference over high volume traffic.
- Attempts to provide predictable response time.
- Type of Service byte in the IP header can be used to classify packets into flows.
- Has some of the characteristics of priority and class based queuing.
- Disadvantages
  - Computational load

Asynchronous Transfer Mode (ATM)

Asynchronous Transfer Mode

- Standardization bodies: ITU and ATM Forum
- Strong QoS guarantees; suitable for real time applications.
- Connection oriented services over a packet switched network.
- QoS provided by:
  - Reserving resources
  - Admission control and policing of connections
- Currently used at the core of the Internet.

ATM Services

- Constant Bit Rate (CBR)
- Variable Bit Rate (VBR)
- Available Bit Rate (ABR)
- Unspecified Bit Rate (UBR)

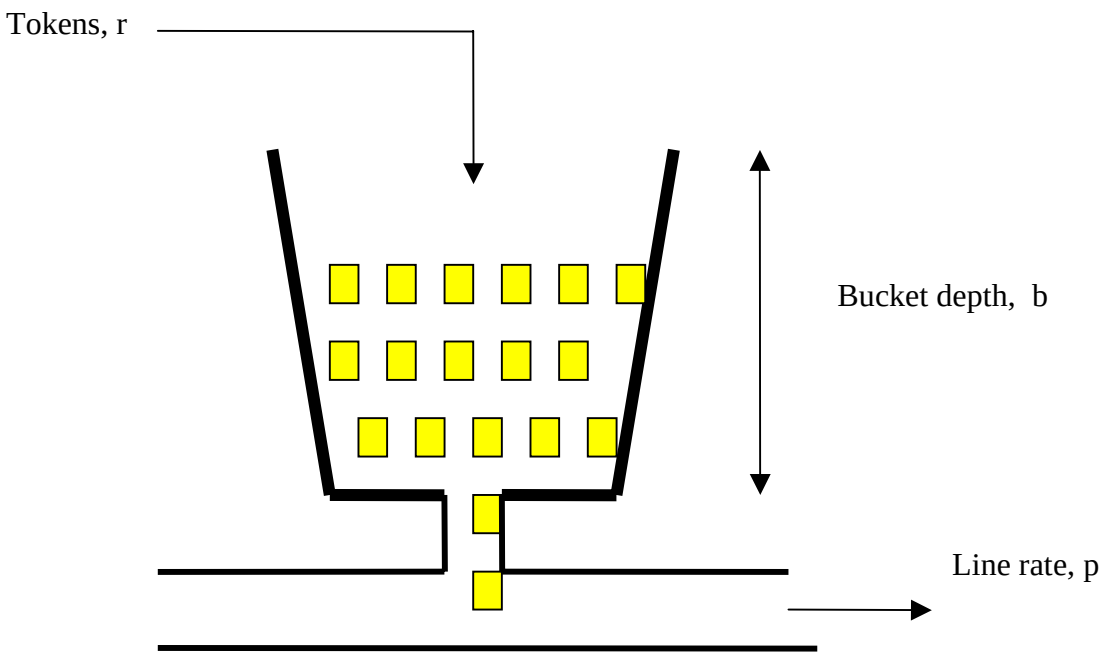
CBR

- Emulates a leased line
- Specified by the Peak Rate
- Waste of bandwidth if the traffic is variable in nature.
- Expensive service.
- Suitable for uncompressed video.

VBR

- Traffic pattern is variable.
- Traffic specified by token bucket parameters
  - Peak rate (p)
  - Bucket size (b)
  - Bucket fill rate (r)
- Suitable for compressed video.

Token Bucket



ABR

- Traffic left over from CBR and VBR are used for ABR service
- Suitable for elastic applications.
- Sources must reduce their rate in the case of network congestion.
- Cheaper service than CBR or VBR.
- Sources will have low loss and delay if they react to control message from the network.
- Resource Management (RM) cells inform the sources about network congestion

UBR

- No guarantees with respect to bandwidth or delay.
- Sources are not informed if packets are dropped by the network.
  - Sources should be able to determine packet losses

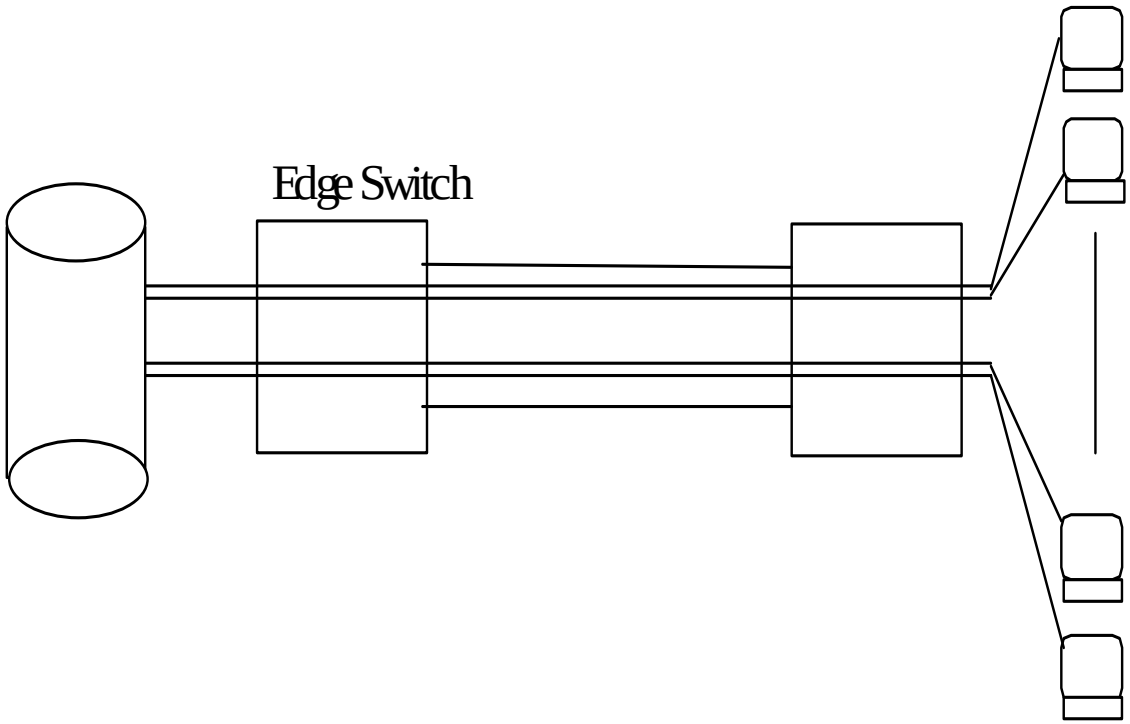
Video on Demand over ATM

- VoD over CBR
  - bandwidth allocation at the PCR
  - waste of bandwidth
  - inefficient utilization of network resources
- VoD over VBR
  - Suitable for variable bit rate video
- VoD over ABR
  - Cost effective.
  - Application has to be elastic.

Example: Video on Demand over ABR

- Students of Visual Arts Department
- Criticize films.
- Need to view video clips several times.
- Damages the tape and VCR.
- Only one person can access the clip
- Not accessible at all times - requires a VCR

VoD over ABR Architecture



VoD Client

- MPEG decoder, buffer and viewer.
- Minimum buffer fill required.
- Client requests sent to the server.

VoD Server

- Compressed video source.
- Server buffer to smooth out disk access.
- Negotiates MCR, ACR, PCR with network.
- Controls transmission rate to the network.

Fast Buffer Fillup

- HIV: Startup delay need to be reduced.
- FFW/FBW/Play: Higher bandwidth negotiated.

Problems with ATM

- High cost.
  - Could not reach the desktop
- Control and management is complex
  - Example: ABR involves too many parameters

Integrated Services

Integrated Services

- Guaranteeing quality of services requires that routers reserve resources for the traffic.
- Resource are *reserved* during connection setup.
  - Buffers
  - Bandwidth
  - Scheduling policy
- Resource Reservation Protocol (RSVP) is used to reserve resources during connection setup (RFC 2205).
- *Per-flow* end-to-end QoS guarantees.
- Traffic policing at the edge; traffic shaping in the core of the network.

Traffic Control Functions

- Packet scheduler
  - Schedules the departures of packets
- Packet classifier
  - Maps each packet to a specific class
- Admission Control
  - Determines whether a flow can be granted the requested QoS without affecting established flows.
- Resource Reservation
  - RSVP used to reserve resources

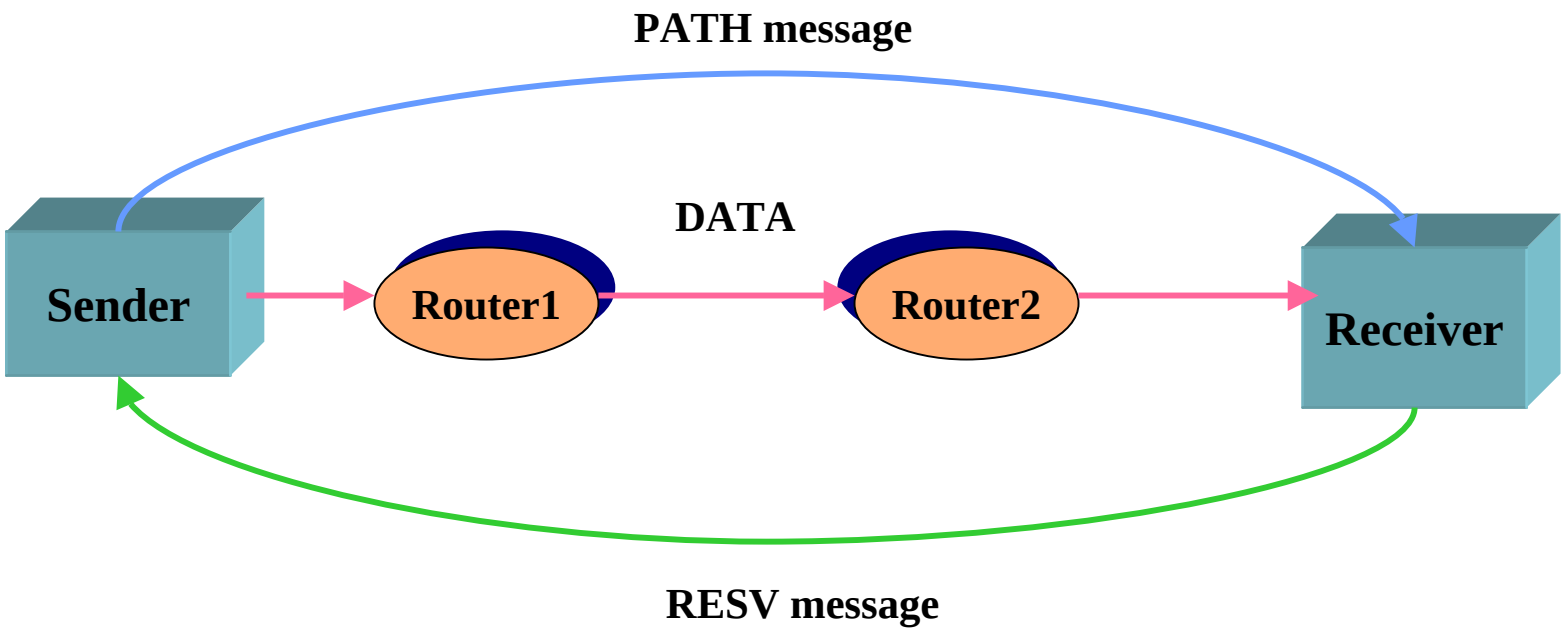
RSVP Signaling

- Reserves a portion of link bandwidth in each router.
- The sender sends a PATH message with resource requirements for a flow.
  - The path of the message is determined by a separate routing protocol.
  - In each node, PATH messages store information such as addresses of previous hops.
- Receiver is responsible for *requesting* the QoS
  - Receiver responds with a RESV message specifying the desired QoS
  - RESV message follows the same path as the PATH message and sets up the reservation state in each node.

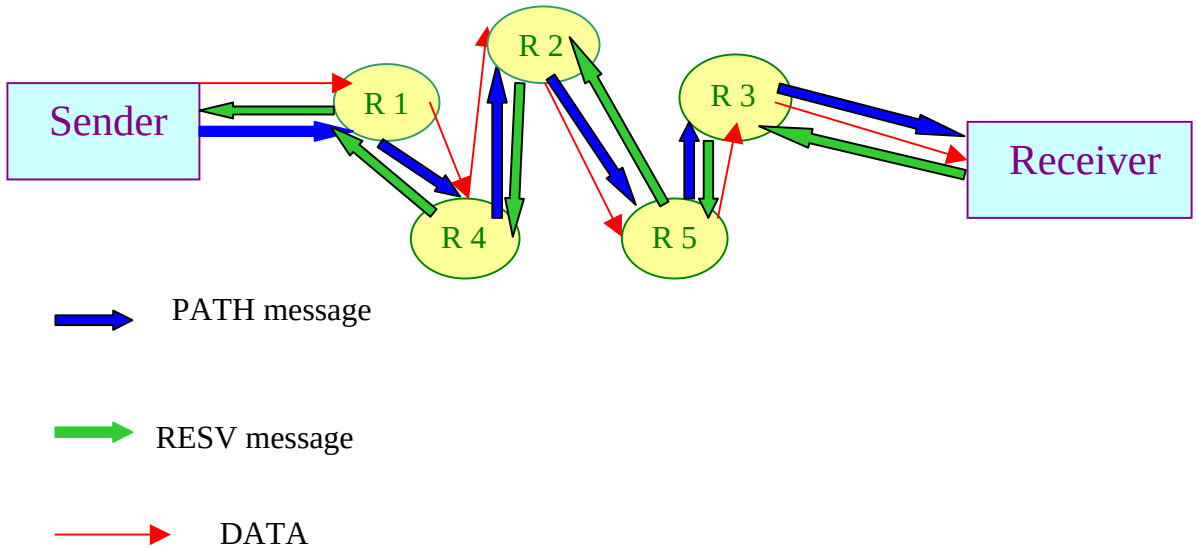
RSVP Signaling (cont.)

- Each router processes the RESV to reserve the required resources requested by the sender.
- Routers can modify the QoS parameters of the RESV message if enough resources are not available to meet the requirements.
- Each router in the entire path confirms the end-to-end reservation for the flow.
- RSVP reservation are soft state.
  - Periodic refresh (using RESV) required to maintain the reservation.
- RSVP provides dynamic QoS.
  - Requested resources may be changed by the sender at any time.

RSVP Signaling



RSVP Signaling and Data Flow



Control and Characterization Parameters

- NON_IS_HOP
  - Provides information about hops that do not implement QoS control services.
- NUMBER_OF_IS_HOPS
  - Counter to inform the endpoint of the number of IS-aware nodes in the path
- AVAILABLE_PATH_BANDWIDTH
  - Provides information about the bandwidth available at the local node along the path followed by a data flow.
- MINIMUM_PATH_LATENCY
  - Minimum latency of the node
    - Includes propagation delay and packet processing delay.
    - Does not include queuing delay at the node.

Control and Characterization Parameters (cont.)

- PATH_MTU
  - Maximum Transmission Unit for packets traversing a path
- TOKEN_BUCKET_TSPEC
  - Used by sender to specify the traffic parameters.

Tspec Parameters

- p Peak rate of flow (bytes/second)
  - Indicates peak data rate.
- b Token bucket depth (bytes)
  - Indicates maximum burst size.
- r Token bucket rate (bytes/second)
  - Indicates average data rate.
- m Minimum policed unit (bytes)
  - All datagrams less than *m* are treated to be of size *m* in terms of resource allocation and policing.
  - Allows a reasonable estimate of the per-packet resources needed to process a flow's packet.
- M Maximum datagram size (bytes)
  - Largest packet size that will conform to the traffic specifications.

Rspec parameters

- R bandwidth (bytes/second)
- S slack term
  - difference between desired delay and the delay obtained by using a reservation level R.

IS Service Classes

- Guaranteed Load Service (RFC 2212)
- Controlled Load Service (RFC 2211)

Guaranteed Load

- Highest priority service.
  - Low end-to-end delay, Jitter, Loss.
- Provides *bandwidth* guarantee and *delay* bound.
  - Guarantees that packets will arrive within a certain delivery time, and will not be discarded because of queue overflows
- Routers reserve
  - Bandwidth, r bytes/sec
  - Buffer space, B bytes
- GL only computes the *queueing delay.*
  - It does *not*
    - control the minimal or *average delay*
    - Control or minimize *jitter*

Guaranteed Load (cont.)

- RSVP messages
  - TSPEC uses
    - TOKEN_BUCKET_TSPEC parameter
  - RSPEC uses
    - Data rate (R)
    - Slack term (S)
- Policing at the edges.
  - To ensure conformance with TSPEC.
- Reshaping at the intermediate nodes.
  - Attempt to restore the flow's traffic characteristics to conform to TSPEC. (Note that traffic characteristic of a flow may change due to aggregation in the core network).

Controlled Load

- Performance similar to that of a best effort service in an unloaded (or lightly utilized) network.
  - *Better than best effort* service
  - Successful delivery of high percentage of transmitted packets.
- Traffic specifications from the Tspec.
- No specified strict bound on delay.
  - High percentage of the packets should not experience delay greater than the propagation and switching delay (i.e. the minimum delay).
  - Queuing delay not greater than that caused by the traffic's own burstiness.
- No or little loss of packets due to congestion over all time scales larger than burst time.

Controlled Load (cont.)

- In the case of *non-conformant* packets arriving:
  - Must provide QoS to conformant packets.
  - Non-conformant packet should not unfairly impact the conforming packets.
  - If sufficient resources are available, attempt to forward the non-conformant traffic in a best effort manner.

Resource Specification

- Application initially specifies the traffic parameters
  - Tspec consisting of p,b,r,m,M
- Policing is done at the edge
  - ensures that the flow traffic conforms to the Tspec. Nonconforming packets are treated with best effort service.
- Reshaping is done at intermediate nodes
  - ensures that flow is in conformance with the Tspec all through the path.
- If the traffic conforms to Tspec, guaranteed service ensures a bounded end-to-end delay.

Advantages of IntServ

- Uses existing protocols to determine path between source and destination.
- Supports multicast
  - Suitable for video broadcast, video conferencing, etc.
- Reservations are not permanent
  - Periodic PATH and RESV messages are required.
  - Alternate paths can be chosen if a different QoS is required.

Disadvantages of IntServ

- Requires each router to participate in the resource reservation process
  - Overhead to maintain the information in the routers
- Resource reservation requires considerable amount of time.
  - No suitable for short lived flow (data and graphics) in the Internet.
- Short–lived flow's of Internet are not suitable for RSVP requiring lot of time.
- Cumbersome to maintain the information on millions of connection in the core network.

Future of Integrated Service

- The core router needs to keep information about a large number of connections.
  - Scalability problem in large networks.
- Suitable for enterprise networks at the edges.
  - Enterprise networks carry fewer connections.

Differentiated Services

Differentiated Services

- Similar traffic are grouped into classes.
- Resources reserved for classes.
- QoS provided to classes.
  - QoS to individual connections is an open research issue.
- QoS maintained by:
  - Classification
  - Traffic policing
    - Metering, dropping, tagging
  - Traffic shaping
- Per Hop Behavior (PHB)
  - Specifies QoS received by packets i.e. how packets are treated by the routers.

QoS with DiffServ

- Packets are mapped to a Behavior Aggregate (BA).
- Different BA are forwarded according to the Per Hop Behavior of the BA
- QoS invoked on a packet by packet basis according to the DSCP code.

DS functionality

- Per Hop behavior (PHB)
- Behavior Aggregate (BA)
- Differentiated Services Code Point (DSCP)

Per Hop Behavior (PHB)

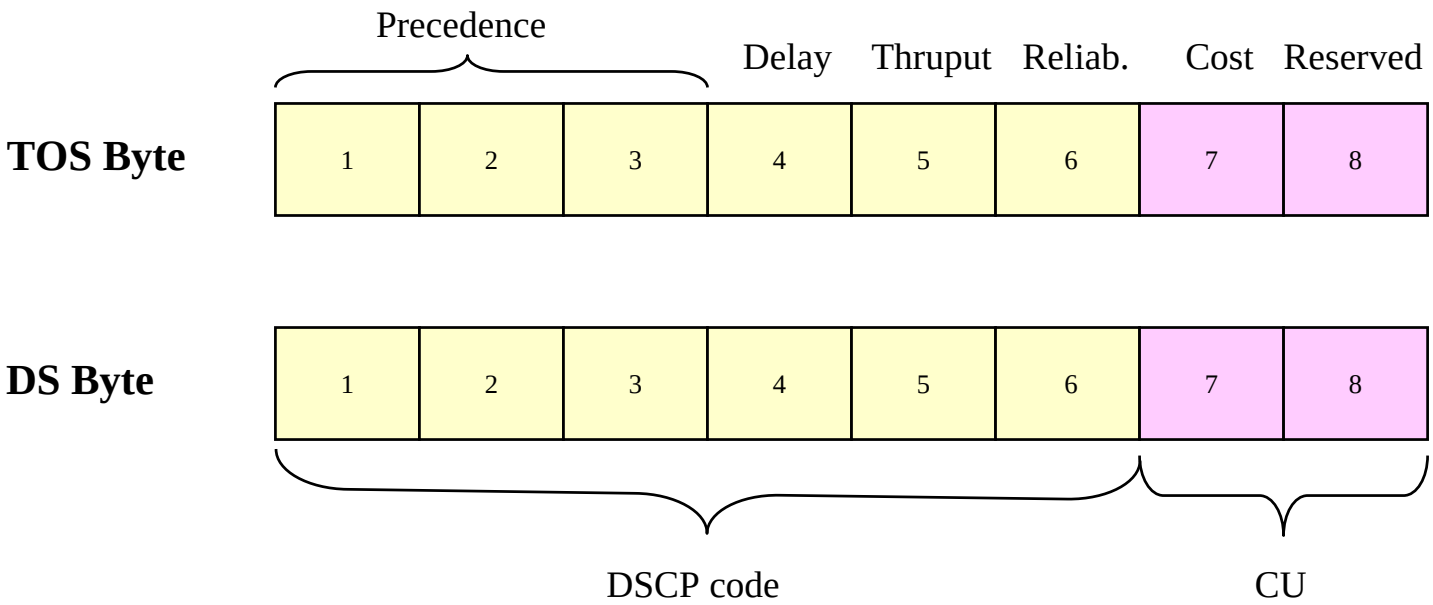
- PHB is related to DSCP
  - Each DSCP maps into a PHB depending on the configuration of the DS domain.
- Default PHB (DCSP=000000) is the Best Effort Service of today's Internet.
  - Should not suffer from bandwidth starvation.

DSCP Code

- Recommended DSCP code may be amended or replaced by the service provider.
  - A DS node must be able to examine fields in the IP header other than the DSCP field.
- Unrecognized DSCP codes are treated as default DSCP.
- DSCP assignments:

Pool	Codepoint Space	Assignment Policy
1	xxxxx0	Standards Action
2	xxxx11	EXP/LU
3	xxxx01	EXP/LU*

DSCP Code (cont.)

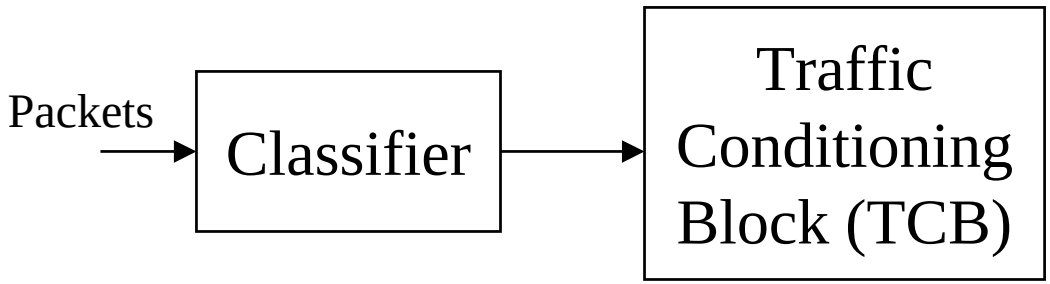


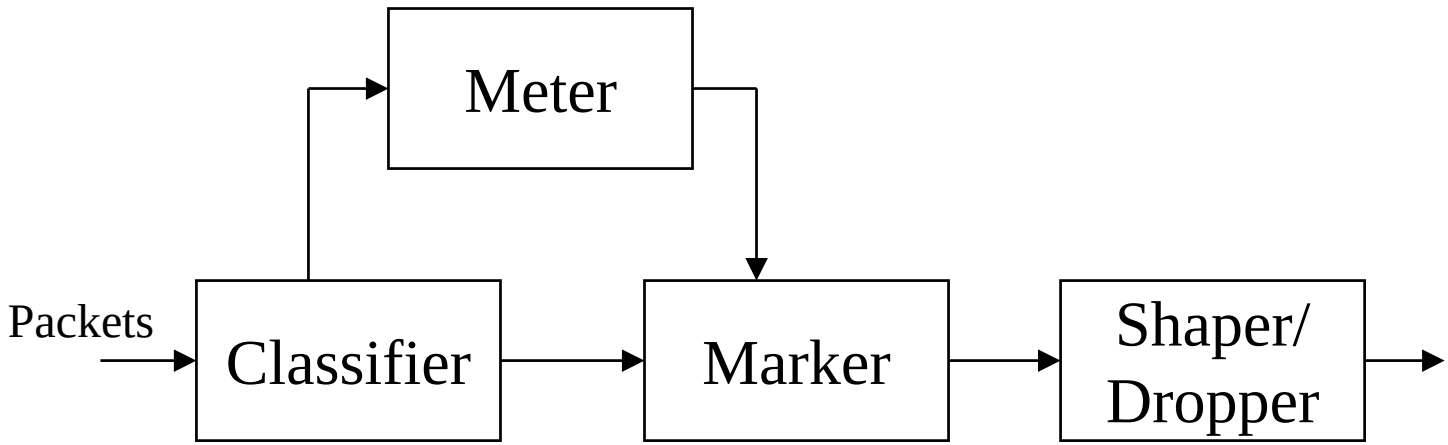
RFC 2474

Traffic Treatment in DiffServ

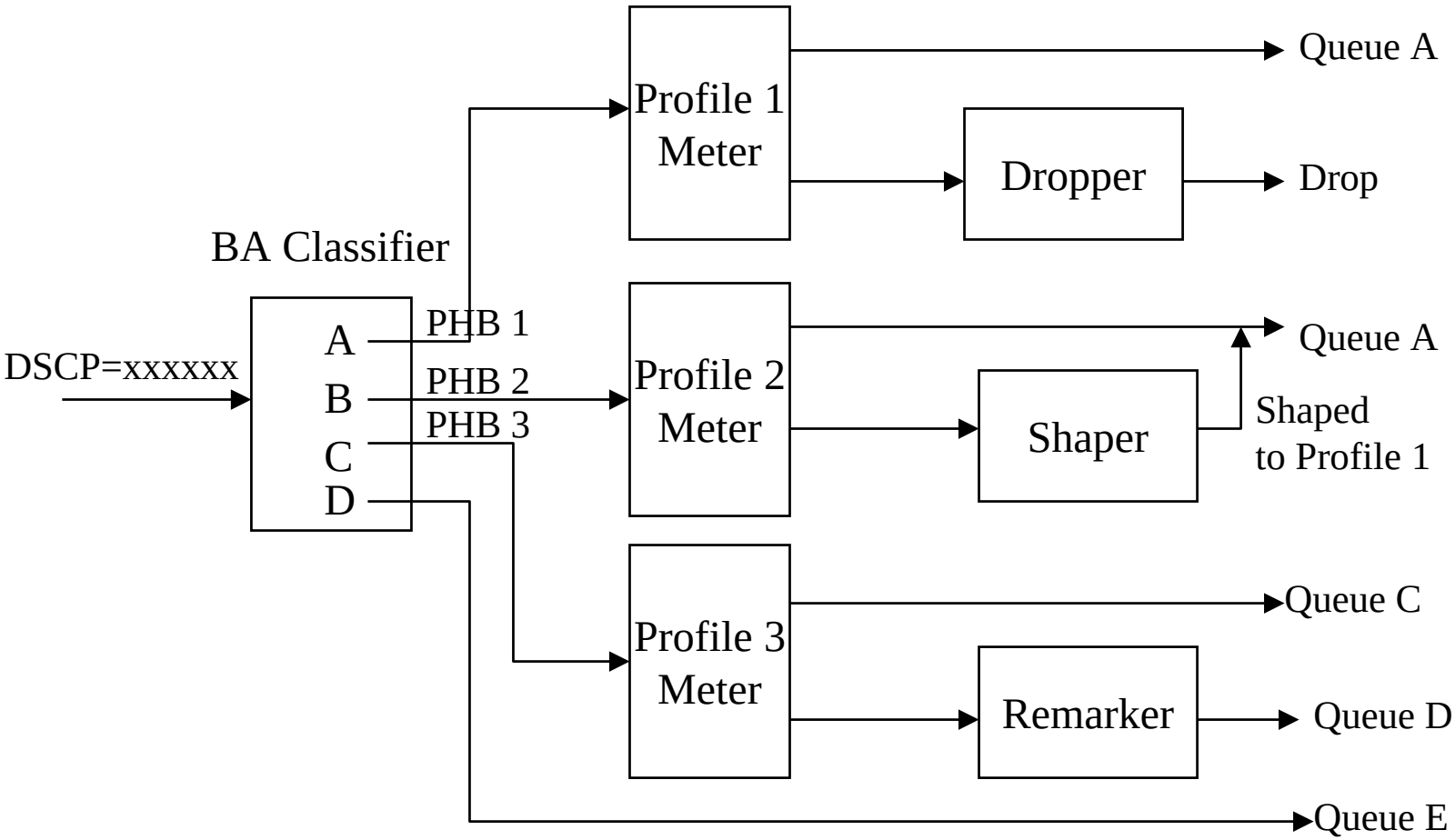
- Classification
- Traffic Conditioning
  - Metering
  - Shaping
  - Marking/Dropping
- Classification and Conditioning usually happens at the ingress node.

Traffic Treatment in DiffServ (cont.)





Example of TCB Implementation



Classifier

- Receives packets and classifies them to receive a particular per hop behavior (PHB)
  - Behavior aggregate (BA) classifies packets according to DSCP code
  - Multifield classifier classifies packets according to multiple fields (ex. DSCP, source/destination address, ports, etc.) in the packet header.
- Output of the classifier is fed to the Traffic Conditioning Block.

Meter

- Measuring the traffic against token bucket to check for resource consumption. Actions taken could be:
  - Mark the packets for further action by the shaper/dropper.
  - Shape the traffic profile.
  - Drop packets.
- Types of meters that can be used
  - Average Rate meter
  - Exponential Weighted Moving Average (EWMA) meter
    - avg(n+1)=(1-Gain)*avg(n)+Gain*actual(n+1)
  - Token Bucket meter
    - Peak rate (p), average rate (r), burst size (b)

Shaper

- *Shaping*: Traffic is shaped by putting out-of-profile traffic in a buffer.

Dropper/Marker

- Non-conformant traffic can be:
  - Dropped for congestion avoidance
  - Marked to be dropped later in the case of congestion

Traffic Treatment in DiffServ (contd.)

- *Policing:* Shaping + Dropping
- *Admission Control*: Limiting the amount of traffic according to the resources in the DS domain.
  - Implicit Admission Control: Performed at each router
  - Explicit Admission Control : Dynamic resource allocation by a centralized bandwidth broker

Per Hop Behavior (PHB)

- Defines how a group of similar packets are treated by the DS domain.
- Some PHBs:
  - Expedited Forwarding(EF PHB)
  - Assured Forwarding (AF PHB)
  - Best Effort (Default)

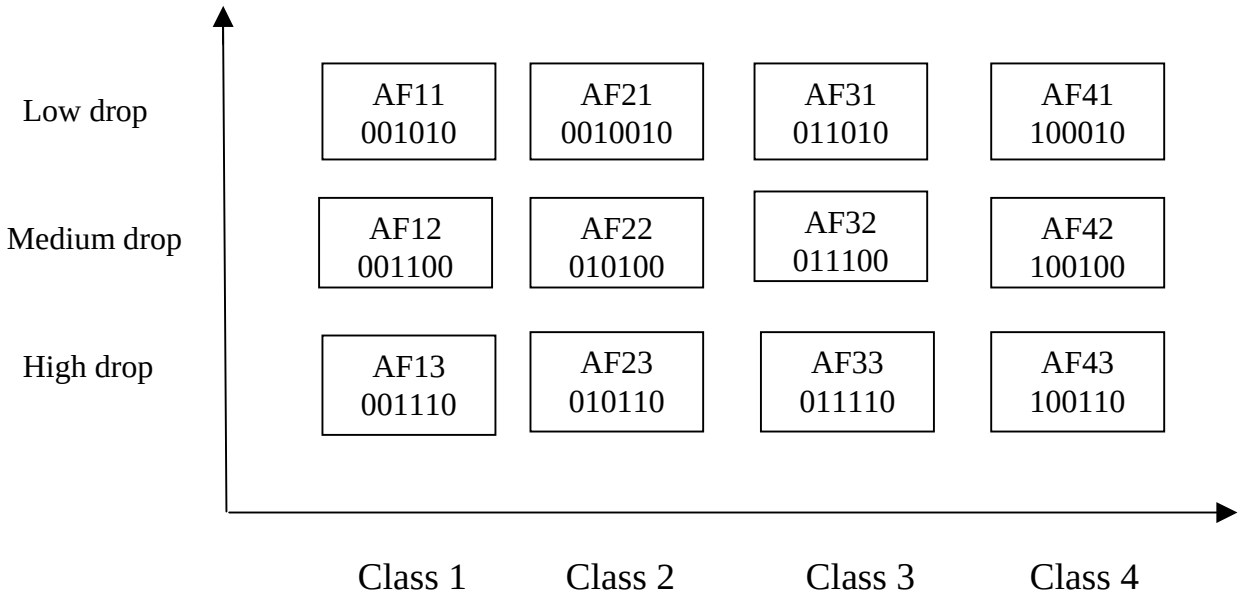
Expedited Forwarding (EF)

- RFC 2598
- DSCP code = 101110
- Highest priority traffic.
  - Minimum delay, jitter, loss.
  - Assured bandwidth.
- Can be implemented by a strict priority queue.
- Only *one* importance level.
  - Marking is not available in EF
- Options for a packet arriving early at the DS domain:
  - Forward immediately (leaves the source to exploit additional bandwidth): implement in interior nodes.
  - Forward packet at scheduled time: implement at ingress node
  - Drop packet: implement at ingress node.

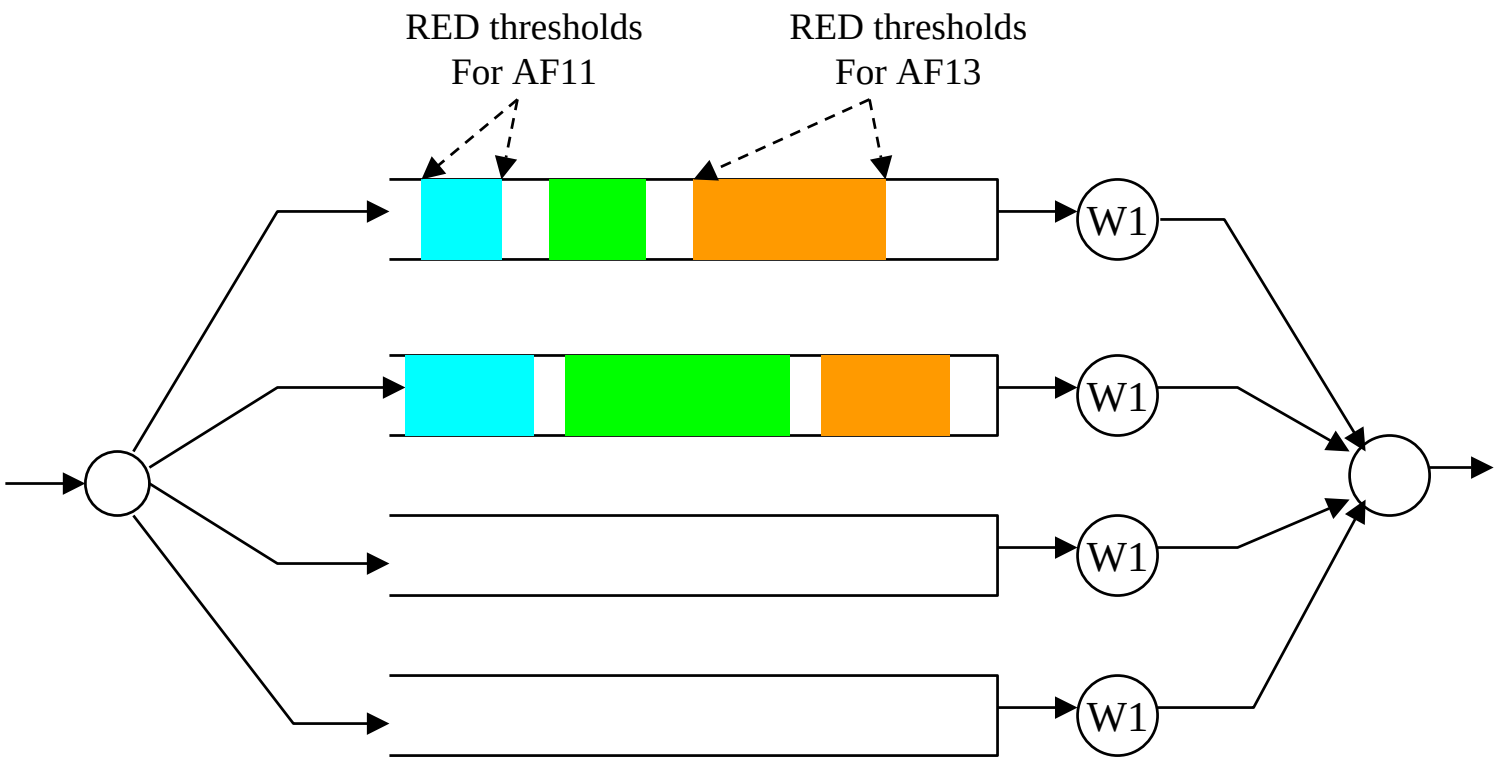
Assured Forwarding (AF)

- RFC 2597
- Different levels of forwarding assurances:
  - Four AF classes and three drop precedence.
  - 12 DSCP are reserved for AF.
- Each class has a configurable minimum amount of buffer space and bandwidth.

AF Classes and Drop Precedence



AF Implementation



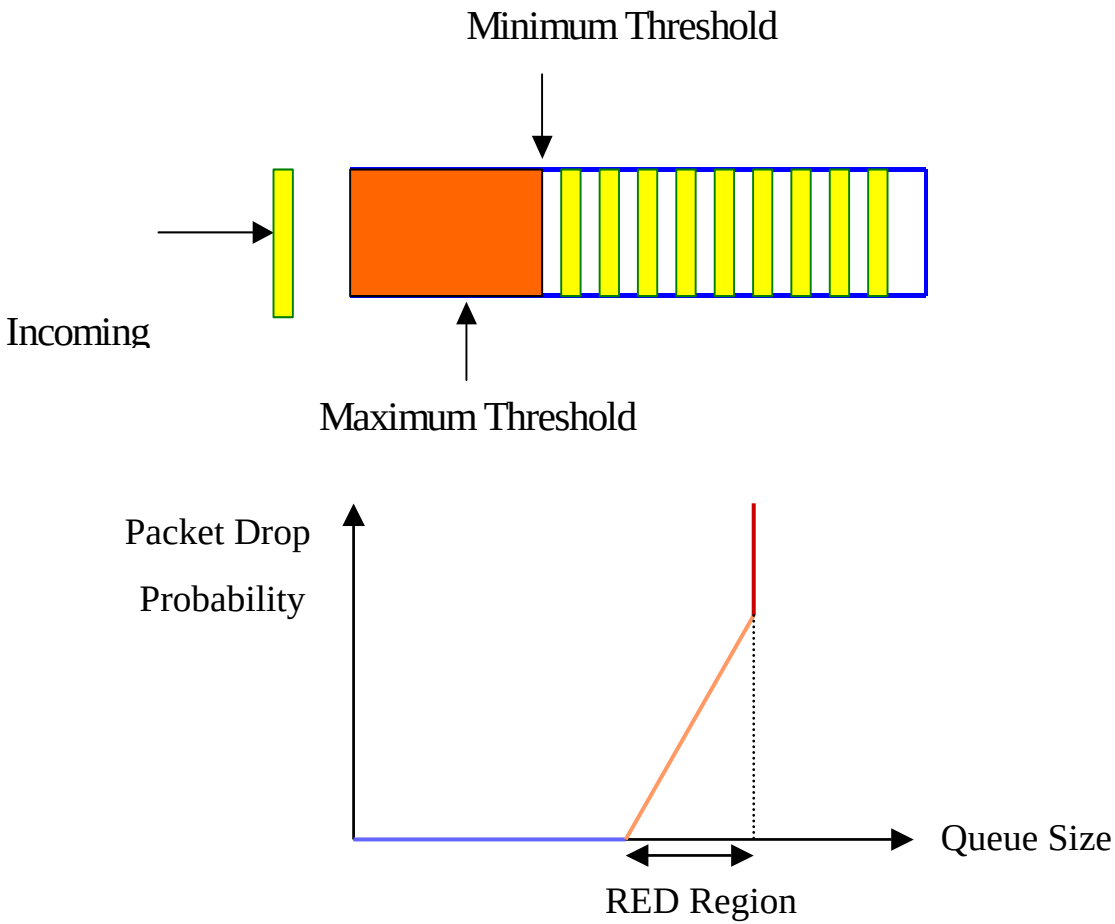
Best Effort

- Default service in the DiffServ domain (DSCP code = 0).
- Packets are forwarded based on availability of resources.
  - Guarantees no bandwidth
- No implementation policy
- No traffic classification
  - All traffic are aggregated to a single flow which receives the same treatment.

Queuing to Support Various PHBs

- Weighted Fair Queuing (WFQ)
- Class Based Queuing (CBQ)
- Random Early Detection (RED)

Random Early Detection (RED)



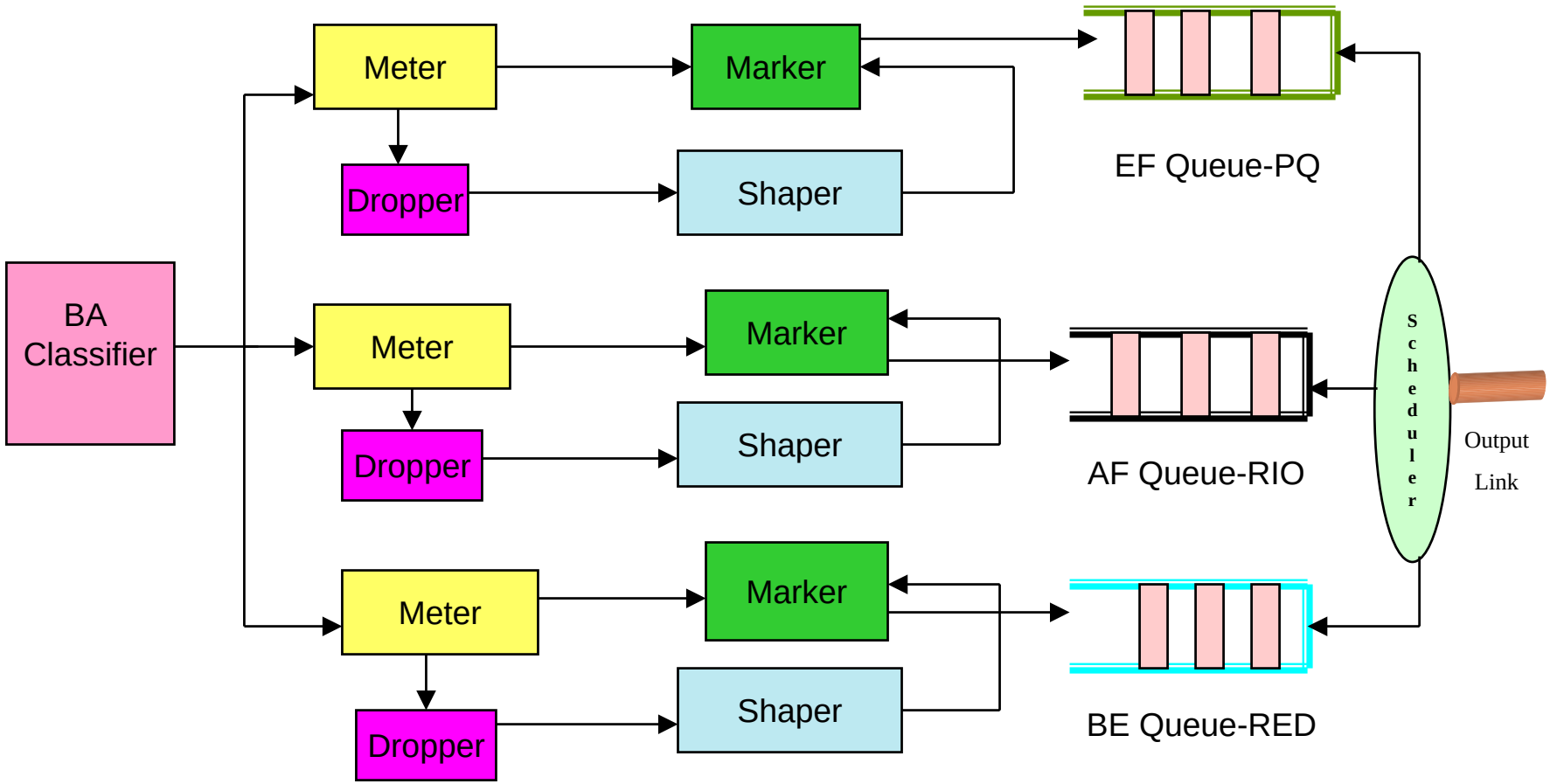
Advantages of DiffServ

- No delay due to connection set up.
  - Suitable for short lived multimedia flows.

Disadvantages of DiffServ

- QoS guarantees based on aggregates.
  - Per flow QoS can not be guaranteed.
- Providing QoS without knowing the destination of traffic is a challenge.
  - Example: Providing guarantees to airline passengers without knowing their destinations is a challenge.

Traffic Conditioning at DS Boundary



Next Generation Internet

- Routers at the edge network will not need to carry too many connections
  - IS can be used at the edge network.
- Core network needs to carry lot of connections.
  - Combination of DS, ATM and MPLS at the core.
- Satellite/Wireless links
  - Remote connectivity and mobility.

IntServ over DiffServ

Service Mapping from IS-DS

- Provide different levels of service differentiation.
- Provide QoS to multimedia and multicast applications.
- Scalability in terms of resource allocation.
- There is no over head due to per flow state maintenance at each router.
- Forwarding at each router according to the DSCP code.
- PHB's along the path provide a scheduling result approximating the QoS requirements and results in IS

Integrated Service	Differentiated Service
Guaranteed Load	Expedite Forwarding
Controlled Load	Assured Forwarding
Best effort	Default best effort

Guaranteed load - EF PHB

- Guaranteed traffic performance can be met effectively using the EF PHB with proper policing and shaping functions.
- Shaping Delay
- Queuing Delay
- Packets in the Scheduler

Controlled Load - AF PHB

- Classified into delay classes based on the B/R ratio of Tspec for each delay class; Aggregate Tspec is constructed for all the admitted traffic.
- For each delay class, police the traffic against a token bucket derived above.
- Size of the queue is set to limit the queuing delay of AF requirement.
- RIO dropping parameters are set according to the drop precedence of the AF class.
- AF instance service rate is set to bandwidth sufficient enough to meet the delay and loss requirements of the CL traffic.
- Bandwidth distributed between AF and BE to prevent the BF from starvation.
- Scheduling done with WFQ (Weighted Fair Queuing) or WRR (Weighted Round Robin)

Mapping Table for IS-to-DS

Flow Id	T Spec Parameters
1	R = 400 P = 500 B = 700
2	R = 450 P = 550 B = 750
3	R = 500 P = 600 B = 800
4	R = 550 P = 650 B = 850
5	R = 600 P = 700 B = 900
6	R = 650 P = 750 B = 950
7	R = 700 P = 800 B = 1000
8	R = 750 P = 850 B = 1050
9	R = 800 P = 900 B = 1100
10	R = 850 P = 950 B = 1150

PHB	DSCP
AF11	OO1O1O
AF32	O111OO
AF41	1OOO1O
EF	OOO1OO

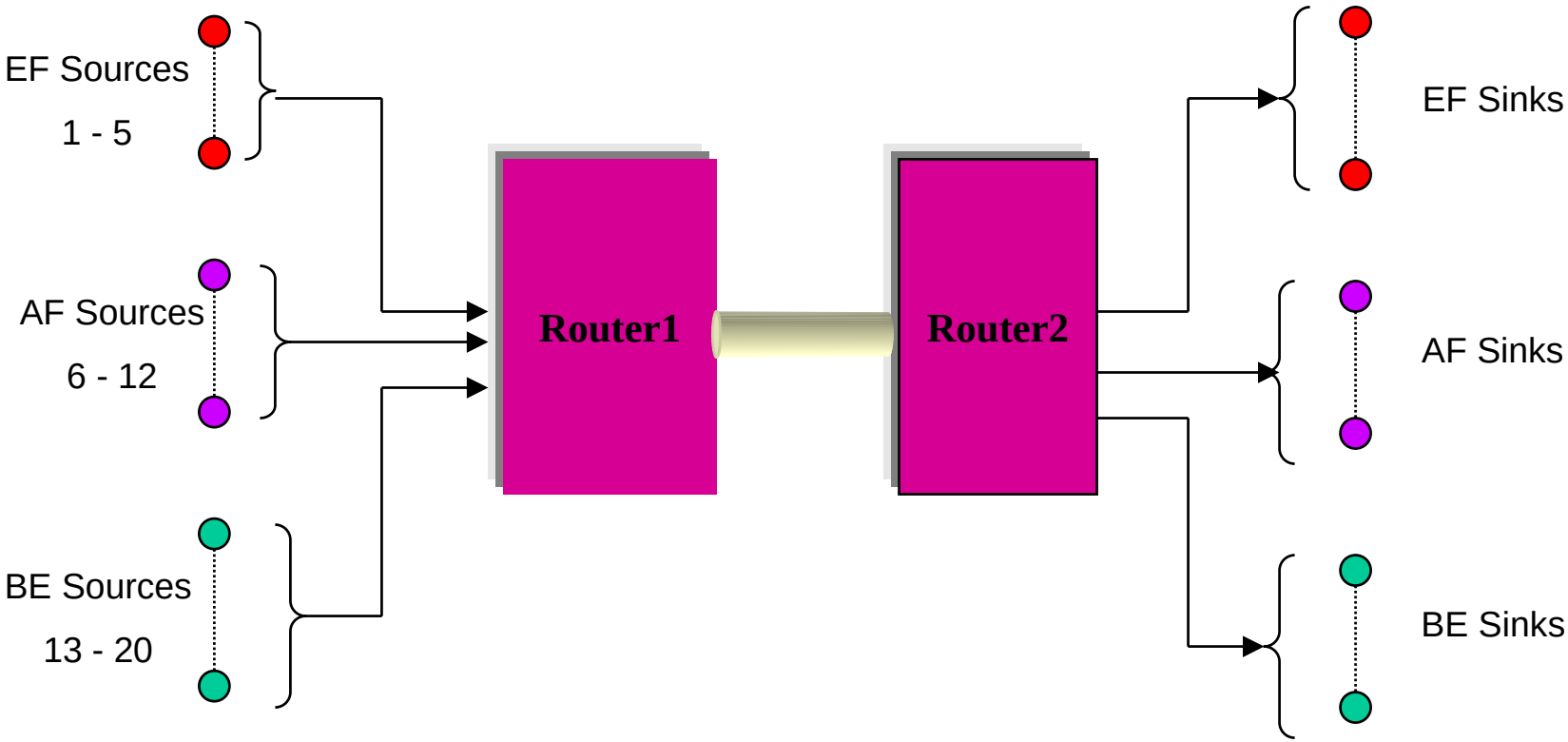
Mapping of IS to DS

- Tspec parameters indicating resource reservation taken from RSVP signaling.
- Table entry contains Tspec parameters, flow IDs, PHB groups and DSCP values.
- Measures actual traffic flow rate against a token bucket according to the initial stored table entry.
- If the traffic is in-profile with the requested reservation, it classifies the packet and marks it with the available DSCP, which can approximately assure the requested QoS.
- The out-of profile traffic is stored in a buffer and shaped to be in conformance with the requested traffic profile.

Mapping of IS to DS (contd.)

- Packets are forwarded in the DS domain according to the DSCP value and the PHB group.
- The forwarding treatment is basically concerned with the queue management policy and the priority of bandwidth allocation; these ensure the required minimum queuing delay, low jitter and maximum throughput.
- Depending on the implementations of the PHB's inside the network, queue management could be RED, WRED, PQ, WFQ.

IS-DS Simulation Configuration



Web Sites

- IETF
  - www.ietf.org/
- ATM Forum
  - www.atmforum.com
- ITU
  - www.itu.int
- MPEG
  - http://www.cselt.it/mpeg/
- Traffic shaping of MPEG streams for QoS
  - www.engr.udayton.edu/faculty/matiquzz

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