Data and Computer Communications

Tenth Edition

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CHAPTER 22

Internetwork Quality of Service

“In the schemes considered, precedence is determined moment-by-moment, automatically for all traffic in the network. Precedence is computed as a composite function of: (1) the ability of the network to accept additional traffic; (2) the ‘importance’ of each user and the ‘utility’ of his traffic; (3) the data rate of each input transmission medium or the transducer used; and (4) the tolerable delay time for delivery of the traffic.”

— Paul Baran, August 1964

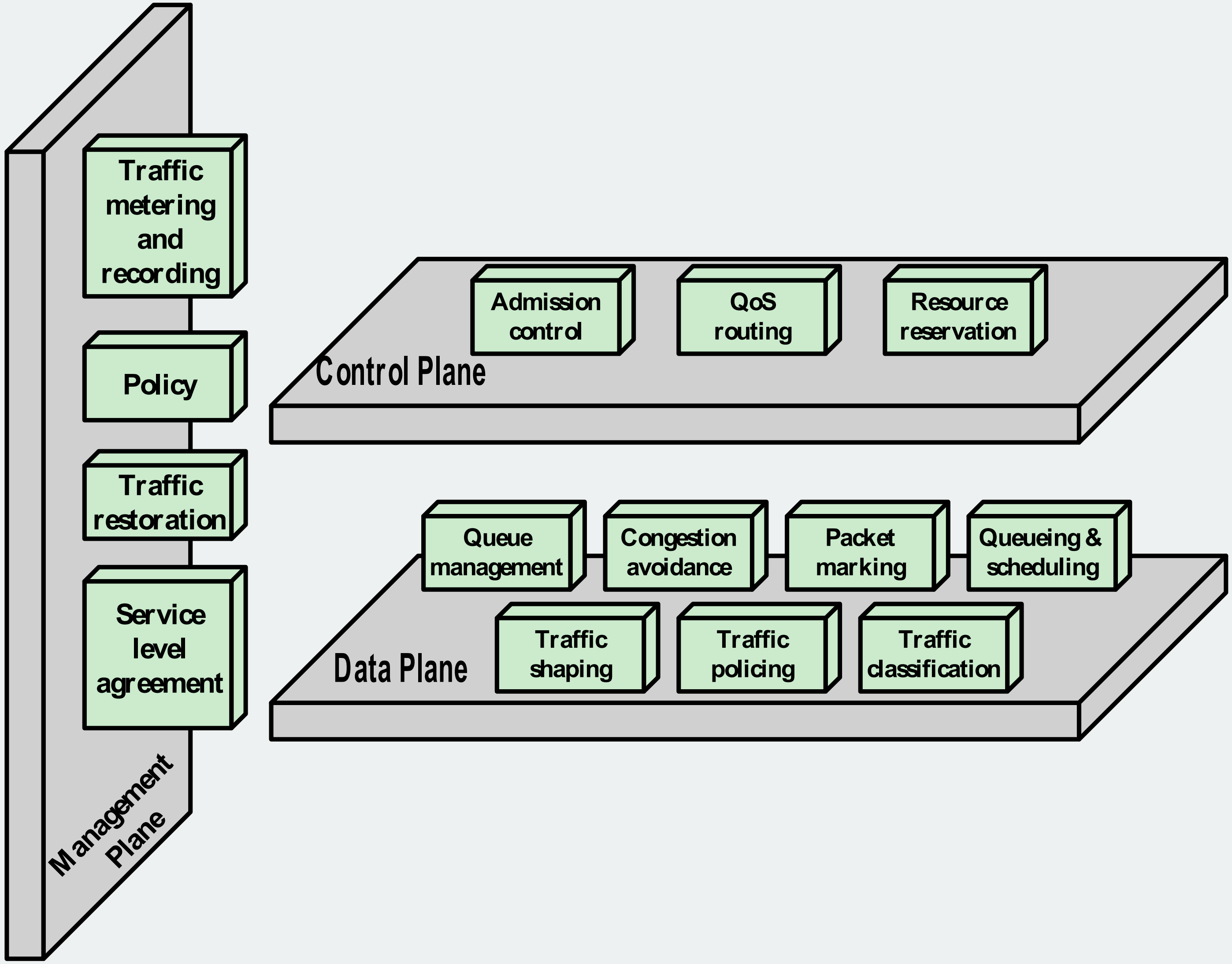


Figure 22.1 Architectural Framework for QoS Support

Data Plane

- Includes those mechanisms that operate directly on flows of data

- Queue management algorithms
- Queueing and scheduling
- Congestion avoidance
- Packet marking
- Traffic classification
- Traffic policing
- Traffic shaping

Control Plane

- Concerned with creating and managing the pathways through which user data flows
- It includes:
  - Admission control
  - QoS routing
  - Resource reservation

Management Plane

- Contains mechanisms that affect both control plane and data plane mechanisms
- Includes:
  - Service level agreement (SLA)
  - Traffic metering and recording
  - Traffic restoration
  - Policy

Integrated Service Architecture (ISA)

- Intended to provide QoS transport over IP-based Internets
- Defined in RFC 1633
- Portions already being implemented in routers and end-system software

Internet Traffic - Elastic

- Traffic that can adjust, over wide ranges, to changes in delay and throughput and still meet the needs of its applications
- Traditional type of traffic supported on TCP/IP-based Internets
- Applications classified as elastic include:

Internet Traffic - Inelastic

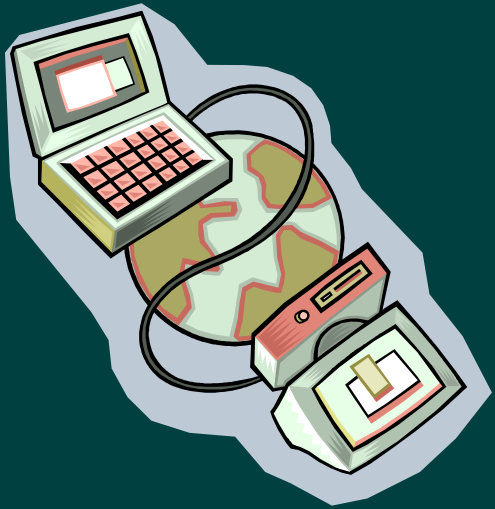
- Does not easily adapt, if at all, to changes in delay and throughput across an internet
  - Prime example is real-time traffic

Requirements for inelastic traffic include:
• Throughput • Delay • Jitter • Packet loss

- New internet architecture requirements:
  - Resource reservation protocol
  - Elastic traffic still needs to be supported

ISA Approach

- Purpose is to enable QoS support over IP-based internets
- Sharing capacity during congestion is the central design issue



- To manage congestion and provide QoS transport ISA makes use of:
  - Admission control
  - Routing algorithm
  - Queuing discipline
  - Discard policy

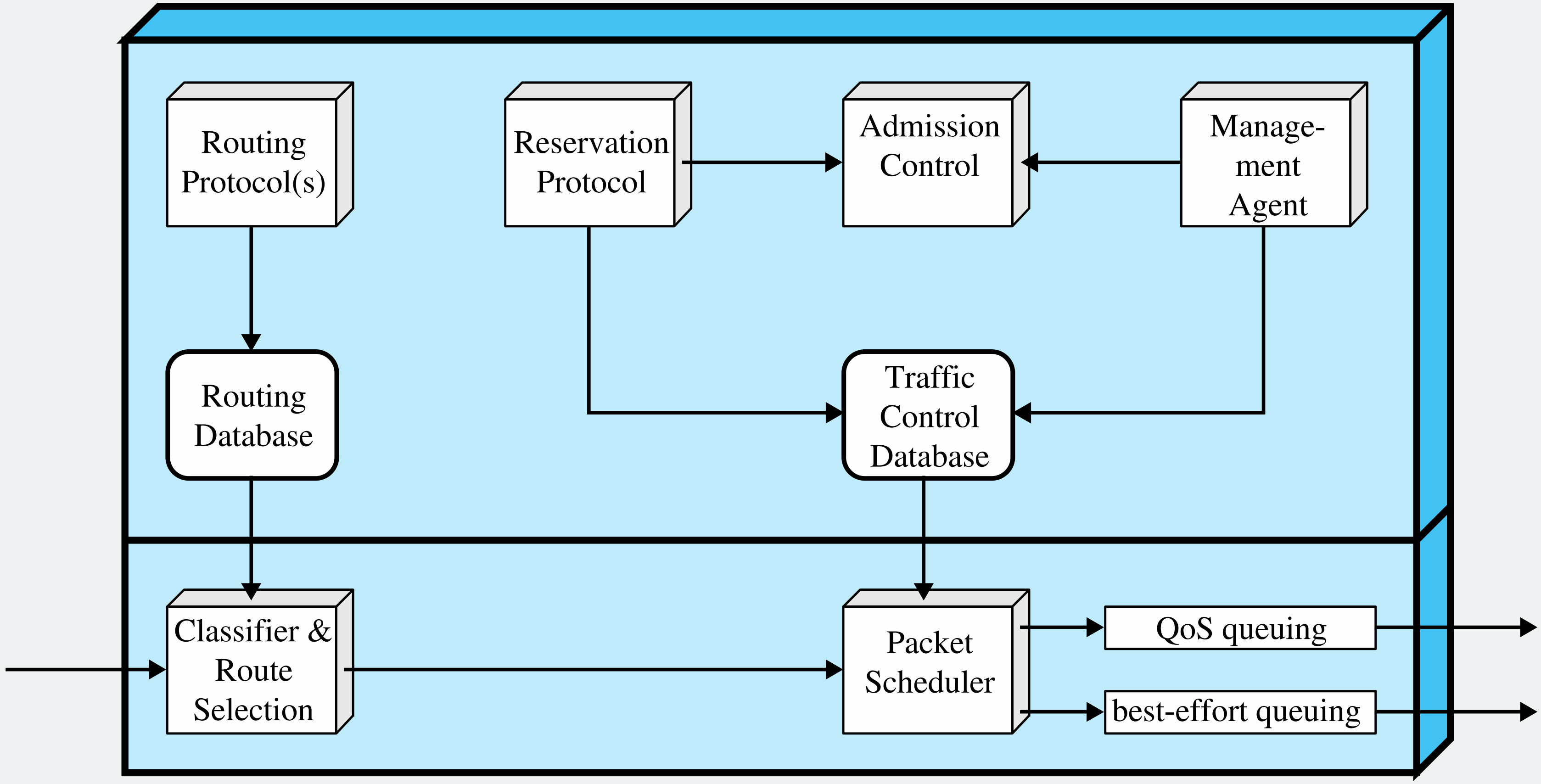
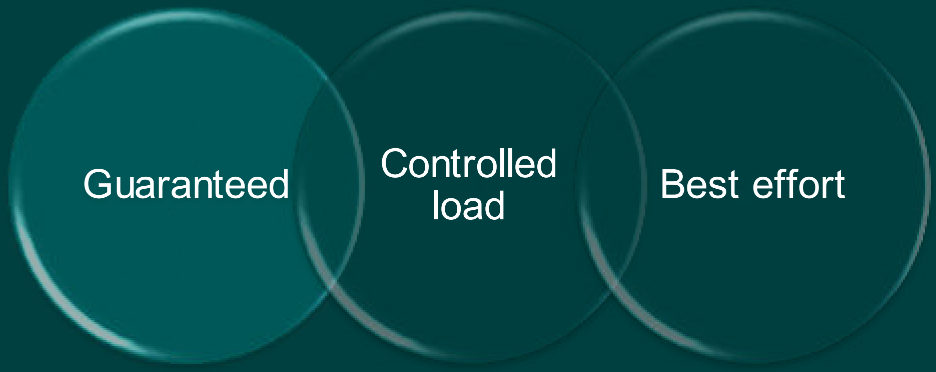


Figure 22.2 Integrated Services Architecture Implemented in Router

ISA Services

- ISA service for a flow of packets is defined on two levels:
  - A number of general categories of service are provided, each of which provides a certain general type of service guarantees
  - Within each category, the service for a particular flow is specified by the values of certain parameters
    - Referred to as a traffic specification (TSpec)
- Three categories of service:



Guaranteed Service

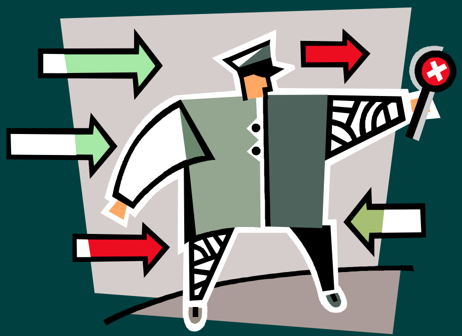
- Key elements are:
  - Service provides assured capacity
  - Specified upper bound on the queuing delay through the network
  - There are no queuing losses
- Application provides a characterization of expected traffic profile and the service determines the end-to-end delay that it can guarantee
- Most demanding service provided by ISA

Controlled Load

- Key elements are:
  - Tightly approximates the behavior visible to applications receiving best-effort service under unloaded conditions
  - No specified upper bound on the queuing delay through the network
  - High percentage of transmitted packets will be successfully delivered
- Useful for adaptive real-time applications

Queuing Discipline

- Routers traditionally use first-in-first-out (FIFO) queuing discipline



- Drawbacks of FIFO
  - No special treatment given to higher priority packets
  - Smaller packets get delayed behind larger packets
  - A greedy TCP connection can crowd out more altruistic connections

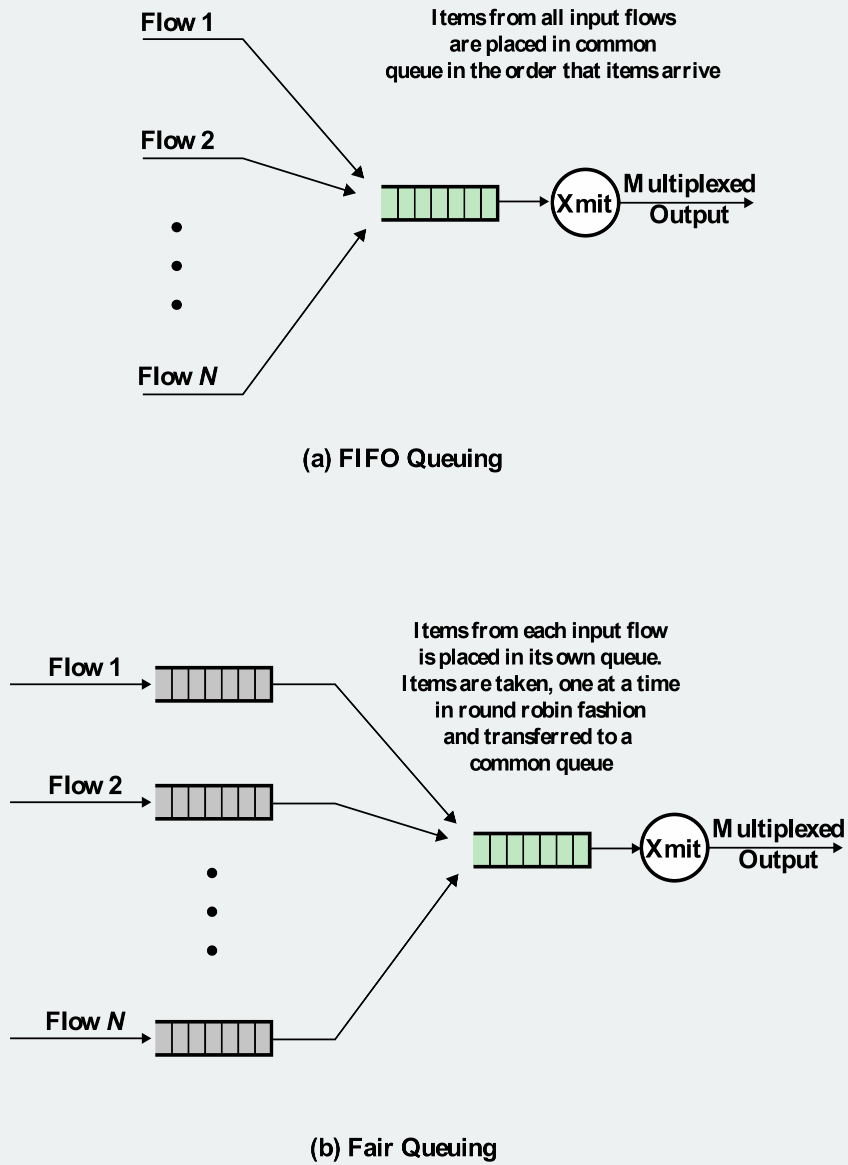


Figure 22.3 FIFO and Fair Queuing

Resource ReSerVation Protocol (RSVP)

- RFC 2205
- Provides supporting functionality for ISA
- Prevention strategy
  - Have unicast applications reserve resources in order to meet a given QoS
  - Enables routers to decide ahead of time if they can meet the delivery requirement for a multicast transmission
- Must interact with a dynamic routing strategy
  - Soft state

RSVP Goals and Characteristics

- Unicast and multicast
- Simplex
- Receiver-initiated reservation
- Maintaining soft state in the internet
- Providing different reservation styles
- Transparent operation through non-RSVP routers

Receiver-Initiated Reservation

- Since receivers specify the desired QoS it makes sense for them to make resource reservations
  - Different members of the same multicast group may have different resource requirements
  - QoS requirements may differ depending on the output equipment, processing power, and link speed of the receiver
  - Routers can aggregate multicast resource reservations to take advantage of shared path segments

Soft State

- Connectionless
- Reservation state is cached information in the routers that is installed and periodically refreshed
- If a new route becomes preferred the end systems provide the reservation to the new routers on the route

Data Flows

- Basis of RSVP operation:

Session

- Destination IP address
- IP protocol identifier
- Destination port

Flow specification

- Service class
- Rspec
- Tspec

Filter specification

- Source address
- UDP/TCP source port

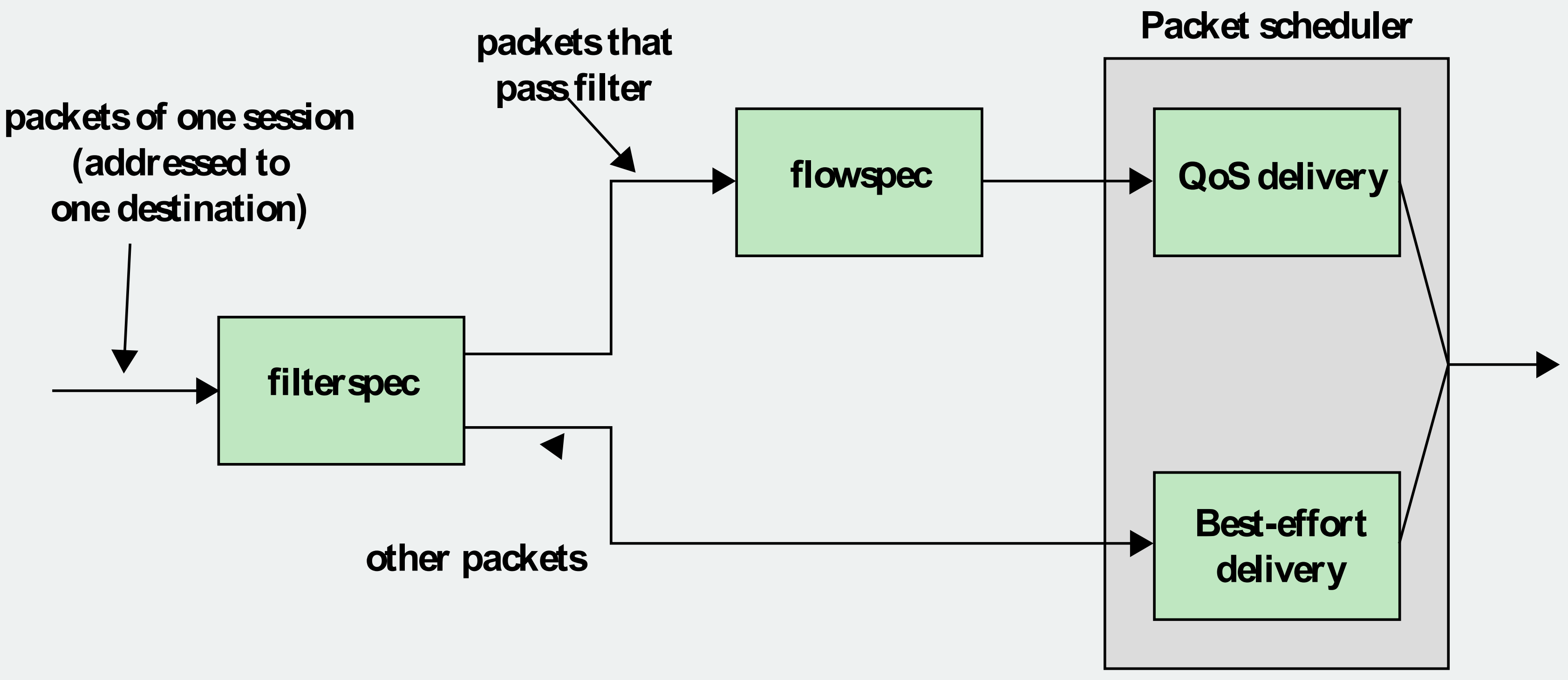


Figure 22.4 Treatment of Packets of One Session at One Router

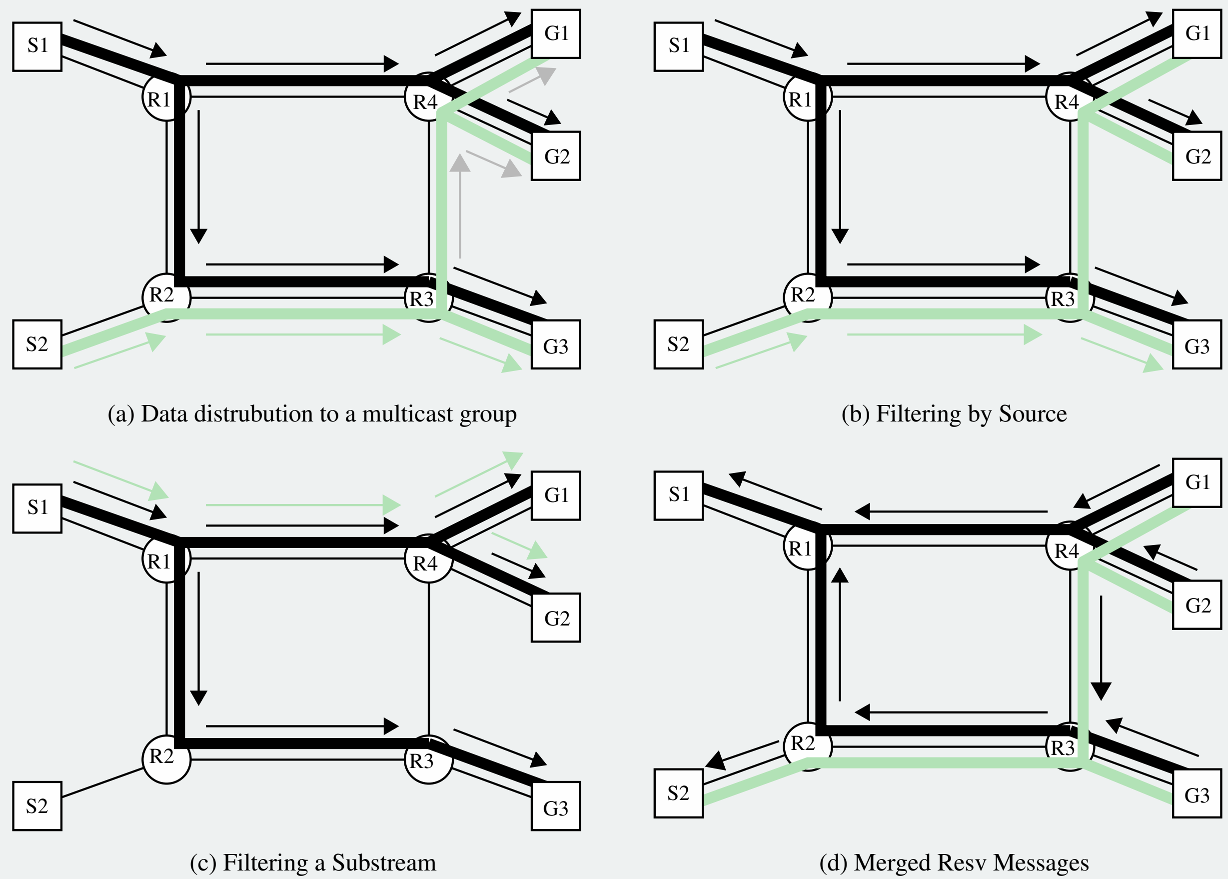


Figure 22.5 RSVP Operation

Table 22.1 Reservation Attributes and Styles

	Reservation Attribute	
Sender Selection	**Distinct**	**Shared**
Explicit	Fixed-filter (FF) style	Shared-explicit (SE) style
Wildcard	—	Wildcard-filter (WF) style

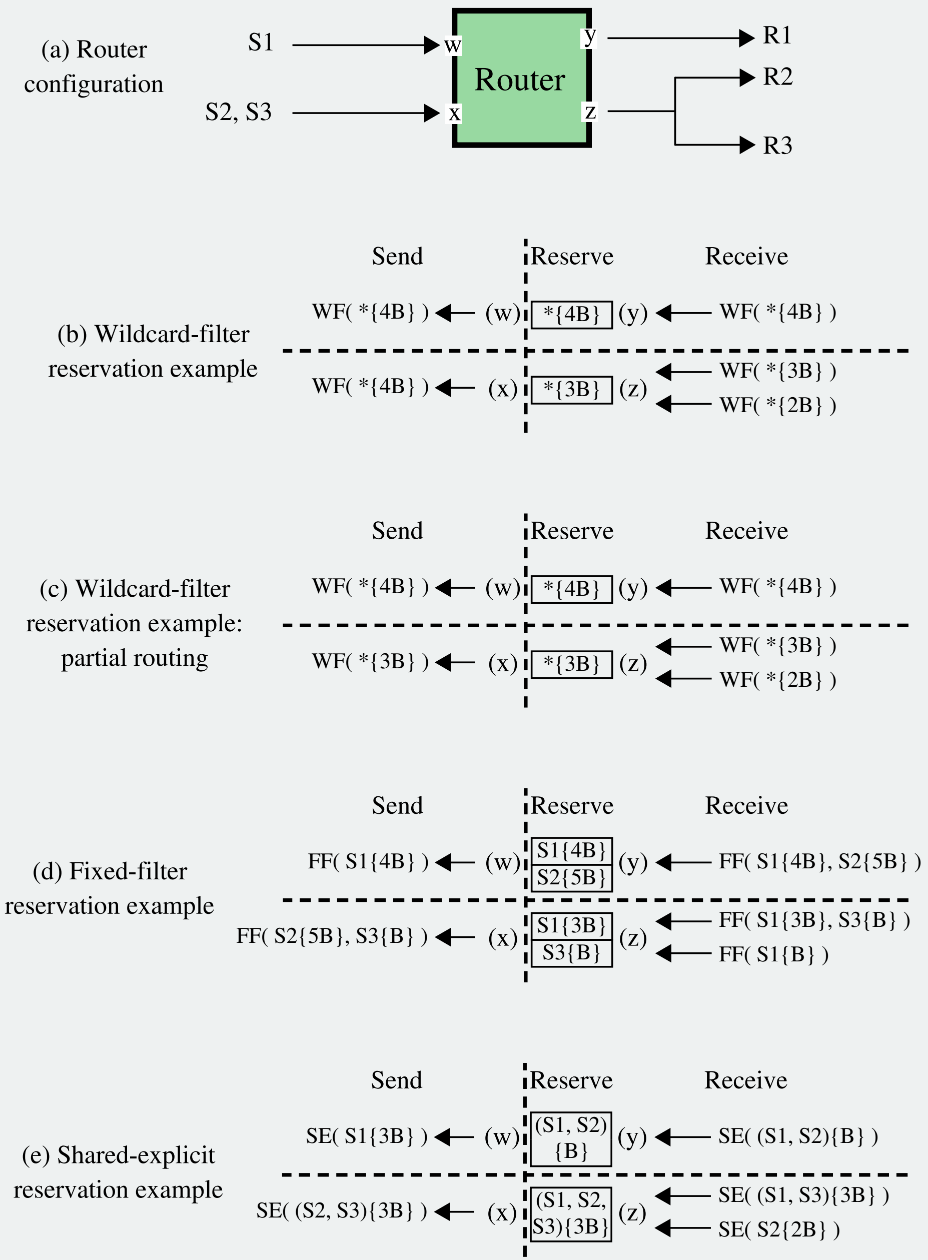


Figure 22.6 Examples of Reservation Styles

RSVP Protocol Mechanisms

- RSVP uses two basic message types:

- **Resv**
  - Originate at multicast group receivers and propagate upstream
  - Create soft states within routers that define resources reserved for the session
  - Hosts set up traffic control parameters for the first hop
- **Path**
  - Used to provide upstream routing information
  - Reverse routing
  - Each router and host creates a path state that indicates the reverse hop for source

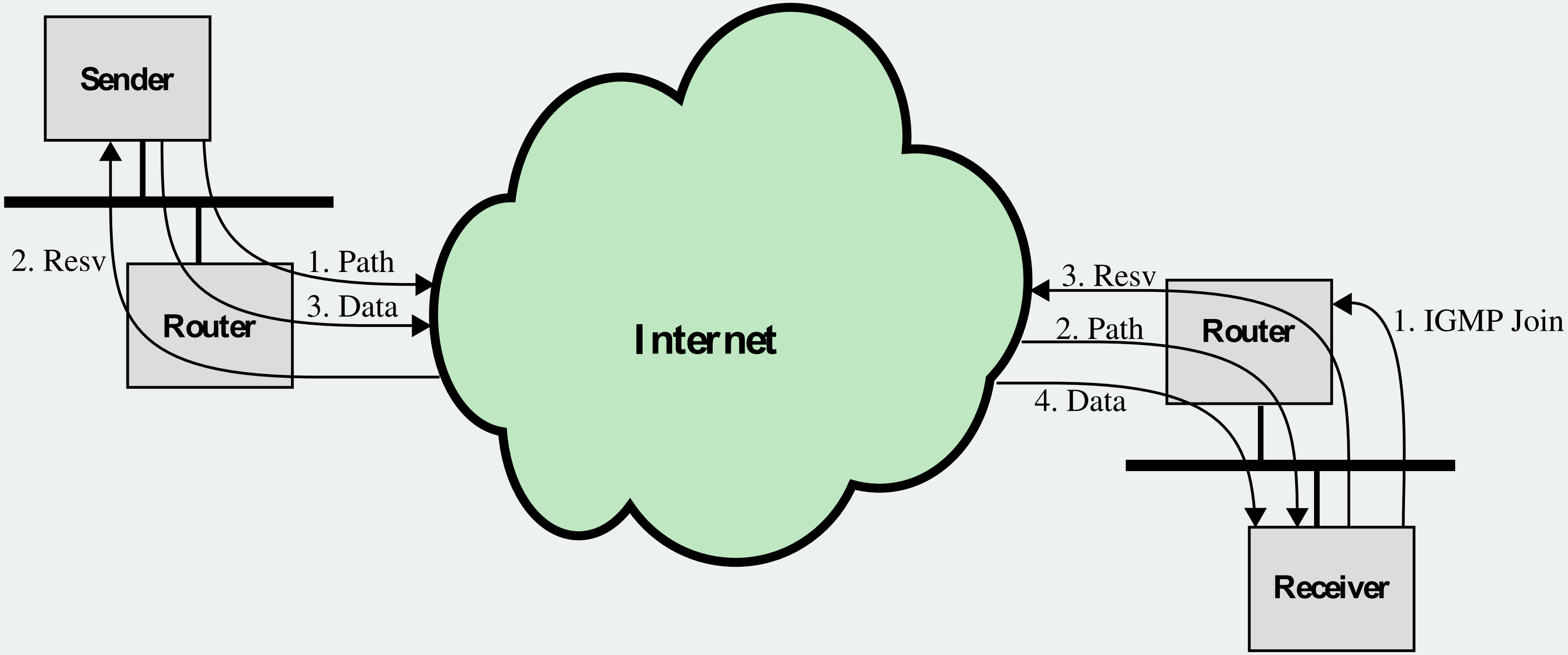


Figure 22.7 RSVP Host Model

Differentiated Services (DS)

- RFC 2475
- Designed to provide a tool to support a range of network services
- Key characteristics:
  - No change to IP is required
  - SLS is established prior to use of DS
    - Applications do not need to be modified
  - Provides a built-in aggregation mechanism
    - Good scaling to larger networks and traffic loads
  - DS is implemented in individual routers
  - Most widely accepted QoS in enterprise networks

Table 22.2

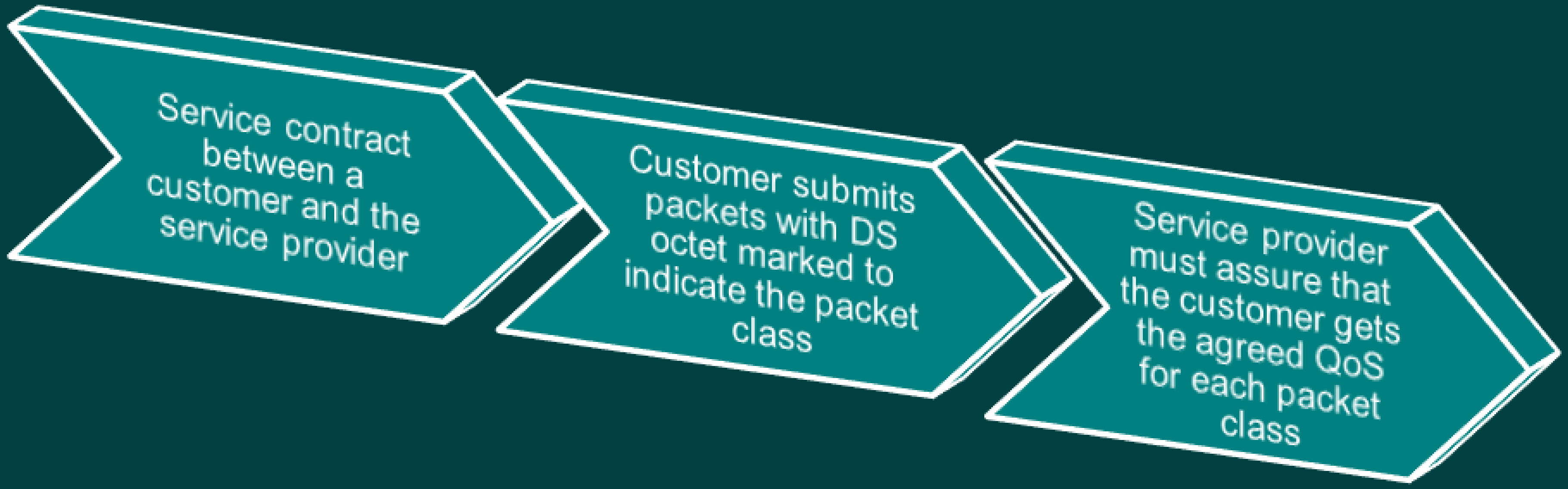
Terminology for Differentiated Services

Behavior Aggregate	A set of packets with the same DS codepoint crossing a link in a particular direction.
Classifier	Selects packets based on the DS field (BA classifier) or on multiple fields within the packet header (MF classifier).
DS Boundary Node	A DS node that connects one DS domain to a node in another domain
DS Codepoint	A specified value of the 6-bit DSCP portion of the 8-bit DS field in the IP header.
DS Domain	A contiguous (connected) set of nodes, capable of implementing differentiated services, that operate with a common set of service provisioning policies and per-hop behavior definitions.
DS Interior Node	A DS node that is not a DS boundary node.
DS Node	A node that supports differentiated services. Typically, a DS node is a router. A host system that provides differentiated services for applications in the host is also a DS node.
Dropping	The process of discarding packets based on specified rules; also called **policing**.
Marking	The process of setting the DS codepoint in a packet. Packets may be marked on initiation and may be re-marked by an en route DS node.
Metering	The process of measuring the temporal properties (e.g., rate) of a packet stream selected by a classifier. The instantaneous state of that process may affect marking, shaping, and dropping functions.
Per-Hop Behavior (PHB)	The externally observable forwarding behavior applied at a node to a behavior aggregate.
Service Level Agreement (SLA)	A service contract between a customer and a service provider that specifies the forwarding service a customer should receive.
Shaping	The process of delaying packets within a packet stream to cause it to conform to some defined traffic profile.
Traffic Conditioning	Control functions performed to enforce rules specified in a TCA, including metering, marking, shaping, and dropping.
Traffic Conditioning Agreement (TCA)	An agreement specifying classifying rules and traffic conditioning rules that are to apply to packets selected by the classifier.

(Table is on Page 756 in the textbook)

DS Services

- Typically DS domain is under the control of one administrative entity
- Services provided across a DS domain are defined in an SLA

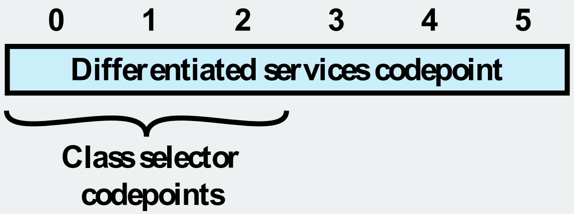


Performance Parameters Included in an SLA

- Detailed service performance parameters such as expected throughput, drop probability, latency
- Constraints on the ingress and egress points at which the service is provided, indicating the scope of the service
- Traffic profiles that must be adhered to for the requested service to be provided, such as token bucket parameters
- Disposition of traffic submitted in excess of the specified profile

Services Provided

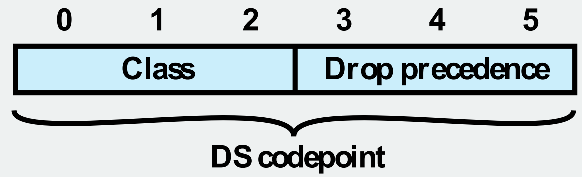
- Traffic offered at service level A will be delivered with low latency
- Traffic offered at service level B will be delivered with low loss
- Ninety percent of in-profile traffic delivered at service level D will be delivered
- Traffic offered at service level E will be allotted twice the bandwidth of traffic delivered at service level F
- Traffic with drop precedence X has a higher probability of delivery than traffic with drop precedence Y



000000	Default behavior
001000	Class selector behaviors
010000	
011000	
100000	
101000	
110000	
111000	
101110	Expedited forwarding (EF) behavior

Increasing priority

(a) DS Field



	Class		**Drop Precedence**
100	Class 4 - best service	010	Low - most important
011	Class 3	100	Medium
010	Class2	110	High - least important
001	Class 1		

(b) Codepoints for assured forwarding PHB

Figure 22.8 DS Field

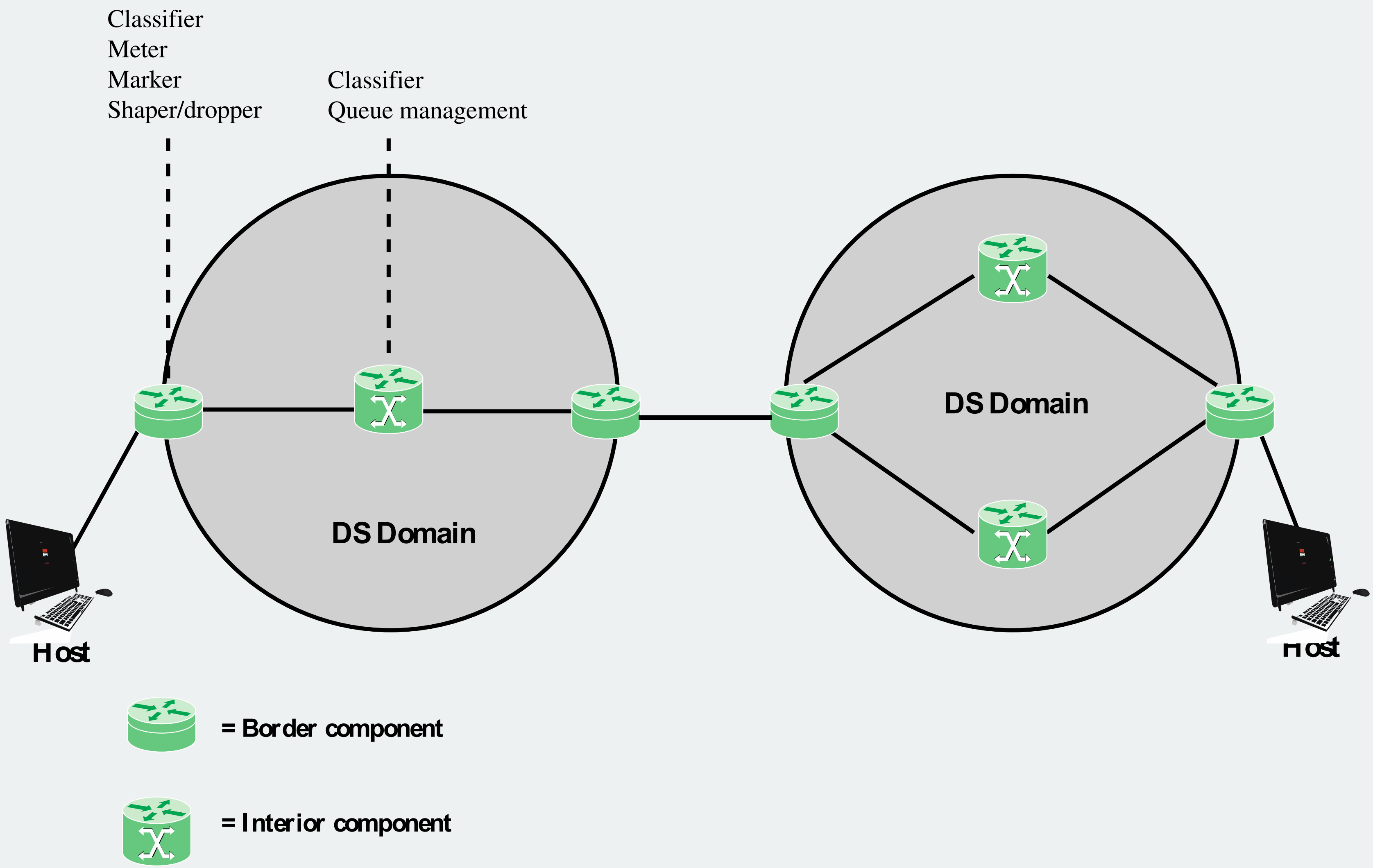


Figure 22.9 DS Domains

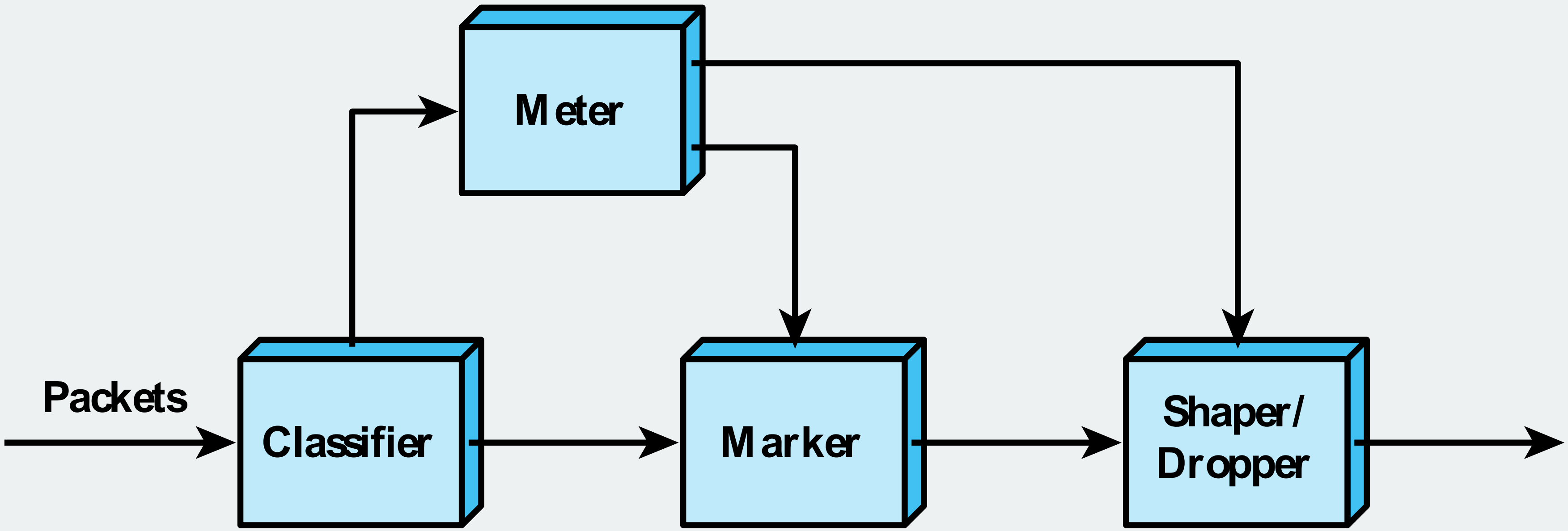
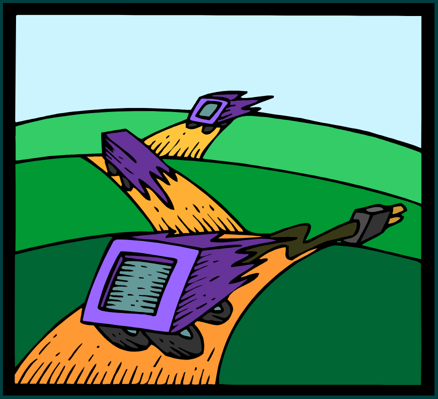


Figure 22.10 DS Traffic Conditioner

Expedited Forwarding PHB (EF PHB)

- RFC 3246
- Building block for low-loss, low-delay, and low-jitter end-to-end services through DS domains
  - Difficult to achieve
  - Cause is queuing behavior at each node
- Intent is to provide a PHB in which packets encounter short or empty queues
- Configures nodes so traffic has a defined minimum departure rate



Assured Forwarding (AF) PHB

- RFC 2597
- Designed to provide a service superior to best-effort but one that does not require the reservation of resources within an internet
- Referredto as explicit allocation
  - Expands by defining four AF classes and marking packets with one of three drop precedence values

Service Level Agreements (SLA)

- Contract between a network provider and a customer that defines specific aspects of the service that is to be provided

SLA includes:

- A description of the nature of service to be provided
- The expected performance level of the service
- The process for monitoring and reporting the service level

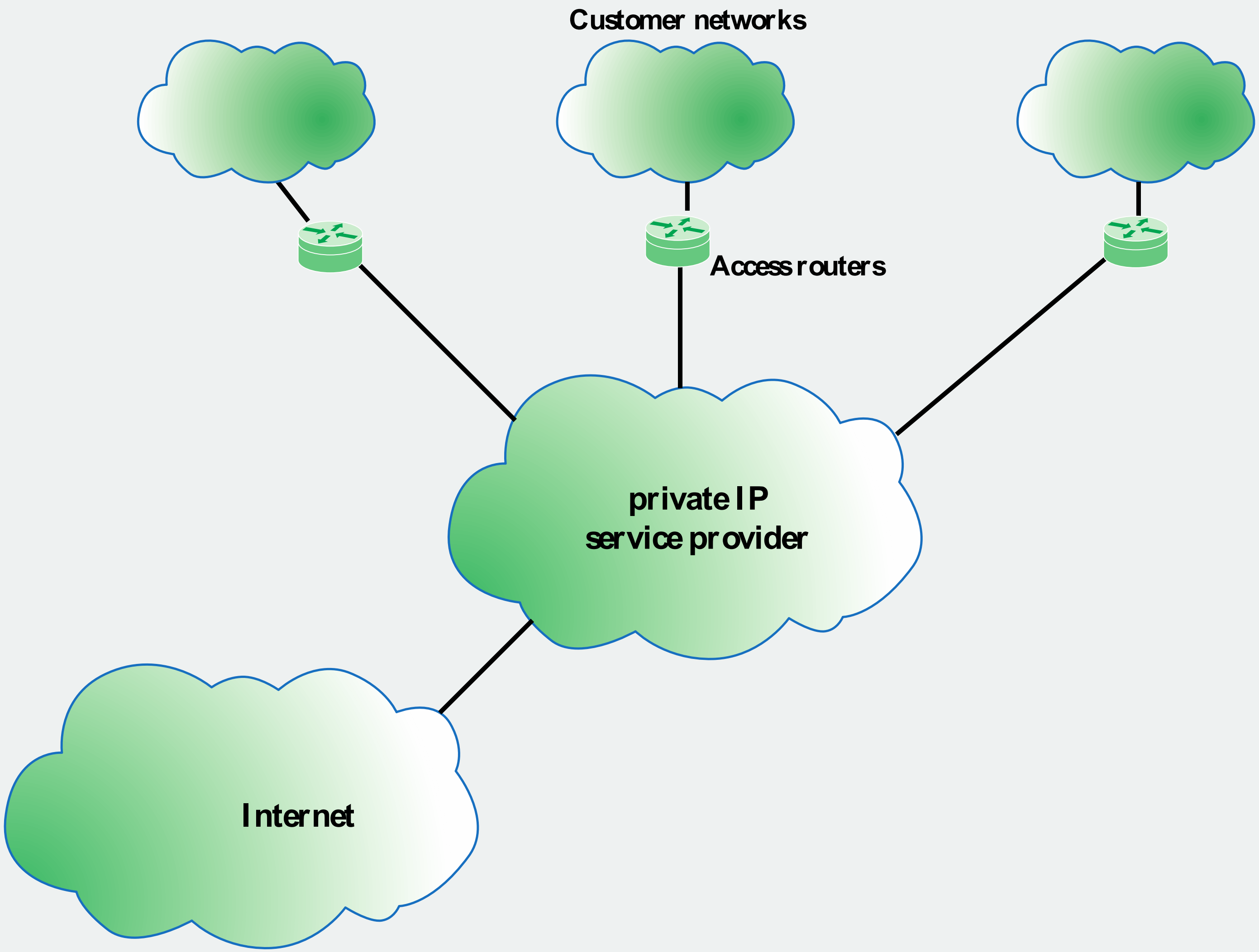


Figure 22.11 Typical Framework for Service Level Agreement

IP Performance Metrics

- Chartered by IETF to develop standard metrics that relate to the quality, performance, and reliability of Internet data delivery
- Need for standardization:
  - Internet has grown and continues to grow at a dramatic rate
  - Internet serves a large and growing number of commercial and personal users across an expanding spectrum of applications

Table 22.3
IP Performance Metrics

Metric Name	Singleton Definition	Statistical Definitions
One-Way Delay	Delay = dT, where Src transmits first bit of packet at T and Dst received last bit of packet at T + dT	Percentile, median, minimum, inverse percentile
Round-Trip Delay	Delay = dT, where Src transmits first bit of packet at T and Src received last bit of packet immediately returned by Dst at T + dT	Percentile, median, minimum, inverse percentile
One-Way Loss	Packet loss = 0 (signifying successful transmission and reception of packet); = 1 (signifying packet loss)	Average
One-Way Loss Pattern	Loss distance: Pattern showing the distance between successive packet losses in terms of the sequence of packets Loss period: Pattern showing the number of bursty losses (losses involving consecutive packets)	Number or rate of loss distances below a defined threshold, number of loss periods, pattern of period lengths, pattern of inter-loss period lengths.
Packet Delay Variation	Packet delay variation (pdv) for a pair of packets with a stream of packets = difference between the one-way-delay of the selected packets	Percentile, inverse percentile, jitter, peak-to-peak pdv

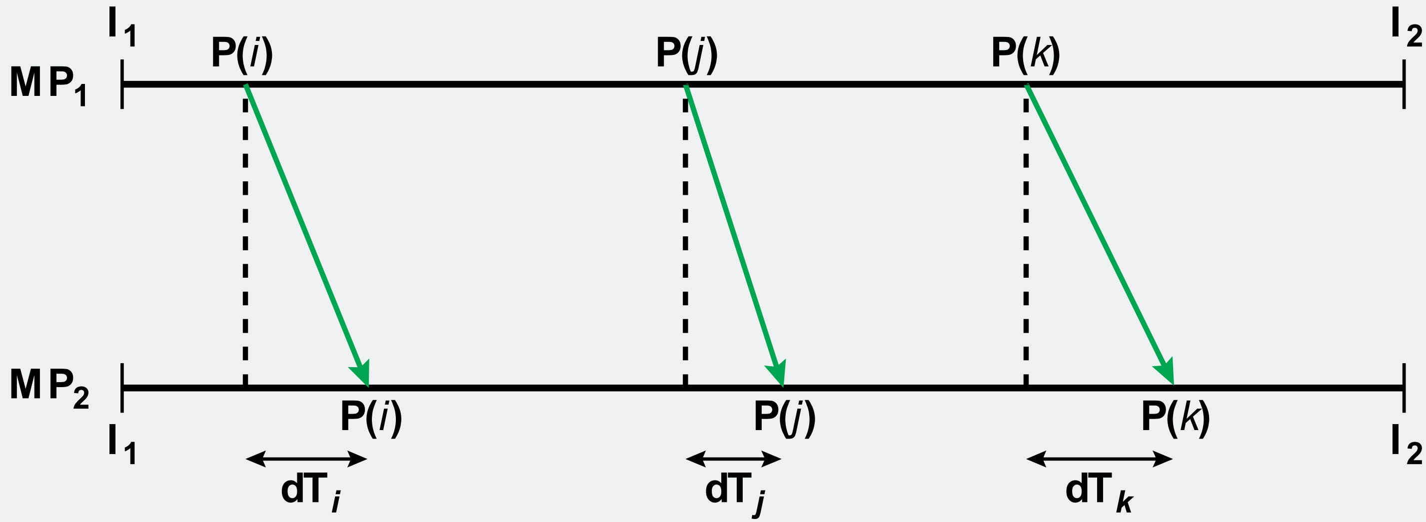
Src = IP address of a host
Dst = IP address of a host

(a) Sampled metrics

Table 22.3
IP Performance Metrics

Metric Name	General Definition	Metrics
Connectivity	Ability to deliver a packet over a transport connection.	One-way instantaneous connectivity, Two-way instantaneous connectivity, one-way interval connectivity, two-way interval connectivity, two-way temporal connectivity
Bulk Transfer Capacity	Long-term average data rate (bps) over a single congestion-aware transport connection.	BTC = (data sent)/(elapsed time)

(b) Other metrics



I_1, I_2 = times that mark that beginning and ending of the interval in which the packet stream from which the singleton measurement is taken occurs.
MP_1, MP_2 = source and destination measurement points
P(*i*) = *i*th measured packet in a stream of packets
dT_i = one-way delay for P(*i*)

Figure 22.12 Model for Defining Packet Delay Variation

Summary

- QoS architectural framework
  - Data plane
  - Control plane
  - Management plane
- Integrated services architecture
  - Internet traffic
  - ISA approach
  - ISA components
  - ISA services
  - Queuing discipline
- Service level agreements
- Resource reservation protocol
  - RSVP goals and characteristics
  - Data flows
  - RSVP operation
  - RSVP protocol mechanisms
- Differentiated services
  - Services
  - DS field
  - DS configuration and operation
  - Per-hop behavior