# Quality of Service in Multimedia Networking

- The QoS Problem in Packet Networks
- Network QoS Operations
  - Shaping
  - Queuing & Dropping
- Architectures: DiffServ & IntServ
- Traffic Engineering
  - Multi Protocol Label Switching



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# QoS – Layered Model

Perceptual Quality of Service Specification - User Layer

Application Quality of Service Specification - Application Layer

System Quality of Service Specification - Operating System Layer

Network Quality of Service Specification - Device / Networking Layer

# Problem Statement

- The standard Internet is 'Best Effort' service
  - Re-routing - Change of link properties (wireless!)
  - Heterogeneous link transitions - Congestion
- New sensitive applications
  - Interactive media streams (for medical treatment …)
  - Remote real-time controls
  - 'Synchronous' IP (I-SCSI)
- ISPs want to sell special services

★ Use bandwidth effectively ★ Avoid congestion collapse



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# Recall: VoIP/VCoIP Real-Time Requirements

- Latency ≈< 100 ms
- Inter-stream Latency ≈< 30/40 ms audio ahead/behind
- Jitter ≈< 50 ms
- Packet loss ≈< 1 %
- Interruption: 100 ms ≈ 1 spoken syllable
- Packet reordering may cause loss & jitter

# Criticial Issue: Jitter
# Main Jitter Sources

⇒ Processing & multiplexing at end systems

- Under user / end system control

⇒ Statistical multiplexing at (physical) network devices

- Mainly LAN controlled

⇒ Random queuing delays at routers

- Accumulate in (unknown) wide area transport


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# Jitter Source: End Systems

- Adjust processing complexity and load
- Introduce Jitter-hiding buffers/delays
  - Fixed Buffer
  - Adaptive Buffer:

  If $p_i$ = Time of playout for the $i$-th packet (of timestamp $t_i$)

  Then for appropriate K (e.g. 4 like in TCP)

  $p_i = t_i + d_i + K J_i$ is an appropriate over estimator

  *But: playout delays may be only adjusted between spurts*

∇ Playout delays distract interactivity



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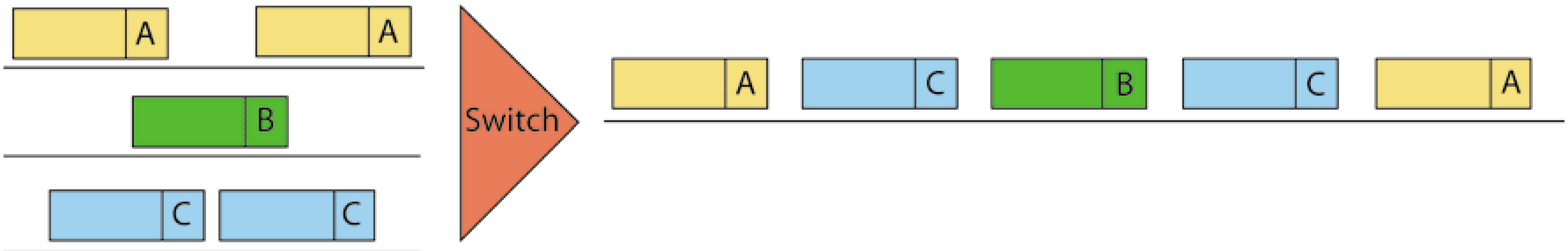
# Jitter Source:
# Network - Statistical Multiplexing




- Packet delays are added randomly
- Sensitive to instantaneous load (UDP bursts)
- Timing 'out of control', even in over provisioned networks

► L2 Approach: 802.1p packet priorisation



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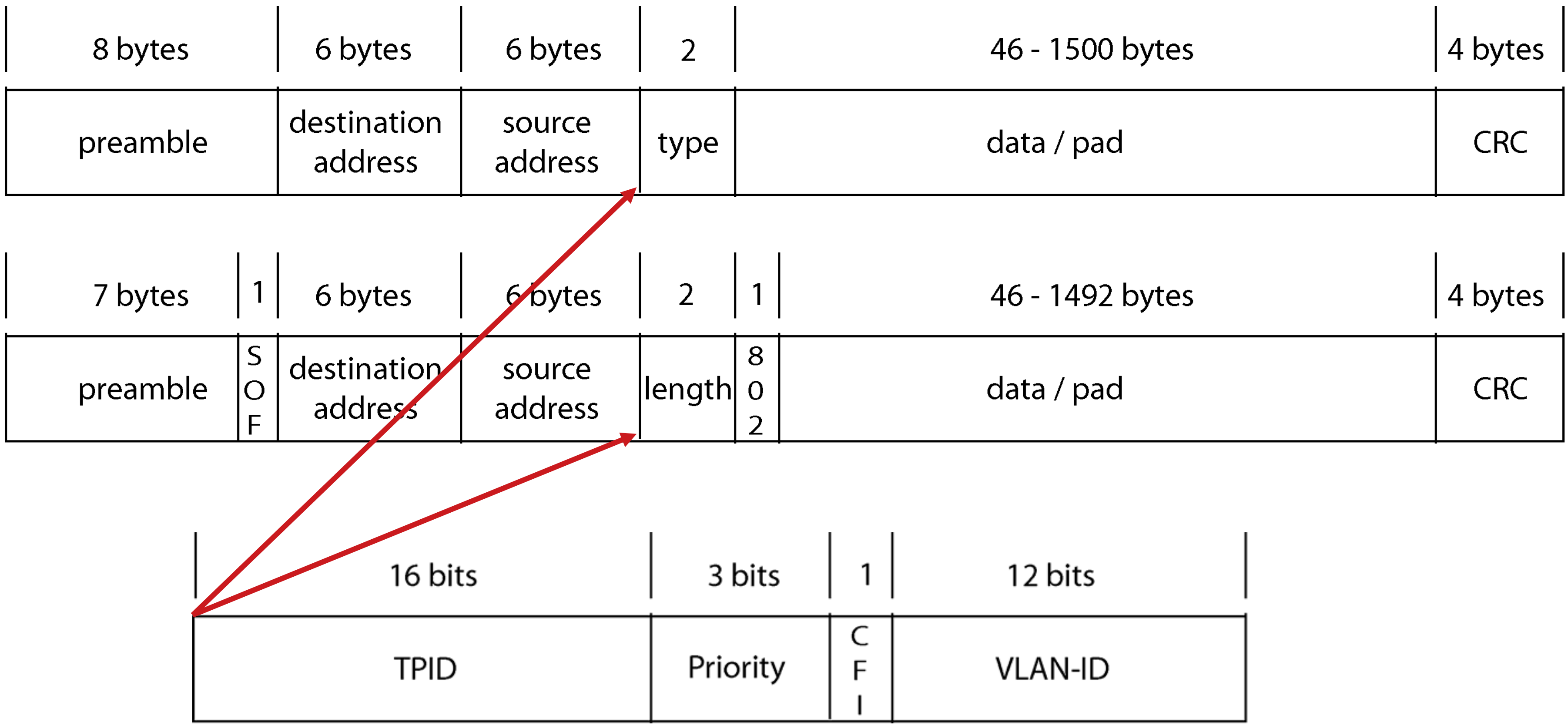
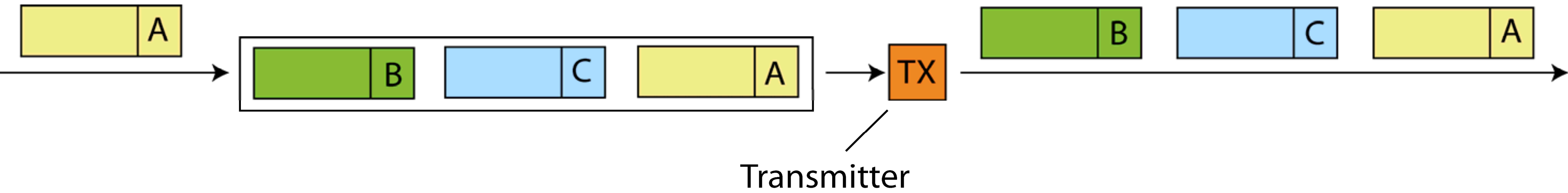
# Ethernet 802.1Q/p - Tagging




Tag Protocol Identifier=0x8100
Priority Tagging for 802.1p

Canonical Format Identifier
VLAN ID: 802.1Q Mapping

# Jitter Source: Routing - Queuing Delays




- Queuing time in FIFO depends on queue length & loss strategy
- Load adds random delays
- Insufficient buffer space results in packet discarding
- May remain bound in over provisioned networks ?

# The Nature of Internet Traffic

Internet traffic is mainly the sum of congestion controlled TCP flows with sudden bursts (UDP sources … viruses/worms)

- Bursts are uncontrolled and unlimited by the transport layer
- 'Regular' TCP traffic is self-similar, not Poissonian
  - Peaks add up on fractional time scales
  - No i.i.d. 'Ups and Downs'
  - Overflow probabilities decrease very slowly, not exponentially

⇒ There is no reliable *and* no reasonable Internetwork resource bound

# What can a Network do?

Shaping & Selecting:

- Control network entry points
- Prevent bursts / overloads entering the network

Priority Queuing:

- Forward packets at different priorities

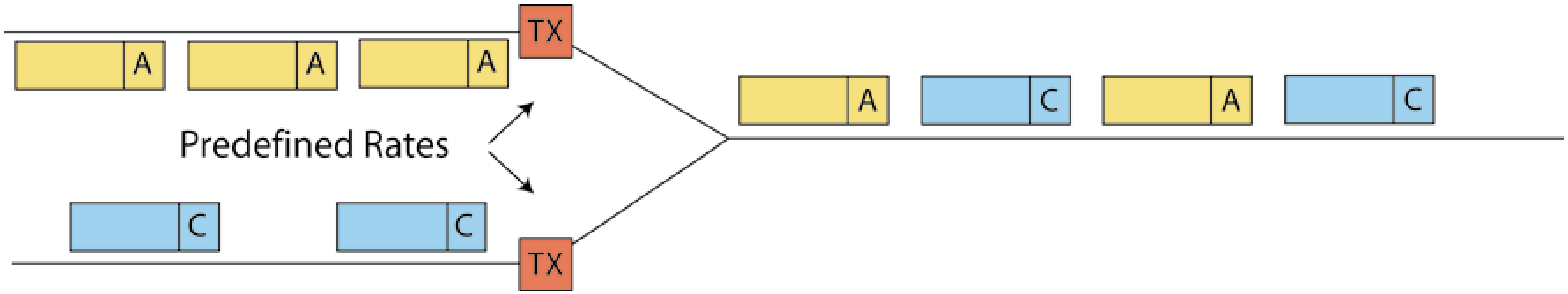
Buffering or dropping:

- Buffer queues add delay, no ‘reasonable’ length
- Rule of thumb in use: link capacity x <RTT>flows
- ‘Blind’ dropping can be harmful
- ➦ Try to use selective mechanisms

Traffic engineering:

- Balance traffic flows according to network resources

# Traffic Shaping




- Simple á priori macro control: Leaky Bucket
- Traffic shaping: controlled distribution across network (per port, per protocol or per flow)
- May limit average rates, peak rates and burst sizes
- Fairly static: needs continuous monitoring
- Problem: network resources unused?



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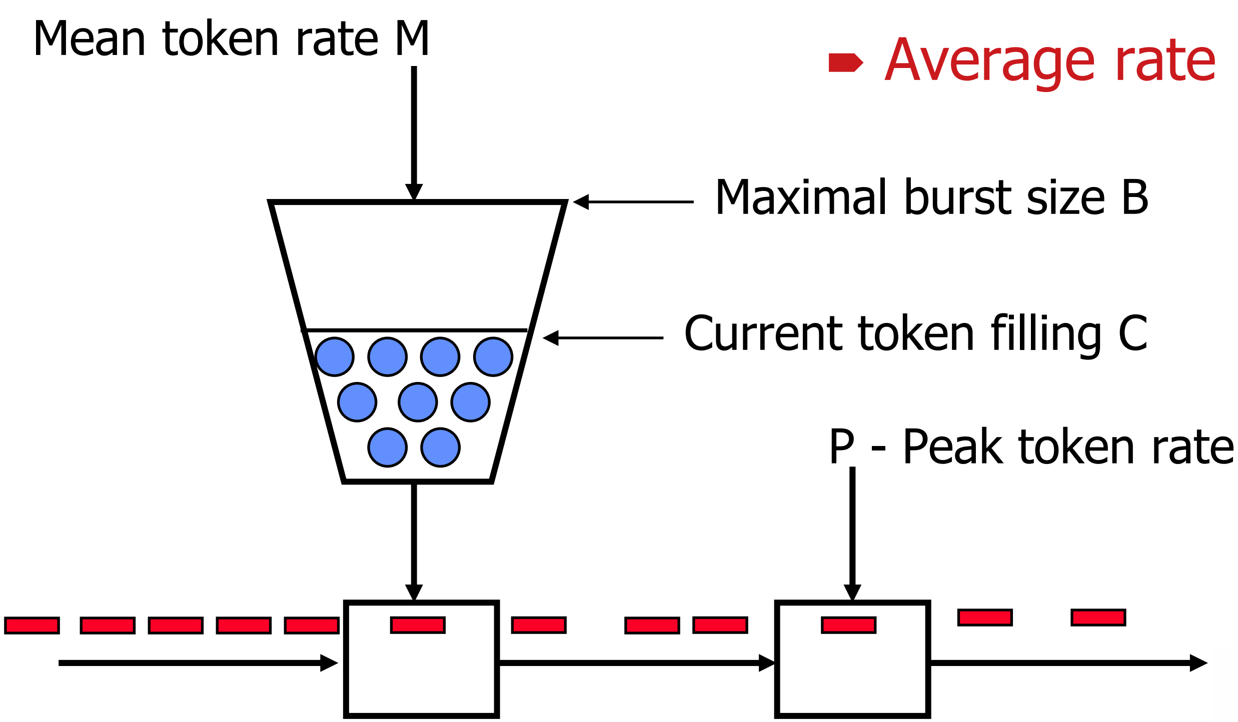
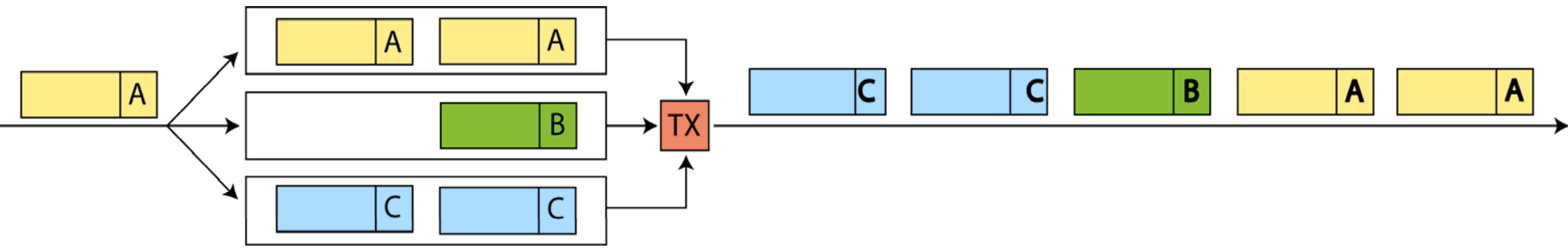
# Leaky Token Bucket (Dual)

- Shape traffic to predefined limits:
  - Maximal burst size: B
  - Peak rate P
  - Average rate M below P



# Priority Queuing




- Identified traffic assigned to different queues
- Needs scheduling:
  - Weighted Round Robin
  - Class Based Queuing
  - Weighted Fair Queuing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# Queuing

**Class Based Queuing - CBQ:**

- Transmits packets from highest nonempty queue first

**(Weighted) Round Robin - WRR:**

- Visits queue after queue in round robin fashion
- Picks 1 ($N_i$ ) packets from queue i
- Problem: does not account for packet lengths

**Weighted Fair Queuing - WFQ:**

- Visits queues in round robin fashion
- Donates a predefined data rate to each queue

# Dropping

**Old better than new (WINE):**

- On overload drop newest packet first (TCP-like)

**New better than old (MILK):**

- On overload drop oldest packet first (Real-time data)

**Random Early Detection (RED):**

- Start discarding packets prior to overload
- Observe watermarks of queue lengths
- Idea: TCP will slow down on packet loss
- Problem: UDP – some ideas of selective discards


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# Example: Balanced Network with Maximal Delay

- Suppose a traffic flow enters a network through a leaky bucket with average rate $M$ and burst limit $B$
- Suppose routers with balanced links of transmission capacity $T$ and WFQ forward this flow with rate $T\omega$
- Furthermore $M \leq T\omega$, then:

$$\frac{B}{T\omega}$$ is the maximum queue delay for any packet.



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# Traffic Classification

How to identify packets for QoS treatments?

- Per port (simple & rough)
- Per TOS/Traffic Class field
  - Labelling from application or at network entry point
- Per flow

  Identifying Quintuple in IPv4
  - Source & Destination Address
  - Transport Protocol
  - Source & Destination Port
  - Problem: Packet fragmentation, header compression, encryption

  IPv6: Flow Label

# Policy-based Routing

- Policy defines
  - Forwarding and queuing strategies
  - Call admission control rules
  - Leaky bucket parameters
  - Dropping conditions
- Policy might depend on
  - Type of traffic (classification)
  - Overall resource consumption (metering results)
  - Externals like time of day, authenticated user, …
- Automatic Policy Distribution: COPS
  - A server actively installs policies into devices


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# IntServ – Integrated Service Architecture

Ambitious Solution (RFCs 2205-2212) with

- Per-flow resource reservation & queuing at all routers
- Quality of service for sessions (end-to-end)
- Hard guarantees desired

Two service types defined:

- Guaranteed Service: guarantied bandwidth, firm bounds on end-to-end queuing delays
- Controlled Load: approximates congestion-free network

But

- High complexity - Low scalability
- Needs support of all routers - Vulnerable to flow state attacks

# IntServ

- Provide mechanisms to reserve resources (link bandwidth, buffers) at routers along the path of each flow.
- Flow context used to drive a token bucket
- Initial call setup to implement QoS states at routers:
  - Requested QoS – Rspec
  - Traffic characteristic – Tspec
- Signalling process with Resource reSerVation Protocol (RSVP)
- Initiates virtual queues at routers: one for each flow


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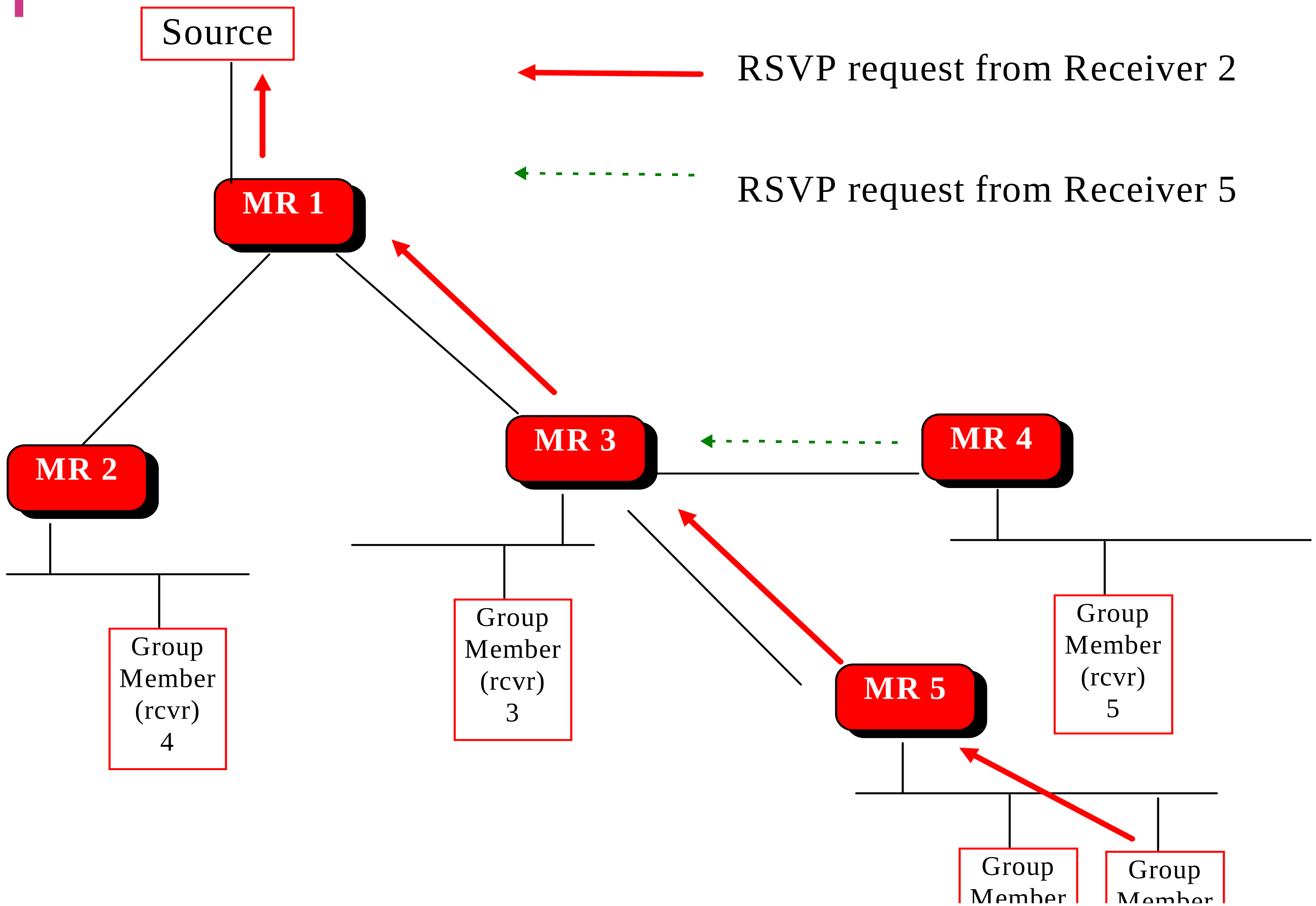
# Resource reSerVation Protocol (RSVP)

- Signalling protocol to reserve router resources along a path
- RFC 2205 (Zhang et al, 1997)
- Resource reservation for multicast distribution trees (including unicast)
- Destination oriented reservations
    - Sender pushes periodically PATH messages (establish router states)
    - Receiver answers with RESV packets
    - Routers interpret these along the paths
- Involves applications and all  intermediate devices
- Soft-State-Concept: reservation states with lifetime

# RSVP

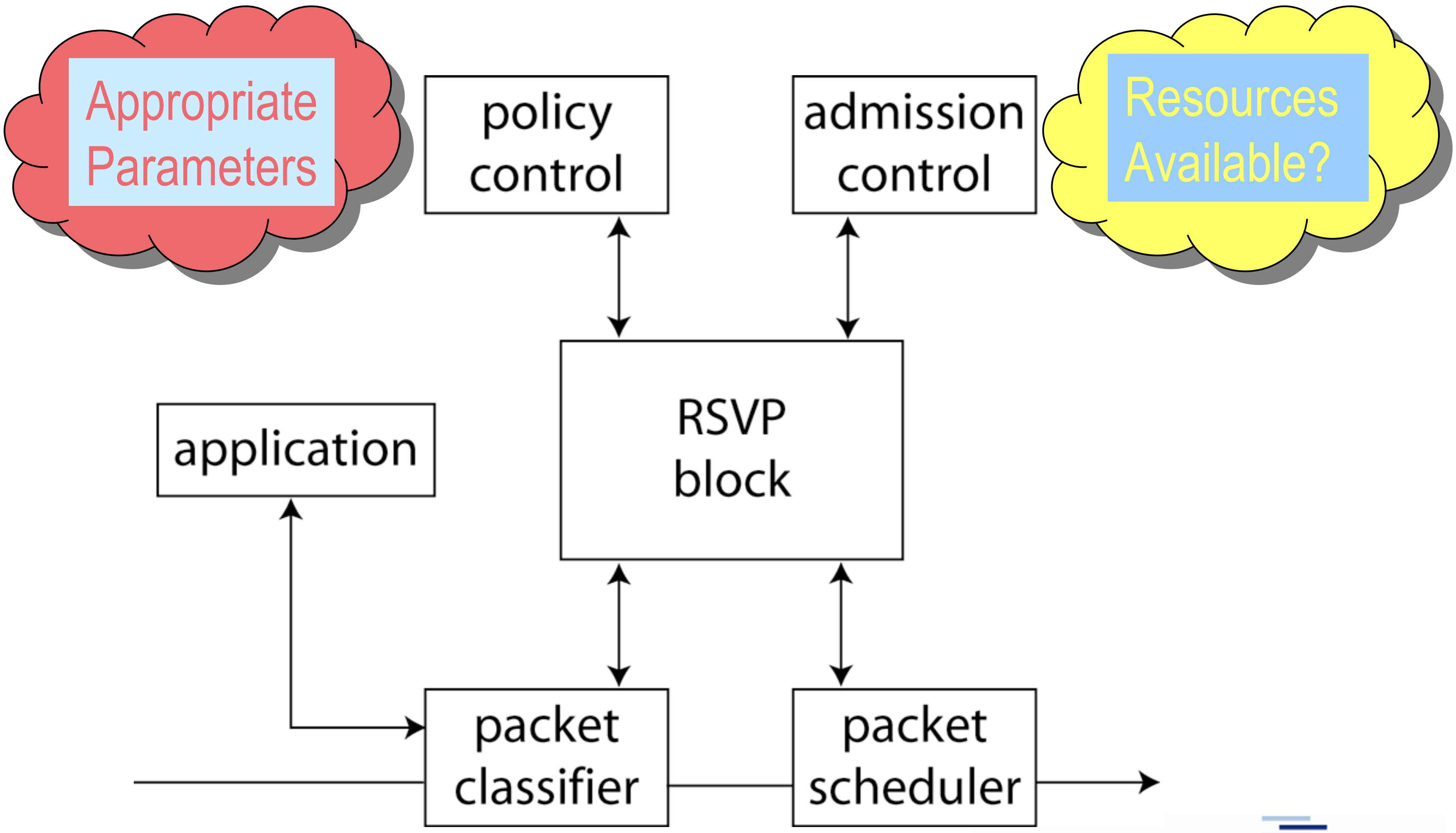



**Group Reservation**

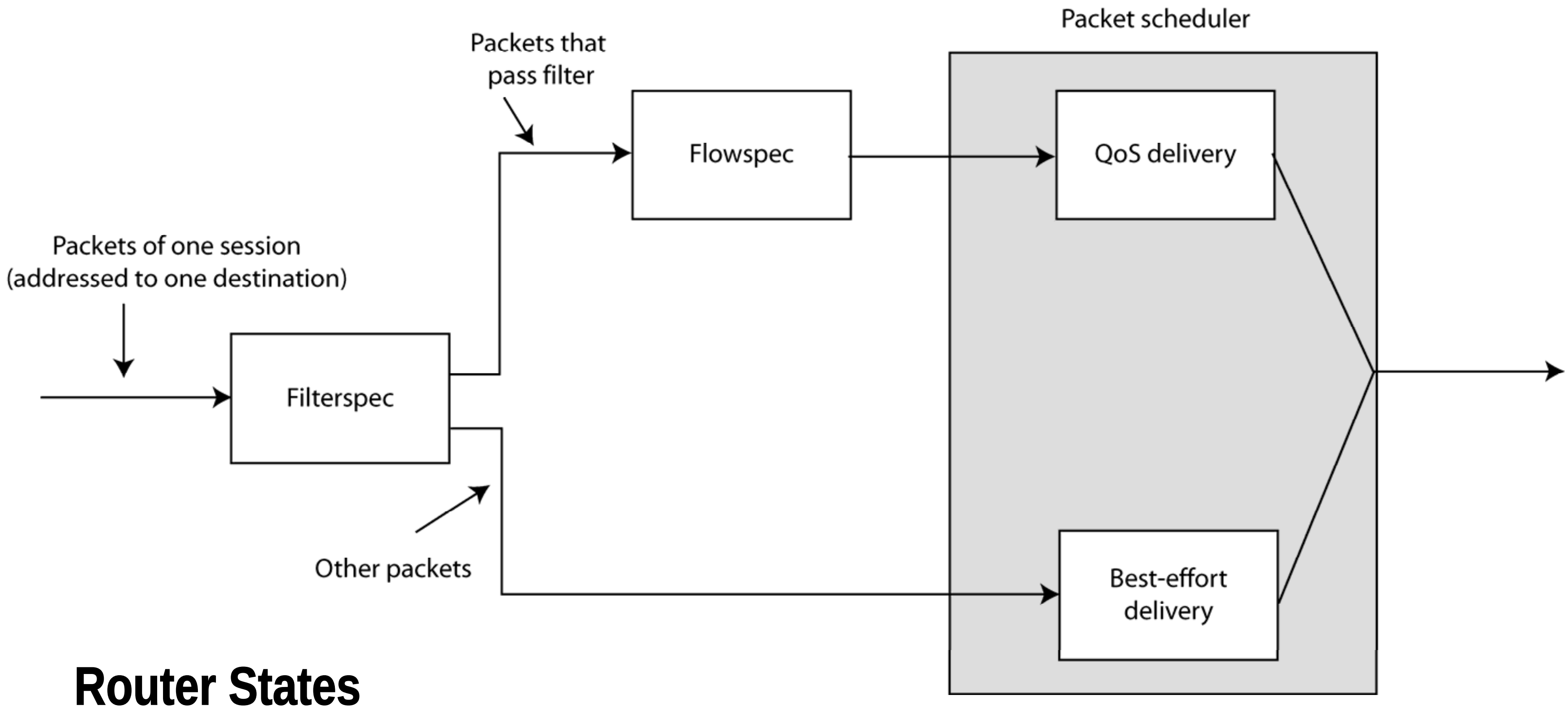
RSVP defines QoS paths from receiver (to specific source)

Resource reservations are merged when possible (on flow identification)

# RSVP Functional Blocks



# RSVP per Router Scheduling




**Router States**

Filterspec: defines packets of flows with QoS reservation

Flowspec: defines QoS parameters per flow for scheduler

# DiffServ- Differentiated Service Architecture

Less ambitious solution (RFC 2475,3260) with

- Different services for different classes of traffic
- No guaranteed quality of service (end-to-end), but
- Controlled Per-Hop Behaviour (PHB):
  Expedited / Assured Service Groups

Using

- Traffic classification (ToS/Traffic Class = DiffServ field)
- Per-class queuing (no distinctive flows)

Aiming at scalable, efficient, easy-to-deploy QoS services

# Differentiated Services: Components & Terminology

- Service Level Specification (SLS): a set of parameters/values, which together define the service offered by a DS domain
- SLS is based on Traffic Condition Specification (TCS): a set of parameters specifying  classifier rules an a traffic profile
- Classifying, metering and marking at boundary nodes, no application dependence

At Router

- Queuing and forwarding based on DiffServ Codepoints
- Traffic aggregation according to Codepoints
- No connection states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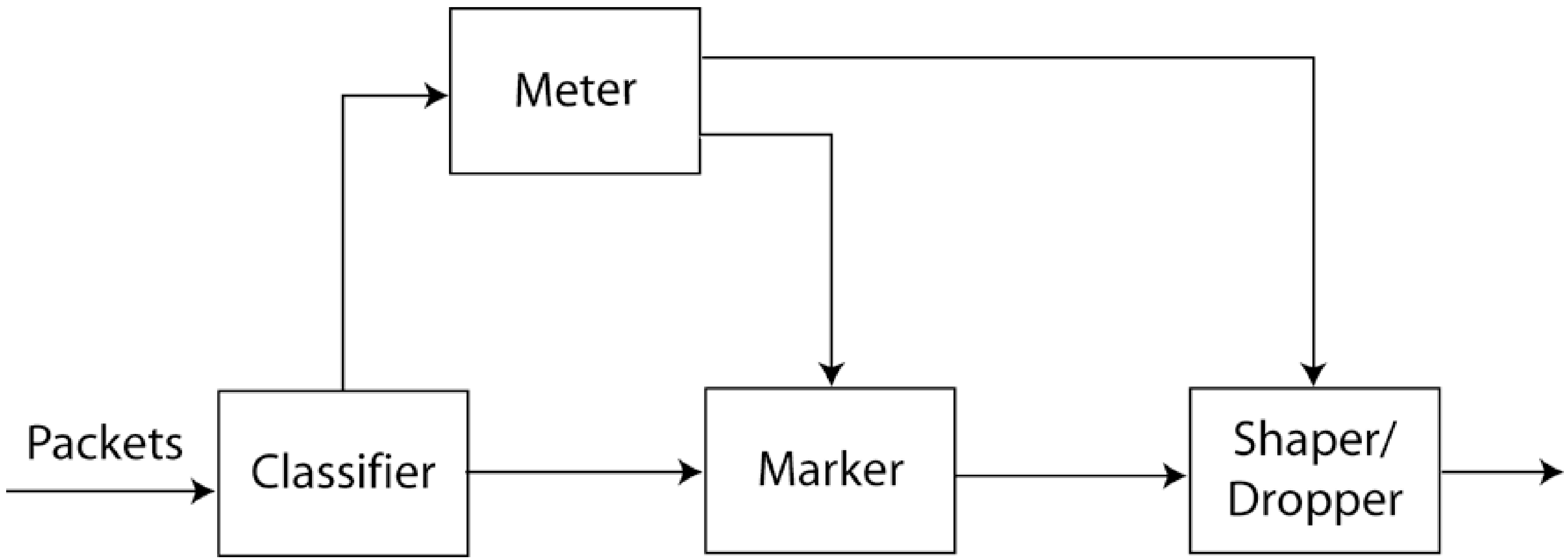
# Diffserv: Traffic Conditioner




- Classifier: Separate packets into classes
- Meter: Measure submitted traffic for conformance profile
- Marker: Polices by (re-)marking packets with codepoints
- Shaper/Dropper: Delays / discards packets

# DiffServ: Service Details

- To attain "Network Services", isolated per-hop behaviours must be coordinated to PHB groups:
- Expedited Forwarding Behaviour (EF):
    - "Virtual leased line" service
    - Simple service model for small delay/real time apps
    - Aggregated flows bound by peak bandwidth
    - Ingress router: policing/dropping – Egress router: shaping
- Assured Forwarding Behaviour (AF):
    - Complex service type with support for bursty flows
    - Defines different classes with independent resources as AF instances
    - Three drop precedences for each class ("Bronze", "Silver", "Gold")

# Resource Allocation

Resources are allocated by marking IP packets with appropriate DiffServ Codepoints at boundary nodes (also network transition points):

- Static: Mark packets by IP-address and/or protocol port
- Bandwidth Broker (RFC 2638): Unit to configure resources from network-wide policy table (at ingress+egress routers)
- Dynamic with BB: Router states are monitored by BB to optimise network resource utilisation and performance (dynamic TCSs).
- QoS signalling: Common Open Policy Service Protocol (COPS, RFC 2748)

# DiffServ Field: Codepoints

- Defined in RFC 2474 ++
- General form: xxxxxxRR (= 64 possible Codepoints)
- Standard Assignment: xxxxx0 (Default: 000000)
- IPv4 compatibility: xxx000
  Queue-Service and Congestion Control as in RFC 1812
- Assured Forwarding as in RFC 2597: Four classes, each with three drop precedences – AF1x, AF2x, AF3x, AF4x, x= 1 … 3:
- Expedited Forwarding as in RFC 3248: 101111
- Experimental: xxxxx1

| Drop Prec: | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|
| Low | 001010 | 010010 | 011010 | 100010 |
| Medium | 001100 | 010100 | 011100 | 100100 |
| High | 001110 | 010110 | 011110 | 100110 |



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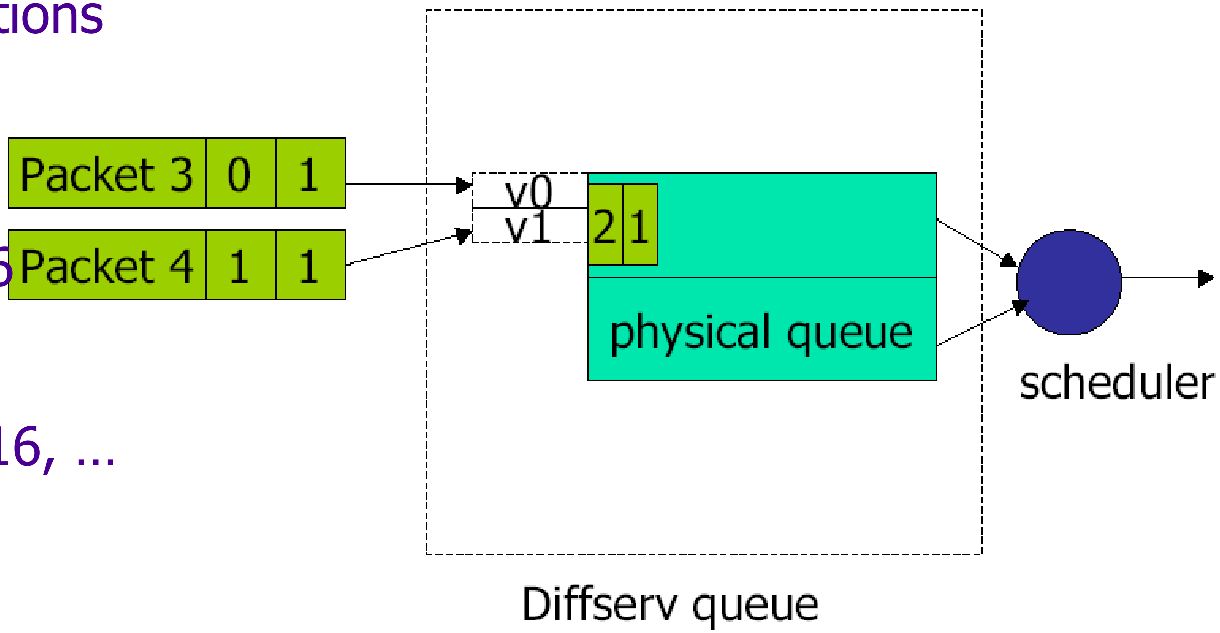
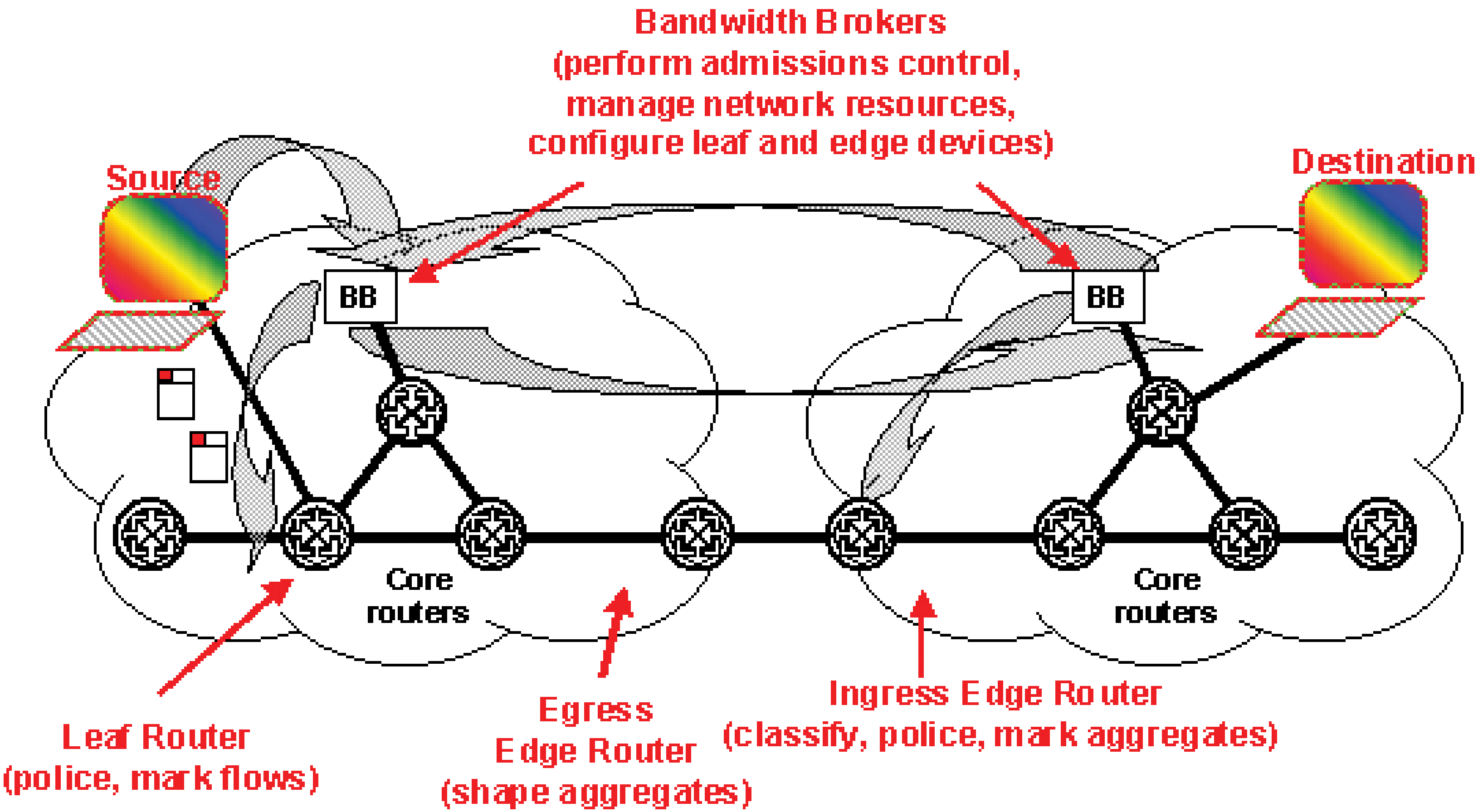
# DiffServ Virtual Queues: Mapping Problem

- DiffServ does not define implementation details (separation of forwarding & control)
- Problem: Mapping of logical to physical resources
- L3 virtual to physical queues: Vendor implementations
- LAN resources (e.g. 802.1p): IEEE & RFC 2814-16
- WLAN resources: IEEE 802.11e, 802.16, …



# Diffserv Architecture



# IntServ vers. DiffServ, Quo vadis QoS ?

IntServ: Flexible, granular, application oriented service

but: does not scale

DiffServ: Scalable, provider oriented, easy deployable service

but: application-ignorant

→ Approach: IntServ (edges) over DiffServ (core)

General Issues (RFC2990 from IAB):

- State versus statelessness in QoS?
- Inter-Domain signalling?
- Which mechanisms will form an end-to-end QoS architecture?
- Transport layer issues – what to do with TCP?
- Security and accounting open …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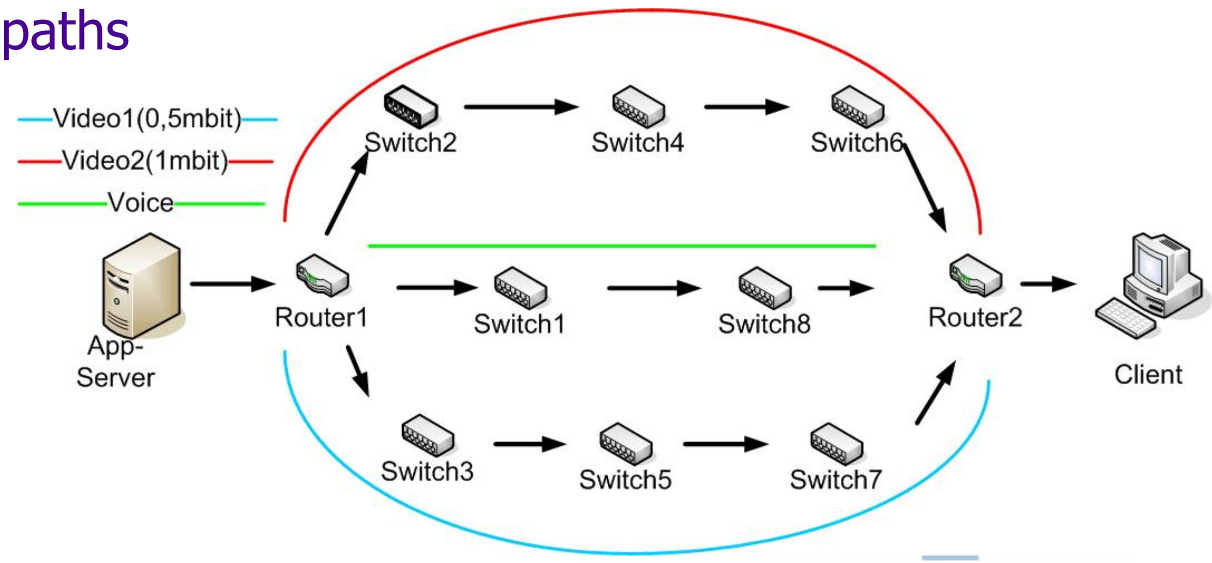
# Traffic Engineering

Problem: IP routing traditionally follows shortest paths. This may lead to overloaded links, while the physical infrastructure offers meshes

Traffic engineering is concerned with

- discovering current traffic load
- discovering alternate paths
- directing traffic



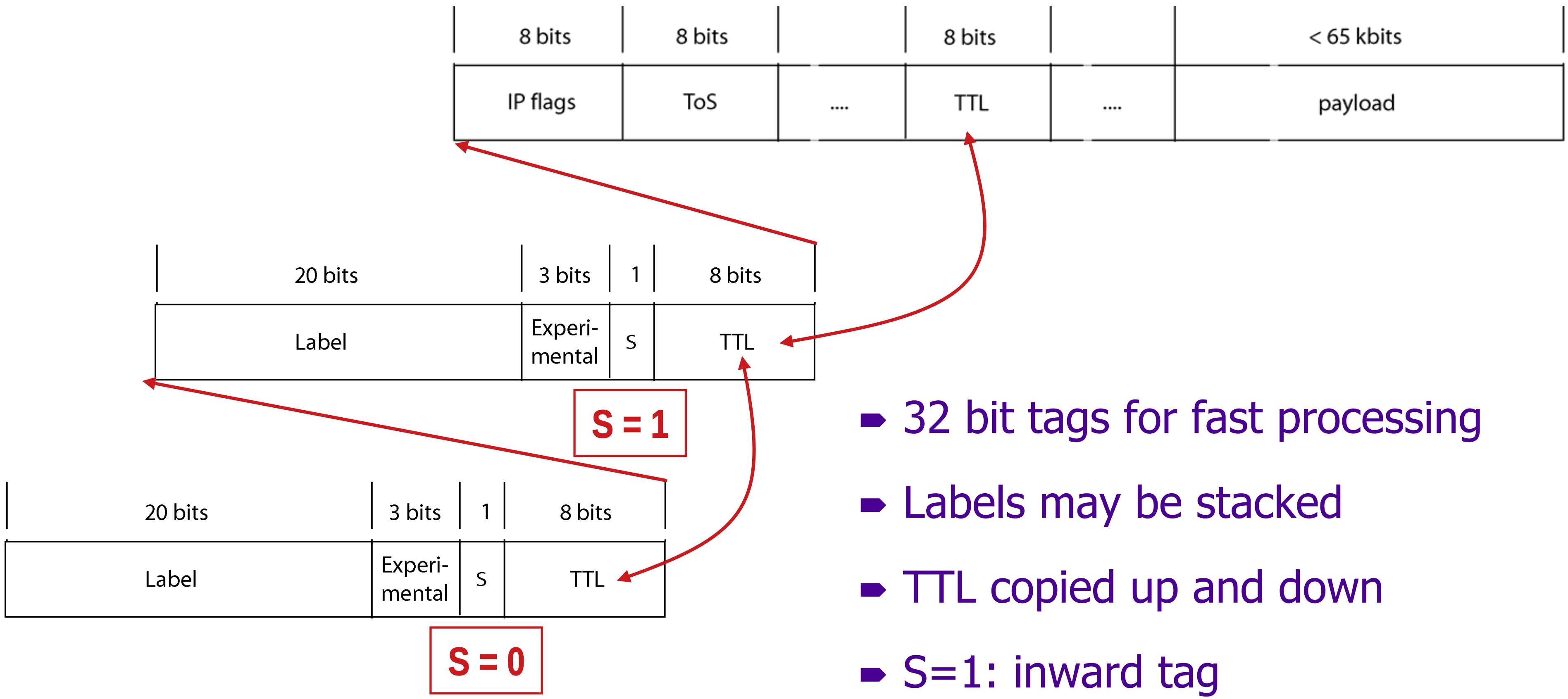
# Traffic Engineering

- Simple Approach: Equal Cost Multipath routing (ECMP)
    - Local decision at branch router
- Discovery of on-local network utilization:
  Explicit Congestion Notification – ECN
    - ECN Codepoints in Traffic Class field
- Problem: Route overlays according to L2 properties or QoS requirements?
    - Initially: Exploit ATM VCs
    - IP: Source Routing or IP in IP tunnelling
- IETF's answer: Simplified 'tunnel' tag (label)
    - Inserted below IP
    - Multi Protocol Label Switching (RFC 3031 ++)

# Multi Protocol Label Switching - MPLS

- Shim header to label packets
- Label data limited to forwarding plane
- Label switching routers (LSR) forward on label switching paths
- Instruction Table: Label Forwarding Information Base (LFIB)
- Insert / remove labels at edge routers (LER)
- Label distribution via Label Distribution Protocol (LDP)

# MPLS Tagging




- 32 bit tags for fast processing
- Labels may be stacked
- TTL copied up and down
- S=1: inward tag
- Routing: push/pop/swap



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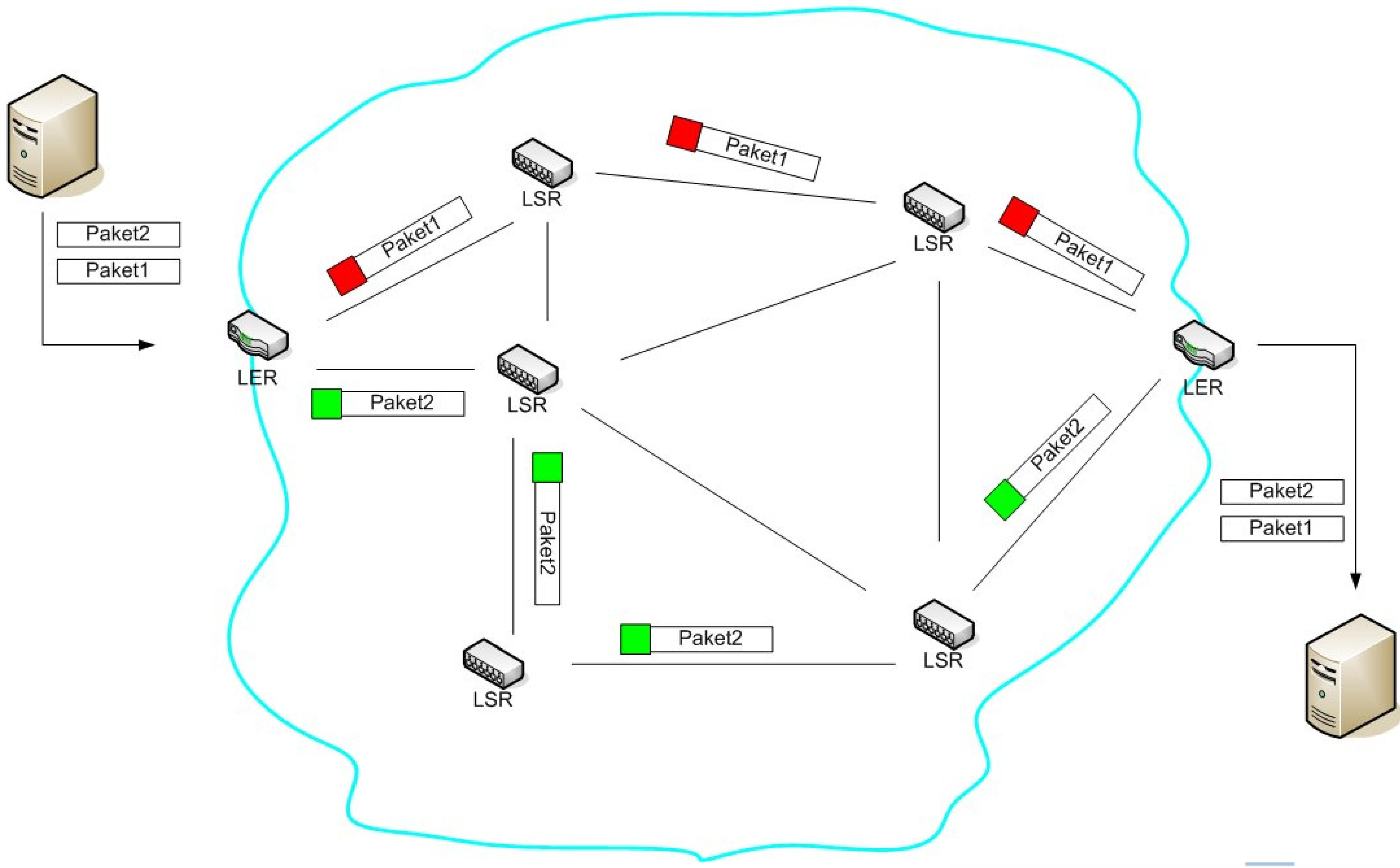
# Label Switched Paths



# Label Distribution Protocol (LDP)

- Functions of LDP
  - Discovery of adjacent LDP peers
  - Control negotiations on capabilities and options
  - Label advertisement and withdrawal
- LDP peers establish sessions after Hello multicast messages that announce a label space
- Label distribution in downstream direction
  - Unsolicited, or
  - On Demand

# Multi Protocol λ Switching - MPλS (GMPLS)

- Basis: Wavelength (λ) Division Multiplexing (WDM)
  - Optical packet switching (based on colours)
- Option to route IP over λs
  - Needs IP layer decision at branches
- Easier and more efficient:
  - MPLS overlays represented as λs ( λ = label)
- But: heavy layer violation!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# QoS via MPLS

- IntServ over MPLS
  - Set up a label switched RSVP tree
  - Extension to RSVP: RSVP-TE (RFC 3209, 3936), Label request/reserve
- DiffServ over MPLS
  - Constraint-based LS-Path setup using LDP (RFC 3212, 3468)
  - Group packets according to Codepoints
  - Differing approaches (E-LSP, L-LSP) on EF and AF service treatment


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# Deployment Practice:

- (G)MPLS is a Success Story
  - Widely deployed at provider level
  - Some deployment across providers (e.g., tagged transit)
- IP-layer Technologies Hesitant to Spread
  - Some commercial DiffServ / Expedited Forwarding offers
  - IntServ bound to 'Walled Gardens'
- Congestion Control & Resource Pooling
  - Tendency to treat congestion on Transport layer (e.g., ECN in TCP)
  - Increasing activities to support multipath Transport

# Reading

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