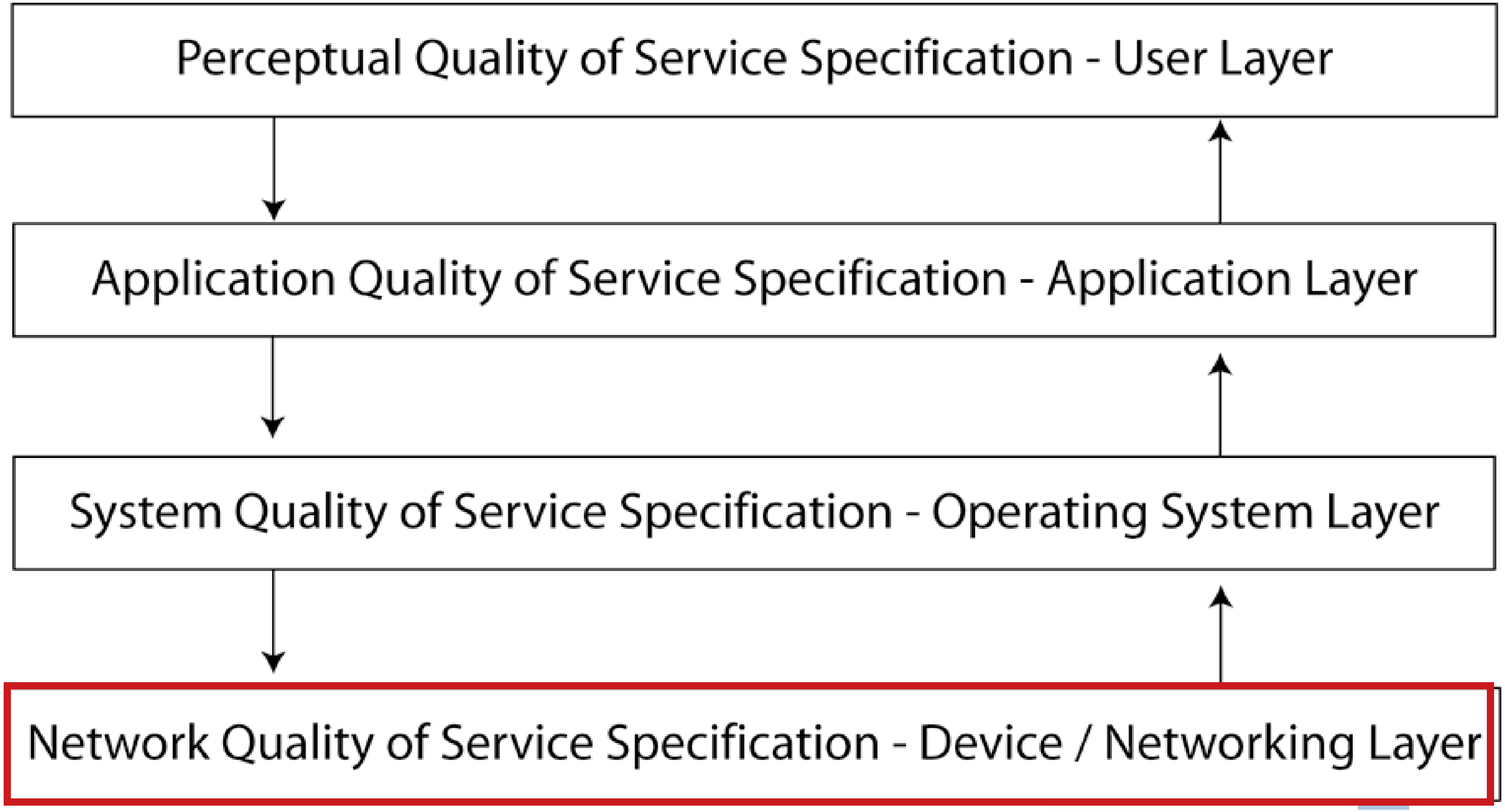
Quality of Service in Multimedia Networking

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

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

Recall: VoIP/VCoIP
Real-Time Requirements

! Latency ≈< 100 ms

! Inter-stream Latency ≈< 30/40 ms audio ahead/behind

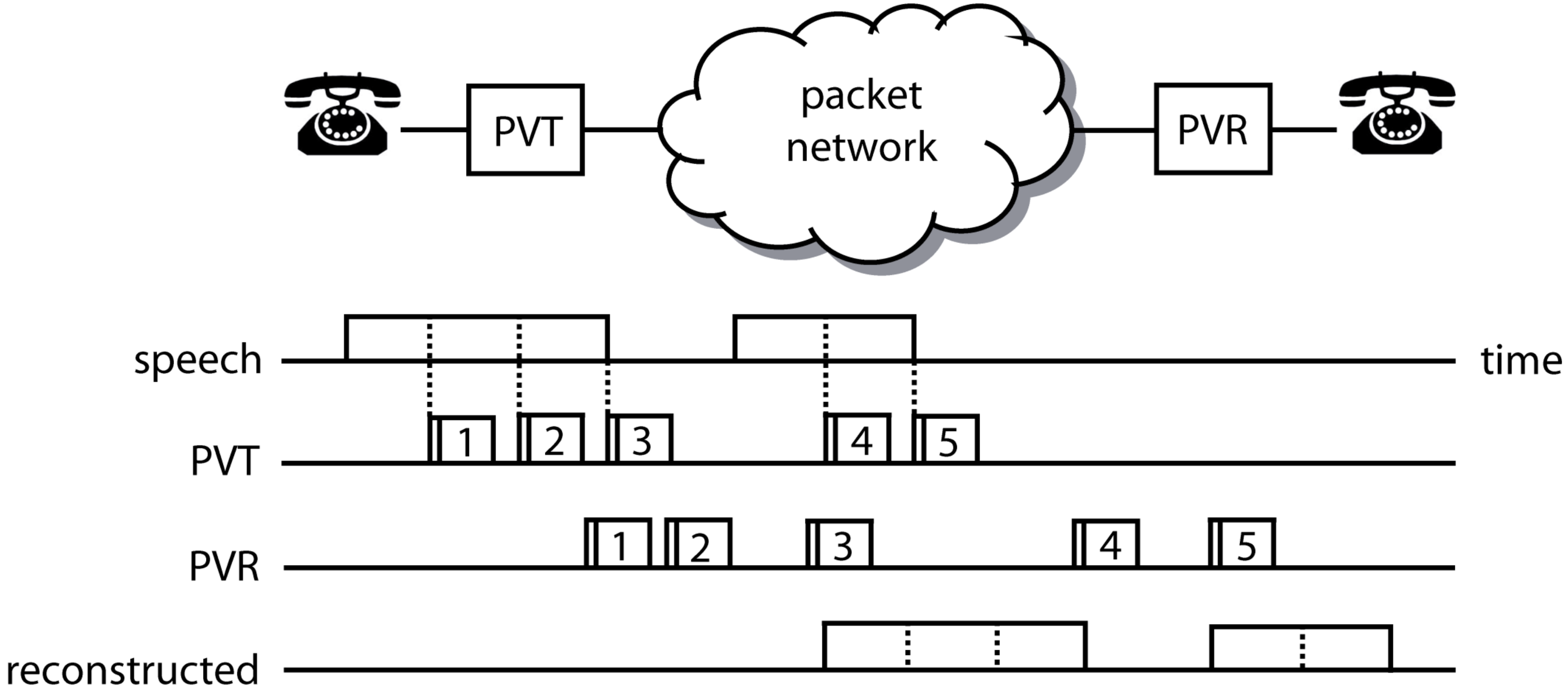
! Jitter ≈< 50 ms

! Packet loss ≈< 1 %

! Interruption: 100 ms ≈ 1 spoken syllable

! Packet reordering may cause loss & jitter

Critical Issue: Jitter in VoIP



Constant Bit-Rate cells transmitted over packet networks: From Packet Voice Transmitter (PVT) to Receiver (PVR) encounter packet wise random delays

Estimators

How to evaluate delay and jitter?

Let

t_i = Timestamp of the *i*-th packet

r_i = Time of reception for the *i*-th packet

Then for appropriate weight $0 < u < 1$

$d_i = (1 - u)\, d_{i-1} + u\,(r_i - t_i)$ (Delay Estimator)

$J_i = (1 - u)\, J_{i-1} + u\,|r_i - t_i - d_i|$ (Jitter Estimator) or

$J'_i = (1 - u)\, J'_{i-1} + u\,|(r_i - t_i) - (r_{i-1} - t_{i-1})|$ (Interarrival Jitter Estimator)

are smoothed temporal averages (exponential moving averages)

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

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)

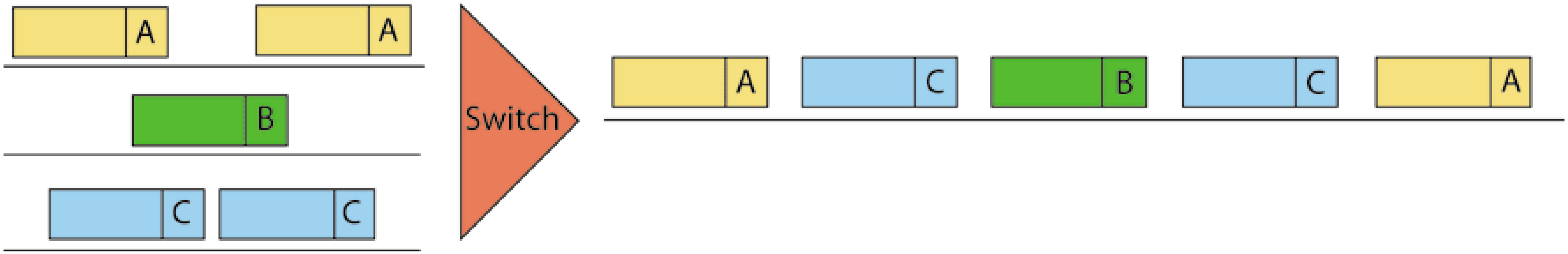
  Then for appropriate K (e.g. 4 like in TCP)

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

  But: playout delays may be only adjusted between spurts

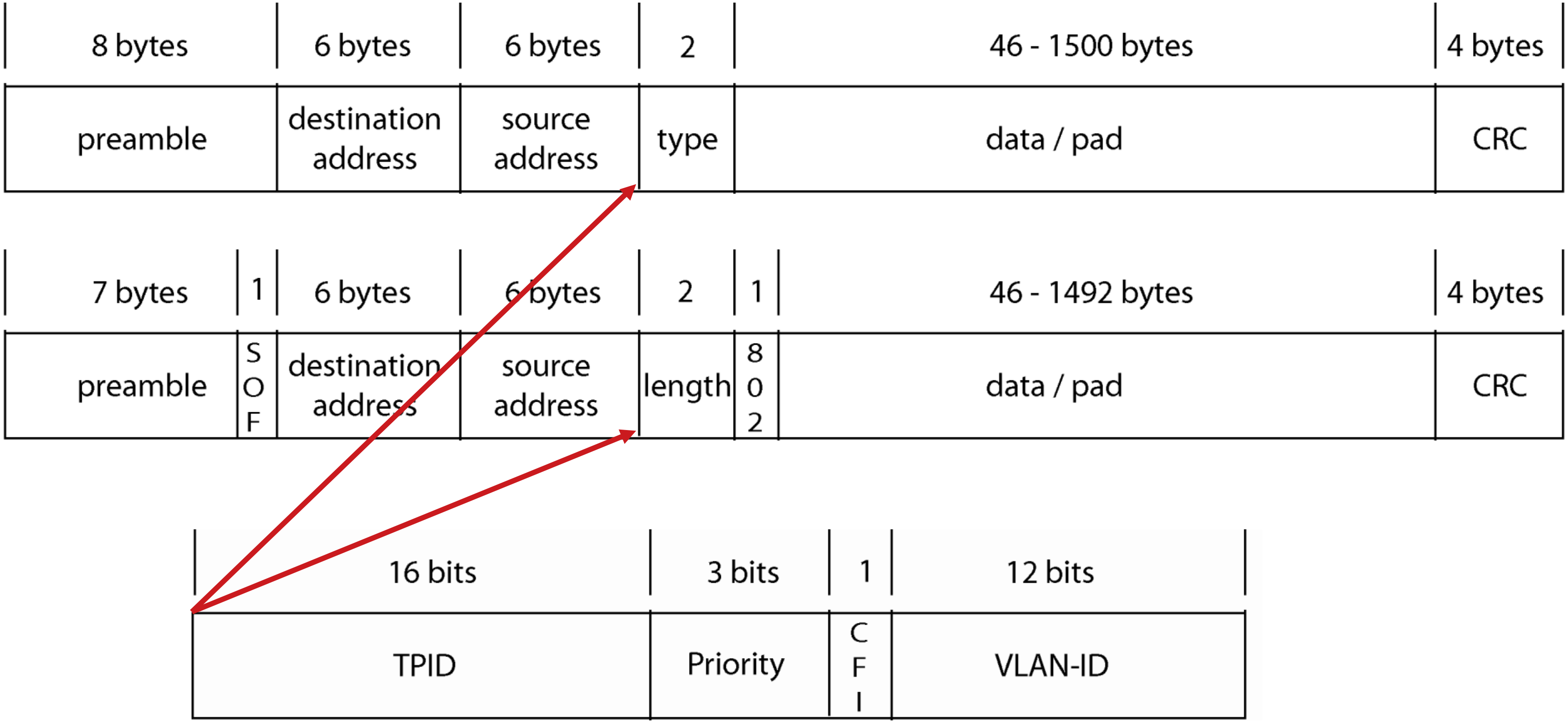
▽ Playout delays distract interactivity

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 Approaches: - 802.1p packet priorisation,
  - 802.1AVB

Ethernet 802.1Q/p - Tagging



8 bytes	6 bytes	6 bytes	2	46 - 1500 bytes	4 bytes
preamble	destination address	source address	type	data / pad	CRC

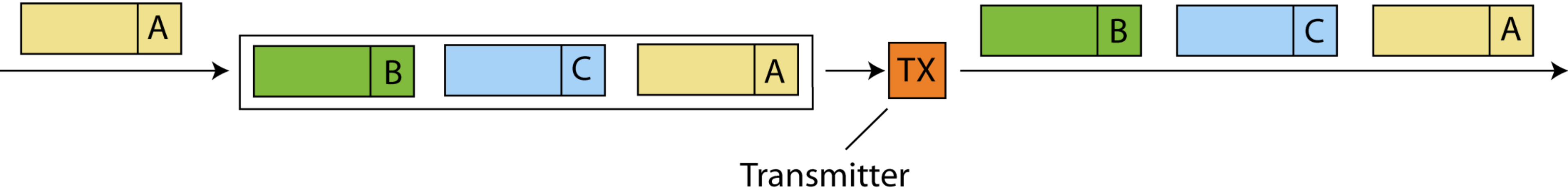
7 bytes	1	6 bytes	6 bytes	2	1	46 - 1492 bytes	4 bytes
preamble	SOF	destination address	source address	length	802	data / pad	CRC

16 bits	3 bits	1	12 bits
TPID	Priority	CFI	VLAN-ID

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

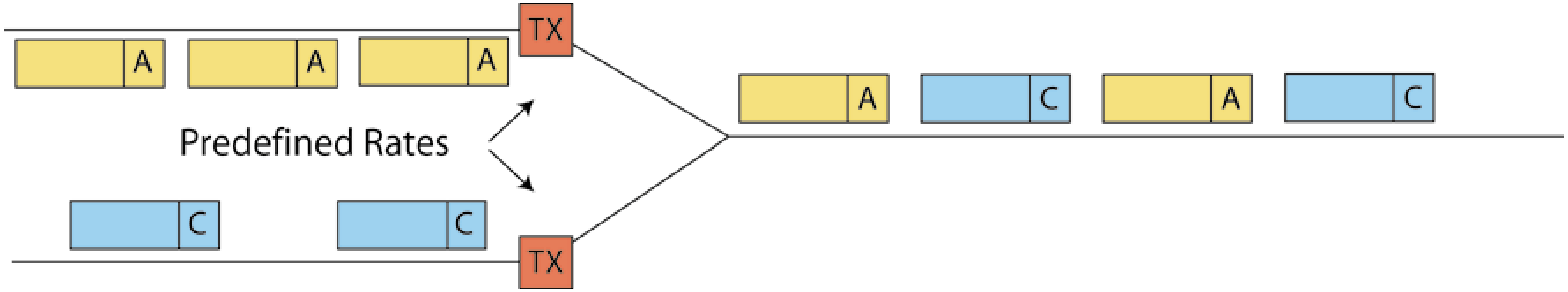
Buffering or dropping:

- 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

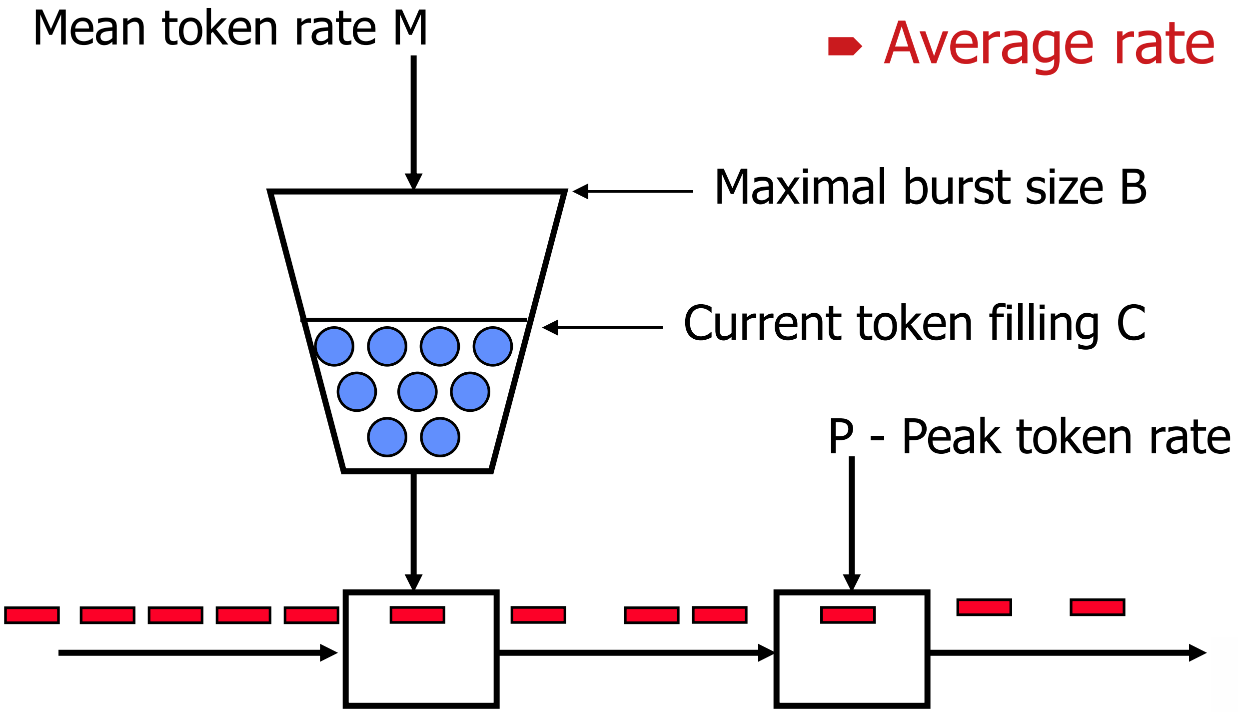
Traffic Shaping



- 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?

Leaky Token Bucket (Dual)

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

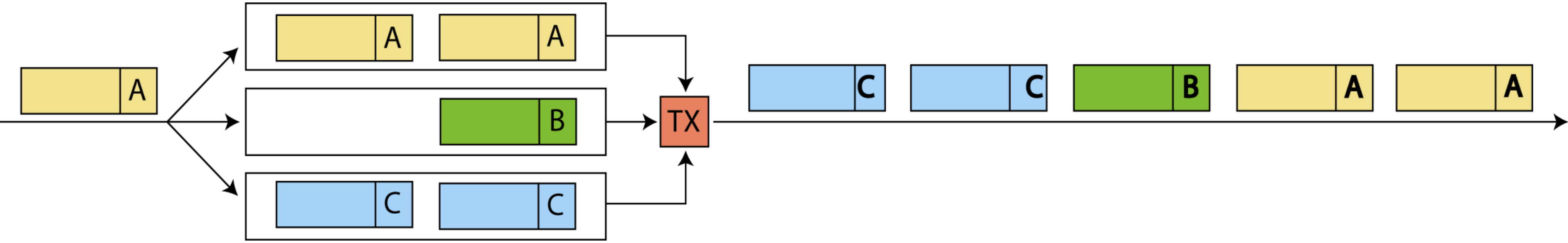

Mean token rate M

Maximal burst size B

Current token filling C

P - Peak token rate

Priority Queuing



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

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

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 $M \le T\omega$, then:

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

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 (RFC 2748 + 4261)
  - A server actively installs policies into devices

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

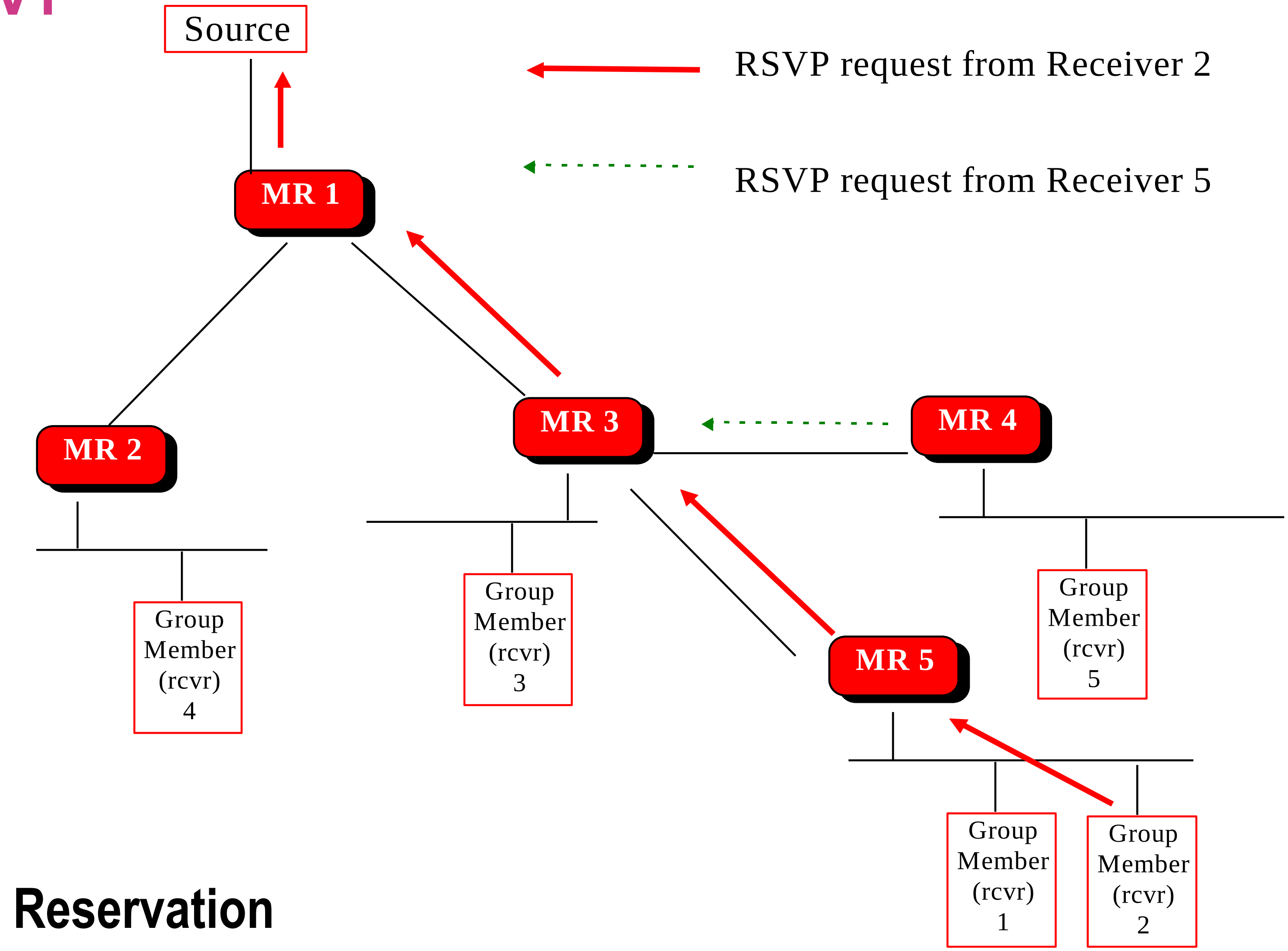
IntServ

- 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

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

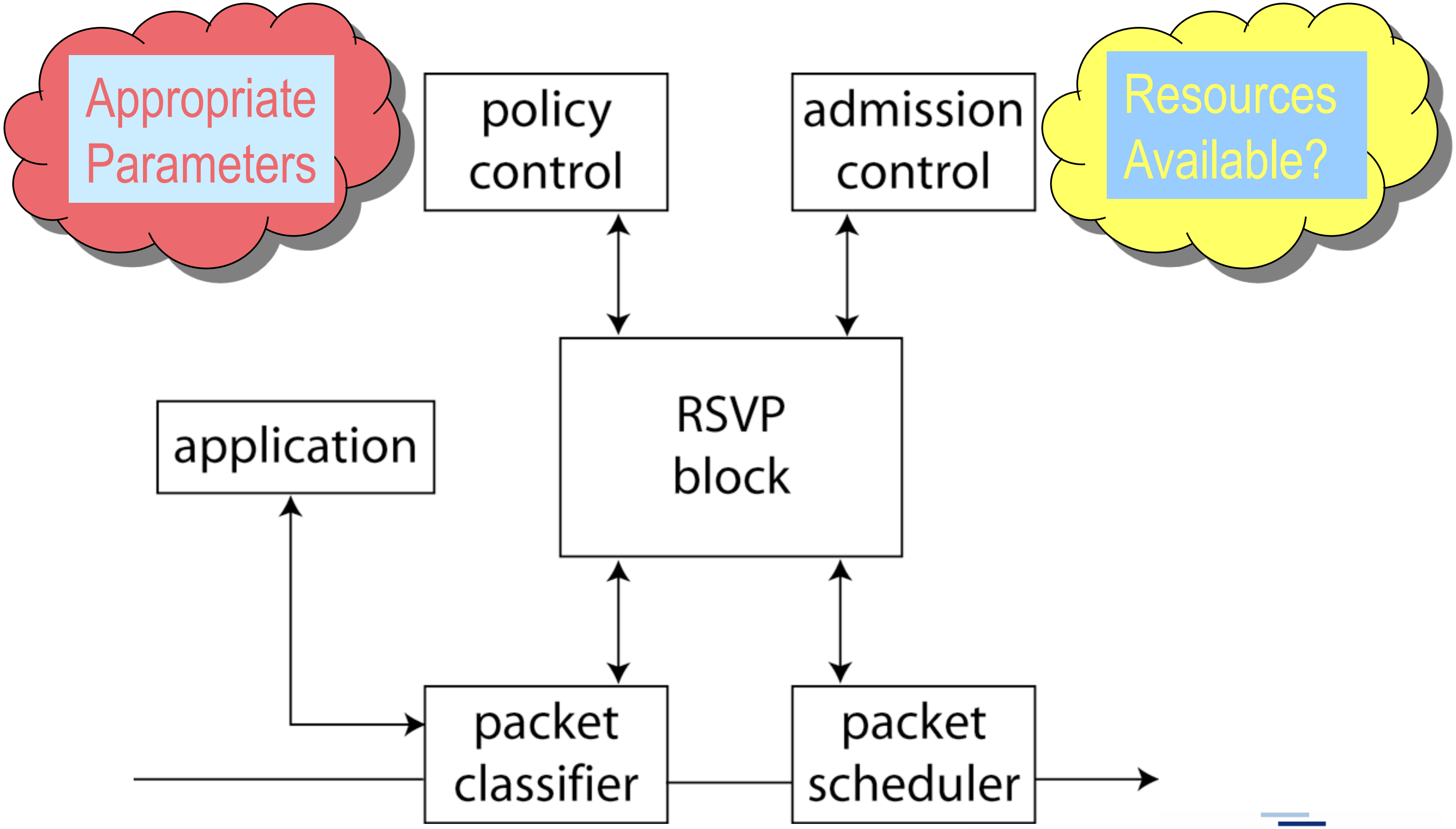


Group Reservation

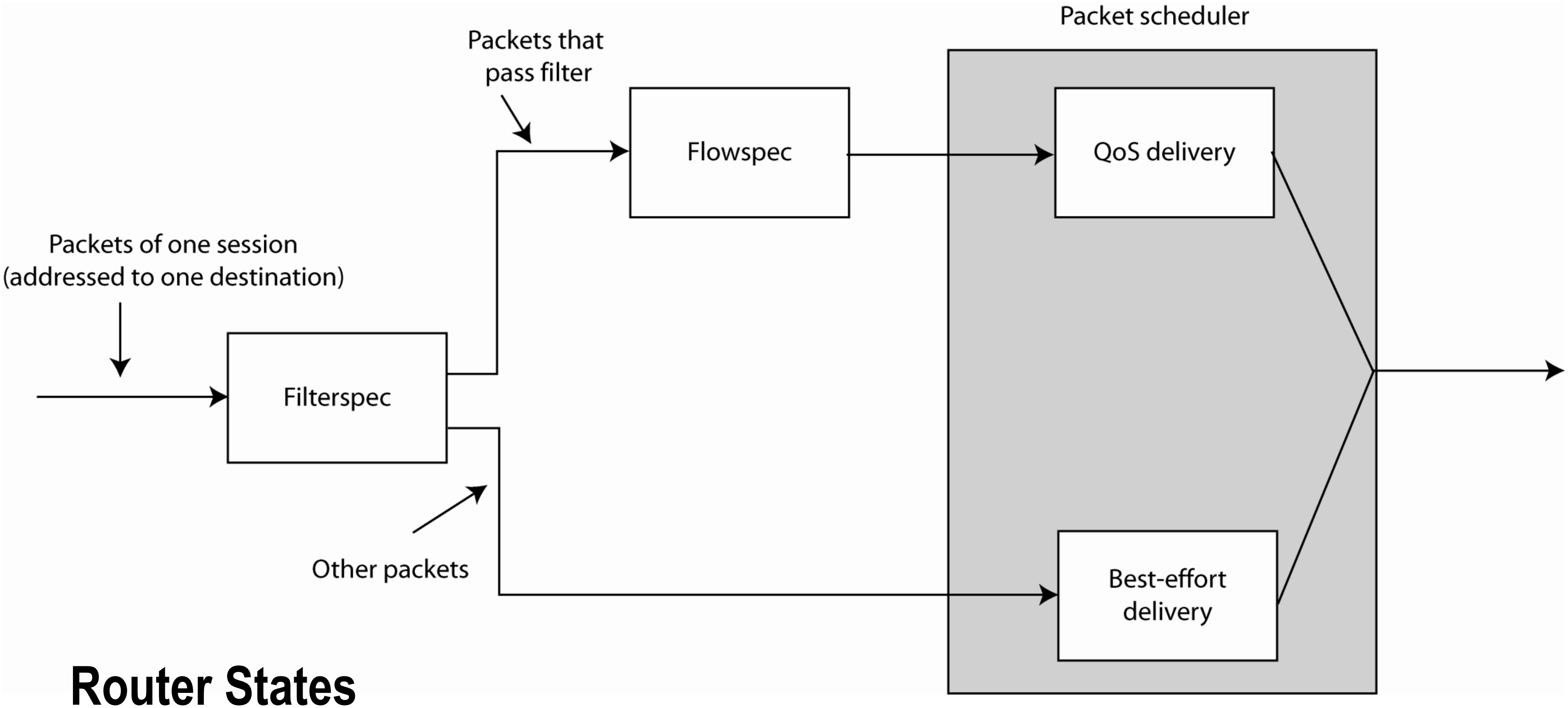
RSVP defines QoS paths from receiver (to specific source)

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

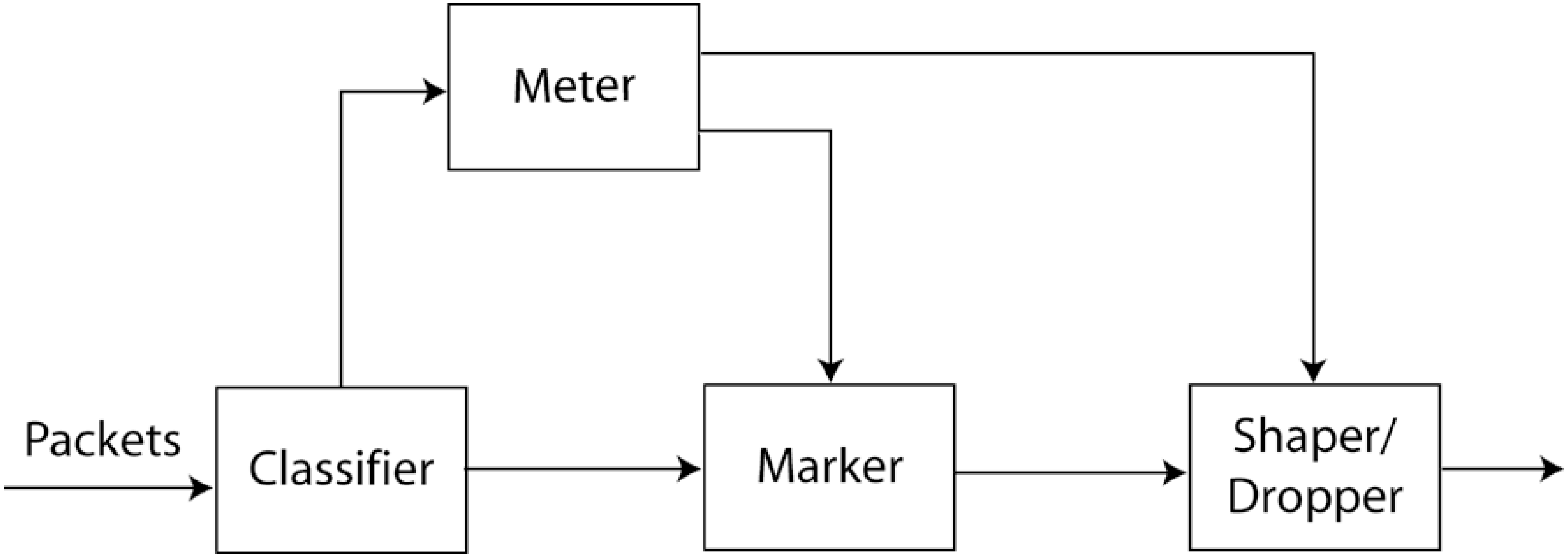
Differentiated Services: Components & Terminology

- 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

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)

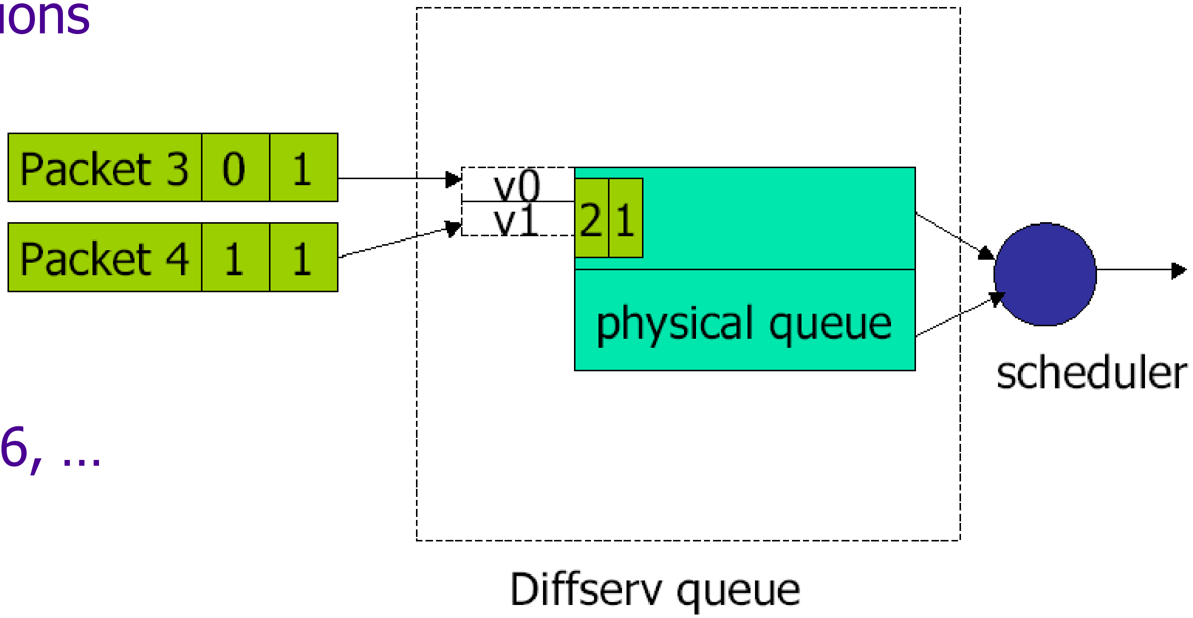
DiffServ Field: Codepoints

- 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

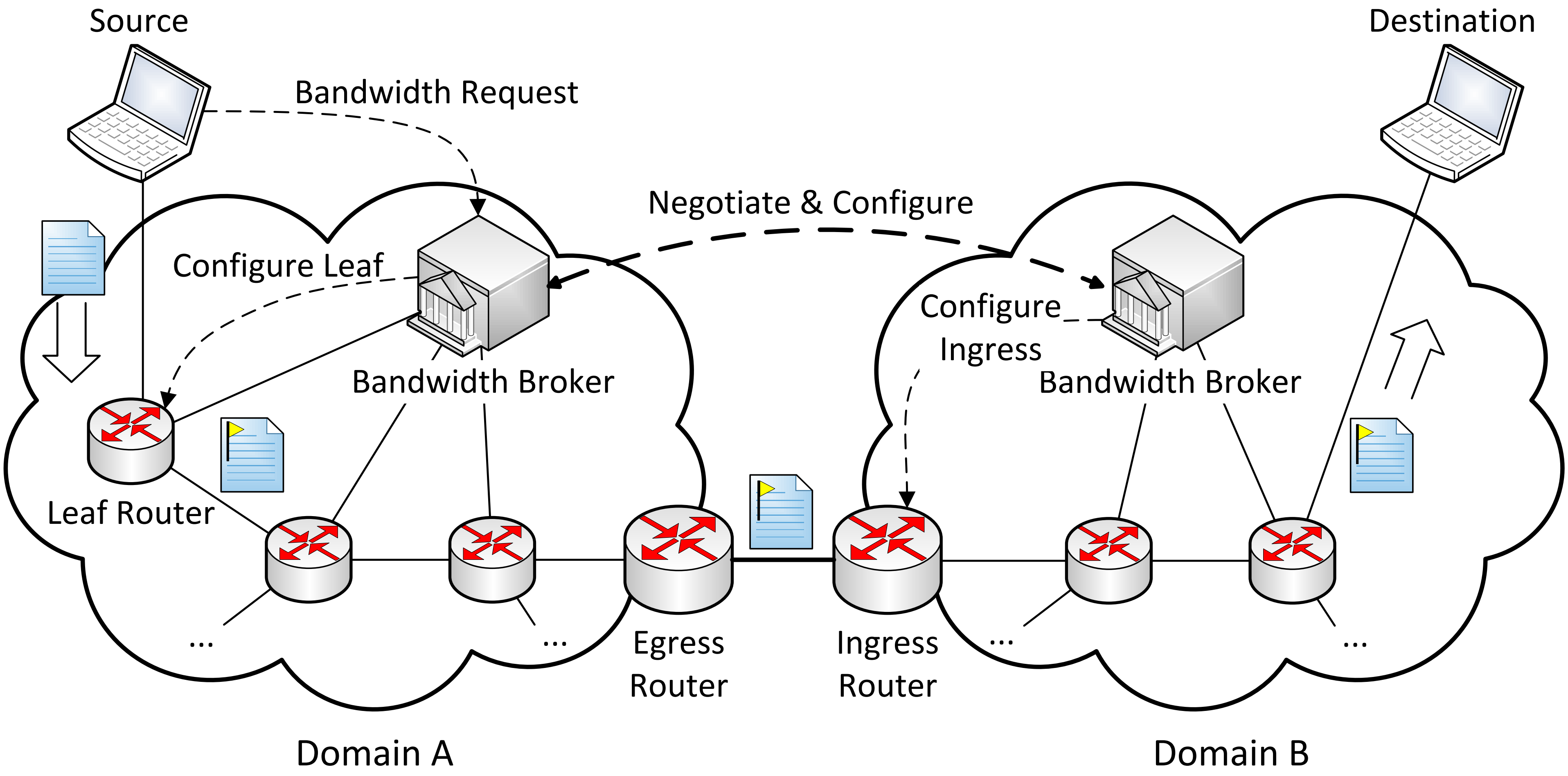
Drop Prec:	Class 1	Class 2	Class 3	Class 4
Low	001010	010010	011010	100010
Medium	001100	010100	011100	100100
High	001110	010110	011110	100110

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):

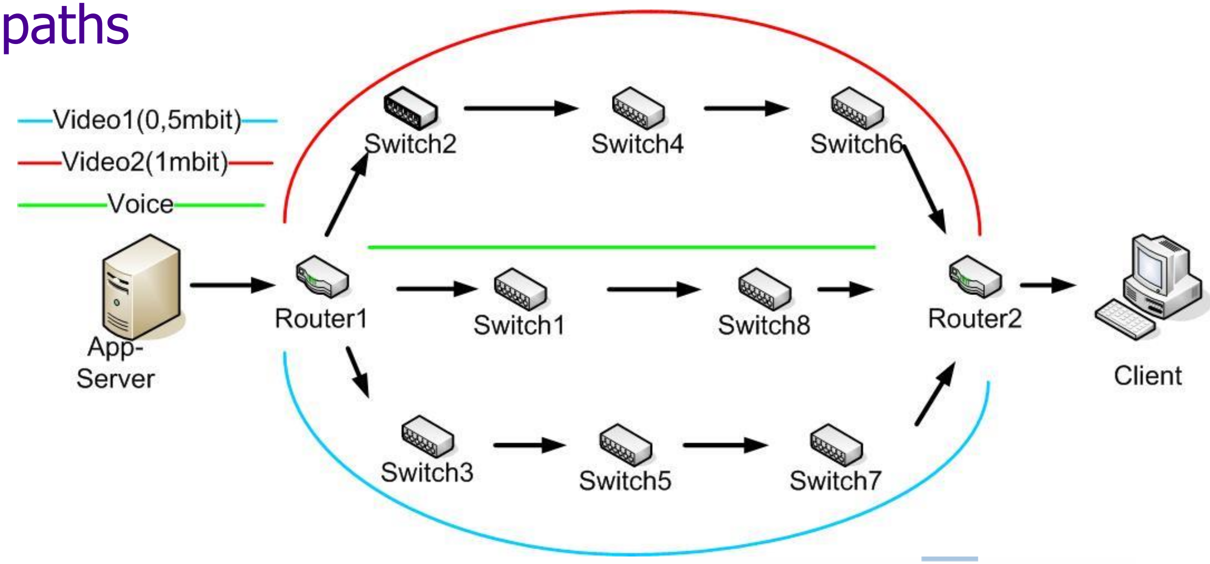
- State versus statelessness in QoS?
- Inter-Domain signalling?
- Which mechanisms will form an end-to-end QoS architecture?
- Transport layer issues – what to do with TCP?
- Security and accounting open …

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



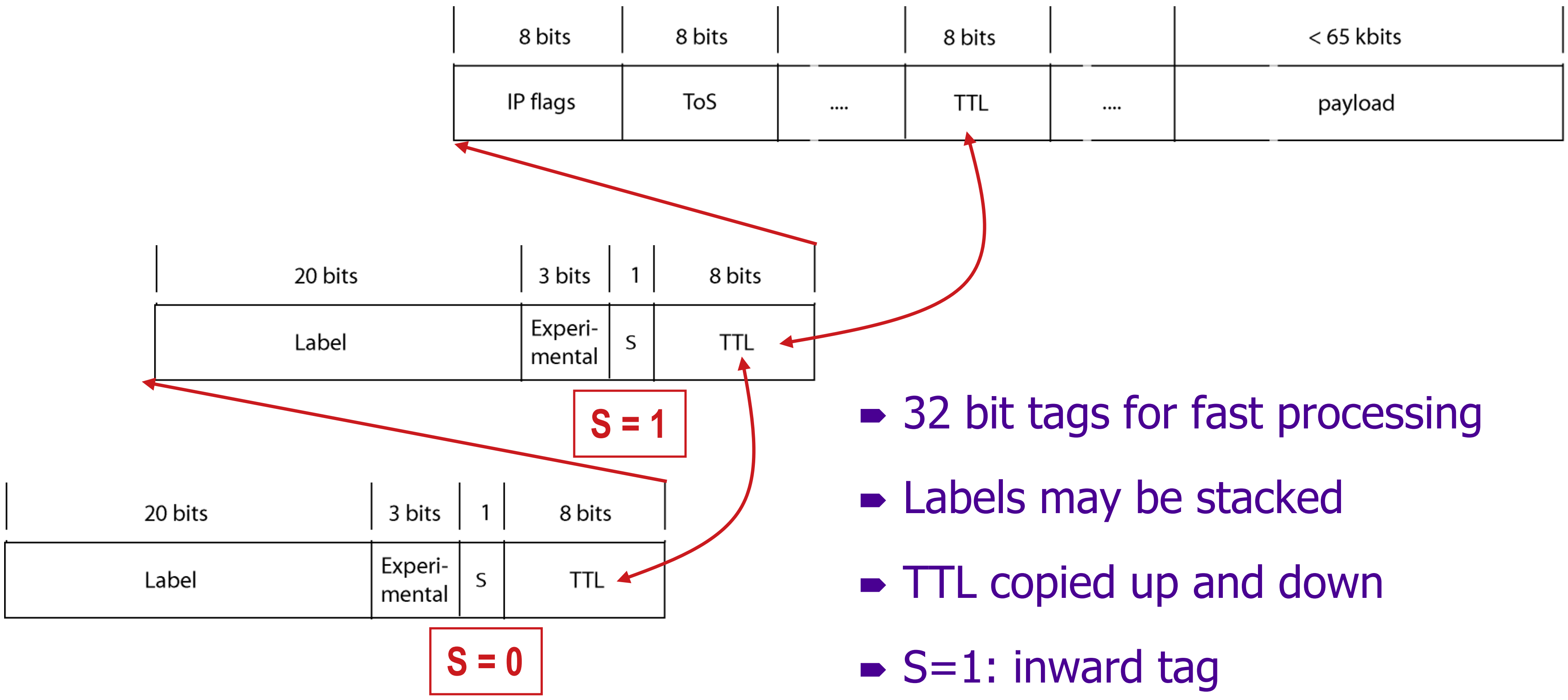
Traffic Engineering

- 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

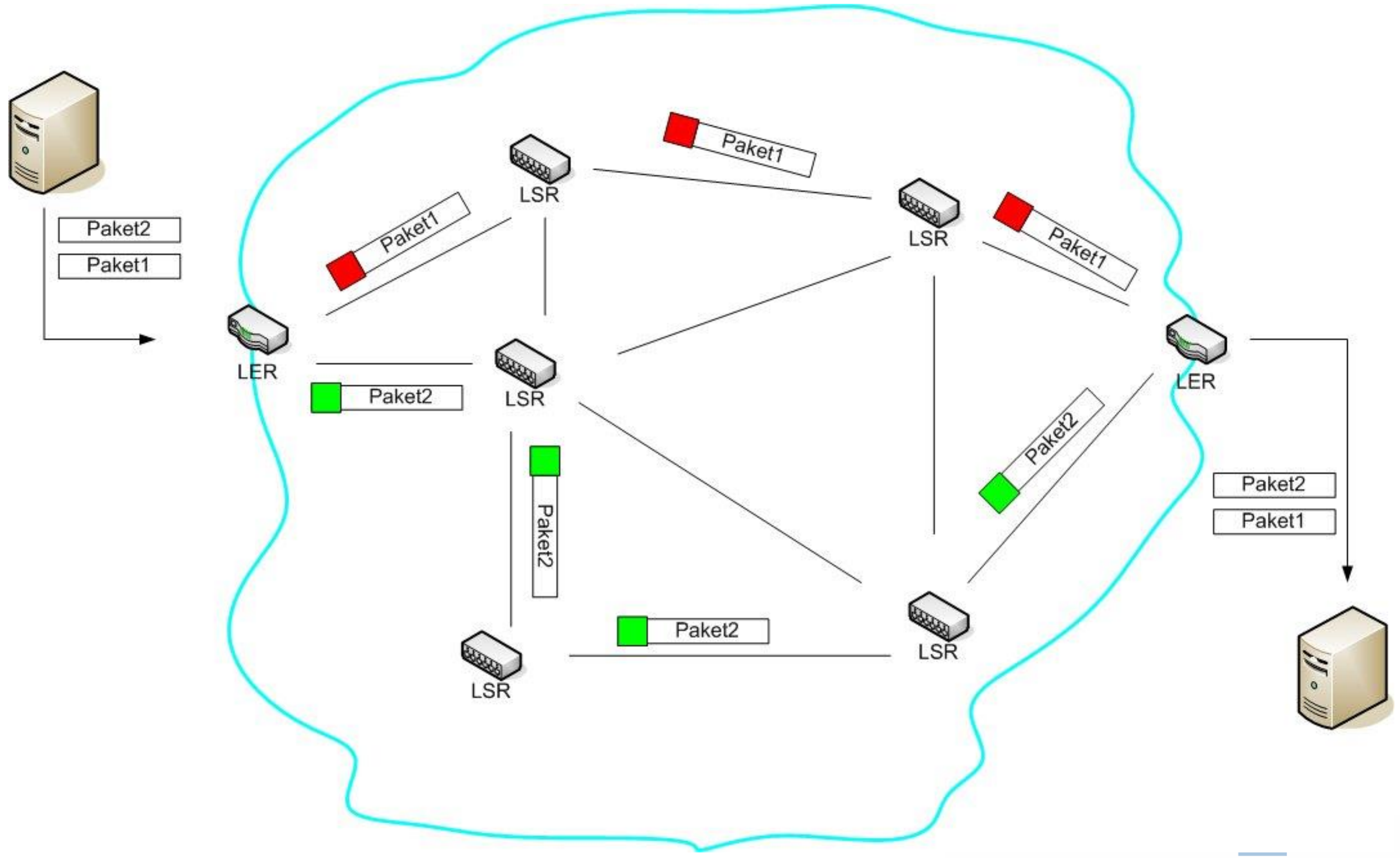
- Shim header to label packets
- Label data limited to forwarding plane
- Label switching routers (LSR) forward on label switching paths
- Instruction Table: Label Forwarding Information Base (LFIB)
- Insert / remove labels at edge routers (LER)
- Label distribution via Label Distribution Protocol (LDP)

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

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!

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

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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