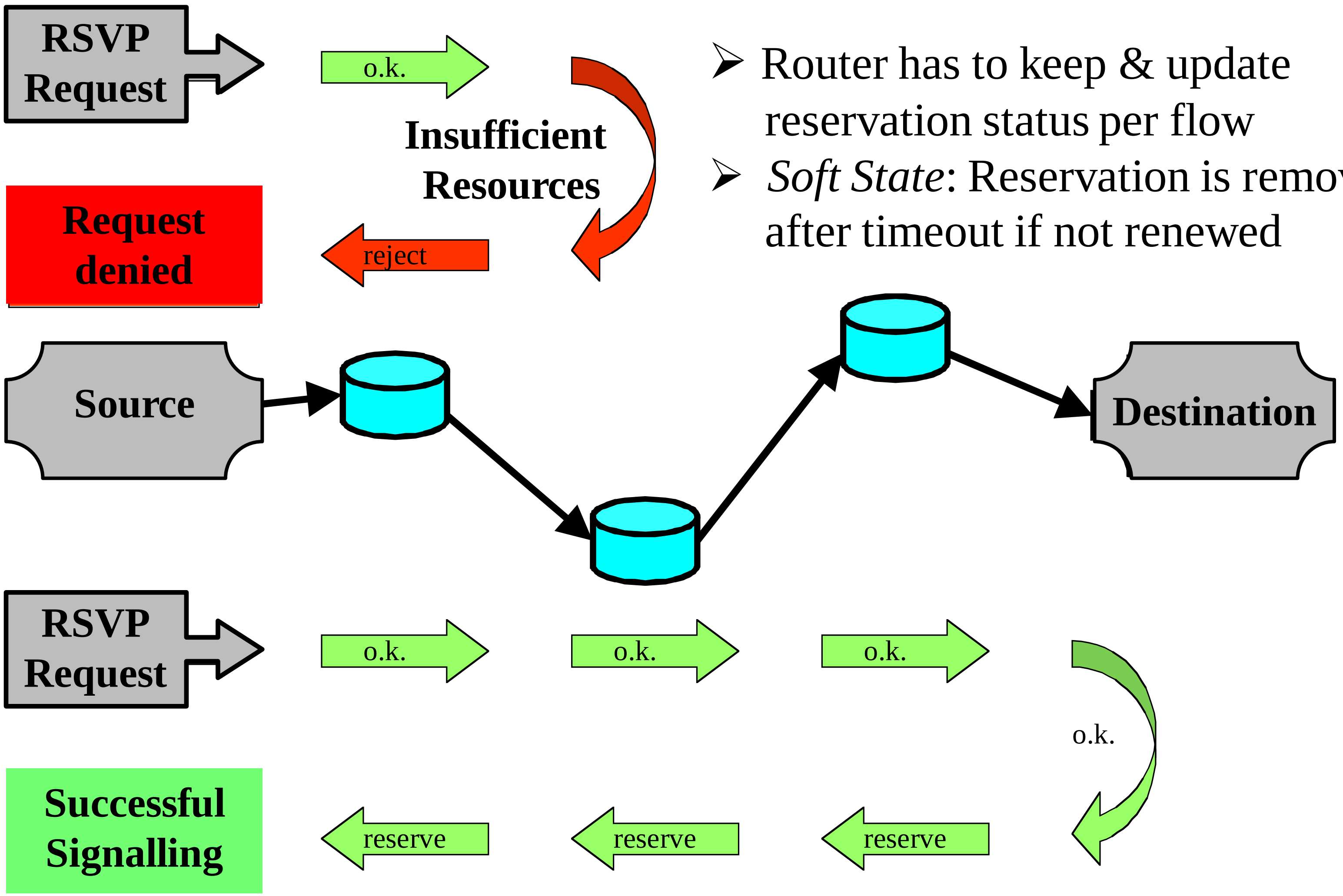
4. QoS Architecture in IP Networks

QoS support approaches in the Internet

IntServ	Integrated Services (since ~ 1993) based on RSVP: Resource Reservation Protocol
DiffServ	Differentiated Services (since ~ 1996) Marking of classes and class based forwarding
Leaky Bucket	Control of sender rates for SLA conformance (SLA: Service level agreement)
QoS $\leftrightarrow$ QoE	End-to-end across multiple domains Service area $\leftrightarrow$ core $\leftrightarrow$ access $\leftrightarrow$ user

Integrated Services with RSVP: Signalling & Resource Reservation

- Router has to keep & update reservation status per flow
- *Soft State*: Reservation is removed after timeout if not renewed



IP QoS: Integrated Services (IntServ)

- Internet QoS initiatives since RFC 1633 (1994)
- RSVP (RFCs 2205-2210): Resource reservation, incl. signalling & routing per flow
- an IP flow is a set of IP packets of a user application with the same source/dest. IP addresses, s./d. transport ports & ToS/DS bits
  → & Flow label in IPv6
  (RFCs 2460, 1809)

- IntServ enables QoS guaranties
- RSVP flows don´t aggregate
  ⇒ doesn´t scale in the core

  ⇒ new initiatives required:
- Differentiated Services: Traffic classes; priorities
- MPLS (→ Slide set QoS06) Multiprotocol Label Switching
- Combinations of DiffServ, MPLS, RSVP & Traffic Engin.
  ~ 100 RFCs on those topics
  Supported also by L1-L3VPNs

RSVP: Resource Reservation Protocol
RFCs 2204-2210 & some later extension

- Signalling of a flow (sender → receiver) … and back with
- Reservation if all routers and the receiver agree

- RSVP is multicast enabled (1:*N* - relationship)
- RSVP is installed on all routers on the path

- Refreshing: RSVP reservation is removed after timeout
  without sender activity (refresh signaling)

- RSVP doesn´t scale on core routers: state change per packet

- Combined approaches:
  RSVP in local networks with DiffServ or MPLS in the core
  RSVP is used for signalling of paths in MPLS

IP-QoS: Differentiated Services

- Traffic is classified & marked at the entrance to a DiffServ network; Class based router forwarding policy

- Type of Service/Traffic Class field is used in the IP-Header (6 bit)

- no resource guarantees per flow, only per class; problem of overload in preferred classes has to be controlled

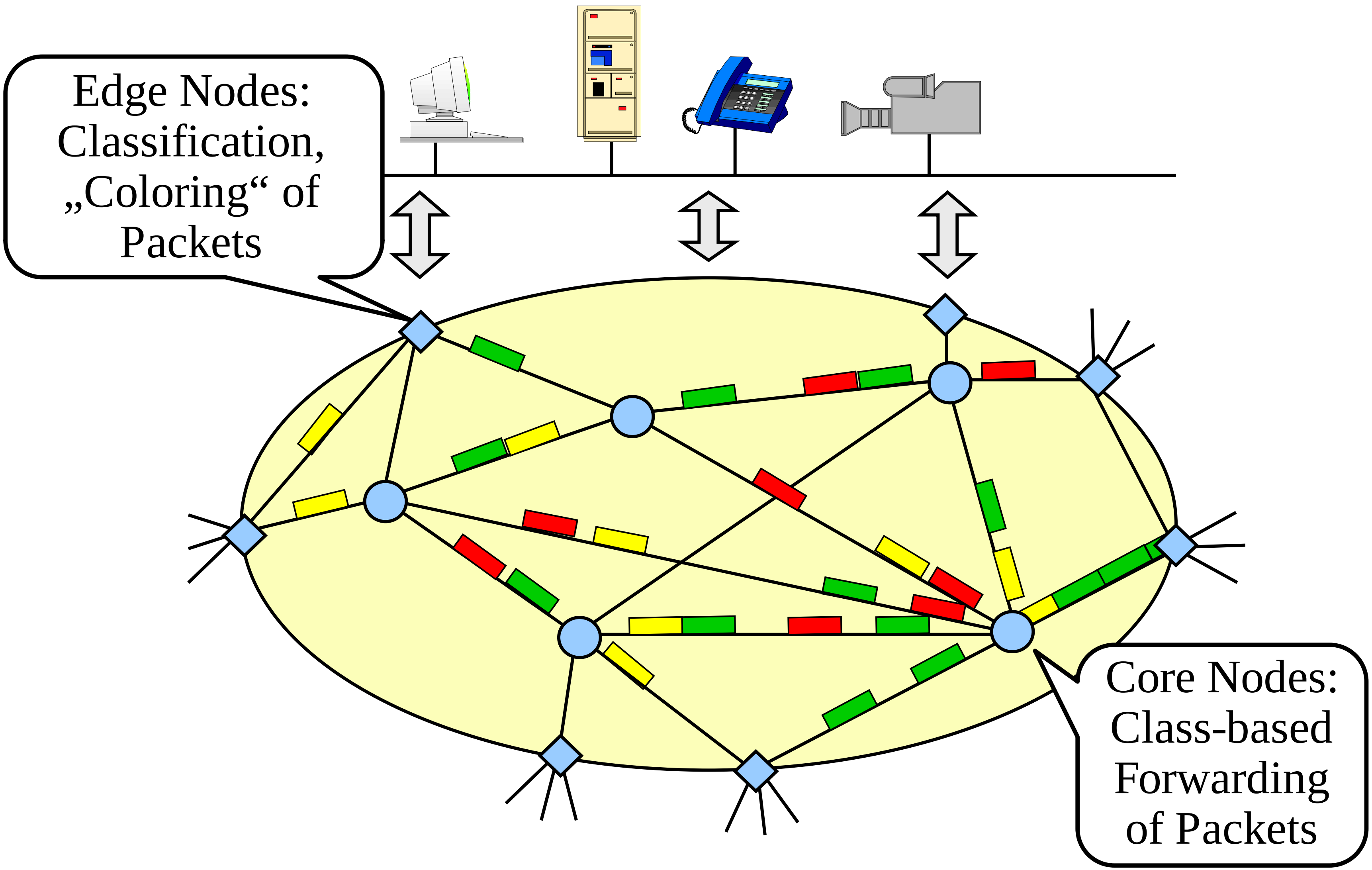
- AF(EF)-PHB: Assured (Expedited) Forwarding Per Hop Behavior (RFCs 2597, 2598)

- Differentiated routing actions per class:
  - Bandwidth assignment
  - Scheduling
  - Packet discard strategy
  - Fairness in each class

- verbindungslose Technik; kein Session-Kontext; $\Rightarrow$ skalierbar im Backbone anders als RSVP

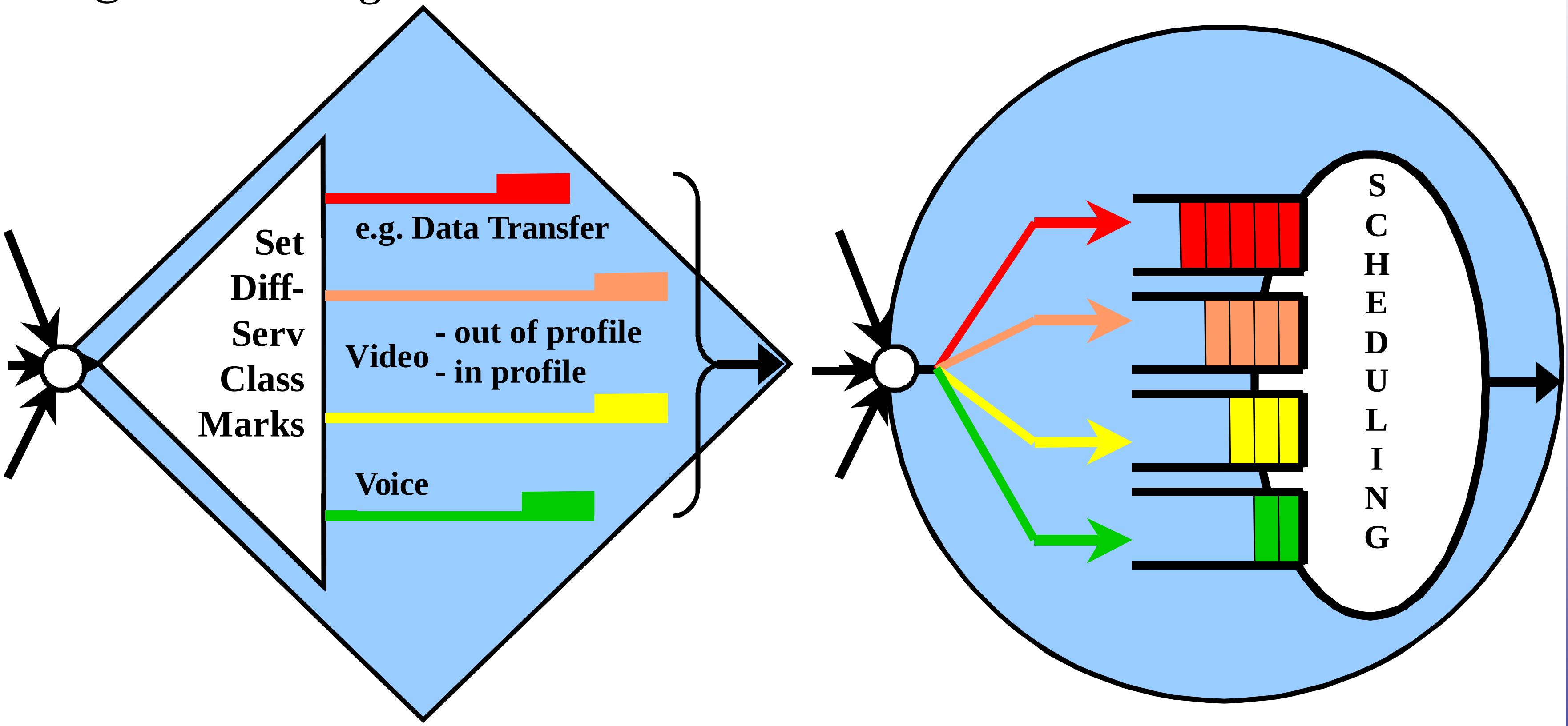
- Long series of DiffServ RFCs starts in Oct. 1998

DiffServ Network Domain with Edge & Core Nodes



IP-QoS: Differentiated Services (DiffServ)

@ DiffServ Ingress/Border Routers @ Routers within a DiffServ Domain



Traffic is classified
at the ingress to a DiffServ domain
with ToS/DS mark in the IP header

Differentiated routing behaviour per class
- Prioritization - Packet drop
- Bandwidth per class, packet scheduling

DiffServ: Options of routing behaviours
(PHB: Per hop behaviour)

- Strict priority classes:
  Packets of classes with higher priority are always perferred in forwarding

  or

- Bandwidth assignment per class:
  Even in overload a class is guaranteed a share of bandwidth;
  ⇒ Low priority, best effort traffic gets some throughput even in overload

- Per class buffering:
  Buffer size depends on application
  e.g. small buffers for voice,
  large buffers for bulk data transfers

- Per class packet drop policy:
  Tail Drop, i.e. at full buffer
  or RED (*Random early detect*):
  drop some packets when buffer is filling; randomly; constant drop rate or increasing with buffer usage

- Fairness, equally treated packets within each class

Differentiated Services: Per Hop Behavior (PBH) and Marking (DSCP)

- **DSCP**s: DiffServ Code Points
- RFC 1349: initially 8 **ToS** classes
  xxx 000 (Best Effort: 000 000)
  specified but unsued before DiffServ
- RFC 2598: **Expedited Forwarding** per hop behavior (**EF-PHB**:101 110) to support strict real time demands
- RFC 2597: **Assured Forwarding** (**AF-PHB**): 12 classes for high QoS:
  001 010 | 010 010 | 011 010 | 100 010
  001 100 | 010 100 | 011 100 | 100 100
  001 110 | 010 110 | 011 110 | 100 110
  EF is preferred to AF and best effort
- xxx x11: not specified; left free for usage by local administrator
- xxx x01: left free, but may be used in future new standards
- 000 000: Default, **Best Effort**
- 001 000: Less than Best Effort: is forwarded as far as bandwidth is available but can be conpletely discarded in overload
- RFC 4594 (2006):
  Update on DSCP Guidelines

Differentiated Services: DSCP Guidelines

Babiarz, et al., Guidelines for DiffServ Service Classes [Page 18]
Informational RFC 4594 August 2006
(CS: Class Selector; EF: Expedited Forwarding; AF: Assured Forwarding)

Figure 3: DSCP to Service Class Mapping

Service Class	Shortcut	DSCP DiffServ Code P.	Application Examples
Network Control	CS6	110000	Network routing
Operation & Mgnt.	CS2	010000	OAM
Signaling	CS5	101000	IP Telephony signaling
Telephony	EF	101110	IP Telephony bearer
Multimedia Conf.	AF41,42,43	100010,100100,100110	Video Conf., adaptive
Interactive RealTime	CS4	100000	Gaming, video conf.
Multimedia Streaming	AF31,32,33	011010,011100,011110	Streaming video & audio
Broadcast Video	CS3	011000	Broadcast TV & live events
Low-Latency Data	AF21,22,23	010010,010100,010110	Client/server transactions
High-Throughput Data	AF11,12,13	001010,001100,001110	Store & forward appl.
Best Effort Standard	Default,CS0	000000	Undifferentiated appl.
Low-Priority Data	CS1	001000	Non-assured bandwidth appl.

Differentiated Services: DSCP ↔ Application Maping Example

Application Class	PHB	Admission Control	Queing and Dropping	Application Examples
VoIP Telephony	EF	Required	Priority Queue (PQ)	Cisco IP Phones (G.711, G.729)
Broadcast Video	CS5	Required	Optional (PQ)	Cisco IPVS/Cisco Enterprise TV
Realtime Interactive	CS4	Required	Optional (PQ)	Cisco TelePresence
Multimedia Conferencing	AF4	Required	BW Queue + DSCP WRED	Cisco Unified Personal Communicator
Multimedia Streaming	AF3	Recommended	BW Queue + DSCP WRED	Cisco Digital Media System (VoDs)
Network Control	CS6		BW Queue	EIGRP, OSPF, BGP, HSRP, IKE
Call-Signaling	CS3		BW Queue	SCCP, SIP, H.323
Ops/Admin/Mgmt (OAM)	CS2		BW Queue	SNMP, SSH, Syslog
Transactional Data	AF2		BW Queue + DSCP WRED	Cisco WebEx/MeetingPlace/ERP Apps
Bulk Data	AF1		BW Queue + DSCP WRED	Email, FTP, Backup Apps, Content Dist
Best Effort	DF		Default Queue + RED	Default Class
Scavenger	CS1		Min BW Queue (Deferential)	YouTube, iTunes, BitTorent, Xbox Live

Source: <http://www.cisco.com/c/dam/en/us/td/i/200001-300000/220001-230000/227001-228000/227133.eps/jcr:content/renditions/227133.jpg>

Leaky Bucket Prinziple for QoS Traffic Control

- For traffic entering a network via access line of a customer or peering / interconnection with another network, some traffic control is usual
- As a precondition of bandwidth reservation for a class or flow other traffic should not block more bandwidth than foreseen / allowed
- Limitation of the sending rate is a simple & usual control option: i.e. the **sending rate** $\boldsymbol{R_t}$ at time t is restricted by $R_t < C$ for an aggreed, reserved bandwidth C
- The **Leaky Bucket** principle extends this type of control (IETF, ATM):

  A data rate C can be exceeded within a time interval Δ only by a data volume B, i.e.:

  $$\forall T, \Delta : \int_T^{T+\Delta} R_t \le \Delta \cdot C + B$$

  holds for any arbitrary starting time T.
- Data that does not conform to this condition may be dropped or transported in the best effort class

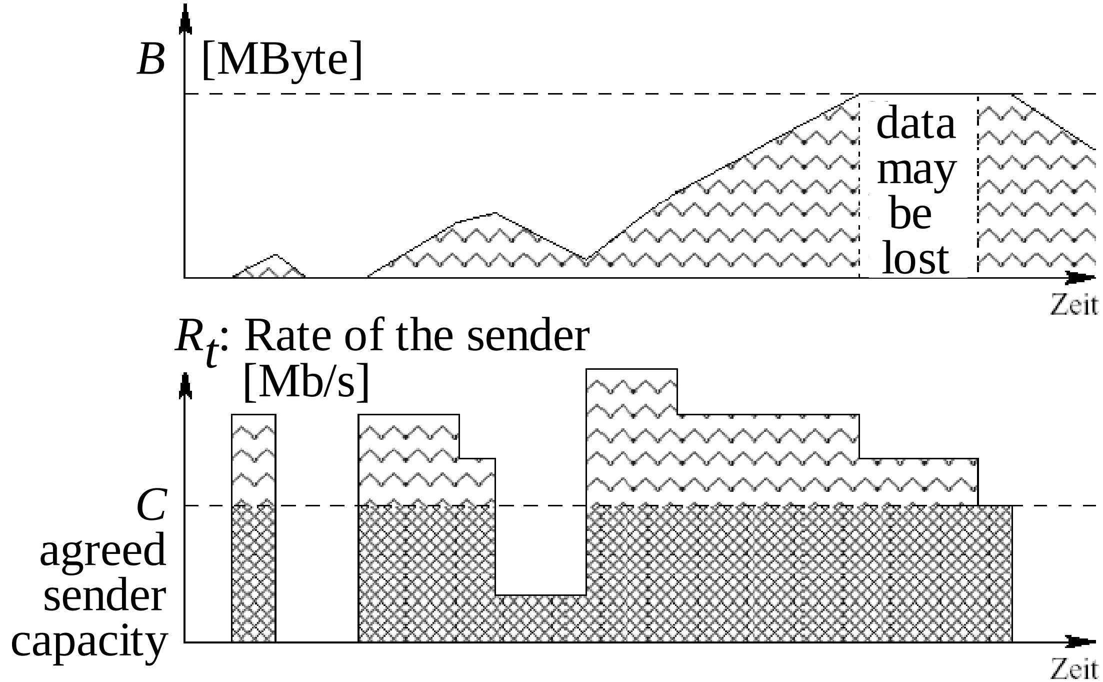
Leaky Bucket Prinziple for QoS Traffic Control

Implementation: network port with capacity *C* and buffer size *B* or as (Byte-)counter

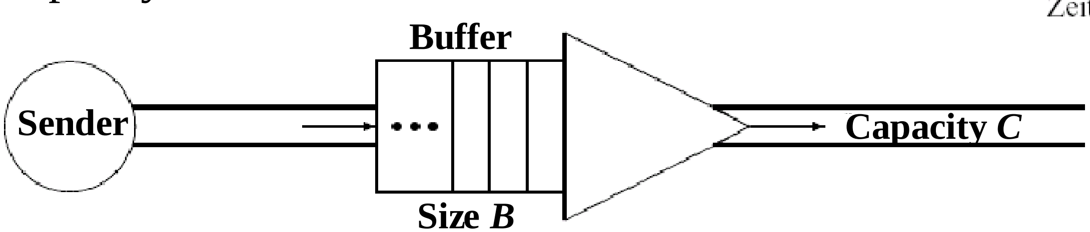
Leaky Bucket counter of the buffer usage

⇑

Traffic volume arriving at the network over time



Leaky buffer as network device with capacity and buffer limitation

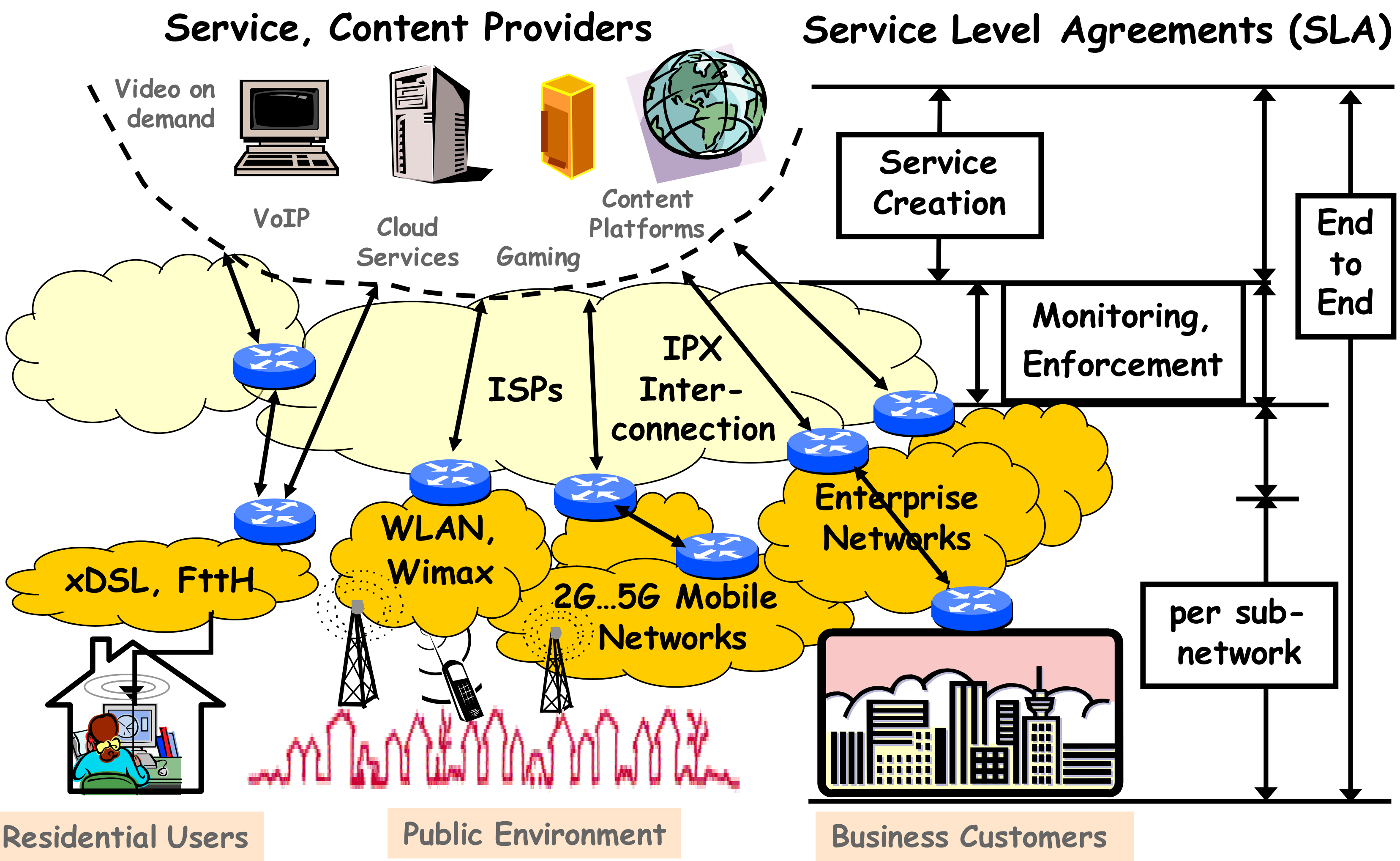


Source: ITU-T, Traffic control and congestion control in B ISDN, Recommendation I.371, Internat. Telecommunication Union (2004) & RFC 3290: An Informal Mgnt. Model for DiffServ Routers

QoE ⇔ QoS: Mapping

Applications Service Level Agreements	⇔	QoS Policies on Transport & Network Layer
QoE: Quality of Experience Applications, Terminals, End-to-end Perspective	Network Access Network Protocols	Network Platforms TCP/IP, MPLS, Ethernet etc.
Voice-, Video-, Data-Transfer Multimedia-Applications etc. Further Properties: Sender Receiver Relationship: Uni-, Bi- Multi-Directional Interactive Client Server Dialog Uni-/Multi-cast (1:1, 1:N, M:N)	Message-, Data-Coding, Packetization, Marking of Applications, Traffic Flows	Demand for Transmission Capacity; Limited (or no) Tolerance Regarding ➢ Delay & Delay Jitter ➢ Transmission Errors, Packet Loss ➢ Resource Availability (Links, Routers, Switches, Caches)
Protocols Supporting Services HTTP, FTP, SMTP, VoIP ... + Advanced Applications Social Cloud Networking	QoE QoS ⇐ ⇒	DiffServ: QoS Codepoints IntServ: Signalling, Flow Reservations MPLS: Label Switched Paths

Inter-domain QoS support in heterogeneous networks?



QoS: Problem Statement & Developments from IETF Perspective (RFC 2990)

DiffServ Classes (RFCs 2578/9 & 4598 ✓)

- fixed standard classes & classes left open for network administrator

QoS ↔ Applications, End Systems

- Direct signaling from application → network incl. QoS parameters ideally with prediction of the traffic profiles to be used over time
- Feedback from network → application: QoS status (→ ECN)
- QoS/SLA monitoring (→ IETF working groups IPPM, LMAP)

QoS ↔ Routing

- e.g. special paths for real time and for other services (QoS routing)
- IP tunnels and other obstacles, remarking at network boundaries

QoS ↔ Fairness versus policies, control, accounting for QoS support

QoS ↔ TCP flow and overload control

Today: New QoS options with IPv6: Address schemes regarding QoS?

Traffic entering a network could get a QoS mark depending on destination

Net Neutrality: EU Guidelines

<ec.europa.eu/digital-single-market/en/net-neutrality-challenges> (Oct. 2015)

Comments & Recommendations by the EU Commission on

Blocking and throttling

- Unfair traffic management practices
- Weakening the competition
- Decrease of innovations

Lack of transparency regarding

- Traffic management practices
- Quality of service level & guarantees

Network congestion

- Quality levels: “Certain IP applications, like VoIP or video, require a degree of prioritisation in order to provide a good user experience”
- Insufficient levels of fast broadband coverage
  Goal: 30Mb/s for all until 2020