

QoS Management in the Internet

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Outline

- Introduction
- IP QoS Technologies
- Management Issues
- Management Approaches
- QoS Management Architectures
- Conclusion
- Additional Information

Content and Non-Content

- Content
 - QoS in IP networks
 - Management of IP networks with focus on Internet Service Providers
 - QoS architectures for layer 2/3
- Non-Content
 - Application level QoS
 - End-system support for QoS

What is QoS?

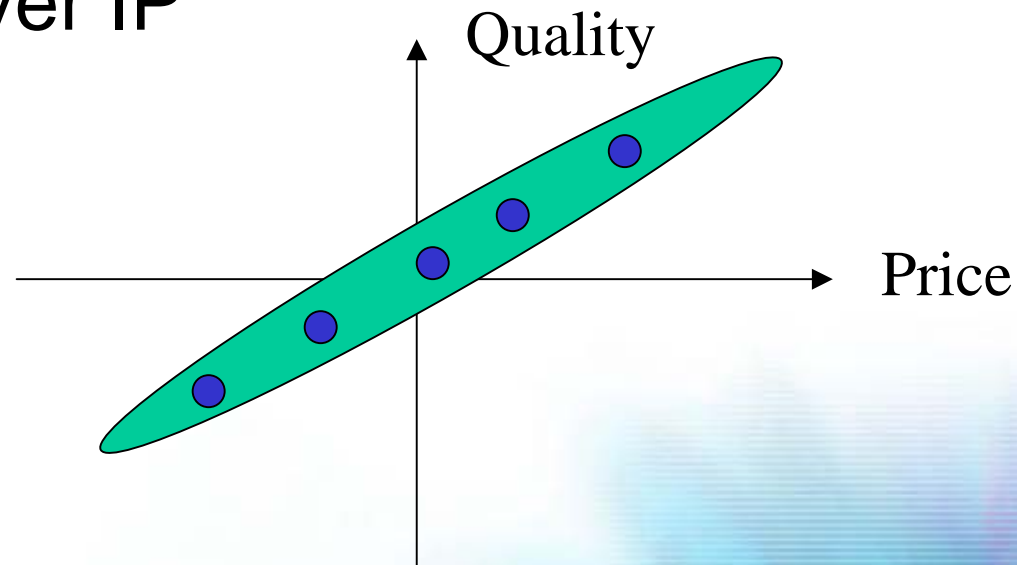
- Different people interpret QoS differently
- Quality
 - better than expected, superior performance
 - grade or goodness
 - long-term: reliability, availability, and predictability
 - short-term: timeliness of packet delivery, etc.
- Service
 - here: provided IP communication capability

Over-provisioning: the better Alternative?

- Economically controversial
- High traffic variability -> high over-provisioning margins
- Fractal nature of traffic -> always some level of resource contention
- Corollary of Moore's Law: "As you increase the capacity of any system to accommodate user demand, user demand will increase to consume system capacity"

QoS: What for?

- Offering more distinguished services by competing ISPs
- Covering various market segments
- Voice over IP



Why not deployed yet?

- ISPs too busy with matching the growth in demand
- Weak Economy
- Requirement on customer side not very strong
- Business models still under investigation
- Provider business is still a growth market
 - cost efficiency and market differentiation only affect saturated markets
- Primitive and coarse grained QoS tools
- Negative impact on packet forwarding performance on deployed routers
- Accounting, pricing, and billing is still open
- Inter-provider, Inter-domain issues

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QoS Technologies for IP networks

- General issues
- Integrated Services (IntServ)
 - Together with Resource reSerVation Protocol (RSVP)
- Differentiated Services (DiffServ)
 - Class of Service (CoS) together with QoS Servers
- Multiprotocol Label Switching (MPLS)
 - IP routing enhancements

Traditional IP: Limited QoS support

- TOS field (precedence & service selector)
 - hardly used
- Reliable transport (TCP)
- Fairness
 - packets are treated equally
 - TCP back-off
- Provider guaranties
 - e.g., guaranteed average round trip for UUNET
SLA: 120ms transatlantic

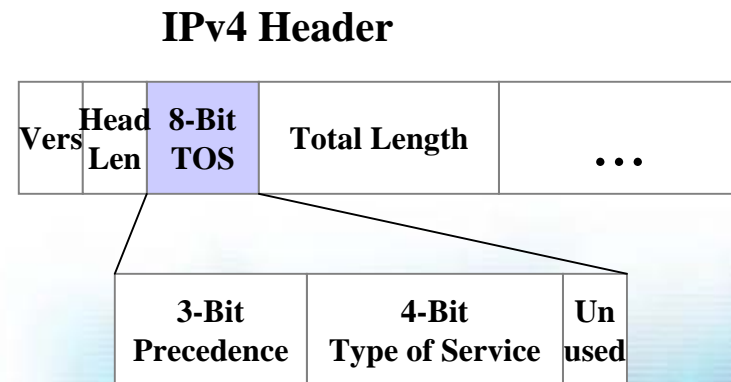
Approaches to QoS in IP networks

- Packet classification
 - fine grained: (Micro-)flow classification, five-tuple
 - coarse grained: Classes of Service
- Differentiated routing and scheduling
- Reservation-based
- Priority-based

- Alternative: over-provisioning

Packet Classification

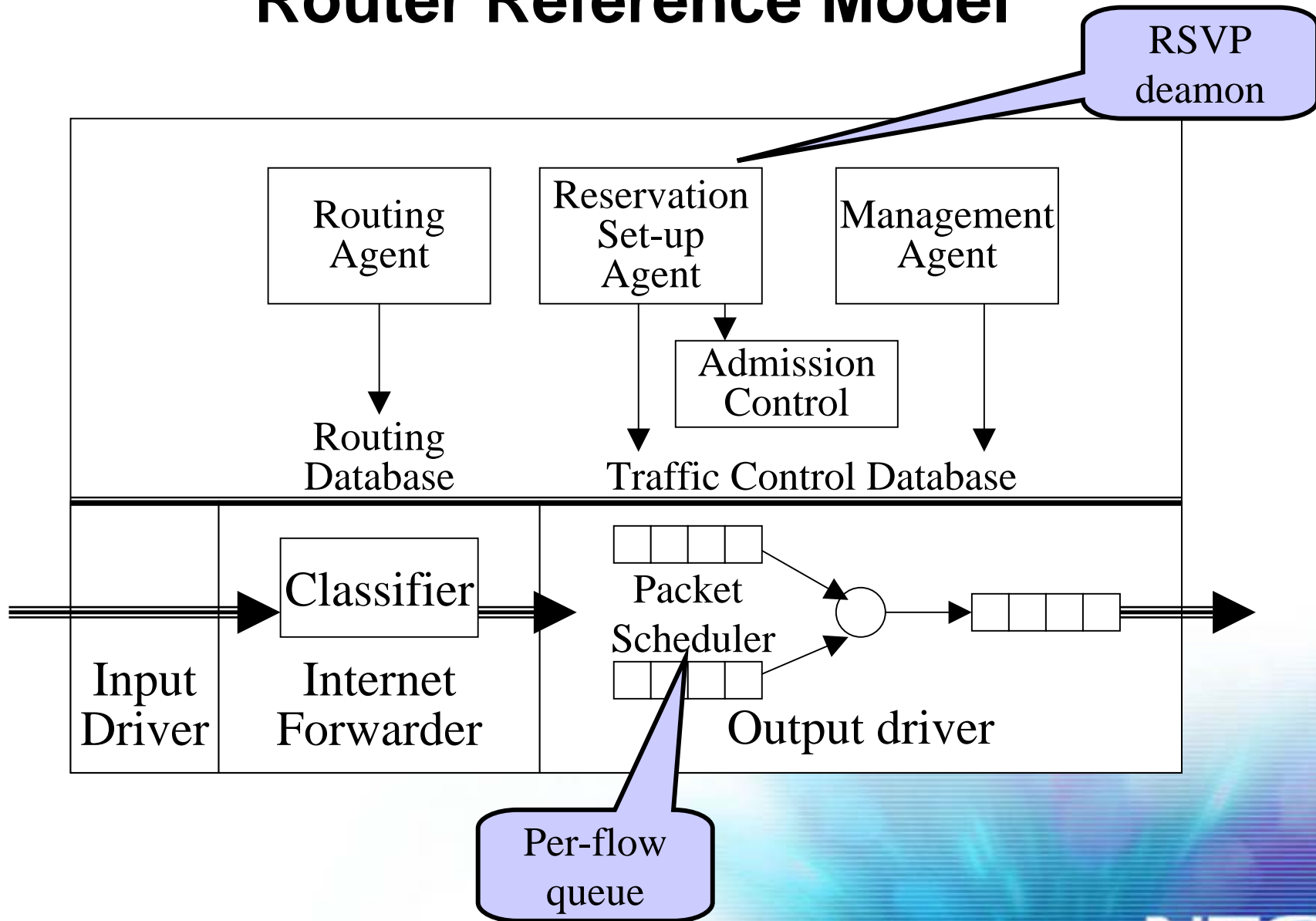
- Layer 2
 - MAC addresses
 - Interfaces
- Layer 3
 - IP addresses (source, destination)
 - Type of Service (TOS)
 - Flow label (IPv6)
- Layer 4
 - UDP/TCP port numbers
- Layer > 4
 - for example HTTP content type



Integrated Services

- Assumptions:
 - Resource management is required by real-time applications: admission control, resource reservation
 - real-time traffic and non-real-time traffic should be integrated into a common IP infrastructure
- Approach
 - per-flow traffic handling at each hop
 - per-flow resource reservation through signaling (RSVP)
- Service types
 - controlled-load service model for tolerant applications
 - guaranteed service models for intolerant applications

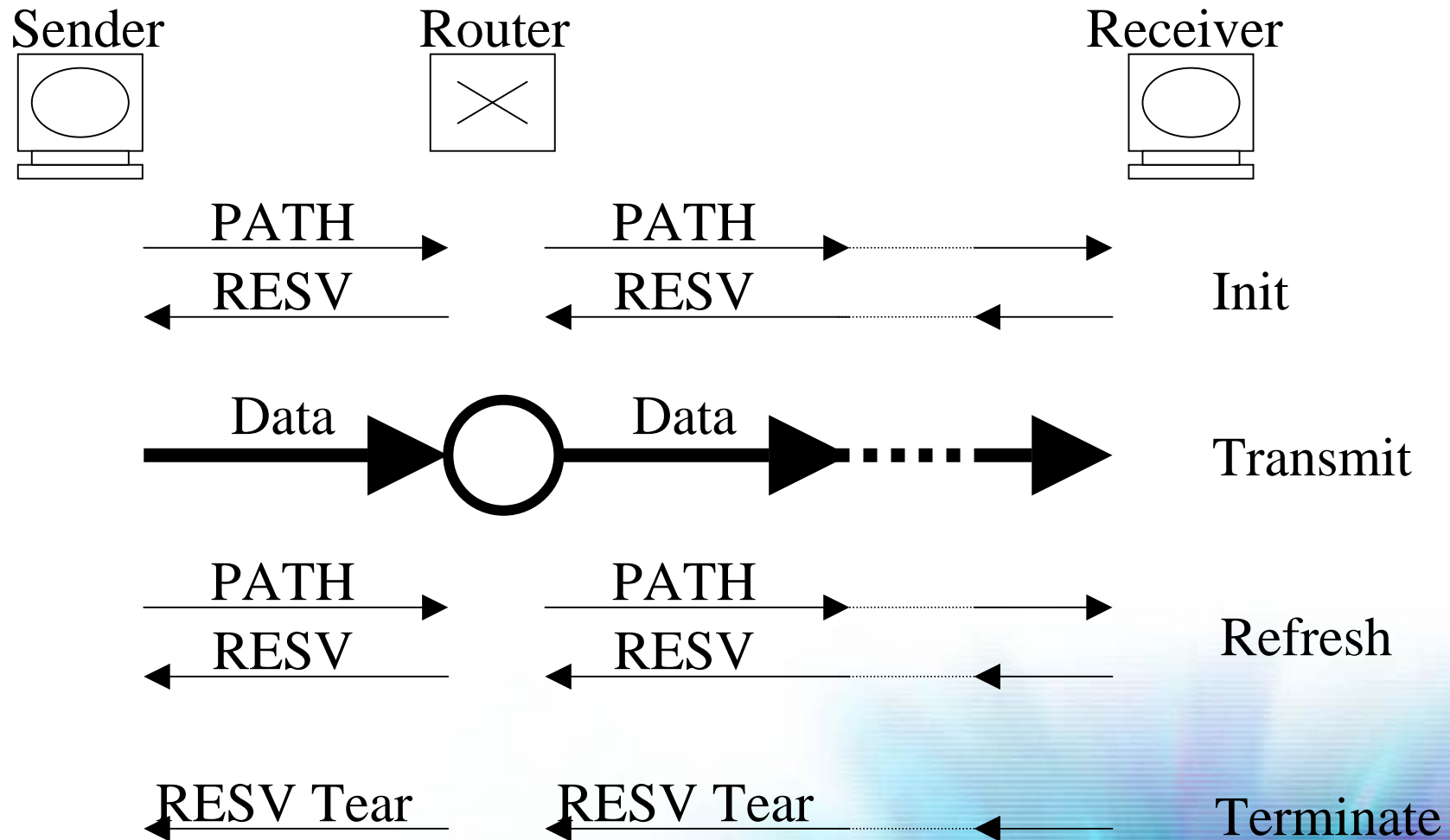
Integrated Services Router Reference Model



Resource reSerVation Protocol (RSVP)

- Hop-by-hop protocol
- Routing protocol independent
- Sender advertisements
- Receiver-issued reservations
- Soft state design
- Support for multicast

Resource reSerVation Protocol (RSVP)



Problems with IntServ

- Complex RSVP implementation
 - large state machine
 - support of multicast
- Poor scalability
 - per-flow reservation and per-flow traffic handling not applicable to backbone core routers: too many flows
 - overload of classifier
 - overload of scheduler (high number of queues)
 - overload of RSVP signaling daemon (soft state!)

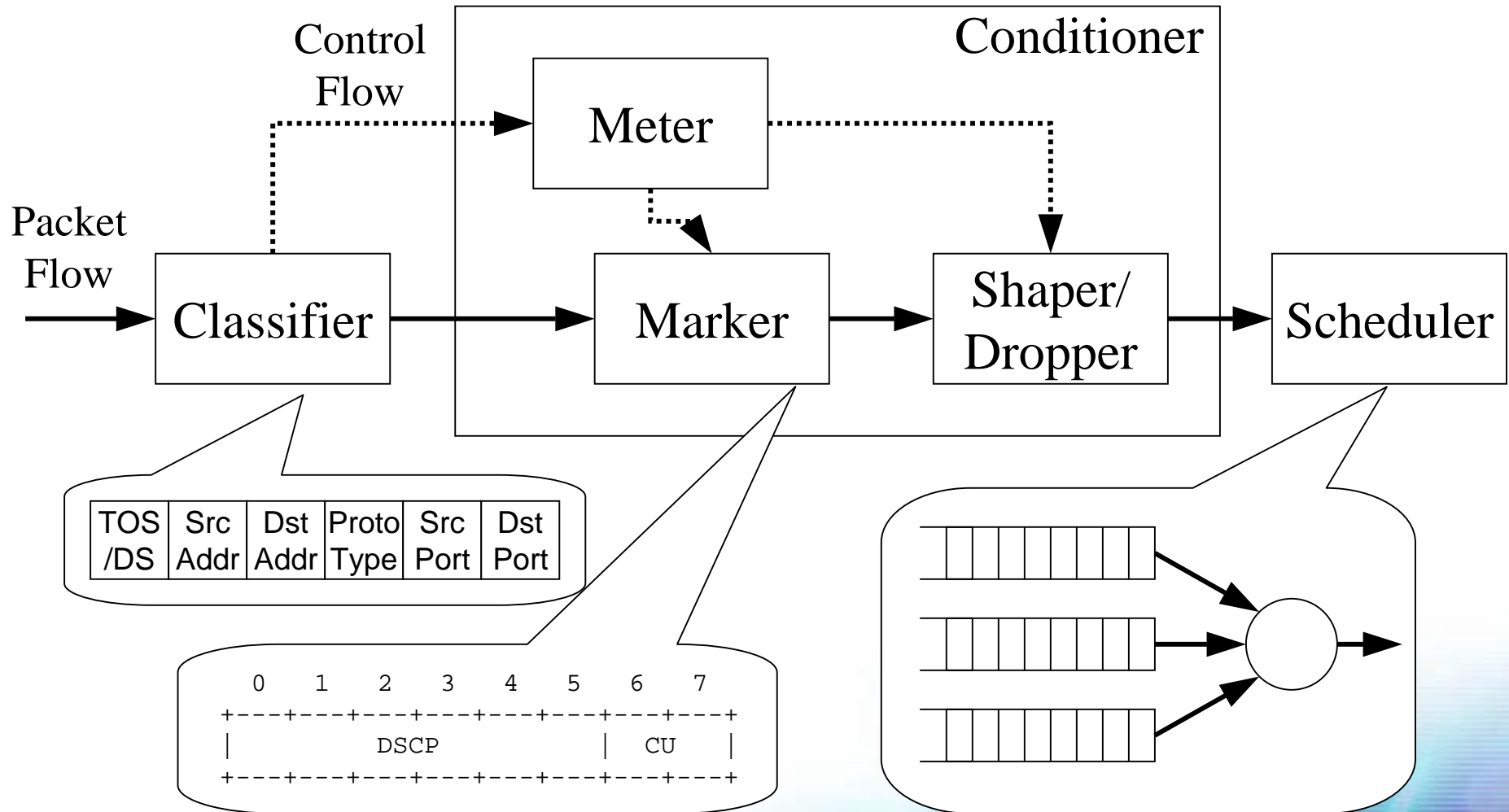
Next Steps in Signaling (IETF NSIS WG)

- Potential step towards RSVP Version 2
 - Service independence (works not only for QoS signaling but also other services e.g. Firewall traversal)
 - Remove some performance, complexity, and scalability problems
 - e.g. Limited multicast, allow for sender orientated reservations,
 - Should work for mobile scenarios
 - Should work in tunneling scenarios

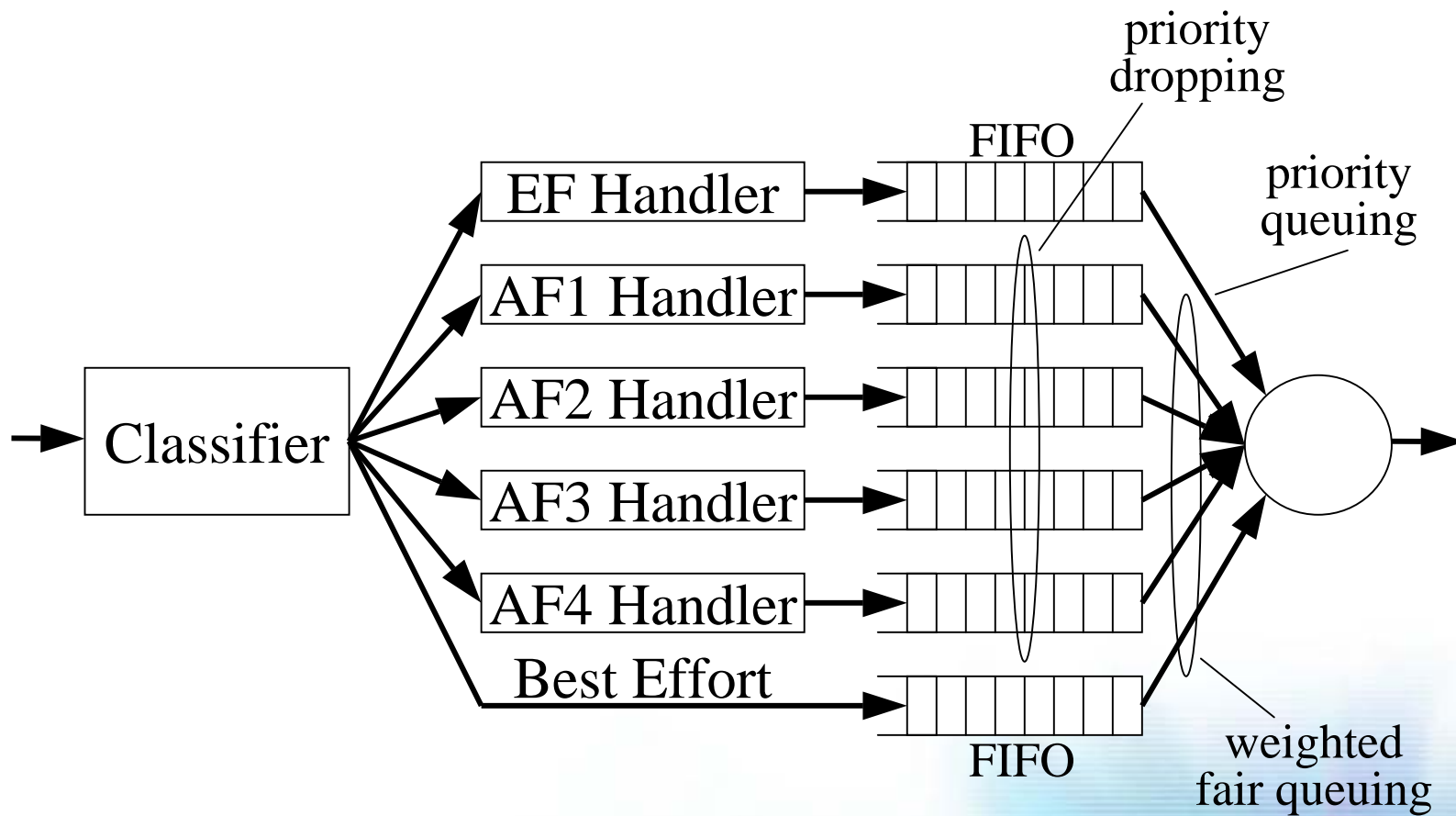
Differentiated Services (DiffServ)

- **Principle: Control traffic at the edge**
- Less complex
 - hop-by-hop instead of end-to-end
 - fast processing on core routers
 - less state signaling, processing, storing
- Small number of Service Classes
- At ingress router (first router in a domain)
 - packet classification into few classes
 - packet marking with DiffServ Code Point (DSCP)
 - stream policing, shaping, dropping
 - packet queuing and scheduling per DSCP/service class
- At core and egress router
 - packet queuing and scheduling per DSCP/service class

DiffServ Building Blocks



Typical Node Configuration



IntServ vs. DiffServ

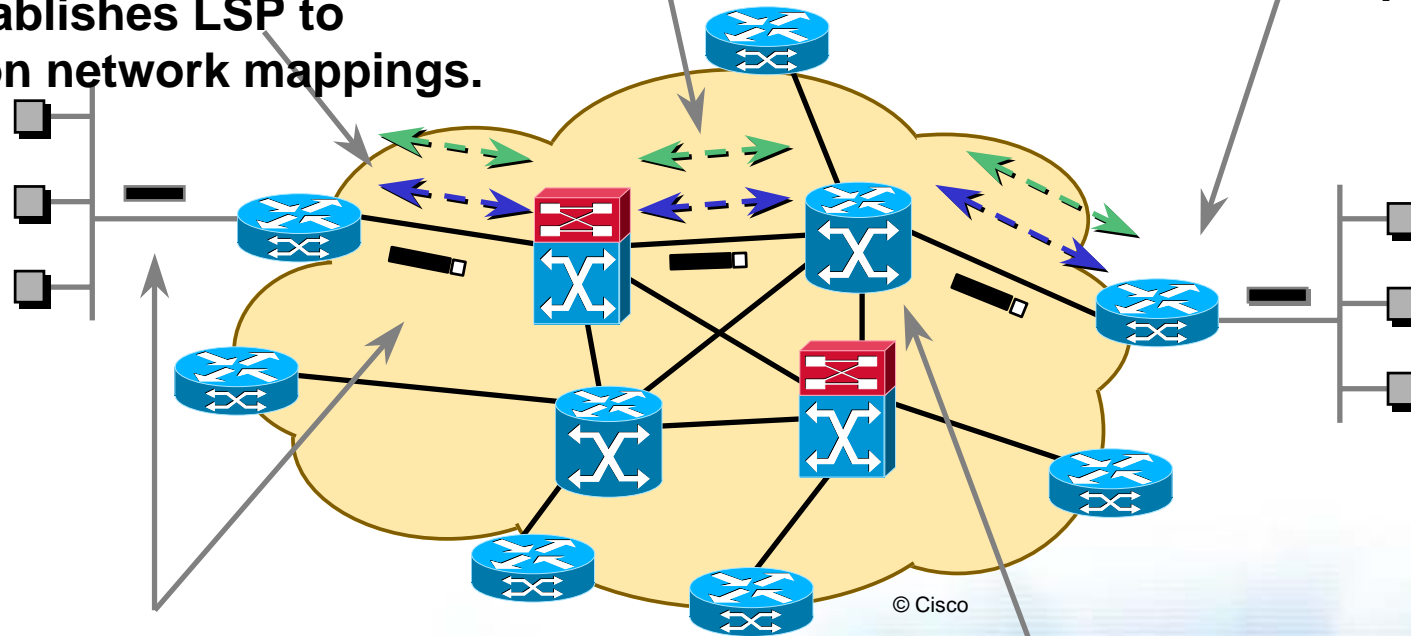
- IntServ
 - provides resource guarantees per flow
 - supports signaling for short-living reservations
 - soft-state does not scale with number of flows
 - replication of functionality (e.g. classification)
- DiffServ
 - provides traffic treatment per class of service
 - only per-hop guaranties
 - no per-domain behavior or end-to-end behavior defined
 - hard guaranties require additional control of admission and routing
 - better match with IP network architecture
 - simpler to implement

MPLS Networks

1a. Existing routing protocols (e.g. OSPF, ISIS) establish reachability to destination networks

1b. Label Distribution Protocol (LDP) establishes LSP to destination network mappings.

4. Egress LSR removes label and delivers packet



2. Ingress Label Switch Router receives packet, performs Layer 3 value-added services, classifies and “labels” packets

3. Core LSR switch packets using label swapping

Advantages of MPLS

- Reduced investments
 - reuse of ATM/FR hardware possible
- Increase of performance
 - less complex packet forwarding
- Higher scalability in network layer
- Flexibility in routing
- Privacy, isolation of traffic
 - useful for VPNs
- Supporting QoS
 - together with other means

Target MPLS Applications

- Traffic Engineering (TE) in ISP networks
 - controlling the path of traffic
 - routing around hot spots
 - routing based on service classes
- Realization of Virtual Private Networks
 - using MPLS tunnels
 - working together with BGP
- Realization of QoS services
 - route pinning for guarantees
- Generalized MPLS (GMPLS) for optical networks
 - not really related to QoS

MPLS Labels

- Abbreviation of packet headers, input for routing decision
- Identifier of an aggregated stream of data (FEC - Forwarding Equivalence Class)
- Valid only between two neighboring routers
- Can be coarse-grained or fine-grained
- Conceptually, labels are on a label stack (push at ingress router, pull at egress router)
 - Allows for hierarchical building tunnels in tunnels
- May carry QoS specifications (e.g. class of service)

MPLS and QoS

- MPLS provides routing, not QoS!
- An additional technology for QoS is required
 - ATM, Frame Relay: label \leftrightarrow VPI/VCI
 - RSVP: label \leftrightarrow reserved data stream
 - DiffServ
 - edge policing and MPLS for traffic engineering?
 - different labels/paths for different traffic classes (DSCP)?
- Label distribution supporting QoS
 - RSVP-TE (RSVP for Traffic Engineering)
 - CR-LDP (Constraint-based Label Distribution Protocol)

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Management Issues (1)

- Number of Managed Objects
 - additional managed objects per node, per interface
- Distributed Managed Elements
 - Consistent configuration
- Inter-Domain
 - Cooperation of competing ISPs
 - Definition of ISP to ISP management interface
 - End-to-End Service
 - Traffic traversing various ISPs

Management Issues (2)

- Edge-to-Edge
 - Modeling? Specification? Implementation?
- Resource Management
 - Admission Control
 - over-booking?
 - choice of granularity
 - Reservation
- Control Loop versus Provisioning
 - usage of network feedback for control
 - no analytical model needed
 - Provisioning
 - needs analytical model to predict the behavior

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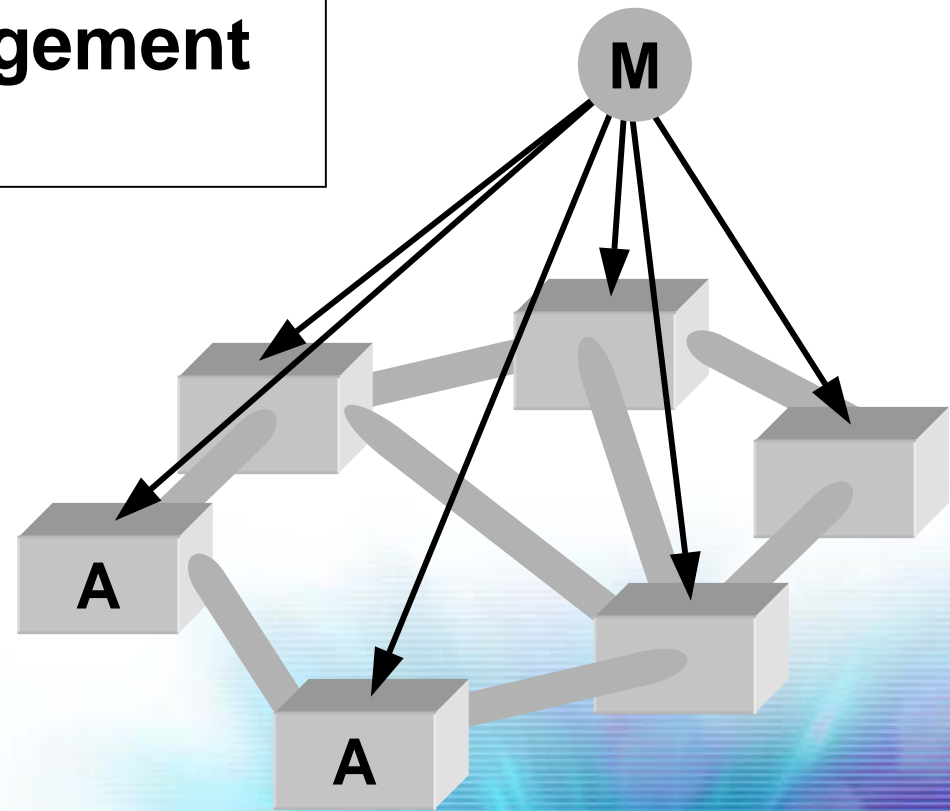
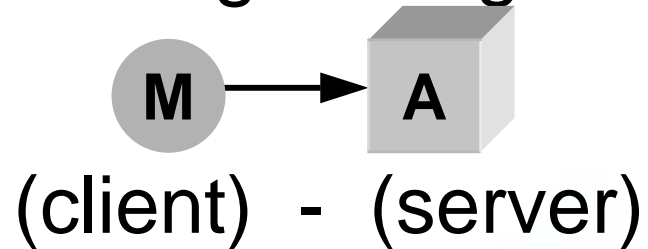
Management Technologies

- Centralized SNMP management
- Policy-based management
 - SNMPconf
 - COPS
 - Policy Framework
- XML-based
- Active technologies
 - distributed management
 - mobile agents

Centralized SNMP Management

Traditional Centralized Network Management Paradigm

Manager - Agent



Simple Network Management Protocol

- MIB - Management Information Base
- SMI - Structure of Management Information
 - tree structure,
 - records (sequence)
 - fields (sequence of)
- Read (get) and write (set) access from manager to managed objects at the agent
- Notifications from agent to manager

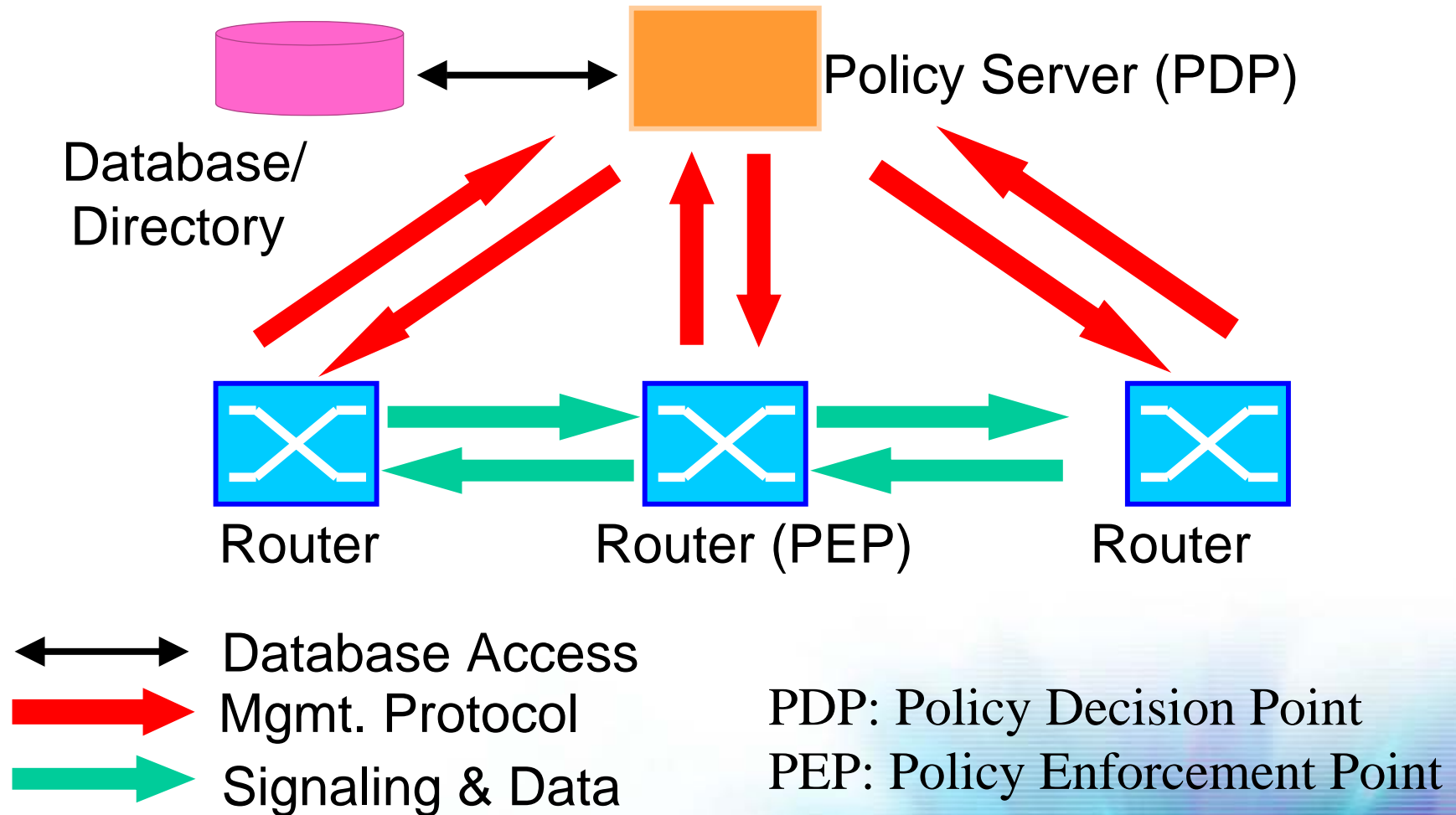
Disadvantages of Central Management

- Low scalability
 - central manager can be a bottleneck
 - slow remote data access
 - monitoring by polling
- Limited flexibility
 - no quick way of inserting new management functions
- Limited robustness
 - single point of failure
 - no management of accidentally disconnected networks
- Many MIBs are implemented read-only (no configuration possible)
- **But:** Alternatives typically introduce new stability and manageability problems and add points of failure.

Policy-based Management: Motivation

- Away from individual device/managed object management
- Consistent configuration of all managed nodes according to network policies
- Independent of protocols and mechanisms
- High-level support for the management and operation of networks
- Automation of management tasks

Policy-based Management: The Big Picture

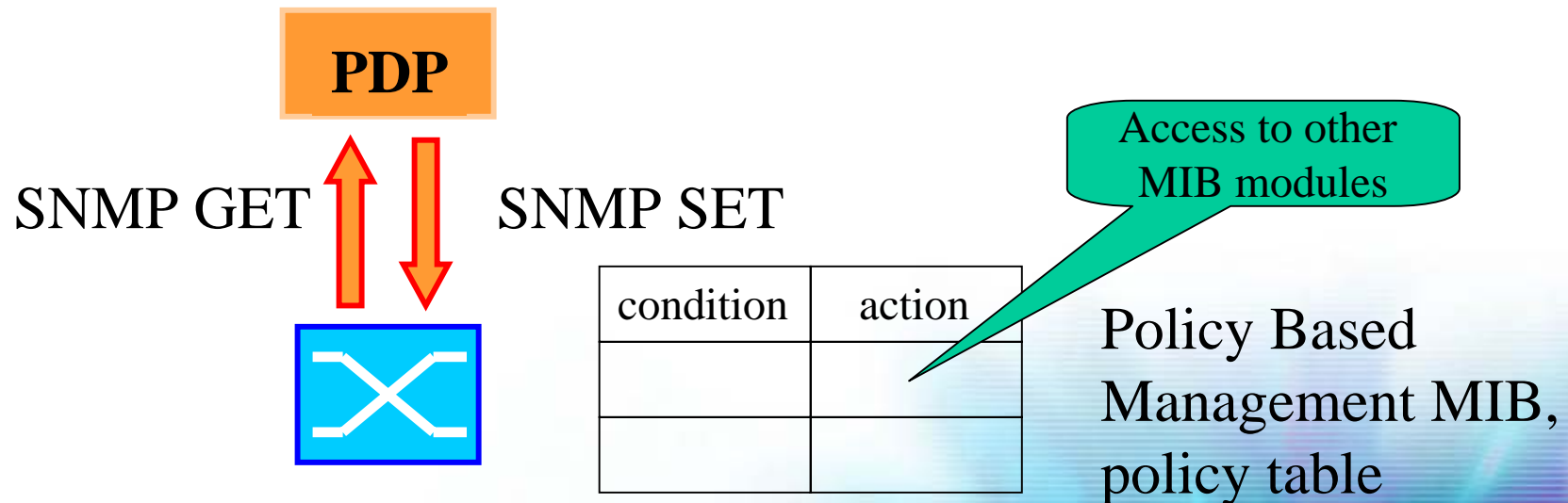


The Standardized IETF Approaches

- Configuration Management with SNMP Working Group (SNMPconf)
 - Policy Based Management MIB
- Resource Allocation Protocol Working Group (rap)
 - COPS, COPS-PR, PIB, SPPI
- Policy Framework Working Group (policy)
 - PCIM, PCIMe, QPIM, QDDIM, plus the LDAP mappings

SNMP for Configuration Approach

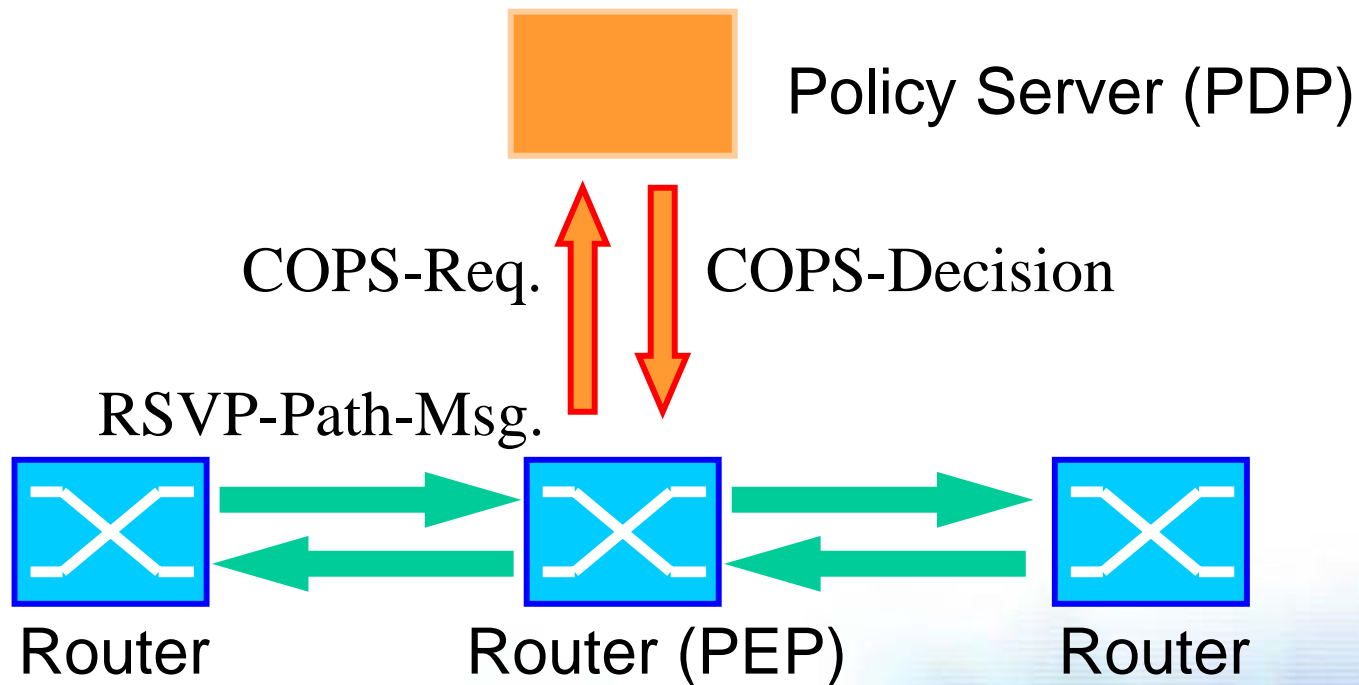
- Uses SNMP for the PDP<->PEP communication
 - no new protocol needed
- Operates on the MIBs of an SNMP agent



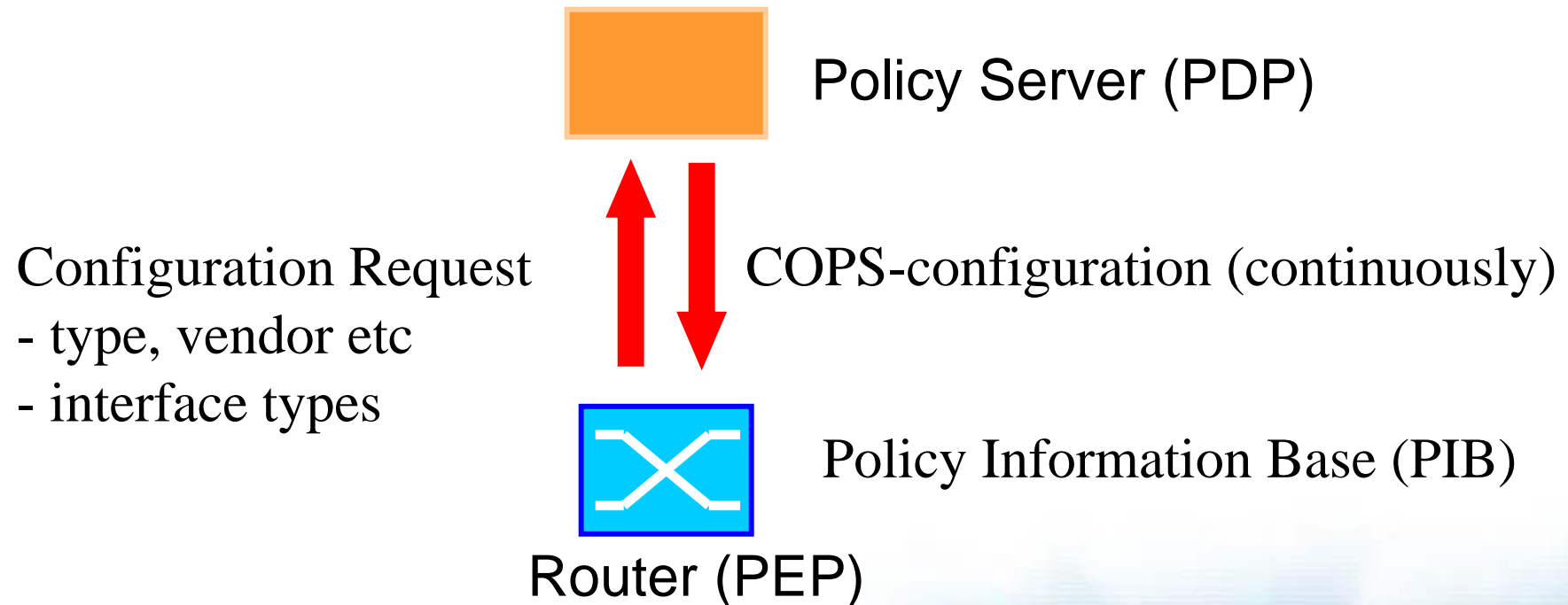
COPS (Common Open Policy Service)

- Communication between PDP and PEP
- Uses TCP
- PEP initiates connection
- Two different models
 - outsourcing (e.g. COPS for RSVP)
 - instantaneous policy decision (request, response)
 - PEP delegates responsibility to PDP
 - configuration (COPS for provisioning, COPS-PR))
 - proactively provision the router
 - requests describe the capabilities of the router

Outsourcing COPS for RSVP

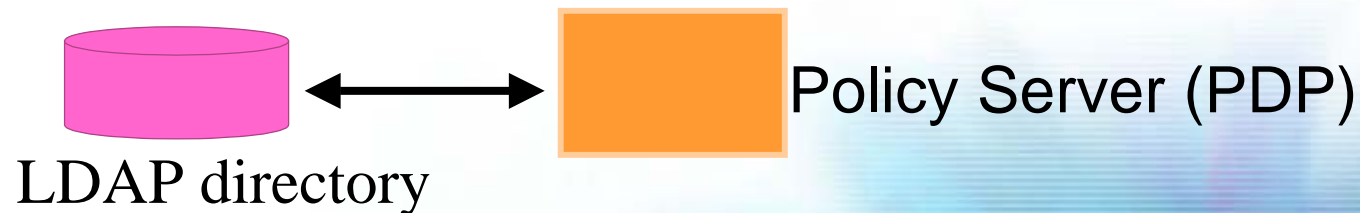


COPS for Provisioning: COPS-PR



IETF Policy Framework

- Focus on information model of policies
- Collaboration with DMTF
- Storage of policies in LDAP
- Policies operate on network model
- Transparent to the configuration protocol, but related to COPS



XML-based Management

- IETF Working Group on XML for configuration
 - Currently: Main discussion is on what protocol to ship XML documents from manager to agent
 - Is SOAP from W3C the RPC mechanisms
 - Or define it within the XML document
- In my opinion
 - Does not solve the modeling problem
 - Does not work for small devices
 - to be checked
 - XML parsing is pretty heavy
 - However is better than CLI (is structured text)
 - Very useful for management system interaction

Active Management Technologies

- Approaches
 - Distributed Management
 - Mobile Agents/Active Networks (mobile code)
- Higher scalability
 - more local data access
 - less data transfer
 - distributed processing
- ‘Localization’ of management functions
- Different distribution models
 - fixed distribution
 - management by delegation
 - mobile agents

Distributed Management Technologies

- Standardized
 - ITU-T CMIP Command Sequencer
 - IETF (Disman WG)
 - REMOPS MIB (remote operations e.g., ping)
 - Expression MIB, Event MIB
 - Script MIB (RFC 2592), Schedule MIB
- Proprietary
 - solutions in network management frameworks
 - Various research prototypes
- Experimental
 - Active Objects in TMN

Drawbacks of Active Management Technologies

- New infrastructure required
 - return of investment?
- Manageability of the management system
 - additional elements to be managed
 - meta-management
- Only a few standards
- Only a few commercial implementations
- Little practical experience

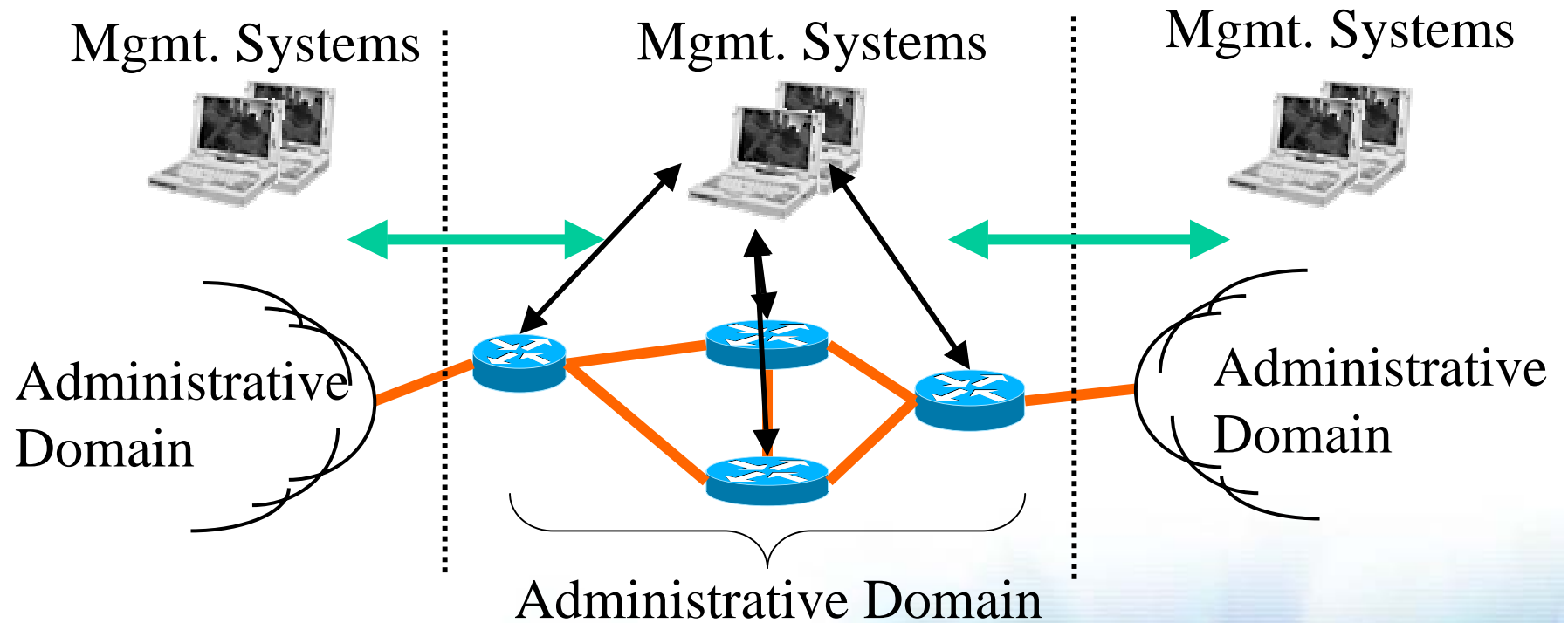
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QoS Management Architecture

- The big picture
- Functionality
- Components
 - Configuration (Policy Server, ...)
 - Admission Control (centralized versus distributed)
 - QoS Routing
 - Metering, measurement -> accounting, charging
- Inter-domain QoS management

Framework for QoS Control in the Internet



 DiffServ Routers
 Physical Connections

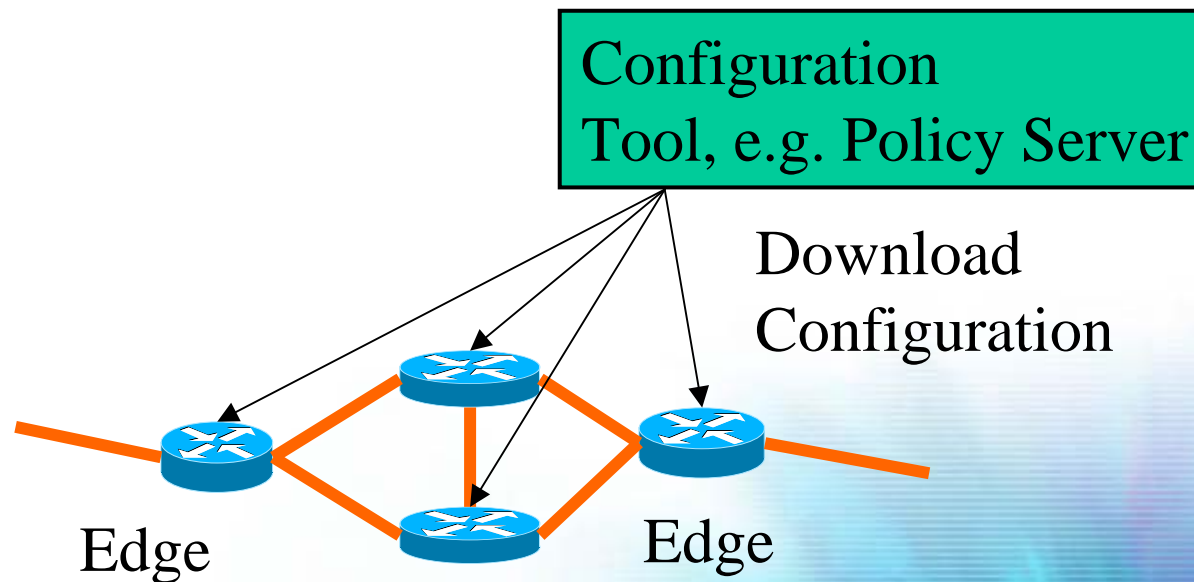
 Service request, negotiation & agreement

Functionality

- During service establishment
 - QoS Mapping (specification to configuration)
 - QoS Negotiation (between customers and providers)
 - Admission Control (resource availability)
 - Access Control (access to the network)
 - Resource Reservation
- During data transfer
 - Traffic shaping
 - Policing (enforcement)
 - Resource separation (classes, flows, users, ...)

(Initial) Configuration

- Each new router in the network gets configured
 - e.g. in DiffServ resource partition between service classes

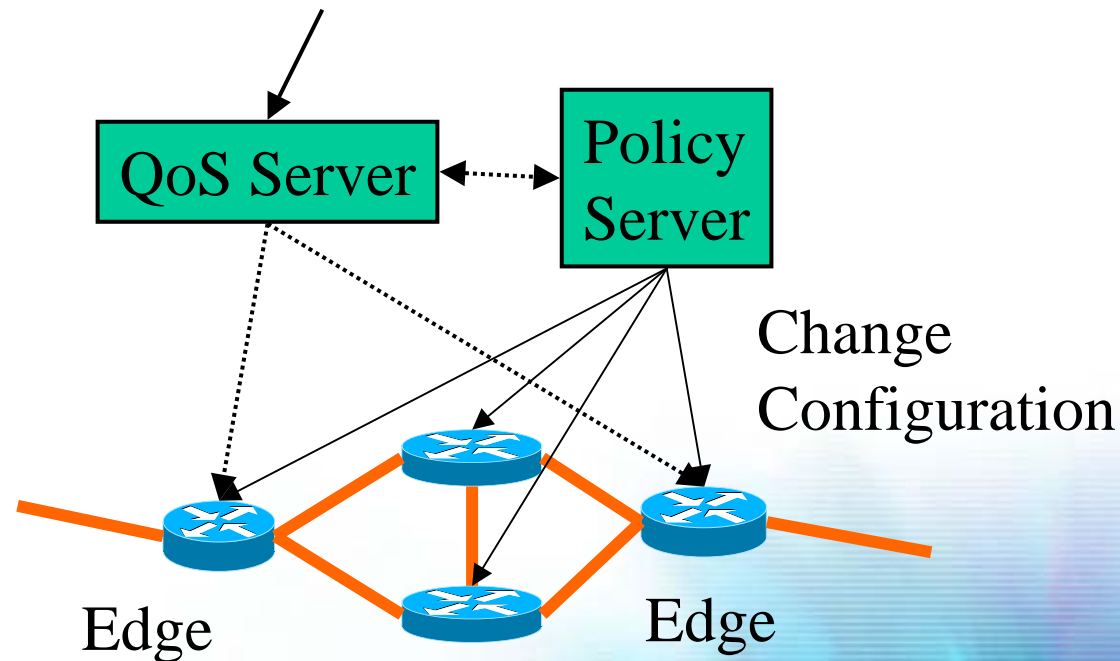


Admission Control

- Input: IP transport service request with guarantees
 - customer, application, network servers, neighboring ISP, etc. request the service
- Output: decision and configuration
 - denied or granted
 - configuration of network performed
 - resource reservation
 - filter configuration etc.
- Centralized vs Distributed Approach

Centralized Admission Control: QoS Server/Bandwidth Broker

Service Request (Service Level Specification)



Bandwidth Broker/ QoS Server

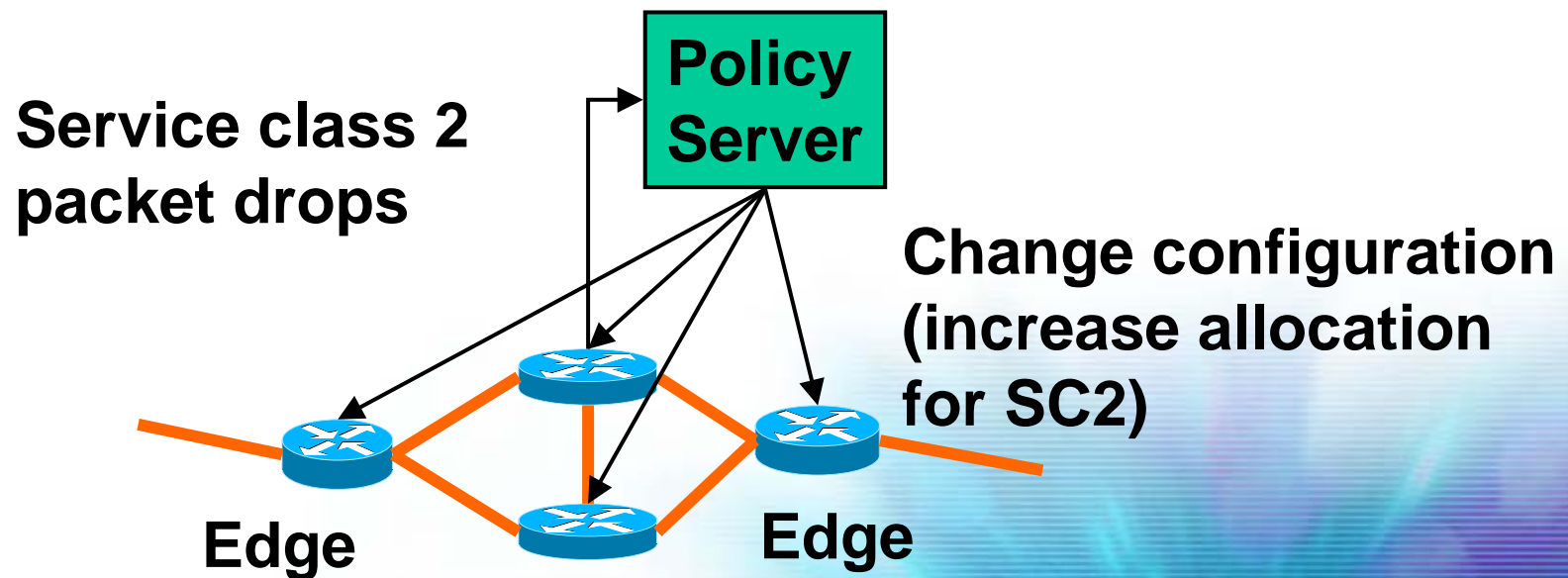
- Gets and processes service request
- Maps the request to edge configurations
 - open network for requesting user
 - determine configuration for policing, shaping, marking
- Performs admission control
 - Are still resources available in the requested service class on the requested path?

Interaction QoS server <-> Policy Server

- Policy Server single point of configuration
 - QoS Server Algorithms (resource management) included
- Policy Server and QoS Server work independent
 - On the same network database or network state
- QoS Server single point of configuration
 - QoS server is under policy control in order to let the high level policies influence the QoS decisions

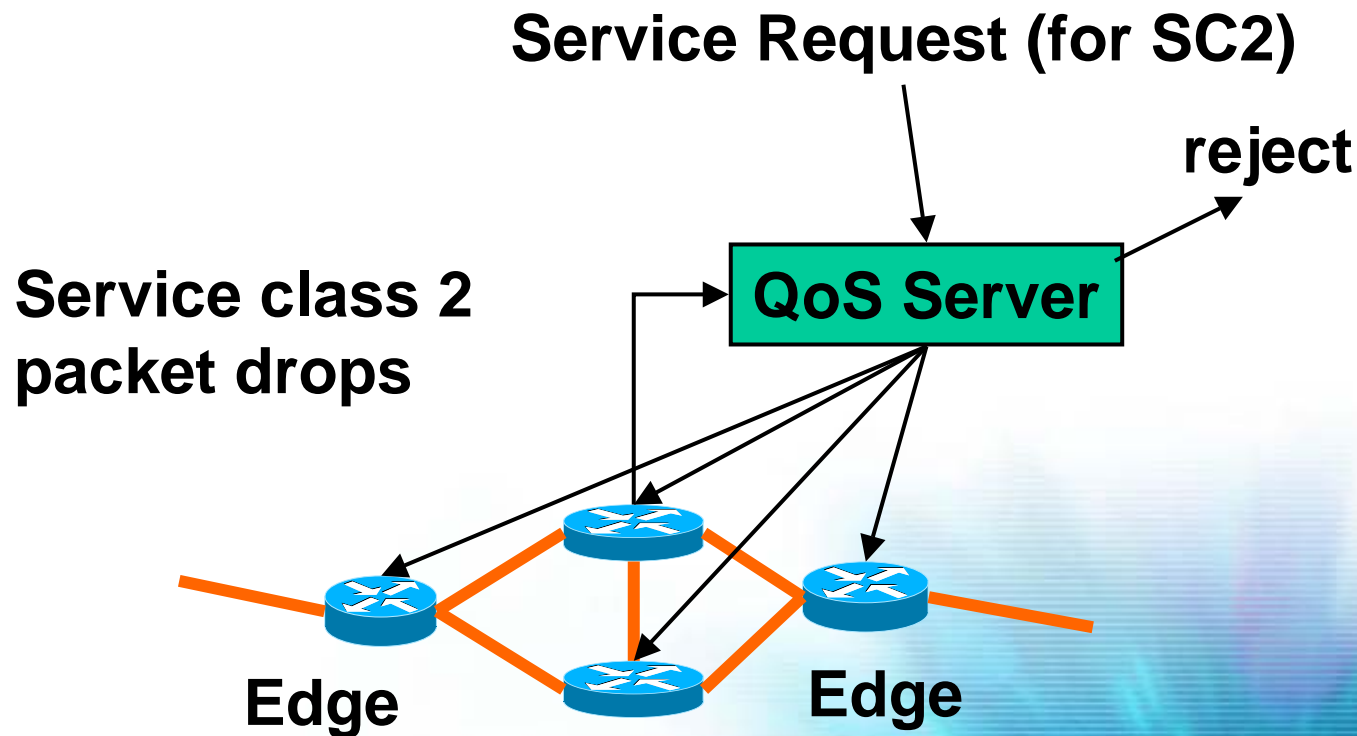
Control Loop based QoS management (1)

- Re-configurations based on network feedback
 - e.g. change resource allocation per service class on congestion



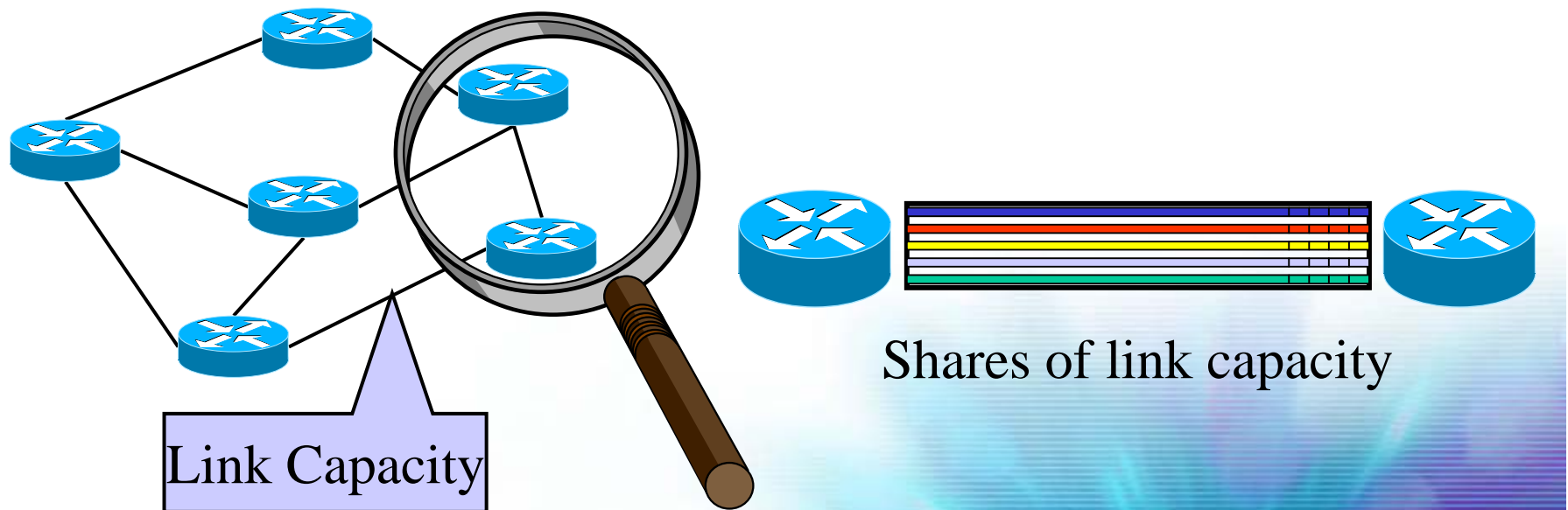
Control Loop based QoS management (2)

- Admission control based on network feedback
 - e.g. detection of a certain amount of packet loss -> no admission of new services



QoS Server for DiffServ (1)

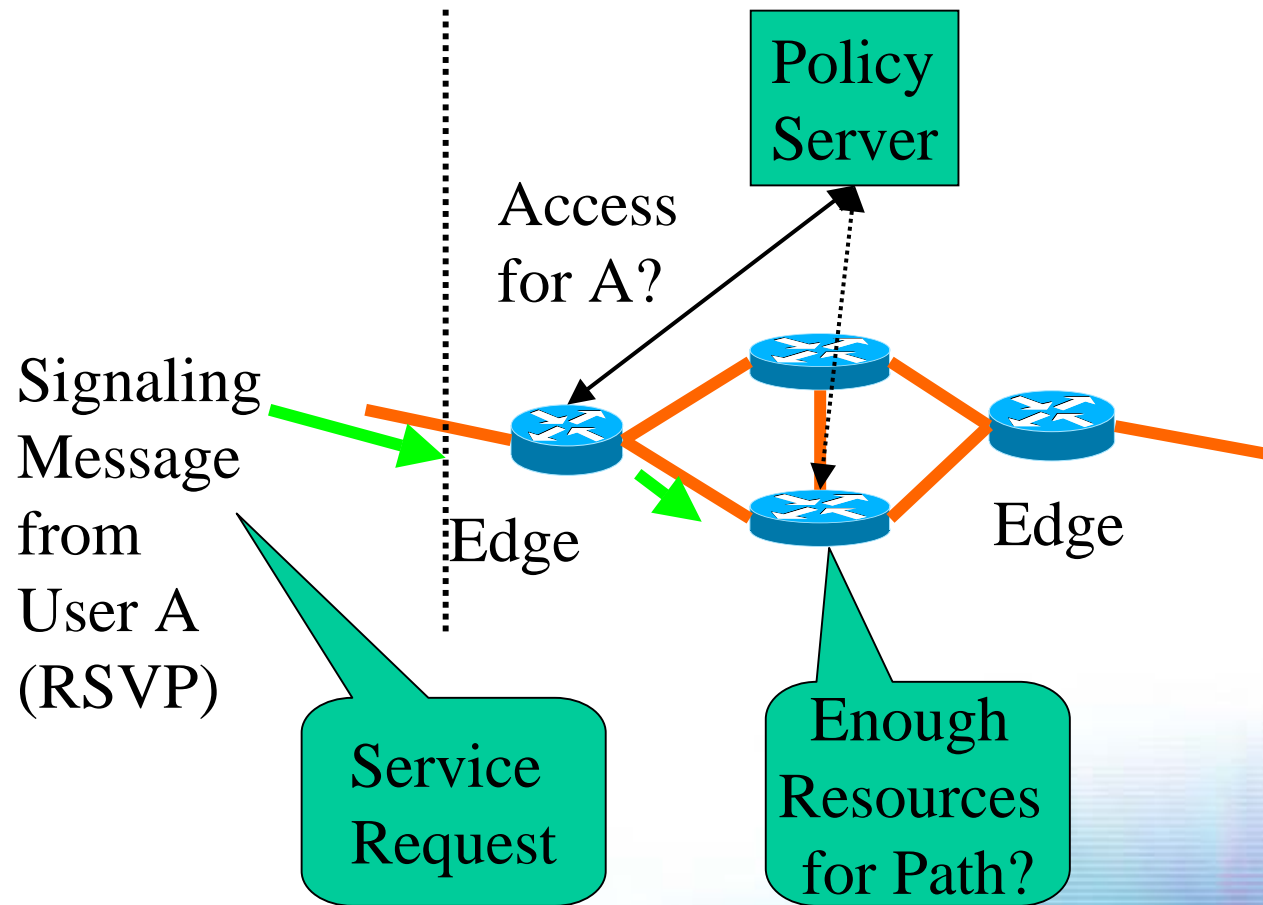
- QoS Server works on network model only
 - network topology (nodes and links) with a set of service classes (allocation per class)
 - Admission Control: check all nodes on path whether there is enough resources on the link and service class
 - reservation within the model



QoS Server for DiffServ (2)

- Different rules for admission control
 - over-booking -> statistical multiplexing -> statistical guarantees
- Handling of Variable Bit Rate service requests
 - different admission rules needed
 - analytical/statistical traffic model taken into account
- Configuration of Policer/Shaper in the ingress router
 - controlled traffic load in the network

Distributed Admission Control (1): Signaling Protocol

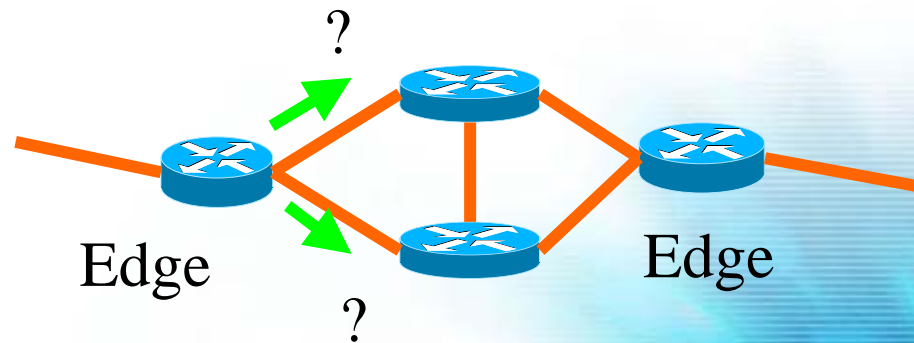


Distributed Admission Control (2)

- The service is requested via a signaling protocol
- Access control (is user allowed to connect)
 - Performed by policy server decision (or AAA server)
 - At edge
- Resource availability is checked at each router on the path
- Resource reservation if performed at each router on the path.

QoS Routing

- Until now, we assumed given routes, based on IP routing protocols
- Now we pro-actively choose the routes
- Routing decision based on resource availability
- Distributed vs Centralized



Centralized QoS Routing

- Performed within Bandwidth Broker/QoS Server using the virtual image of the topology and resource availability
- Routes need to be enforced (e.g. MPLS)
- Issues
 - Needs full topology and resource information at the central place (but is needed in a centralized QoS server anyway)
 - Problems for fast re-routing in case of errors (MPLS switching to backup path)

Distributed QoS Routing

- Performed by signaling and routing protocol
 - resource availability information distributed together with routing information (e.g. OSPF extension)
 - decision on route to be chosen and reserved by the signaling protocol (CR-LDP)
- High routing protocol load due to frequent resource utilization changes
 - reduced number of service classes for routing
 - trade-off between fast resource info distribution and higher deny rate

QoS Measurement

- Goals
 - QoS monitoring (quality management)
 - Control Loop based management
 - Charging, Accounting, Billing
- Problems
 - amount of data
 - association of data to users/customers/service
- Perform metering at the edge
 - edge-to-edge performance measurement
 - less data, easier association

IETF Metering Approaches

- Real Time Flow Measurement (RTFM)
 - SNMP MIB for flow measurement (RFC 2720)
- IP Flow Information eXport WG (IPFIX)
 - export flow information (IP header) out of a router
 - NetFlow (Cisco), LFAP (ex Cabletron), sFlow (InMon), CRANE (Xacct)
- RMON2-MIB (RFC 2021)
- Various MIBs and PIBs for MIB-2, DiffServ, IntServ, MPLS, etc.

Inter-Domain QoS Management

- Service Level Agreement (SLA)
 - contract between two organizations
 - end-to-end or edge-to-edge service contract
 - contains legal, administrative, pricing information
 - e.g. what happens if the service was not provided (pay fine (money, access for free))
 - includes service level specification
 - scope (where)
 - flow description (which packet QoS is enforced)
 - traffic parameters (characteristics of packet stream)
 - performance guarantee (for conformant traffic)

Conclusion

- QoS management versus Over-provisioning
- QoS Deployment
 - profitable business models under investigation
- Technologies not yet mature
 - IntServ not scalable
 - DiffServ/MPLS hard to configure properly
- Many open QoS management issues
- Policy-based management seems to be appropriate
 - but deployment is still slow
- QoS management architecture still under discussion
 - Service Level Agreements
 - end-to-end QoS provisioning
 - overall architecture (integration of components)

Conclusion: Research Issues

- DiffServ configuration strategies
 - how to simplify
 - e.g. reduce configurable parameter set
 - Per-Domain Behavior specification
- Inter-domain QoS service provisioning
 - inter-domain management interface
 - interworking of heterogeneous QoS technologies
- QoS provisioning in different time scales
 - QoS routing: layered MPLS routing
 - aggregation in data and control plane
 - dynamic and static configuration concurrently

Recent IETF activities

- Several activities concerned with QoS have been started among them
 - Next Steps in Signaling (nsis)
 - <http://www.ietf.org/html.charters/nsis-charter.html>
 - IP Flow Information Export (ipfix)
 - <http://www.ietf.org/html.charters/ipfix-charter.html>
 - Packet Sampling WG (psamp)

Additional Information: Books

- Paul Ferguson, Geoff Huston, “Quality of Service”, John Wiley & Sons, 1998, ISBN 0-471-24358-2.
- Geoff Huston, “Internet Performance Survival Guide”, Wiley Computer Publishing, 2000, ISBN 0-471-37808-9.
- Dinesh Verma, “Supporting Service Level Agreements on IP Networks”, MacMillan Technical Publishing, 1999, ISBN 1-57870-146-5.
- David Durham, Raj Yavatkar, “Inside Internet’s Resource reSerVation Protocol”, John Wiley & Sons, 1999, ISBN 0-471-32214-8.
- Kalevi Kilkki, “Differentiated Services for the Internet”, MacMillan Technical Publishing, 1999, ISBN 1-57870-132-5.
- Grenville Armitage, “Quality of Service in IP Networks”, MacMillan Technical Publishing, 2000, ISBN 1-57870-189-9.
- Bruce Davie, Yakov Rekhter, “MPLS - Technology and Applications”, Morgan Kaufmann, 2000, ISBN 1-55860-656-4.

Additional Information WGs

- IETF Working Groups in the Transport and Sub-IP Area
 - Differentiated Services (diffserv),
<http://www.ietf.org/html.charters/diffserv-charter.html>
 - Resource Reservation Setup Protocol (rsvp),
<http://www.ietf.org/html.charters/rsvp-charter.html>
 - Multiprotocol Label Switching (mpls),
<http://www.ietf.org/html.charters/mpls-charter.html>

Additional Information IETF WGs

- IETF Working Groups in the Operations and Management Area
 - Configuration Management with SNMP (snmpconf),
<http://www.ietf.org/html.charters/snmpconf-charter.html>
 - Distributed Management (disman),
<http://www.ietf.org/html.charters/disman-charter.html>
 - Policy Framework (policy),
<http://www.ietf.org/html.charters/policy-charter.html>
 - Resource Allocation Protocol (rap), COPS-related,
<http://www.ietf.org/html.charters/rap-charter.html>

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