CE693: Adv. Computer Networking

L-5 QoS

Acknowledgments: Lecture slides are from the graduate level Computer Networks course thought by Srinivasan Seshan at CMU. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Overview

- Why QOS?
- Integrated services
- Adaptive applications
- Differentiated services

Motivation

- Internet currently provides one single class of **"best-effort" service**
  - No assurances about delivery
- Existing applications are ***elastic***
  - Tolerate delays and losses
  - Can adapt to congestion
- Future "real-time" applications may be ***inelastic***

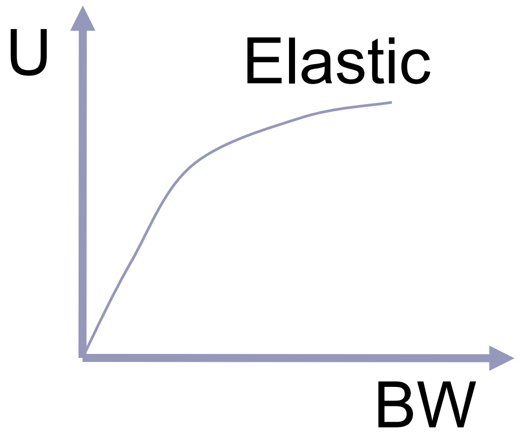
Inelastic Applications

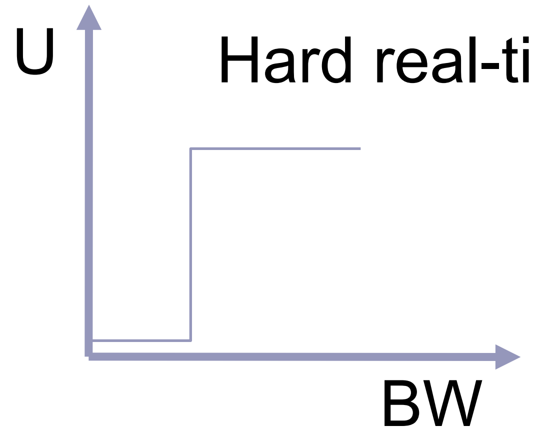
- Continuous media applications
  - **Lower and upper limit** on acceptable performance.
  - BW below which video and audio are not intelligible
  - Internet telephones, teleconferencing with high delay (200 - 300ms) impair human interaction
- Hard real-time applications
  - Require **hard limits on performance**
  - E.g. control applications

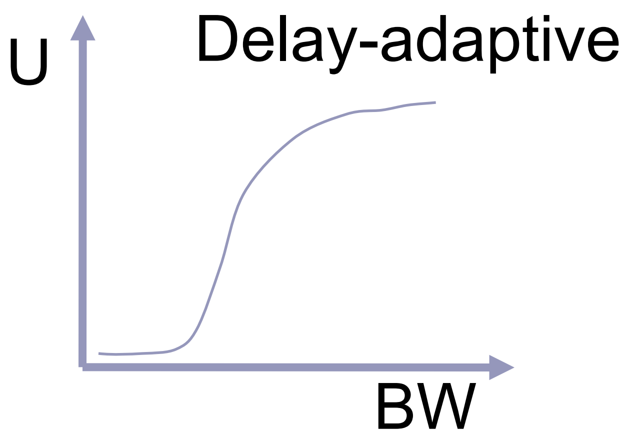
Why a New Service Model?

- What is the **basic objective** of network design?
  - Maximize total bandwidth? Minimize latency?
  - **Maximize user satisfaction** – the total **utility** given to users
- What does utility vs. bandwidth look like?
  - Must be non-decreasing function
  - Shape depends on application

Utility Curve Shapes

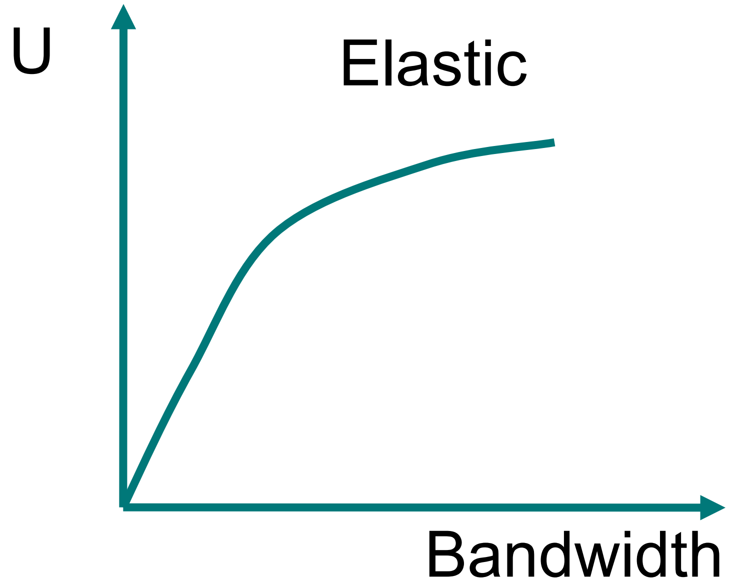






Stay to the right and you are fine for all curves

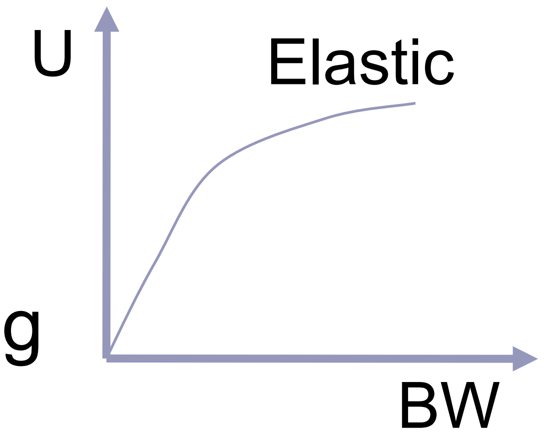
Utility curve – Elastic traffic



Does equal allocation of bandwidth maximize total utility?

Admission Control

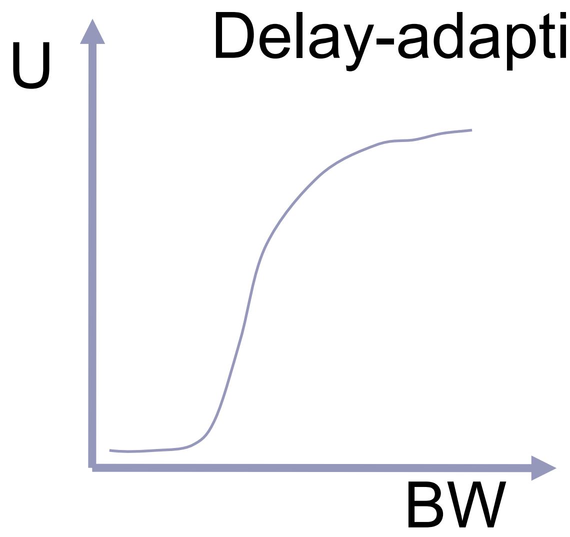
- If U(bandwidth) is concave → elastic applications

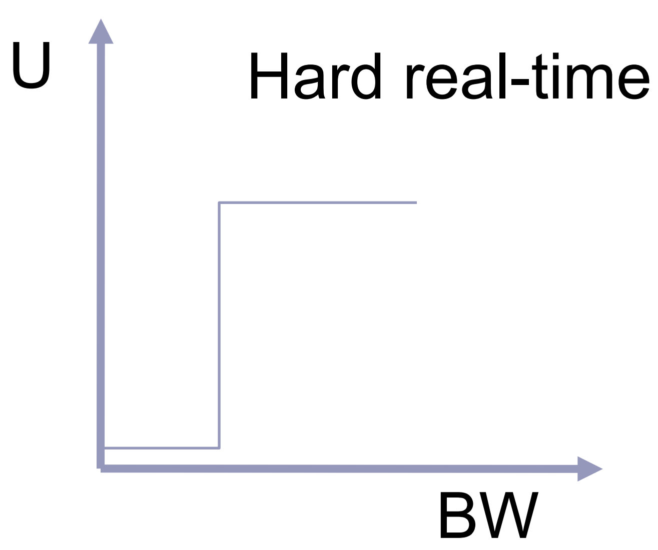


  - Incremental utility is decreasing with increasing bandwidth
  - Is always advantageous to have more flows with lower bandwidth
    - No need of admission control;

  This is why the Internet works!

Utility Curves – Inelastic traffic

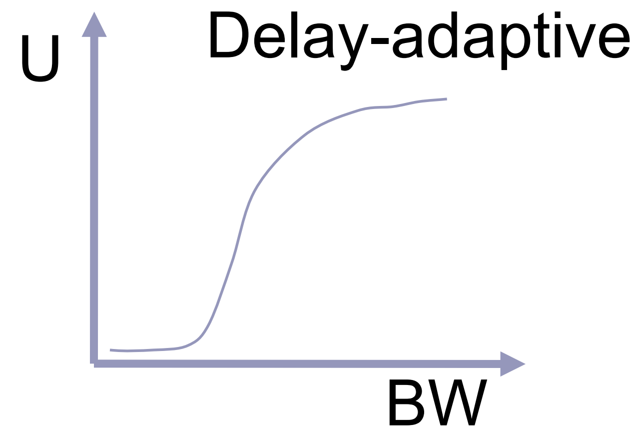




Does equal allocation of bandwidth maximize total utility?

Admission Control

- If U is convex → inelastic applications
  - U(number of flows) is no longer monotonically increasing
  - Need admission control to maximize total utility
- **Admission control** → deciding when the addition of new people would result in reduction of utility
  - Basically avoids overload



Overview

- Why QOS?
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- Adaptive applications
- Differentiated services

Components of Integrated Services

1. **Type of commitment**

   What does the network promise?

2. Packet scheduling

   How does the network meet promises?

3. Service interface

   How does the application describe what it wants?

4. Establishing the guarantee

   How is the promise communicated to/from the network

   How is admission of new applications controlled?

1. Type of commitment

What kind of promises/services should network offer?

Depends on the **characteristics of the applications** that will use the network ….

Playback Applications

- Sample signal → packetize → transmit → buffer → playback
  - Fits most multimedia applications
- Performance concern:
  - Jitter – variation in end-to-end delay
    - Delay = fixed + variable = (propagation + packetization) + queuing
- Solution:
  - Playback point – delay introduced by buffer to hide network jitter

Characteristics of Playback Applications

- In general lower delay is preferable.
- Doesn't matter when packet arrives as long as it is before playback point
- Network guarantees (e.g. bound on jitter) would make it easier to set playback point
- Applications can tolerate some loss

Applications Variations

- Rigid & adaptive applications
  - Rigid – set fixed playback point
  - Adaptive – adapt playback point
    - Gamble that network conditions will be the same as in the past
    - Are prepared to deal with errors in their estimate
    - Will have an earlier playback point than rigid applications
- Tolerant & intolerant applications
  - Tolerance to brief interruptions in service
- 4 combinations

Applications Variations

Really only two classes of applications

1) **Intolerant and rigid**
2) **Tolerant and adaptive**

Other combinations make little sense

3) Intolerant and adaptive
   - Cannot adapt without interruption
4) Tolerant and rigid
   - Missed opportunity to improve delay

So what service classes should the network offer?

Type of Commitments

- **Guaranteed** service
  - For **intolerant and rigid** applications
  - Fixed guarantee, network meets commitment as long as clients send at match traffic agreement
- **Predicted** service
  - For **tolerant and adaptive** applications
  - Two components
    - If conditions do not change, commit to current service
    - If conditions change, take steps to deliver consistent performance (help apps minimize playback delay)
    - Implicit assumption – network does not change much over time
- **Datagram/best effort service**

Components of Integrated Services

1. Type of commitment

   What does the network promise?

2. **Packet scheduling**

   How does the network meet promises?

3. **Service interface**

   How does the application describe what it wants?

4. Establishing the guarantee

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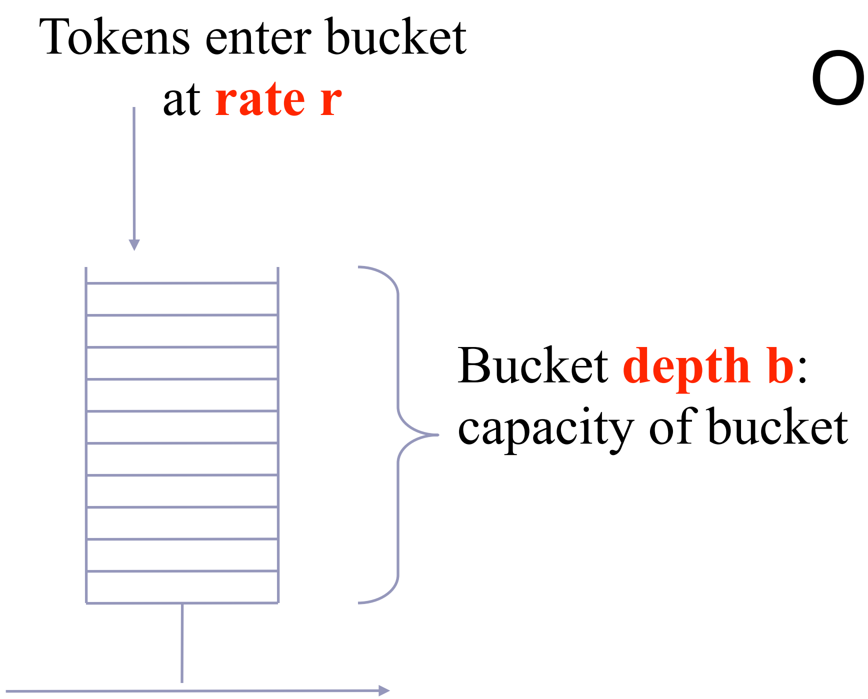
Scheduling for Guaranteed Traffic

- Use **token bucket filter** to characterize traffic
  - Described by rate *r* and bucket depth *b*
- Use **WFQ** at the routers
- Parekh's bound for worst case queuing delay = b/r

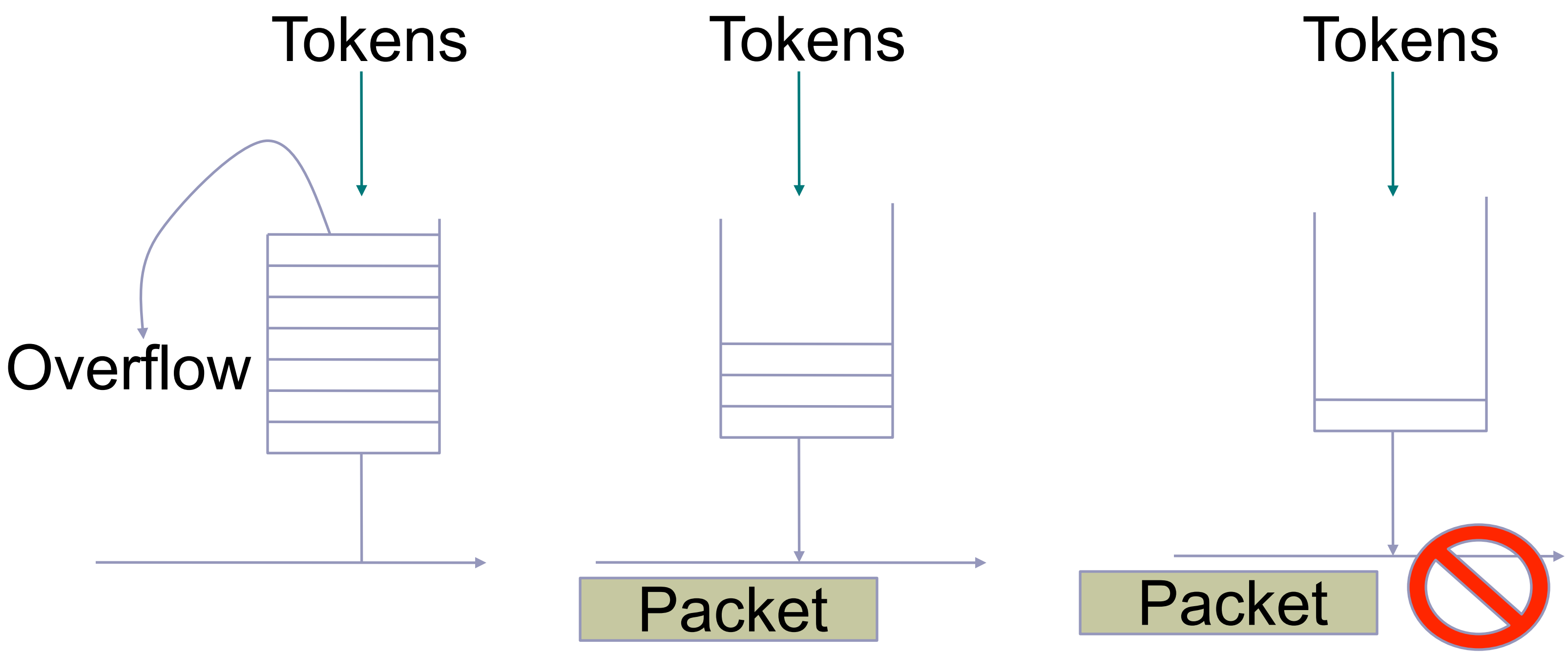
Token Bucket Filter



Operation:

- If bucket fills, tokens are discarded
- Sending a packet of size P uses P tokens
- If bucket has P tokens, packet sent at max rate, else must wait for tokens to accumulate

Token Bucket Operation



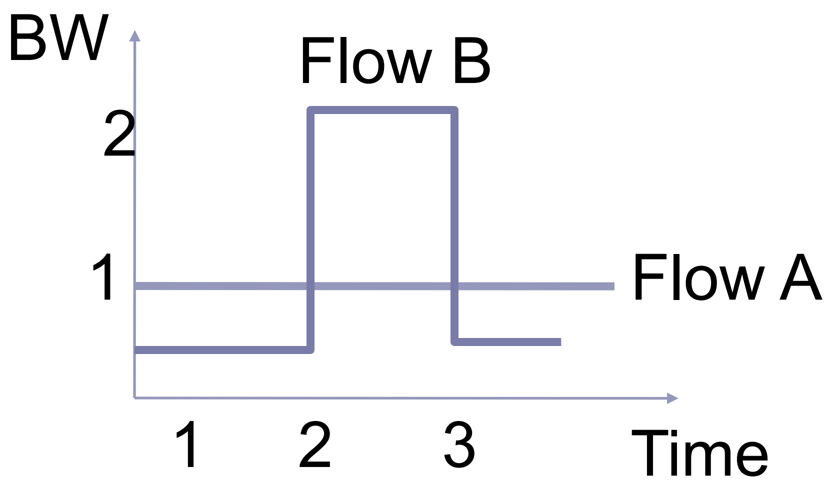
Enough tokens → packet goes through, tokens removed

Not enough tokens → wait for tokens to accumulate

Token Bucket Characteristics

- On the long run, rate is limited to r
- On the short run, a burst of size b can be sent
- Amount of traffic entering at interval T is bounded by:
  - Traffic = b + r*T
- Information useful to admission algorithm

Token Bucket Specs



Flow A: r = 1 MBps, B=1 byte

Flow B: r = 1 MBps, B=1 MB

Predicted Service

Goals:

- Isolation
  - Isolates well-behaved from misbehaving sources
- Sharing
  - Mixing of different sources in a way beneficial to all

Mechanisms:

- WFQ
  - Great isolation but no sharing
- FIFO
  - Great sharing but no isolation

Predicted Service

- FIFO jitter increases with the number of hops
  - Use opportunity for sharing across hops
- FIFO+
  - At each hop: measure average delay for class at that router
  - For each packet: compute difference of average delay and delay of that packet in queue
  - Add/subtract difference in packet header
  - Packet inserted into queues expected arrival time instead of actual
    - More complex queue management!
- Slightly decreases mean delay and significantly decreases jitter

Unified Scheduling

- Assume 3 types of traffic: guaranteed, predictive, best-effort
- Scheduling: use WFQ in routers
- Each guaranteed flow gets its own queue
- All predicted service flows and best effort aggregates in single separate queue
  - Predictive traffic classes
    - Multiple FIFO+ queues
    - Worst case delay for classes separated by order of magnitude
    - When high priority needs extra bandwidth – steals it from lower class
  - Best effort traffic acts as lowest priority class

Service Interfaces

- Guaranteed Traffic
  - Host specifies rate to network
  - Why not bucket size b?
    - If delay not good, ask for higher rate
- Predicted Traffic
  - Specifies (r, b) token bucket parameters
  - Specifies delay D and loss rate L
  - Network assigns priority class
  - Policing at edges to drop or tag packets
    - Needed to provide isolation – why is this not done for guaranteed traffic?
      - WFQ provides this for guaranteed traffic

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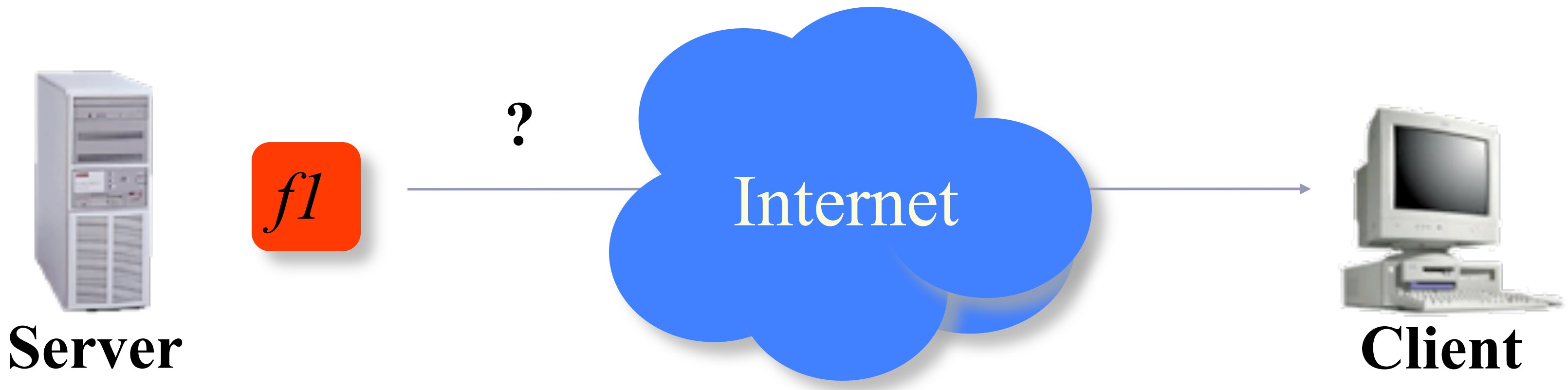
Internet Video Today

- Client-server streaming
  - Skype video conferencing
  - Hulu
- DVD transfer
  - BitTorrent → P2P lecture
- Synchronized video (IPTV)
  - Overlay multicast → multicast lecture

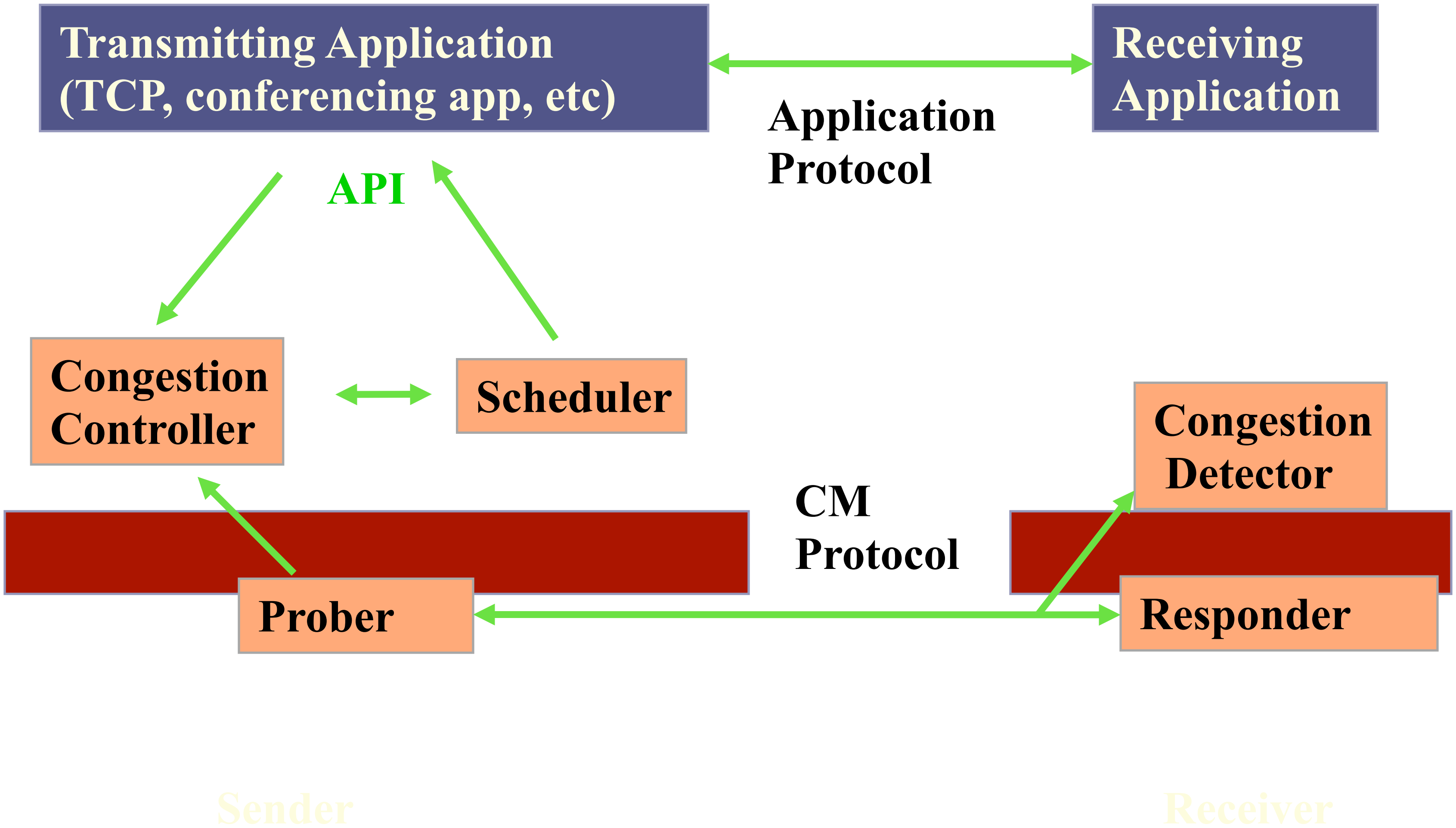
Problems Adapting to Network State



- TCP hides network state
- New applications may not use TCP
  - Often do not adapt to congestion

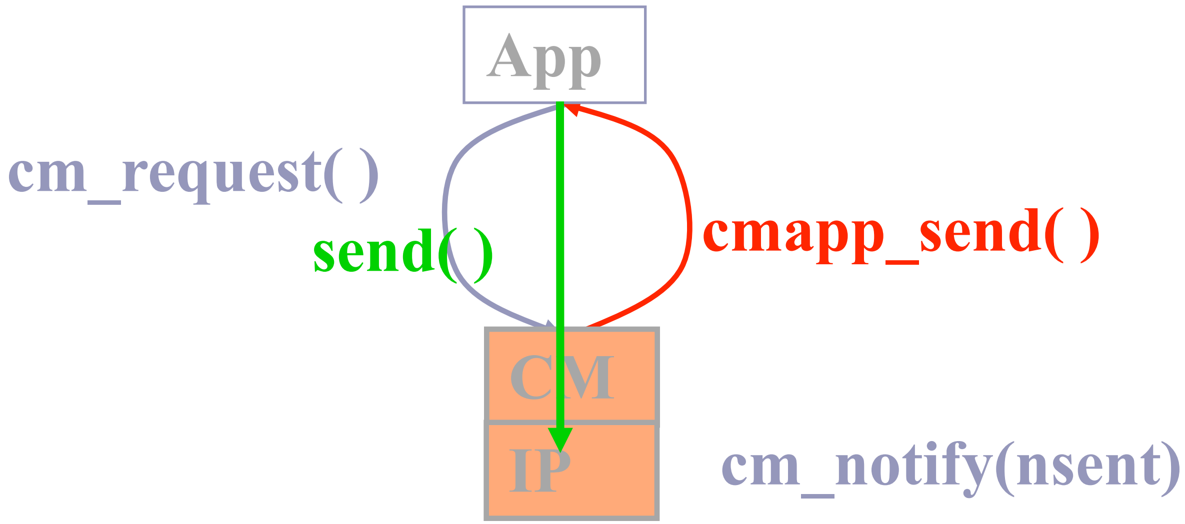
Need system that helps applications learn and adapt to congestion

Congestion Manager Architecture



Transmission API

- Buffered send
  - cm_send(data, length)
- Request/callback-based send



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DiffServ

- Analogy:
  - Airline service, first class, coach, various restrictions on coach as a function of payment
- Best-effort expected to make up bulk of traffic, but revenue from first class important to economic base
- Not motivated by real-time! Motivated by economics and assurances

Basic Architecture

- Agreements/service provided within a domain
  - Service Level Agreement (SLA) with ISP
- Edge routers do traffic conditioning
  - Perform per aggregate shaping and policing
  - Mark packets with a small number of bits; each bit encoding represents a class or subclass
- Core routers
  - Process packets based on packet marking and defined per hop behavior
- More scalable than IntServ
  - No per flow state or signaling

Per-hop Behaviors (PHBs)

- Define behavior of individual routers rather than end-to-end services – there may be many more services than behaviors
- Multiple behaviors – need more than one bit in the header
- Six bits from IP TOS field are taken for Diffserv code points (DSCP)

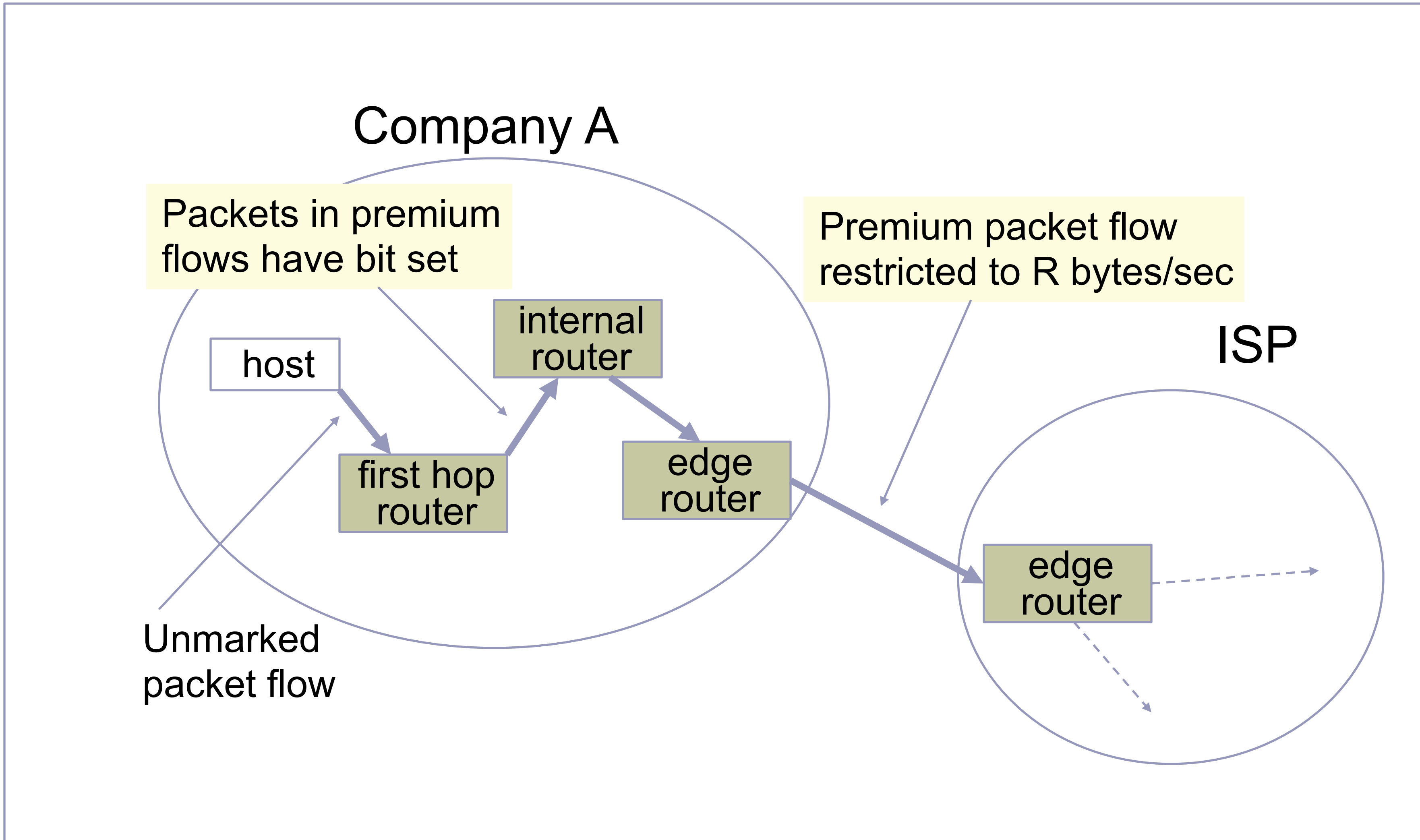
Per-hop Behaviors (PHBs)

- Two PHBs defined so far
- Expedited forwarding aka premium service (type P)
  - Possible service: providing a virtual wire
  - Admitted based on peak rate
  - Unused premium goes to best effort
- Assured forwarding (type A)
  - Possible service: strong assurance for traffic within profile & allow source to exceed profile
  - Based on expected capacity usage profiles
  - Traffic unlikely to be dropped if user maintains profile
  - Out-of-profile traffic marked

Expedited Forwarding PHB

- User sends within profile & network commits to delivery with requested profile
  - Signaling, admission control may get more elaborate in future
- Rate limiting of EF packets at edges only, using token bucket to shape transmission
- Simple forwarding: classify packet in one of two queues, use priority
  - EF packets are forwarded with minimal delay and loss (up to the capacity of the router)

Expedited Forwarding Traffic Flow



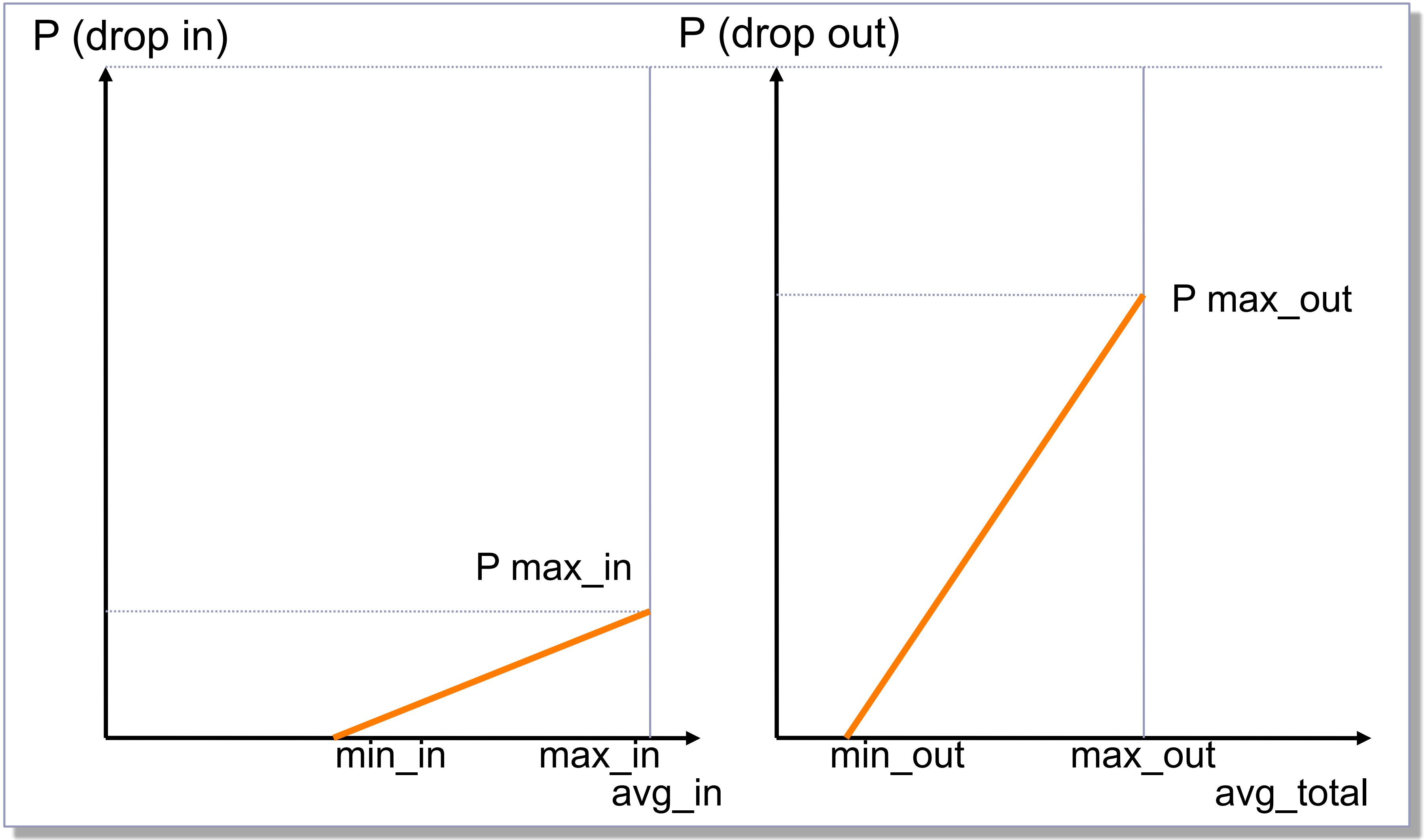
Assured Forwarding PHB

- User and network agree to some traffic profile
  - Edges mark packets up to allowed rate as “in-profile” or low drop precedence
  - Other packets are marked with one of 2 higher drop precedence values
- A congested DS node tries to protect packets with a lower drop precedence value from being lost by preferably discarding packets with a higher drop precedence value
  - Implemented using RED with In/Out bit

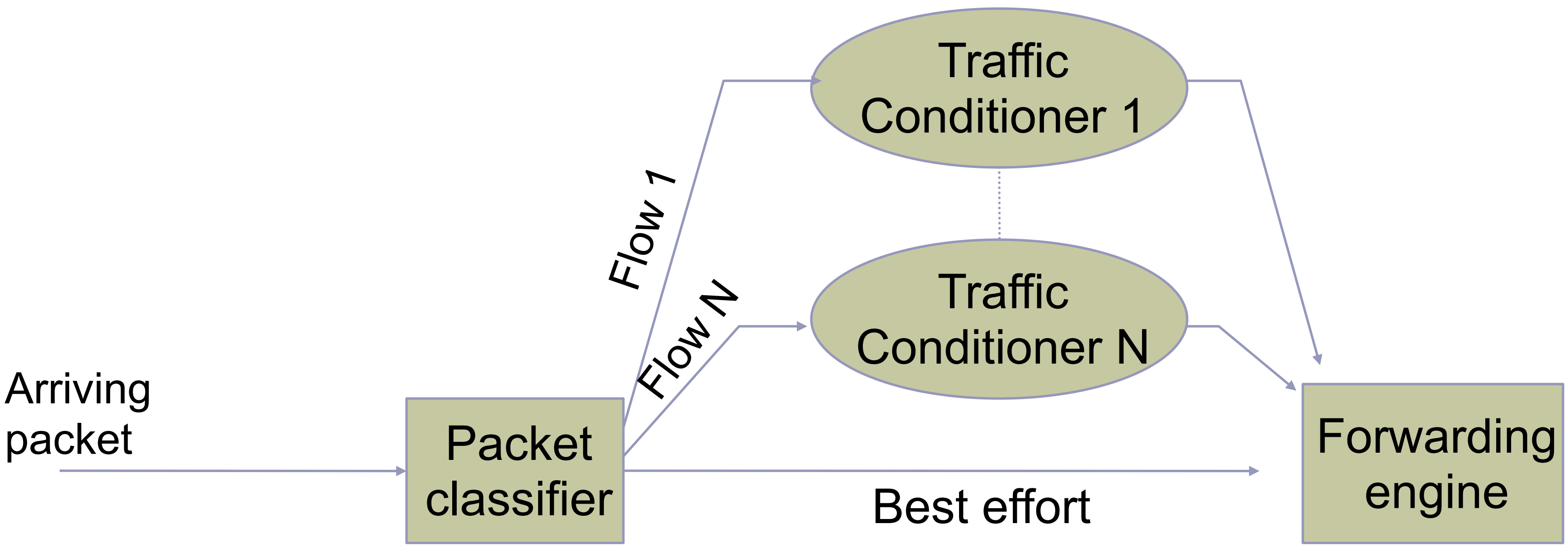
Red with In or Out (RIO)

- Similar to RED, but with two separate probability curves
- Has two classes, “In” and “Out” (of profile)
- “Out” class has lower Min_{thresh}, so packets are dropped from this class first
  - Based on queue length of all packets
- As avg queue length increases, “in” packets are also dropped
  - Based on queue length of only “in” packets

RIO Drop Probabilities

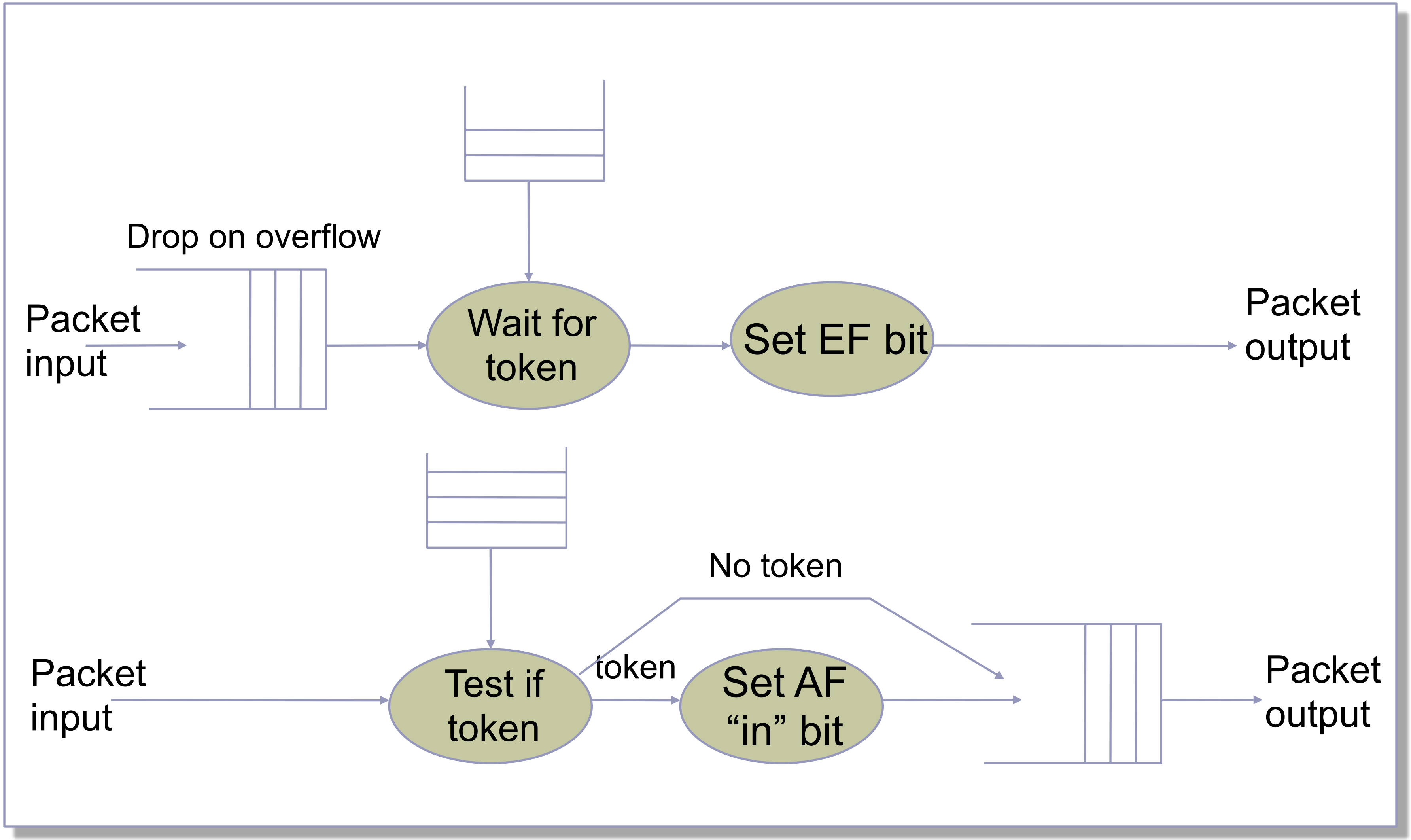


Edge Router Input Functionality



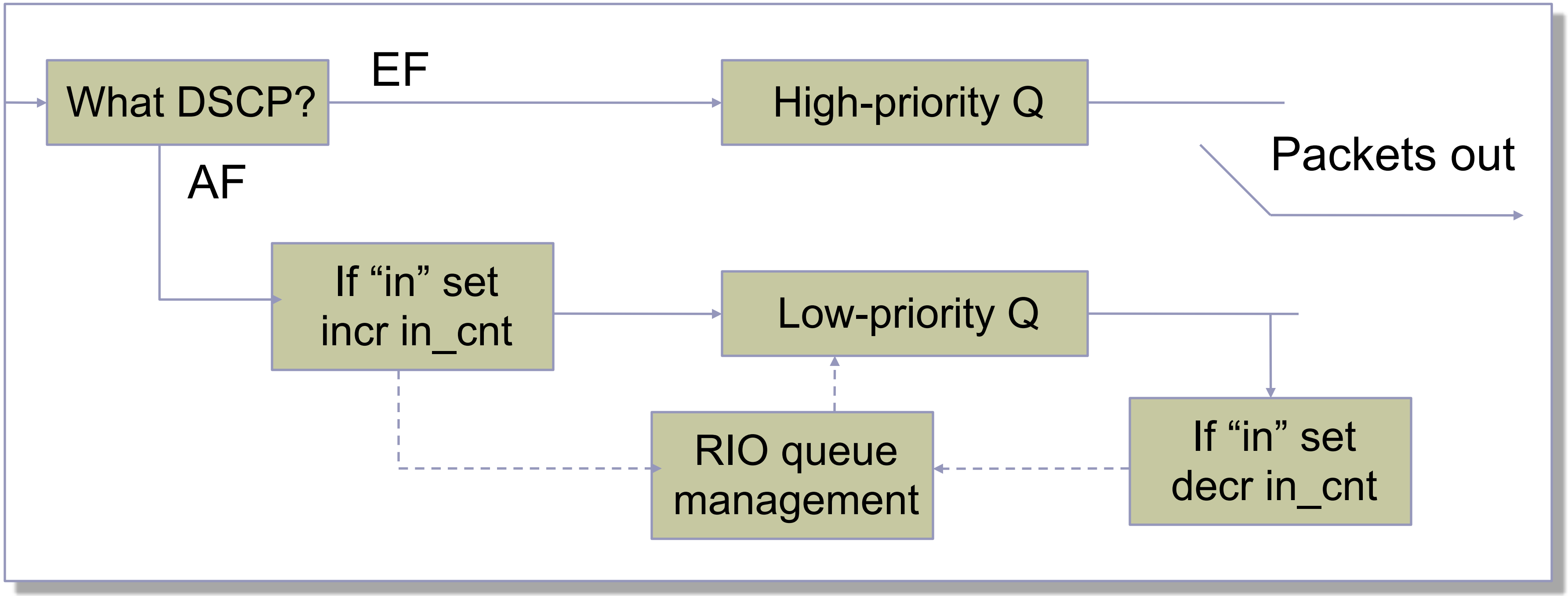
classify packets based on packet header

Traffic Conditioning

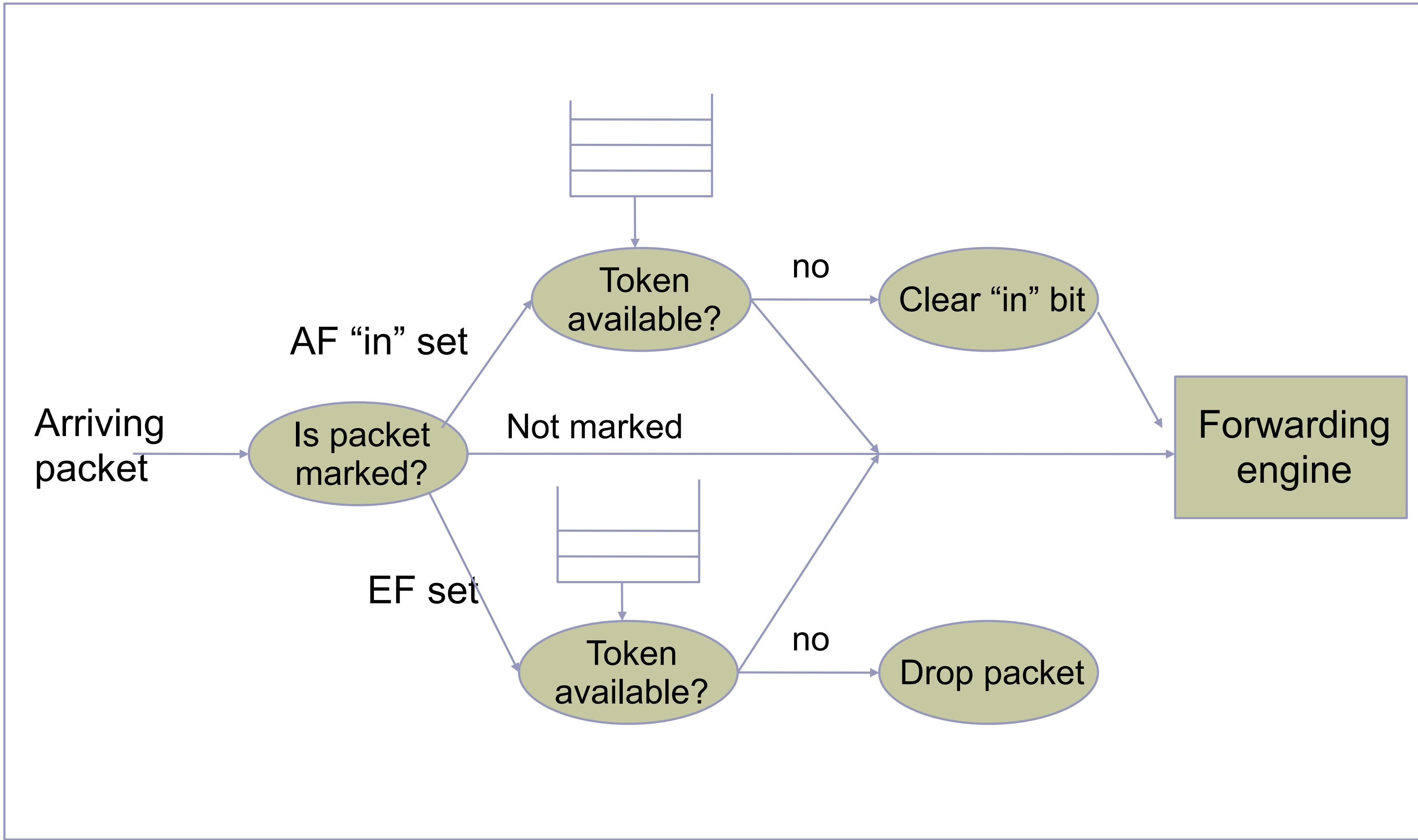


Router Output Processing

- 2 queues: EF packets on higher priority queue
- Lower priority queue implements RED “In or Out” scheme (RIO)



Edge Router Policing



Comparison

	Best-Effort	Diffserv	Intserv
Service	• Connectivity • No isolation • No guarantees	• Per aggregation isolation • Per aggregation guarantee	• Per flow isolation • Per flow guarantee
Service Scope	• End-to-end	• Domain	• End-to-end
Complexity	• No set-up	• Long term setup	• Per flow setup
Scalability	• Highly scalable • (nodes maintain only routing state)	• Scalable (edge routers maintains per aggregate state; core routers per class state)	• Not scalable (each router maintains per flow state)

Next Lecture: Router Design

- Forwarding
- IP lookup
- High-speed router architecture
- Readings
  - [McK97] A Fast Switched Backplane for a Gigabit Switched Router
  - [KCY03] Scaling Internet Routers Using Optics
  - Know RIP/OSPF