EE 122:
Quality of Service and Resource Allocation

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Limitations of IP Architecture in Supporting Resource Management

- IP provides only best effort service
- IP does not participate in resource management
  - Cannot provide service guarantees on a per flow basis
  - Cannot provide service differentiation among traffic aggregates
- Early efforts
  - Tenet group at Berkeley (Ferrari and Verma)
  - Asynchronous Transfer Mode (ATM)
- IETF (Internet Engineering Task Force) efforts
  - Integrated services initiative
  - Differentiated services initiative
Service Classes

- Multiple service classes
- Service can be viewed as a contract between network and communication client
  - End-to-end service (multicast and anycast)
  - Other service scopes possible, e.g.,
    - Aggregates – all packets between to points (not necessary end-hosts) in the Internet
- Three common services
  - Best-effort (“elastic” applications)
  - Hard real-time (“real-time” applications)
  - Soft real-time (“tolerant” applications)
Example: Integrated Services

- Enhance IP’s service model
  - Old model: single best-effort service class
  - New model: multiple service classes, including best-effort and QoS classes

- Create protocols and algorithms to support new service models
  - Old model: no resource management at IP level
  - New model: explicit resource management at IP level

- Key architecture difference
  - Old model: stateless
  - New model: per flow state maintained at routers
    - Used for admission control and scheduling
    - Set up by signaling protocol
QoS Network

- Flow or session as QoS abstractions
- Each flow has a fixed or stable path
- Routers along the path maintain the state of the flow
QoS Network Operations

- Control plane: admission control
  - Reserve resources (i.e., link capacity and buffer space) at every router along the path

- Data plane: perform per flow
  - Classification: classify each packet to the flow it belongs to
  - Buffer management: decide when and which packet to drop
  - Packet scheduling: decide when and which packet to send
Control Plane: Admission Control

- Example: achieve per-flow bandwidth and delay guarantees
  - Example: guarantee 1MBps and < 100 ms delay to a flow
Control Plane: Admission Control

- Allocate resources - perform per-flow admission control
Control Plane: Admission Control

- Install per-flow state
Control Plane: Admission Control

- Install per flow state
Data Plane

- Per-flow classification
Data Plane

- Per-flow buffer management
Data Plane

- Per-flow scheduling
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Service Specification

- **Loss**: probability that a flow’s packet is lost
- **Delay**: time it takes a packet’s flow to get from source to destination
- **Delay jitter**: maximum difference between the delays experienced by two packets of the flow
- **Bandwidth**: maximum rate at which the source can send traffic
Hard Real Time: Guaranteed Services

- **Service contract**
  - Network to client: guarantee a deterministic upper bound on delay for each packet in a session
  - Client to network: the session does not send more than it specifies

- **Algorithm support**
  - Admission control based on worst-case analysis
  - Per flow classification/scheduling at routers
Soft Real Time: Controlled Load Service

- **Service contract:**
  - Network to client: similar performance as an unloaded best-effort network
  - Client to network: the session does not send more than it specifies

- **Algorithm Support**
  - Admission control based on measurement of aggregates
  - Scheduling for aggregate possible
Traffic and Service Characterization

- To quantify a service one has two know
  - Flow’s traffic arrival
  - Service provided by the router, i.e., resources reserved at each router

- Examples:
  - Traffic characterization: token bucket
  - Service provided by router: fix rate and fix buffer space
Token Bucket

- Characterized by three parameters (b, r, R)
  - b – token depth
  - r – average arrival rate
  - R – maximum arrival rate (e.g., R link capacity)
- A bit is transmitted only when there is an available token
  - When a bit is transmitted exactly one token is consumed

\[ \text{bits} = \frac{b \cdot R}{R-r} \]

\[ \text{slope } R \]

\[ \text{slope } r \]
Characterizing a Source by Token Bucket

- Arrival curve – maximum amount of bits transmitted by time $t$
- Use token bucket to bound the arrival curve
Example

- Arrival curve – maximum amount of bits transmitted by time $t$
- Use token bucket to bound the arrival curve

![Diagram showing arrival curve and token bucket](image-url)

(b = 1, r = 1, R = 2)
Per-hop Reservation

- Given $b, r, R$ and per-hop delay $d$
- Allocate bandwidth $r_a$ and buffer space $B_a$ such that to guarantee $d$
End-to-End Reservation

- Source S sends a message containing traffic characteristics
  - r,b,R
  - This message is used to compute the number of hops
- Receiver R sends back this information + worst-case delay (D)
- Each router along path provide a per-hop delay guarantee and forwards the message
  - In simplest case routers split the delay D

\[(b,r,R,0,0)\]  \[\rightarrow\]  \[(b,r,R,1,D-d_1-d_2)\]  \[\rightarrow\]  \[(b,r,R,2,D-d_1)\]  \[\rightarrow\]  \[(b,r,R,3)\]  \[\rightarrow\]  \[(b,r,R,3,D)\]

num hops  \[\downarrow\]

worst-case delay
Summary

- Service: a contract between end-hosts and network
- QoS goal: provide better than best-effort services to support new applications with more stringent delay and bandwidth requirements, e.g., IP telephony, videoconferencing
- QoS requires to manage flows/aggregates both on data and control plane
- Two major proposals:
  - Integrated Services
  - Differentiated Services