EECS 122, Lecture 26

Today's Topics:

Introduction to Quality of Service

Traffic Regulation and Scheduling

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Another Look at Sharing

- Computer network are shared resources, leading to contention
- By specific allocation of resources to entities (individuals, traffic classes), can adjust the quality of service provided
- QoS important in an economically-driven environment with limited resources
- Upshot: more $ will probably get you better QoS

Problem Set #5 (the last)

- Peterson & Davie
  - Ch 8: 16, 19
  - Ch 9: 15, 16
  - Reading: p.368-378, 382-386
  - Ch 7: 21, 22
  - Due May 6

Why QoS Anyhow?

- Assumption of 2 types of applications:
  - elastic (adapt to available resources)
  - guaranteed/in-elastic (non-adaptable)
- Service provided
  - elastic apps are usually ok with best-effort service model
  - in-elastic apps may be unusable if not given enough bandwidth or too high delay (audio)

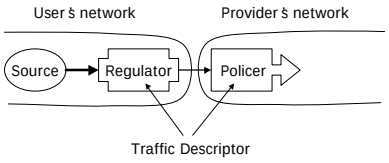
Basic Service Model

- Assume that a server provides access to a resource, and incoming requests are queued in a service queue
- Requests may contain traffic descriptors describing desired Quality of Service
- Servers use a scheduling discipline to determine which request to provide service to next

Expressing Reservations

- For applications wishing to reserve network resources, need two items:
  - traffic descriptor (TD): QoS parameters
  - signaling protocol: a way to indicate the TD to the network/service
- Traffic descriptor used in 3 ways:
  - traffic contract (used for $ and legal)
  - input to regulator
  - input to policer

Traffic Regulation and Policing



- Policer and regulator basically identical except for their location, and that a regulator usually only delays traffic (rather than dropping it)

Common Traffic Descriptors

- Peak Rate: maximum source rate
  - for fixed size pkts: inverse of inter-pkt time (time between start of each packet)
  - for variable size: max rate over some period
  - easy to compute and police, but very sensitive to outliers, so useful by itself only for networks with smooth traffic
- Average rate: average over some time
  - [t, a]: a bits may be sent over a window of time t

Average Rate Descriptor Window

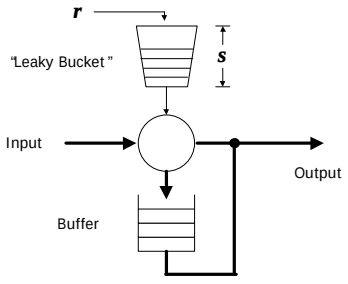
- For [t, a] average rate descriptor, how should the window work?
- Jumping window
  - source will not inject more than a bits in hops of time t
  - sensitive to start time
- Moving window
  - source will not inject more than a bits in any window of time t (not sensitive to start time)

Linear Bounded Arrival Processes (LBAPs)

- An LBAP-constrained source bounds the number of bits it transmits in any interval of length *t* by a linear function of *t*. The number of bits transmitted in any interval of length $t \leq \rho t + \sigma$
- *r* is roughly the long-term average rate allocated by the net to the source and ***s*** the longest burst a source may send, given the choice of *r*

Leaky Bucket Regulators

- Regulates an LBAP descriptor



Leaky Bucket Operation

- Leaky bucket accumulates fixed-size *tokens* in a *token bucket*
- Transmits a packet (from buffer, if any are there) or arriving packet only if the sum of the token sizes in the bucket add up to the packet size
- More tokens are periodically added to the bucket (at rate *r*). If tokens are to be added when the bucket is full, they are discarded.

Properties of Leaky Bucket

- Can think of this as a single-server queuing system with constant service rate
- Can act as peak rate or moving-window average rate regulator
  - peak-rate reg if r =peak rate, s =1
  - ave-rate reg if r =avg rate, s =1
- Can act as policer (no packet buffer)

Properties of Leaky Bucket

- Does not bound the peak rate of small bursts (sometimes augmented for this)
  - because bucket may contain enough tokens to cover a complete burst size
- Performance [loss rate] depends only on the sum of the packet buffer size and the token bucket size (one trades off the other exactly)

Example

- 2 tokens of size 100 bytes added to bucket of capacity 500 each second
  - avg rate=200 bytes/s, largest burst size is 500 bytes, peak rate is unbounded (500 bytes can be transmitted arbitrarily fast)
  - can never send packets bigger than 500 bytes
  - if a 400 byte packet arrives when bucket contains 200 bytes of tokens, will have to wait between just over 0.5 and 1 sec to send

Constructing End-to-End QoS

- In combination with packet scheduling, regulation/policing can be used to achieve end-to-end Quality of Service…
- How to do the scheduling?

What Can be Scheduled?

- Given an output link scheduler, can allocate:
  - mean delay (using service order)
  - bandwidths (using service ratios)
  - loss rates (adjusting buffering)
- For individual application requirements, need a per-flow reservation/allocation capability

Scheduling Disciplines

- Really two parts:
  - service ordering (who goes when)
  - loss rate allocation (who to delete/drop)
- For networking, want to allocate:
  - link bandwidth
  - buffer space
- Most published results are studies of output queues to links operating at the network layer

Requirements of a Scheduler

- Ease of implementation
  - both best-effort and guaranteed traffic
- Fairness and protection (for best-effort)
- Performance bounds (for guaranteed)
- Ease and efficiency of corresponding admission control procedure

Ease of Implementation

- Scheduling choices are made per-packet
  - map packet to flow/connection
  - want O(1) not O(N) scaling [N connections]
- Execution time considerations
  - algorithm itself may run fast
  - issue is amount of scheduling state (variables, records, pointers, etc) and how long it takes to access these…
  - memory bandwidth/latency issues

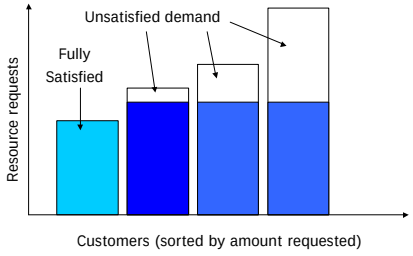
Protection and Fairness

- Best effort flows may affect others:
  - especially when congestion-controlled flows (eg TCP) compete against non-congestion-controlled flows (eg UDP)
  - protection provides local isolation
- Fairness
  - local notion of fair meaning equal
  - commonly, the max-min fairness criteria

Max-Min Fairness Criteria

- How to share equally with different resource demands
  - small users will get all they want
  - large users will evenly split the rest
- More formally, perform this procedure:
  - resource allocated to customers in order of increasing demand
  - no customer receives more than requested
  - customers with unsatisfied demands split the remaining resource

Water-Filling Analogy



Max-Min Weighted Fair Share

- Can extend basic max-min fairness with a weight vector $\vec{w} \quad (w_1, w_2, \ldots, w_n)$
- Now can prefer some customers to others:
  - resource allocated to customers in order of increasing demand, normalized by weight
  - no customer receives more than requested
  - customers with unsatisfied demands split the remaining resource in proportion to their weights

Max-Min Example

- demands: 2, 2.6, 4, 5; capacity: 10
  - 10/4=2.5 looks good, but 1st customer needs only 2, so excess of 0.5, distribute among 3, so 0.5/3=0.167
  - now we have allocs of [2, 2.67, 2.67, 2.67], leaving an excess of 0.07 for cust #2
  - divide that in two, gets [2, 2.6, 2.7, 2.7]
- Maximizes the minimum share to each customer whose demand is not fully satisfied

Weighted Max-Min Example

- demands: 4, 2, 10, 4; capacity(C): 16; weight vector $\vec{w}$ $(2.5,4,0.5,1)$
  - first normalize weights so that minimum weight is 1: $\vec{w}$ $2\vec{w}$ $(5,8,1,2)$
  - use sum of normalized weights n as # custs
  - C/n=16/16=1 -> alloc 1 $\vec{w}$ $(5,8,1,2)$
  - 7 extra to go to custs #3 and #4 (by weight)
  - 7/3=2.3, so add (0,0,2.33,4.66)
  - with (4,2,3.33,6.66), give #4's excess to #3
  - final allocation is (4, 2, 6, 4)

Performance Bounds

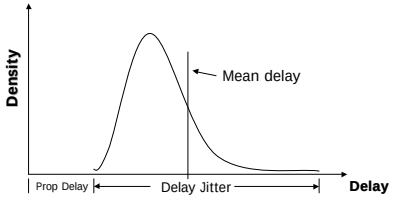
- For guaranteed service, scheduler should support end-to-end performance bounds as requested by applications and possibly controlled by network admin
- Types of performance bounds
  - deterministic: always holds
  - statistical: holds with some probability over some space. Ways of expressing this:
    - numbers (like 98% of green pkts delivered)
    - one-in-N (at most 1 in 100 pkts dropped)

Common Performance Bounds

- Bandwidth
  - some minimum bandwidth over some time
  - some systems provide only these types
- Delay
  - bound on some parameter of the delay distribution
    - worst-case delay
    - (measured/sampled) mean delay
    - 99-percentile of delay

Common Performance Bounds-2

- Delay-jitter
  - difference between largest and smallest delay seen by packets on a connection
- End-to-End delay distribution:



Common Performance Bounds-3

- Loss bound
  - requires the fraction of packets lost over a connection to be less than some bound
  - can achieve zero loss bound with good admission control

Choices in Scheduler Design

- Number of priority levels/classes
- Work conserving or non-work-conserving
- Degree of aggregation within a level
- Service order within a level

Priority Scheduling

- each connection gets a priority level
  - n priority levels total
  - service highest (to exhaustion) first, then on to next, etc [simple priority]
  - in worst case, leads to starvation [hence need for admission control]
  - in practice, only a few levels used (say, 3; one for network control, 1 for high priority and 1 for lower priority)

Work Conserving or Not

- Work-conserving scheduling is idle only when there is no traffic to send
- Non-work-conserving may be idle at any time, in an effort to smooth out the traffic pattern
  - limits buffer requirements at receiver
  - contributes to longer overall delay

Non-Work-Conserving Approach

- Other advantages
  - sum of per-hop bounds can tightly bound the end-to-end delay and delay-jitter
  - if performed at each hop, works on heterogeneous networks
- Idea is to compute packet eligibility time
  - time at which a packet is eligible to be sent out the link to maintain desired traffic characteristics

Eligibility Time Computations

- Rate-jitter regulation
  - scheduler guarantees traffic departing switch obeys a rate descriptor [peak rate regulator]

$$E(1) \quad A(1)$$
$$E(k+1) \quad \max(E(k) + X_{\min}, A(k+1))$$

- E(k)=eligibility time of kth packet, A(k)=arrival time of kth packet at scheduler,Xmin=inverse of peak rate

Eligibility Time Computations

- Delay-jitter regulation
  - scheduler guarantees sum of queuing delay in previous switch and regulation delay in current switch are constant. Removes the effect of variability in queuing delay in previous switch

$$E(0,k) \quad A(0,k)$$
$$E(i+1,k) \quad E(i,k) + D + L$$

- E(i,k)=eligibility time of kth packet at switch i, D=delay bound at previous switch, L is largest possible delay on [i,i+1] link

Perspective

- Delay-jitter harder to implement
  - network operator must know bound on prop delay of each link
  - must maintain synchronized clocks at switches
  - provides perfect traffic reconstruction, but may be only of academic interest
- The real-world
  - none of the non-work-conserving disciplines are in use, or are currently really proposed

Aggregation

- Degree of "grouping" used for scheduling
  - max aggregation: single state for all
  - min aggregation: state for each connection
  - in between: classes [will be important later]
- Benefits
  - less scheduler state (good for implementation and for advertising info in routing protocols)
  - evenly distributes the jitter induced by bursts due to other members of the class

Service Order

- Straightforward: either in-order or not in order. If not in-order, must be tagged and essentially sorted according to some ordering.
- With FCFS, cannot have higher-priority jump ahead of low priority traffic
- FCFS also does not achieve max-min fairness (rewards bandwidth hogs)