Adaptive Scheduling for quality differentiation

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Outline

- Introduction
- Contribution
- Differentiation models
- Packet schedulers
- Simulation model
- Simulation results
- Conclusions
- Current and future work

Introduction

- The Internet has developed from a research network into a multiservice network
  - diverse applications and customers
- New QoS schemes are required
  - Packet scheduler is a key component in QoS provisioning
    - shares the common resources by deciding the order at which packets are served

Contribution

- Starting point:
  - Service differentiation is based on DiffServ architecture
- We study two important differentiation models
  - Capacity and delay differentiation
- We propose schedulers for implementing these models
- By simulations we evaluate
  - The viability of the differentiation models
  - Performance of the proposed schedulers

Differentiation models

- Two differentiation models are examined:
  - Absolute capacity differentiation
  - Proportional delay differentiation with delay bound
- In proportional models the highest class is assigned with a delay bound
  - This is because proportional models as such are not able to guarantee small delays

Differentiation models

- Notations:
  - w_i = weight of class i
  - g_i = guaranteed rate of class i
  - C = link capacity
  - δ_i = differentiation parameter
  - d_i = average queuing delay of class i

Differentiation models

- Absolute capacity differentiation:
  - each service class is allocated a predefined amount of link capacity, determined by the class weight w_i.
  - In an ideal case, class *i* should receive service in any interval (τ, t) with a rate

$$g_i \geq \frac{w_i}{\sum_{j=1}^{N} w_j} C$$

Differentiation models

- Proportional delay differentiation:
  - the ratio of average queuing delays in any two classes *i* and *j* should equal the ratio of differentiation parameters in these classes for the interval (τ, t) :

$$\frac{d_i(\tau, t)}{d_j(\tau, t)} = \frac{\delta_i}{\delta_j}$$

Packet schedulers

- The differentiation models were implemented with the following schedulers

Packet scheduler	**Quality parameter**	**Differentiation model**
DRR	Capacity	Absolute
ADRR with delay bound	Delay	Proportional with delay bound
HPD with delay bound	Delay	Proportional with delay bound

Packet schedulers

- Notations:
  - w_i = weight of class i
  - $q_i(t)$ = filtered queue length of class i at time t
  - $d_i(t)$ = average delay of class i at time t
  - $w_i(t)$ = head waiting time of class i at time t
  - δ_i = differentiation parameter of class i
  - g = constant

Packet schedulers

- DRR scheduler:
  - aims at approximating an ideal, fluid based GPS scheduler
- Each class is assigned with a weight w_i
  - In each service round, a frame of N bits is divided among the classes in proportion to the weights
  - Provides fairness also when variable size packets are used

Packet schedulers

- Adaptive DRR scheduler (ADRR)
  - aims to provide proportional delay differentiation. Furthermore, we have assigned the highest class with a delay bound
- The weights for the interval (τ, t) are updated in the following way:

$$w_i(t) = \frac{q_i(t)}{\sum_{k=1}^{n} \frac{\delta_i}{\delta_k} q_k(t)}$$

Packet schedulers

- HPD scheduler
  - also aims to provide proportional delay differentiation. Again, we have assigned the highest class with a delay bound.
  - When the server becomes free, HPD selects for transmission a packet from a backlogged class *j* with maximum normalized hybrid delay:

$$j = \arg\max(g d_i(t) / \delta_i + (1 - g) w_i(t) / \delta_i)$$

Simulation model

- A specific simulator was implemented with CNCL
  - CNCL is a freeware C++ class library package
  - It consists of basic functionality required to support event-driven simulation
  - The user has to implement most of the functionality by herself

Simulation model

- The simulation model consisted of the following components:
  - Node and link models
  - Simple traffic generator models
    - Control traffic
    - VoIP
    - Video (short flows)
    - WWW
    - FTP
  - Simple TCP model (including slow start and RTT estimation)

Simulation model

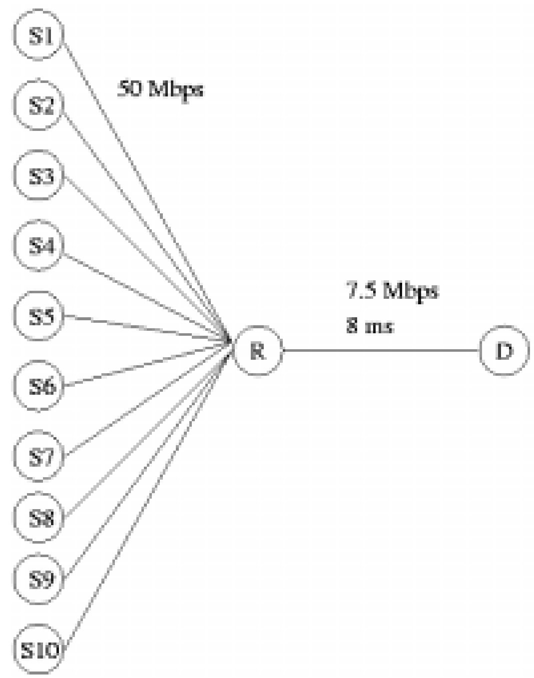
- Baseline:
  - A best effort scenario with FCFS scheduler
- Then, simulations were performed in eight scenarios for each scheduler:
  - Four scenarios where different traffic types were separated based on some criteria (transport protocol, application type etc.)
  - Four scenarios where different traffic types were allowed to be mixed.

Simulation model

- Provisioning rules for the schedulers:
  - DRR:
    - real time traffic was provisioned two times the expected load share and the remaining capacity was divided between other classes in proportion to their load shares
  - HPD and Adaptive DRR with delay bound:
    - Delay bound for the highest class was set to 5 ms, delay ratio between other classes was set to 4.
  - Queue management method was TailDrop

Simulation model

- The following topology was used in the simulations:



Simulation results (DRR)

- In the table below results are shown when traffic is mixed
  - Only minor difference between throughputs and delay of WWW sessions of different classes
  - Huge losses especially for WWW

		Queueing delay		Throughput		Loss	
Traffic	**Class**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
FTP	0	196 ms	152 ms	1170370 bps	558410 bps	0.3 %	1.5 %
WWW	1	19 ms	17 ms	173090 bps	387350 bps	0.01 %	0.5 %
WWW	2	22 ms	16 ms	185270 bps	359040 bps	7.4 %	11.9 %
Video	2	19 ms	5 ms	481490 bps	16760 bps	3.7 %	3.4 %
VoIP	3	2 ms	0 ms	30450 bps	6130 bps	0 %	0 %
Control	3	3 ms	0 ms	71250 bps	0 bps	0 %	0 %

Simulation results (DRR)

- In the following table different traffic types are separated
  - losses are smaller
    - however, FTP suffers from overprovisioning for real-time traffic

		Queueing delay		Throughput		Loss	
Traffic	**Class**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
FTP	0	335 ms	259 ms	865480 bps	458460 bps	1.2 %	3.8 %
WWW	1	44 ms	37 ms	131220 bps	313100 bps	0.8 %	3.9 %
Video	2	7 ms	7 ms	493190 bps	13140 bps	1.4 %	2.6 %
VoIP	3	2 ms	0 ms	30210 bps	6170 bps	0 %	0 %
Control	3	3 ms	0 ms	71250 bps	0 bps	0 %	0 %

Simulation results (ADRR)

- In the table below results are shown for ADRR when traffic is mixed
  - Better differentiation compared with DRR
    - Delay bound is met but target ratios are not
    - Quite high losses due to weight adaptation

		Queueing delay		Throughput		Loss	
Traffic	Class	Mean	Stdev	Mean	Stdev	Mean	Stdev
FTP	0	284 ms	122 ms	1626380 bps	583450 bps	1.0 %	3.7 %
FTP	1	167 ms	48 ms	1440270 bps	842350 bps	5.2 %	7.2 %
WWW	1	50 ms	55 ms	146700 bps	351600 bps	0.9 %	3.9 %
WWW	2	22 ms	18 ms	192130 bps	378980 bps	8.8 %	13.3 %
Video	2	17 ms	7 ms	479790 bps	16090 bps	4.0 %	3.2 %
VoIP	3	4 ms	1 ms	30160 bps	5550 bps	0 %	0 %
Control	3	4 ms	0 ms	71250 bps	0 bps	0 %	0 %

Simulation results (HPD)

- The table below shows the results for delay bounded HPD when traffic is separated
  - Both delay bound and delay ratios are met
    - FTP does not suffer so much, because overprovisioning for real-time traffic is not required

		Queueing delay		Throughput		Loss	
Traffic	**Class**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
FTP	0	300 ms	132 ms	1345400 bps	613160 bps	1.3 %	4.1 %
WWW	1	67 ms	54 ms	119480 bps	303010 bps	1.9 %	6.0 %
Video	2	17 ms	7 ms	498950 bps	2050 bps	0.2 %	0.3 %
VoIP	3	4 ms	1 ms	30220 bps	6340 bps	0 %	0 %
Control	3	5 ms	0 ms	71250 bps	0 bps	0 %	0 %

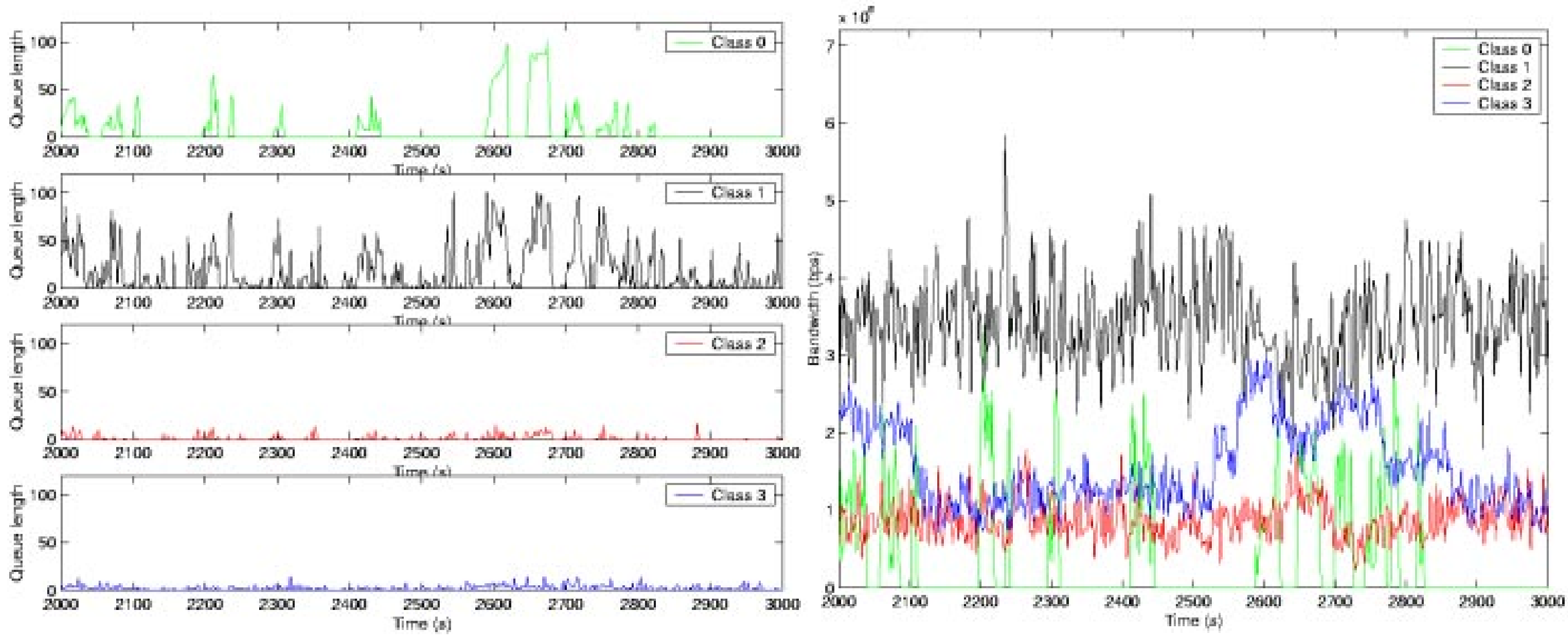
Simulation results (HPD)

- When different traffic types are mixed
  - Delay bound and ratios are still met
    - However, losses become intolerable

		Queueing delay		Throughput		Loss	
Traffic	**Class**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
FTP	0	276 ms	175 ms	1211400 bps	547050 bps	0.7 %	3.0 %
FTP	1	156 ms	43 ms	1557670 bps	676790 bps	4.0 %	3.9 %
WWW	1	63 ms	54 ms	120880 bps	303790 bps	0.8 %	4.0 %
WWW	2	17 ms	14 ms	182010 bps	393090 bps	2.9 %	7.3 %
WWW	3	6 ms	2 ms	220470 bps	451800 bps	1.0 %	3.2 %
Video	2	17 ms	9 ms	493700 bps	5190 bps	1.3 %	1.0 %
Video	3	5 ms	0 ms	499320 bps	350 bps	1.4 %	0 %
VoIP	3	4 ms	1 ms	30290 bps	6250 bps	0.1 %	0.1 %
Control	3	5 ms	0 ms	71030 bps	0 bps	0.5 %	0 %

Simulation results (HPD)

- Bandwidth allocation follows queue lengths



Conclusions

- From applications point of view it is beneficial to separate different traffic types:
  - two classes for TCP traffic: one for short flows, one for long flows
  - one or two classes for real time traffic: streaming type traffic and VoIP etc.
- Differentiation and provisioning with static schedulers (DRR) is problematic
  - measurement based schedulers are more suitable for changing load conditions

Conclusions

- Schedulers for proportional delay differentiation have to be integrated with a delay bound for the highest class
  - HPD with delay bound was best able to meet the differentiation target due to its robust delay estimator
    - however, if traffic is mixed arbitrarily, losses become intolerable

Current and future work

- A simulation environment in ns2 has been constructed
  - more accurate traffic models (full-tcp, MPEG4 traffic etc.)
- With this simulation environment we aim to
  - verify the results from previous research
  - investigate larger network topologies: end-to-end aspect
  - investigate intra-class performance
  - study the effect of different active queue management and policing mechanisms

Current and future work

- Future work will also include
  - Further development of the algorithms and measurement based estimators
  - Implementation and measurements of the delay-bounded HPD algorithm in the prototype environment