DELAY MINIMIZATION AND PRICING METHOD FOR THE NETWORK SERVICES

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SUMMARY

This paper proposes a scheduling model for ensuring delay as a Quality of Service requirement in the communications network. Different delays are allocated for different pricing classes, say gold, silver, and bronze classes. Our purpose is to minimize weighted mean delay for connections, where weights are the pricing factors of different classes. An adaptive and optimal solution is derived for weights of the scheduler. Simulations show that in addition to the mean delay minimization, the revenue of the service provider is also maximized in the linear pricing scenario. In addition, adaptive updating rule is simple to implement, since it converges fast. Our scenario is independent on the statistical assumptions, and therefore it is robust against possible erroneous estimates of the customers' behavior.

1. INTRODUCTION

The success of the Internet is diminished by the fact that there are no successful models of pricing and its use to both provide incentives, and be used as control mechanisms. Institutional end-users and network providers are typically billed flat-rate except that excess load is billed based on usage during overload/congested periods. Such crude pricing mechanisms are not sufficiently responsive to the rapidly changing costs of supply and the extremely complex dynamics and large scale user demand. Furthermore, little incentive is provided for users to appropriately employ emerging differential classes of service and provisioned circuits. The very distributed nature of the Internet makes deployment of pricing and billing mechanism challenging. According to the Finnish Consumer Agency, consumers are disturbed by breaks and slowness of the data traffic. By means of formulating the texts of agreement operators have succeeded in avoiding payment of compensation to customers in these cases. The Consumer Agency supervises operators in the drafting of fair terms of agreement. However, our approach is straightforward and fair in the sense that the price is decreased in real time when the QoS parameters, namely delays, become worse. Because Voice over IP (VoIP) applications are rapidly increasing, packet delay and jitter management becomes more and more important.

A significant amount of work has been done in resource scheduling for traditional network. Network resources in traditional networks mainly refer to bandwidth [1, 3]. Packet Fair Queueing (PFQ) disciplines such as WFQ and WF2Q [3] provide perfect fairness among contending network flows. However, WFQ and WF2Q cannot readily be used for processor scheduling because they require precise knowledge of the execution times for the incoming packets at time of their arrival in the node. Another PFQ algorithm for bandwidth scheduling is Start-Time Fair Queueing (SFQ) [4, 5], which does not use packet lengths for updating virtual time, and therefore seems suitable for scheduling computational resources (since it would not need prior knowledge of the execution times of packets) [5]. However, the worst-case delay under SFQ increases with the number of flows and it tends to favor flows that have a higher average ratio of processing time per packet to reserved processing rate [2]. A significant amount of work has also been done on CPU scheduling [6, 7, 10], but most of them are on CPU scheduling for end systems and work on task level (not on packet level).

In this paper we propose a scheduling model that optimizes the weighted mean delay of the network, not just in the worst case as in [8], but in a general case. The proposed algorithm ensures less delay for the users paying more for the connection (i.e. higher service class) than those paying less. This work extends our previous pricing and QoS research [9], to take into account scheduling issues by introducing fair delay guaranteeing mechanism. We describe a scheduling mechanism that achieves this goal without requiring knowledge of the users' utility functions and without requiring any explicit feedback from the network. An adaptive form algorithm for updating weights is obtained. It is fast - converging typically in one iteration for given number of connections - and robust against erroneous estimates of customers' behavior.

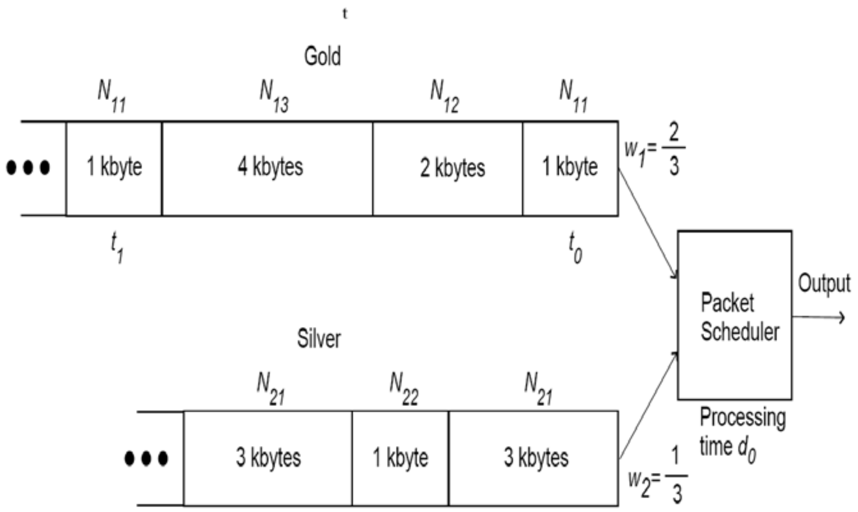

Fig. 1 An example of a packet scheduler with two classes

The rest of the paper is organized as follows. First, in Section 2 the scheduler is discussed and an expression for the delays of the connections in different service classes is derived. Section 3 presents and generally defines the proposed pricing scenario, while experiments justifying the derivation of the algorithm are made in Section 4. The next section contains discussion of theory and experiments. Finally, in last section we conclude the study.

2. THE PACKET SCHEDULER AND DELAYS

In this section, we formulate expression for delays of the data traffic. Consider the packet scheduler in Fig. (1). There are now two service classes. Gold class customers pay most of money while getting best service, and silver class customers pay least of money. Parameter Δt_i denotes time which passes when data is transferred through the queue i to the output in the switch, when $w_i = 1$. If the queue is almost empty, delay is small, and when the buffer is full, it is large. Variable w_i is the weight allocated for class i. Constraint for weights w_i is

$$\sum_{i=1}^{m} w_i = 1, \quad w_i > 0. \tag{1}$$

Variables w_i give weights, how long time queues i are served per total time. Therefore, delay d_i in the queue i is actually

$$d_i = \frac{\Delta t_i}{w_i}, \tag{2}$$

Without loss of generality, only non-empty queues are considered, and therefore

$$w_i \neq 0, \quad i = 1, \ldots, m, \tag{3}$$

where m is number of service classes. When one queue becomes empty, $m \to m-1$. Parameter N_i denotes the number of connections in the ith service class. Mean overall delay is formulated as follows:

$$E(d) = E\left(\frac{\Delta t_i}{w_i}\right) = \frac{1}{\sum_{l=1}^{m} N_l} \sum_{i=1}^{m} N_i \frac{\Delta t_i}{w_i} + \lambda\left(1 - \sum_{i=1}^{m} w_i\right).$$

In our approach, we use *weighted* mean delay, where weighting factors are r_i, $i = 1, \ldots, m$. In addition, $r_i > r_j$, where the class i (e.g. gold class) has higher priority than the class j (e.g. silver class). Weighted mean delay has the form

$$E(r_i d) = E\left(\frac{r_i \Delta t_i}{w_i}\right) = \frac{1}{\sum_{l=1}^{m} N_l} \sum_{i=1}^{m} N_i r_i \frac{\Delta t_i}{w_i} + \lambda\left(1 - \sum_{i=1}^{m} w_i\right).$$

Weighted mean delay is minimized by putting the derivative to zero:

$$\frac{\partial E(r_i d)}{\partial w_i} = -\frac{N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l w_i^2} - \lambda = 0. \tag{6}$$

Thus

$$w_i = \sqrt{-\frac{1}{\lambda} \frac{N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l}}. \tag{7}$$

Penalty factor λ is solved out as follows:

$$\lambda = -\frac{N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l w_i^2}. \tag{8}$$

On the other hand:

$$\lambda = \lambda \sum_{i=1}^{m} w_i = -\frac{1}{\sum_{l=1}^{m} N_l} \sum_{i=1}^{m} \frac{N_i r_i \Delta t_i}{w_i}. \tag{9}$$

Then

$$w_i = \sqrt{\sum_{l=1}^{m} N_l \frac{1}{\sum_{k=1}^{m} \frac{N_k r_k \Delta t_k}{w_k}} \frac{1}{\sum_{l=1}^{m} N_l} N_i r_i \Delta t_i}$$

$$= \sqrt{\frac{1}{\sum_{k=1}^{m} \frac{N_k r_k \Delta t_k}{w_k}} N_i r_i \Delta t_i}.$$

Uniqueness of the solution is seen by taking second order derivative. First order derivative is

$$\frac{\partial E(r_i d)}{\partial w_i} = -\frac{N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l w_i^2} + \frac{1}{\sum_{l=1}^{m} N_l} \sum_{k=1}^{m} \frac{N_k r_k \Delta t_k}{w_k}.$$

Second order derivative is

$$\frac{\partial^2 E(r_i d)}{\partial w_i^2} = -\frac{2 N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l w_i^3} - \frac{N_i r_i \Delta t_i}{\sum_{l=1}^{m} N_l w_i^2} > 0.$$

Therefore, mean weighted delay is convex, and has global unique minimum.

Fixed point type algorithm for optimizing the weights is performed as follows:

1. At time step t, update the weights:

$$\upsilon_i(t) = \sqrt{\frac{1}{\sum_{k=1}^{m} \frac{N_k(t) r_k(t) \Delta t_k(t)}{w_k(t)}} N_i(t) r_i(t) \Delta t_i(t)}.$$

2. Perform scaling

$$w_i(t+1) = \frac{\upsilon_i(t)}{\sum_{k=1}^{m} \upsilon_k(t)}. \tag{14}$$

3. If the weights are converged using some predetermined criterion - e.g. $|w_i(t+1) - w_i(t)| < \delta$, where δ is some small positive number - stop the iteration; otherwise, go to step 1.

3. PRICING AND REVENUE

We concentrate on the pricing and fair resource guarantee from the point of view of the customers. On the other hand, from the point of view of the service provider, we try to maximize revenue. First, we introduce the concept of *pricing functions*. For delay, pricing functions are denoted by $f_i(d)$, where d is the delay, and f_i is decreasing with respect to d. In addition, $f_i(d)$ is (strictly) convex with respect to d. Revenue obtained for one user in the class i is just $f_i\left(\frac{\Delta t_i}{w_i}\right)$. Because there are N_i connections in the class i with all having the same delay, revenue corresponding to the delays in the class i is

$$R_i(w_i) = N_i f_i\left(\frac{\Delta t_i}{w_i}\right). \tag{15}$$

Total revenue is then

$$R = \sum_{i=1}^{m} R_i(w_i). \tag{16}$$

In our study, we use *linear* pricing function for delays d. Then

$$f_i(d) = -r_i d + k_i, \quad k_i > 0, \tag{17}$$

$$f_i'(d) = -r_i, \tag{18}$$

$$f_i''(d) = 0. \tag{19}$$

Here $k_i > 0$ guarantees positive revenue with minimum delay. For the classes that have better service, factors r_i are larger compared with those classes, that have service of lower priority. Notice that we use here the same pricing factors than those in the weighted mean delay calculation. In addition, for classes having better service, k_i are larger. Notice that the pricing function may be even negative, when the delay is too large. However, Call Admission Control (CAC) mechanism takes care that this situation is prevented. From Eqs. (15)-(17) we see that the total revenue in the linear pricing scenario is

$$R = -\sum_{i=1}^{m} \frac{N_i r_i \Delta t_i}{w_i} + \sum_{i=1}^{m} N_i k_i. \tag{20}$$

4. EXTENSION TO THE MULTINODE CASE

In this section, we extend our approach for multinode case. In the multinode case, there are n nodes with m serice classes. Number of connections in the switch i and class j is denoted by N_{ij}. Weights for switch and class (I, j) is denoted by w_{ij}, and the constraint

$$\sum_{j=1}^{m} w_{ij} = 1 \tag{21}$$

must be satisified. The delays are denoted by Δt_{ij}. By using these notations, we obtain the weighted mean delay as follows:

$$E(r_j d) = \frac{1}{\sum_{i=1}^{m} \sum_{j=1}^{m} N_{ij}} \sum_{i=1}^{m} \sum_{j=1}^{m} \frac{N_{ij} r_j \Delta t_{ij}}{w_{ij}} + \sum_{i=1}^{m} \lambda_i \left(1 - \sum_{j=1}^{m} w_{ij}\right). \tag{22}$$

The first order derivative is

$$\frac{\partial E(r_j d)}{\partial w_{ij}} = -\frac{N_{ij} r_j \Delta t_{ij}}{\sum_{k=1}^{n}\sum_{l=1}^{m} N_{kt} w_{ij}^2} - \lambda_i. \quad (23)$$

Solving λ_i out, we obtain the updating rule

$$w_{ij} = \sqrt{\frac{N_{ij} r_j \Delta t_{ij}}{\sum_{h=1}^{m} \frac{N_{ih} r_h \Delta t_{ih}}{w_{ih}}}}. \quad (24)$$

5. SIMULATIONS

In the first simulation, we used static data traffic in the single node case to illustrate the fast convergence of the algorithm. Matlab code is as follows:

```
  function w, d, revenue=...
delayminimization(N,r,t,k,iteration
s,sd)

  rand('seed', sd);
w=rand(3,1);
w=w/sum(w);
d=1/sum(N)*sum(N.*r.*t./w);
revenue=-sum(N.*r.*t./w)+sum(N.*k);

  for iteration=1:iterations
v=sqrt(N.*r.*t.*sum(1./(N.*r.*t./w(
:,iteration))));
w(:,iteration+1)=v/sum(v);
d(iteration+1)=1/sum(N)*sum(N.*r.*t
./w(:,iteration+1));
revenue(iteration+1)=-
sum(N.*r.*t./w(:,iteration+1))+sum(
N.*k);
end
```

The parameters are as follows:

- Number of connections for gold, silver, and bronze classes are $N_1 = 10$, $N_2 = 20$, and $N_3 = 50$.
- Penalty factors r_i are $r_1 = 5$, $r_2 = 2$, and $r_3 = 1$.
- Time delays are $\Delta t_1 = 20$, $\Delta t_2 = 50$, and $\Delta t_3 = 100$.
- Shifting factors are $k_1 = 1000$, $k_2 = 700$, and $k_3 = 500$.

We performed 100 simulations by using our Matlab code. In all simulations, weights $w_i(0)$ was initially randomly guessed. All simulations show, that the weights converge *in one iteration step* to the solution $w = 0.2150, 0.3041, 0.4808$. In addition, weighted mean delays are $E(r_i d) = 270.3140$. Revenue was converged to $R = 273750$.

We made also simulation using brute-force method, where weights belong to the $1000 * 1000 * 1000$ grid. Matlab code is as follows:

```
  function revenue,
delay=brutedelayminimization(N, r,
t, k)

  revenue=-100000;
delay=100000;
for w1=0.001:0.001:0.998
for w2=0.001:0.001:0.999-w1
w(1,1)=w1;
w(2,1)=w2;
w(3,1)=1-w(1,1)-w(2,1);
revenue1=-sum((N.*r.*t)./w(:,1))+
sum(N.*k);
if revenue1 > revenue
revenue=revenue1;
end
delay1=1/sum(N)*sum(N.*r.*t./w(:,1)
);
if delay1 < delay
delay=delay1;
end
end
end
```

Simulation with brute-force method shows that the results are the same as with our fixed point algorithm. Conclusion is that our algorithm produces both minimum weighted mean delay as well as revenue maximization in the linear pricing scenario.

6. DISCUSSION

We make the following conclusions shown by algorithm and experiments:

- In the single and multi class network scenario, we have formed model for the mean delay as well as weighted mean delay.
- We have shown that the weighted mean delay has global unique minimum.
- Our fixed point algorithm achieves that minimum, which has been tested by comparing it to the brute-force algorithm.
- Fixed point algorithm is very fast, converging typically at one iteration step to the sufficient accurate solution.
- Algorithm also optimizes the network provider's revenue, and thus it is satisfactory from both point of view of customers and service provider.
- Algorithm is quite simple, needing about $O(m^2)$ multiplications and additions per iteration. When eg. gold, silver, and bronze classes exist, $m = 3$.
- When the penalty pricing factors are high, the corresponding connections obtain less delay.
- Because all penalty and gain factors are positive, all classes obtain service in a fair way.

7. CONCLUSIONS

This paper has presented adaptive resource sharing model that work as the superstructure over scheduling disciplines and use the weighted mean delay criteria to calculate the optimal parameters for the scheduler.

Most important conclusion is that *we have combined revenue optimization, weighted mean delay minimization, and scheduler weight updating in the unique manner.*

One of our future topic is to add other QoS parameters than delay, too, to our model. This leads to fast iterative fixed point algorithms. The other study is to handle the data by statistical methods, and compare the results with our deterministic approach.

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BIOGRAPHIES

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