Evaluation of Network Packet Scheduling Disciplines using Multimedia Traffic
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Abstract: - Multimedia traffic makes network configuring a key issue. The selection of network packet scheduling disciplines is crucial for reducing the service cost of multimedia transmission. This paper presents a new framework of experiments to compare packet scheduling disciplines using multimedia traffic. As an example, we studied the Generalized Processor Sharing (GPS) and Earliest Deadline First (EDF). The calculus for the network delay in both theories differs significantly, so it is difficult to compare their efficiency analytically. An important result of this comparison is that GPS schedulers can achieve a similar or even better efficiency to that of practical EDF schedulers but avoiding their implementation complexities.

Key-Words: - Resource allocation, Traffic policing, Network Packet scheduling, Quality of Service.

1 Introduction
Multimedia network traffic has grown exponentially in recent years. Providing Quality-of-Service (QoS) requirements is a key issue in today’s network communication. The goal was to select the optimal service discipline for routers transmitting multimedia traffic guaranteeing end-to-end delay (the practical scenario was a Digital CCTV Video Surveillance network). In addition, the results of this paper can be applicable to every class of network approach using GPS or EDF service disciplines (like Integrated and Differentiated Services).

For our study we selected two of the most widely spread approaches for packet scheduling to provide QoS in real-time transmission [1]. These approaches are based on the Generalized Processor Sharing (GPS) [2] and Earliest Deadline First (EDF) [3,4] theories. The paper considers the problem of providing end-to-end delay guarantees to individual flows using admission control tests.

One of the main attractions of the GPS theory is that the proposed calculus for network delay calculation takes into account delay dependencies in the successive nodes, thus providing smaller delays. Another advantage of GPS is its simplicity, which has led to widely used and low-cost implementations in the market. EDF scheduling, on the other hand, has been proven to be optimal in terms of the schedulable region at a single node [3]. However, the study of the multiple node case is much more difficult. Because of that, the end-to-end delay is obtained as the sum of the delays at each node, so the total delay is usually more pessimistic. Some proposals for reducing this delay using per-hop traffic shaping [5] have been introduced. These proposals are based on the combination of rate control (input regulation) and EDF schedulers (this is known as Rate-Controlled EDF or RC-EDF). Although RC-EDF could offer performance gains over GPS, the admission control tests for this policy are considerably more complex than those for GPS, requiring the use of approximation techniques [6,7].

Several experiments have been introduced in the literature to compare service disciplines. In pioneering works [8,9], the comparisons are based on the number of accepted connections and link utilization using simple traffics characterizations. In [7] the authors compared EDF versus GPS using the number of accepted channels in a network as a level of performance. One important drawback of this experiment is that the workload used is not real and reduced to four types of traffics. Other papers obtained the schedulable regions for a given network discipline [3,10]. A more elaborated experiment was introduced in [6] and it is based on obtaining the call blocking ratio of a given workload via simulations. In [11] GPS and EDF are compared in the setting of statistical delay service.

The experiments presented in this paper are used to compare an optimisation of the GPS service discipline based on a fast and bounded method to optimize the bandwidth reservation [12], and several EDF disciplines presented recently in the literature. Results show that for one node this GPS scheme practically offers the same efficiency as the optimal EDF scheduler. However, simulations in a network
with several nodes prove that the GPS scheme is as efficient as the best-known RC-EDF policies. Moreover, when the end-to-end delay is high, simulations show that with GPS, 55% bandwidth utilization can be achieved (better than RC-EDF 50% utilization).

2. Background

This section described the GPS and EDF service disciplines. The most important aspects of a service discipline is the end-to-end delay calculus and the admission control test (that is, a test to determine if a new flow is accepted or rejected).

2.1. GPS Scheduling

The Generalised Processor Sharing theory is based on assimilating network traffic to an idealised fluid model. The packetized version of this theory is known as WFQ (Weighted Fair Queuing).

The calculus of the end-to-end delay in this theory usually assumes that the input traffic is leaky or token bucket regulated at the input. Using this assumption, a seminal work by Parekh and Gallager [2] introduced an equation to compute the delay bound $D_i$ for a flow $i$:

$$D_i = \frac{\sigma + n L_i}{R} + \sum_{j=i}^{N} \frac{L_{max,j}}{C_j}, \quad R \geq \rho$$  

This equation expresses the delay as a function of the reserved bandwidth ($R$) in the links, the leaky bucket traffic parameters ($\sigma$) and some network parameters: $L_i$ is the maximum packet size for session $i$, $L_{max,j}$ is the maximum packet size in node $j$, $C_j$ the bandwidth of the link $j$, and $n$ the number of nodes along the path.

With this equation, the control admission test becomes very simple. For a new connection $i$ with a given end-to-end delay $D_i$, it is necessary to calculate the bandwidth reservation that makes equation (1) less than $D$ and the sum of the bandwidth reservation of all the channels in the node must be less than the total link bandwidth $C_j$.

From equation (1) it is easy to see that the network resource reservation mainly depends on the selection of the appropriate traffic characterization parameters of a traffic workload ($\sigma$ and $\rho$ parameters) for a given delay $D$ and network configuration. In GPS lower delays always imply higher bandwidth reservations.

2.2. EDF Scheduling

The EDF (Earliest Deadline First) scheduling discipline is well known in the context of real-time processor scheduling. The adaptation of this scheduler to real-time transmission works as follows [4]: each flow $i$ at switch $m$ is associated with a local delay bound $d_{im}^m$; when a packet of flow $i$ arrives to the scheduler at time $t$, a deadline $t + d_{im}^m$ is assigned, and packets are dispatched by increasing order of deadline. Unlike GPS, in the EDF theory delay and bandwidth reservation are decoupled. Georgiadis et al. [3] also demonstrated that EDF is the optimal scheduling policy at a single node in terms of the schedulable region for a set of flows with given deterministic delay requirements.

The problem of this theory is that the end-to-end delay in a network, taking into account delay dependencies in the successive nodes, is too complex to compute. The total delay is thus obtained as the sum of the worst-case delay at each node, yielding usually very pessimistic delay bounds.

Georgiadis et al. obtained an expression for the end-to-end delay assuming per-hop traffic shaping, known as RC-EDF [5]. The total delay is computed as the sum of the shaper delay $d_{im}^{sh}$ and the sum of the local delay of the switches $d_{im}^l$.

$$d_i = d_{im}^{sh} + \sum_{m=1}^{M} d_{im}^l$$  

The efficiency of these schemes critically depends on the choice of the shapers at each node. Sivaraman et al. [4] demonstrated that identifying the “optimal” shaper is infeasible, in general, since it requires the entire network state to be known. Therefore, the selection of the shaper parameters is based on some heuristics or cost functions [13]. The concave hull approach in [14] selects the first $m$ leaky bucket parameters from the concave hull of the empirical envelope, but it needs a multi-leaky bucket shaper in each node.

Some necessary and sufficient conditions for EDF schedulability on a single node have been proposed in [3,10]. A set of flows characterized by their envelope $A_i^t$ with a maximum packet delay requirement of $d_i$ at a node with a total bandwidth $c$ is schedulable in that node if and only if:

$$ct \geq \sum_{j=1}^{N} A_i^t(t - d_i) \quad \forall t \geq 0 \quad \land \quad \lim_{t \to \infty} \frac{\sum_{j=1}^{N} A_i^t(t)}{ct} < 1$$  

The theoretical optimality of EDF and the existence of these conditions, used as admission control tests, make EDF an attractive choice for real-time transmission. However, the EDF scheduler has important drawbacks: the high computational cost of its implementation. Although the schedulability test of EDF is simple at first sight, the procedure used to test it can be computationally very complex.

In order to simplify this test, Firoui et al. [6] devised an RC-EDF scheme that smoothes the traffic at the sender using a shaper and use a piecewise linear traffic characterization that provides a low computational complexity control admission test. Siva-
raman et al. [4] proposed an improvement to the method of Firoui et al. based on using heuristics to obtain the shaper delay.

3. Scheduler Evaluation

This section is devoted to compare the efficiency of different service disciplines. The experiments are based on the bandwidth utilization level and blocking ratio. These experiments were done using a test program called RTNOU (Real-Time Network Optimization Utilities). This program and the C source code of the experiments tests of the services disciplines are freely available in: http://www.disca.upv.es/enhor/RTNOU.html.

The bandwidth utilization is defined as the sum of the mean bandwidth of the accepted flows in a node divided by the link bandwidth. This level gives a clear evidence of the efficiency of the service discipline to be evaluated. The blocking ratio level is defined as the probability that a new traffic may not be admitted because there are not enough network resources to transmit this traffic.

Flow arrivals are generated according to a Poisson process with parameter $\alpha$ and their durations are exponentially distributed with mean $1/\beta$. The ratio $\alpha/\beta$ characterizes the load offered to the link (the average number of flows that would exist at any time at a link with no capacity limitation). Each flow has traffic characteristics, which are chosen randomly from the characteristics of a traffic mix consisting in different video traces. A million flows were generated in each simulation run. The bandwidth utilization level is obtained calculating dynamically the mean bandwidth level (the sum of the mean bandwidth of the channels accepted). When a channel is accepted or leaves the node, the temporal mean bandwidth level is updated, so this value gives a dynamic vision of the bandwidth utilization. Therefore, the bandwidth utilization level is obtained as the average of the mean bandwidth level divided by the link bandwidth.

Two sets of VBR traffic were used for these simulations and evaluations: the first one is the well-known MPEG-1 traces studied by O. Rose [15] from the University of Wurzburg. The second group is from the Technical University of Berlin [16] and contains MPEG-4, H.261, H.263 and H.263+ traces.

At last, the service disciplines evaluated in the experiments are described in table 1.

4.1. Single node experiments

The goal of the first simulation was to compare the bandwidth utilization in a single node. It is also assumed that the switch operates at 155 Mbps (corresponding to an industry standard over an OC-3/STM 1 line) and multiplexes a traffic mix consisting of 10 classes of video with different codification algorithms as detailed in table 2.

<table>
<thead>
<tr>
<th>Scheduler Description</th>
<th>Traffic</th>
<th>Origin</th>
<th>Codec</th>
<th>Frame</th>
<th>Mean</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDF (Exact)</td>
<td>Lambs</td>
<td>Rose</td>
<td>MPEG1</td>
<td>40,000</td>
<td>182,788</td>
<td>3,355,600</td>
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<tr>
<td></td>
<td>Mtv</td>
<td>Rose</td>
<td>MPEG1</td>
<td>40,000</td>
<td>615,105</td>
<td>5,730,000</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Rose</td>
<td>MPEG4</td>
<td>40,000</td>
<td>272,618</td>
<td>1,989,000</td>
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<td></td>
<td>TheFirm</td>
<td>Berlin</td>
<td>H261(64k)</td>
<td>90,000</td>
<td>63,890</td>
<td>397,800</td>
</tr>
<tr>
<td></td>
<td>Troopers</td>
<td>Berlin</td>
<td>H261(VBR)</td>
<td>90,000</td>
<td>435,277</td>
<td>2,045,400</td>
</tr>
<tr>
<td></td>
<td>Robin Hood</td>
<td>Berlin</td>
<td>H263(VBR)</td>
<td>71,146</td>
<td>765,231</td>
<td>3,812,000</td>
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<tr>
<td></td>
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<td>H263(256k)</td>
<td>31,226</td>
<td>737,843</td>
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<td>275,282</td>
<td>1,874,000</td>
</tr>
</tbody>
</table>

Table 1: Service disciplines evaluated

Table 2: Traffic workload.

The end-to-end delay requirement $d$ (excluding propagation delays) of the flow was uniformly distributed in [50ms, 1s]. Figure (1a) shows the bandwidth utilization when the workload was varied from 0 to 500 flows. The results of this simulation reveal that there is a critical load that causes the tests start to reject channels (in this sample, approximately 100). When load is higher than 200, the utilization increases very slowly and the number of rejected workloads are very high. This can be shown in figure (1b). The call blocking ratio increases rapidly for load 100 in all tests. The CBR(Mean) is a straight line in figure (1a) for a load range of [0, 350] because practically all channels were accepted for this load range, so it can be used as an upper bound on the efficiency.

The best acceptance test is the EDF(Exact) with an utilization level reaching up to a 42% (it is
known to be the optimal scheduling policy for one link [10]). The RC-EDF(SHS) curve is a little worse, but it follows the same pattern than the EDF(Exact) curve, reaching a utilization of 41%. The results of the other tests are very similar and a little worse than EDF(Exact).

4.2. Multiple node experiments

The goal of the second simulation was to compare admission control in a network of nodes. Therefore, the hop-length was uniformly chosen in [1,10] and the end-to-end delay requirement $d$ was the same of the previous experiment. The traffic and switch characteristics are the same of the single node experiment. The results for the bandwidth utilization and blocking ratio are shown in Figure (2a) and (2b). Results, at first sight, seem to be very similar to the one node experiment. The first difference is that the critical load (when the call blocking ratio increases rapidly) is a bit lesser than the one node experiment (approximately load 90).

A closer examination in a load range of [100, 200] of the bandwidth utilization reveals more differences. In this case, the results show two groups. The worst tests are those based on EDF. The other three curves, corresponding to RC-EDF and GPS tests, present a similar pattern. In this case, the GPS curve is between the RC-EDF(STS) and RC-EDF(SHS) curves.

From the results of the previous experiments it can be deduced that a factor that affects these results is the number of hops. Thus, Figure (3) represents the results of bandwidth utilization varying the numbers of hops. Using a workload of 200, the number of hops was varied from 1 to 15 (the delay range was the same as the previous experiment). This figure shows that GPS is the best test when the number of hops is moderately high (more than 3). Although the RC-EDF(SHS) bandwidth utilization is high for one or two nodes, this utilization decreases rapidly for three nodes or more. The GPS curve decrements very slowly as compared to RC-EDF(SHS). This is the effect of the GPS optimization scheme, which obtains the shaper parameters that optimize the bandwidth depending on the delay and network parameters (the number of hops), dynamically at channel establishment time. This optimization cannot be done in the RC-EDF(STS) discipline, since the shaper is selected before the network is known. The heuristics introduced in [4] to overcome this problem, and used in RC-EDF(SHS), work well with a reduced number of hops; but when the numbers of hops is high it has the same efficiency of the RC-EDF(STS) test (as it can be seen in Figure (3)). Regarding to the EDF tests, the efficiency is very low when the number of hops is high.

Another factor that affects the results is the end-to-end delay requirements. Figure (4) represents the results of bandwidth utilization versus the required
end-to-end delay. The workload used in this experiment was 200 and the hop-length was uniformly chosen in [1,15]. The experiment was performed for different delay ranges (labelled in the x-axis). As expected, higher delays imply higher utilization (low delays require higher bandwidth reservations). The results of this experiment show that for delay ranges between 0 to 2 seconds, the bandwidth utilization is very similar in GPS and RC-EDF disciplines (a little better for RC-EDF disciplines). However, for higher delays the bandwidth utilization for GPS is better than the RC-EDF disciplines, achieving utilization near to 55% (reaching the optimal utilization of the CBR model). It can be seen that the EDF(Exact) rises to the optimal efficient very slowly because when the end-to-end required delay is higher, the required delay in the node becomes less demanding. And more important, the RC-EDF disciplines do not reach the CBR optimal utilization (stops at 50%).

![Fig. 3. Utilization depending on network hops](image)

The reason of this relative low efficiency of the RC-EDF segment-based disciplines when the delay is high is due to the method used to select the shapers. In the RC-EDF admission test, the traffic is totally shaped at the network entrance when the delay is high, so the four-segment shaper is reduced to a simply leaky bucket shaper. These leaky bucket parameters are simply the last segment of the four-segment traffic specification. This selection of the leaky bucket parameters does not seem to be very efficient because it does not take into account the network parameters so no on-line optimization is done.

![Fig. 4. Utilization depending on delay](image)

For reasons of brevity, in this paper we present only some results. The experiments with other load and network capacities are very similar to the ones presented.

### 4.3. Complexity of the admission tests

As mentioned in the background section, a drawback of the EDF test is its complexity. The implementation of the GPS admission test for a node is straightforward: a channel is accepted if the sum of the bandwidth reservation for the accepted channels is less than the link bandwidth (O(1) complexity). Nevertheless, for a node using an EDF scheduler, the most efficient RC-EDF test has a complexity of O(K*N), where K is the number of segments (in our experiments 4) and N is the number of accepted channels in the node. This matches the experimental results of Table (3): the computational cost of the EDF test grows dramatically, making it impractical when the number of channels is high. Another issue is the spatial complexity: in GPS a simple variable is needed to store the current bandwidth reservation in the node, versus a sorted list with over K*N elements to store the segments of the admitted channels in the RC-EDF test.

![Table 3: Mean computational cost (µs 3GHz PentiumIV)](image)

5. Conclusions

Efficient network resources reservation for video traffic is crucial for reducing the service cost of real-time transmissions. Several combined packet scheduling and shaping disciplines have been devised in order to increase the utilization of network resources and make end-to-end delays more predictable. These disciplines require developing an associated admission control test in order to perform resource
reservation.

This paper introduces a framework of experiments that allows to evaluate the utilization level achieved by a service discipline for a given workload and to compare the effectiveness of different service disciplines and their admission tests via simulations.

Results show that for one node the GPS based disciplines are a little less efficient than the optimal EDF scheduler (as expected). However, in a network with several nodes, the experiments show that GPS is nearly as good as the RC-EDF policies, and when the number of hops is moderately high (greater than 3) or the delay is high the GPS is better.

The efficiency of the service disciplines depends critically on the required maximum delay of the workload. The tests show that GPS can achieve up to a 55% utilization level for large delays (the optimal utilization), which is a little bit better than the 50% utilization of RC-EDF disciplines.

The results of this paper can contribute significantly in the design and use of service disciplines. In this sense, they show that GPS is a right choice for deterministic real-time transmission. Although RC-EDF has been proposed as being more efficient than GPS, the performance of RC-EDF crucially depends upon the choice of the shaping parameters. As shown in the simulation results, GPS can achieve an efficiency similar or better to that of EDF schedulers, but avoiding their complexities. Furthermore, the computational complexity of the EDF admission tests is very high.

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References