Enhancing the End-to-End Schedulability Condition of EDF Scheduling for Real-Time Applications

Khaled M. F. Elsayed
Department of Electronics and Communications Engineering
Faculty of Engineering, Cairo University
Giza, Egypt 12613
kelsayed@alpha1-eng.cairo.eun.eg

Abstract

Earliest Deadline First (EDF) schedulers are known to be optimal with respect to achieving delay bounds in the single node case [4]. For a session traversing a multi-node network, applying EDF schedulability condition at each node separately leads to very restrictive admission control policy for delay sensitive applications. Other scheduling disciplines such as PGPS, that take into account the delay dependency in the network, outperform EDF in such situations. In this paper, we present a heuristic method to enhance the schedulability condition for EDF schedulers as compared to PGPS. The method is based on matching the delay bound obtained by EDF schedulers and PGPS schedulers in a homogeneous network of nodes where all sessions traverse the same number of hops and require the same maximum delay. The method leads to enhancing the performance of the EDF schedulers in a multi-node network. Our simulation results show that the method works well in practice.

1 Introduction

In this paper, we address the problem of providing per-session end-to-end delay guarantees in an integrated service packet network [1]. Various scheduling disciplines has been proposed in the literature to achieve end-to-end delay bounds for guaranteed service (see [8] for a review of scheduling disciplines for real-time applications). Among them WFQ or PGPS [10] attracted special attention since it provides session isolation and greater schedulability region than other disciplines for sessions traversing multiple nodes. The main reason why PGPS is able to provide smaller delay bounds is its ability to take into account dependencies in the successive nodes a session has to traverse.

EDF scheduling is known to be optimal [4] in the sense that if any scheduler is capable of achieving a specific delay bound then it is achievable under EDF. This is valid for a single node. It is known that applying the EDF schedulability test at each node individually, the end-to-end delay bound may be very high compared to PGPS (see [5, 2] for examples).

In [5], a policy based on rate-controlled service disciplines with EDF scheduling at each node is presented. The policy is shown to provide better or at least a performance that is as good as PGPS. However, the problem with this approach is the need to do traffic shaping of each session at each node which is an expensive operation, while PGPS scheduling does not need shaping (except possibly at the ingress node of the network).

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In [7], a framework for providing end-to-end delay bound for various disciplines is presented. This includes PGPS, virtual clock, and EDF scheduling disciplines. EDF can then be treated in a similar manner to PGPS, however, the problem with this approach is that the assignment of local deadlines at each node is not specified.

In this paper, we present a method that can greatly enhance the performance of EDF schedulers for multi-node networks. The method is valid for traffic that is regulated by means of a leaky-bucket at the ingress node of the network. Our method guarantees that the resulting schedulability region will be at least as good as that provided by PGPS schedulers in a homogeneous multi-node network. The usefulness of this methodology is that it provides a uniform efficient scheduling mechanism for all types of traffic. It is known that EDF scheduling is the best discipline for the predictive service class of traffic of reference [1]. We currently provide no proof that the deadlines of each session will be met by using our approach. We note here that for PGPS scheduling, it has been shown [11] that the *actual* delay experienced by a session can be much less than the delay bound guaranteed by the network. If we relax the schedulability condition for EDF and match its performance with PGPS, we argue that it is highly likely that all deadlines will be met.

The rest of this paper is organized as follows. In section 2, we describe the system considered and the traffic model characterizing the sessions. In sections 3, we show how the end-to-end schedulability condition of EDF schedulers can be matched with the PGPS case for leaky-bucket constrained traffic sources. Sections 4 presents some results on the developed theory. Section 5 concludes the paper.

2 System Model and Description

We consider a network comprised of store-and-forward packet switching nodes. Each node implements a packet scheduler. The network provides service to various classes of applications: applications that require deterministic service from the network, these are termed *guaranteed service* applications; applications that request a predictable performance from the network and which can adapt its transmission rates and play-back points based on network conditions, these are termed *predictive service* applications; and finally *best-effort* applications which require no specific service from the network. In this paper, we concentrate only on applications and their associated sessions that belong to the *guaranteed service* class.

Input traffic from a particular session is regulated by means of a leaky bucket filter. A session i is characterized by the (b_i, ρ_i) leaky bucket parameters used to regulate its traffic, where b_i is the bucket token buffer size in bits and ρ_i is the token generation rate bits/sec. We assume that the maximum packet size is P. In the literature, b_i is known as the burst size and ρ_i is the average rate of the session.

A session i belonging to guaranteed class will request a maximum delay d_i from the network upon its initiation. The Call Admission Controller (CAC) process in the network should decide whether the requested end-to-end delay bound could be provided based on the session's declared traffic characteristics and requested delay bound (b_i, ρ_i, d_i), current network load and the scheduling discipline used at each node in the selected path for the session.

Consider a session with (b_i, ρ_i, d_i) traversing a set of N nodes, where the link capacity at node n is equal to C_n and where the set of session currently admitted at node n is denoted by S_n. The following summarizes the schedulability conditions used by CAC for PGPS and EDF schedulers.

PGPS Schedulability Condition
It has been shown [6, 10] that if

$$d_i \leq \frac{b_i}{g_i} + \sum_{n=1}^{N-1} \frac{P}{g_i} + \sum_{n=1}^{N} \frac{P}{C_n} \tag{1}$$

where g_i is the minimum bandwidth that should be reserved for session i at each node, and $\rho_i + \sum_{j \in S_n} \rho_j \leq C_n$ and $g_i + \sum_{j \in S_n} g_j \leq C_n$, for $n = 1, 2, \cdots, N$, then the set of sessions $i \cup S_n$ is schedulable at each node n.

EDF Schedulability Condition
For leaky-bucket constrained connections with traffic descriptor (b_i, ρ_i) and delay bound d_i^n at scheduler n with connections ordered such that $d_j^n < d_k^n$ if $j < k$, and as long as $\sum_{k=1}^{U_n} \rho_k < C_n$, where $U_n = |S_n|$ is the number of sessions admitted at node n including session i then at scheduler n, we have the schedulability condition as [9]:

$$d_j^n \geq \frac{b_j + \sum_{k=1}^{j-1}(b_k - \rho_k d_k^n) + P}{C_n - \sum_{k=1}^{j-1} \rho_k} \tag{2}$$

for $j = 1, 2, \cdots, U_n$, $n = 1, 2 \cdots, N$.

3 Enhancing the End-to-End Schedulability Condition for EDF Schedulers

In this section we show how the schedulability condition for EDF schedulers can be enhanced for end-to-end delay bound in a multi-node network. Consider a fictitious network configurations where all sessions traverse the same set of nodes from source to destination and where all nodes in the path has the same link capacity C. Let us further assume all sessions have the same traffic descriptor and delay bound, i.e. all session have the descriptor (b, ρ, d). In the following we obtain the number of sessions that can be admitted using PGPS and EDF schedulers. We then modify the schedulability condition for EDF scheduler such that in a multi-node network, EDF and PGPS provide the same admissibility region for the above scenario.

Lemma 1
In a network of N homogeneous nodes and homogeneous sessions, the number of sessions that can be admitted by PGPS denoted by U_{PGPS} is governed by

$$U_{PGPS} \leq \frac{dC - NP}{b + (N-1)P} \tag{3}$$

The proof is as follows: from equation 1, we get the reserved bandwidth g for each session verifies $g \leq \frac{b+(N-1)P}{d - N\frac{P}{C}} = \frac{b+(N-1)P}{dC-NP}C$, hence the maximum number of sessions is $U_{PGPS} \leq C/g$ and the result follows.

Lemma 2
In a network of N homogeneous nodes and homogeneous sessions, if the delay bound at each node is set to $\acute{d} = \frac{d}{N}$ the number of sessions that can be admitted by EDF scheduling U_{EDF} is governed by

$$U_{EDF} \leq \frac{\acute{d}C - P}{b} \tag{4}$$

The proof is as follows: from equation 2, we get:

$$\begin{aligned} \acute{d} &\geq \frac{b + \sum_{k=1}^{U_{EDF}-1}(b - \rho\acute{d}) + P}{C - \sum_{k=1}^{U_{EDF}} \rho} \\ \acute{d} &\geq \frac{U_{EDF}b + P}{C} \end{aligned}$$

and the result follows.

Lemma 3
In a homogeneous network of N nodes where all sessions traverse the same set of nodes and have the same traffic envelope and end-to-end delay bound, if the burst size of a session b is modified such that $\hat{b} = \frac{b}{N} + \frac{N-1}{N}P$ is used in the

sechedulability test of EDF schedulers instead of b, then $U_{EDF} = U_{PGPS}$

4 Results

In this section, we provide results that illustrate the usefulness of the methodology presented in sections 3. In the first experiement, we compare the performance of applying the node-by-node schedulability condition using the declared burst size of the source and the modified burst size that accounts for the multi-node path of the session as described in sections 3. We call the first method the naive EDF (NEDF) and the second the modified EDF (MEDF) in the results. In the second set of experiments, we evaluate MEDF in a heterogeneous setting and compute the actual delay experienced by the sessions.

In the first experiment we set the link capacity C to 155 Mbps and all packets are constrained to be of fixed length of 53 bytes. We assume a connection characterized by the descriptor (ρ, b). We fix ρ at 3550 bps. This is selected such that the condition $U\rho < C$, where U is the maximum number of connections admitted by a specific scheduling discipline, is always true. In other words, the obtained U is not constrained by the stability condition of the system. We vary the number of hops traversed by the connections from 1 to 10. In figure 1, we compare the performance of the NEDF and MEDF for a value of the delay bound $d = 50$ msec for $b = 0.1$ and $b = 8$ Kbytes. We obtain the maximum number of connections that can be admitted at each node using the the two scheduling methods.

As can be seen, the modified method (MEDF) for applying EDF schedulability condition allows much more connections than the naive EDF (NEDF) schedulability on a node-by-node basis. The efficiency of MEDF is further increased in the case of large bursts and when a large number of nodes is traversed in the sessions route. For example, for $b = 8$ Kbytes and number of hops equal to 10, the number of connections obtained by MEDF is 117 while for the NEDF the number is 12. This is a 975

5 Conclusions

In this paper, we presented a metholdogy that can be used to enhance the performance of EDF scheduling for achieving end-to-end delay bounds. The method has been shown to provide much better performance than the naive EDF method in multi-node networks.

It remains to provide a proof that the method does not cause violation of the deadline or use this as a starting point to develop another similar methodology to show that EDF scheduling can be used to provide good performance in multi-node networks.

The work presented here can be integrated with the work in [3] to reduce the time needed to check for schedulability condition.

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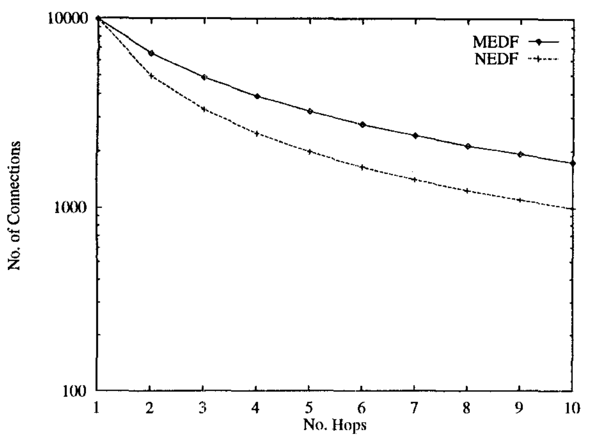
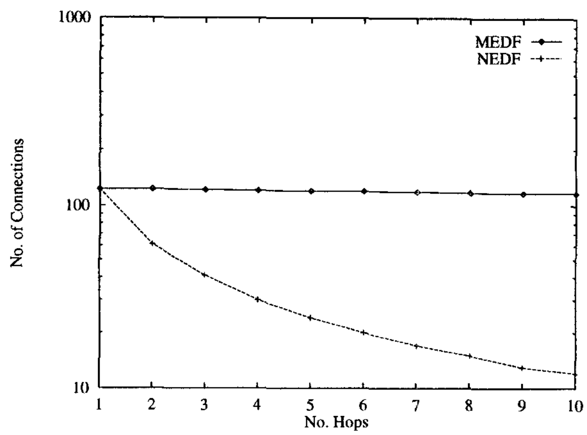


(a) b=0.1 Kbytes



(b) b=8 Kbytes

Figure 1: Comparison of NEDF and MEDF with $d = 50$ msec

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