EBBPS: An Efficient Weight Assignment Process for GPS Servers

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ABSTRACT. *The introduction of* Quality of Service *in high-speed networks requires the use of more complex service policies than the simple FIFO policy commonly used on servers today. Among those policies, GPS is the paradigm of a large set of policies aiming at sharing the bandwidth among sources in a very efficient way. Moreover, tight end-to-end delay bounds results are provided in the deterministic and statistical frameworks.*
However, the weight assignment process commonly used, RPPS, appears to perform poorly and the resulting admission procedure is cumbersome. To fill this gap, we propose a new weight assignment policy, called EBBPS, which captures the QoS requirement of sources. Moreover, the corresponding admission procedure is shown to be scalable, and provides an efficient use of resource capacity.

MOTS-CLÉS : ...

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1. Introduction

Provision of *Quality of Service* is a challenging issue for the Internet. Service discipline and admission procedures are key issues.
FIFO discipline, despite its simplicity and ease of implementation, shows its limitations when it comes to provide QoS. Indeed, it is not able to differentiate among sources which is a basic requirement in the QoS provisioning context. To fill this gap, various complex policies have been proposed in the literature (see [ZHA 95] for a survey). Among them, Generalized Processor Sharing (GPS) can be seen as an idealized prototype of a set of policies which provide highly desirable features such as isolation between sources and tight control in the bandwidth distribution. These policies rely on the weight assigned to each source at connection setup.
While most of the studies have focused on the end-to-end delay bounds achievable with GPS [PAR 94, GOY 95, ZHA 97] or on the implementation issue [STI 98], the method to allocate weights has received little attention. This is a main contribution of this work to provide a new method for the weight assignment process which is called Effective Bandwidth Based Processor Sharing (EBBPS) .
To offer a complete QoS provisioning service, one must also derive a connection admission control procedure associated to the chosen service policy. We focus on this issue, which is shown to be related to the major issue of scalability.
The remainder of this paper is organized as follows. In Section 2, we describe the GPS policy, its general features and the related work concerning implementation and end-to-end studies. In Section 3, we analyze Rate Proportional Processor Sharing (RPPS), the classical GPS implementation, emphasizing its limits. We also propose and discuss a connection admission control procedure for RPPS. In Section 4, we present the new weight assignment method, comparing its admission capabilities possibilities with the ones of RPPS. We also derive a simple and scalable call admission for EBBPS. In Section 5, we conclude and provide insights for future work.

2. GPS policy

2.1. *General Features*

Generalized Processor Sharing (GPS) is the general model of a work-conserving policy where each connection is assigned a weight and is served according to its relative weight among the backlogged sources. GPS assumes a fluid model of all flows, which have to be infinitely divisible. Let $S_i(t, \tau)$ denote the amount of work received by connection i ($i \in \{1, N\}$) during $[t, \tau]$. Then, if session i is continuously backlogged during $[t, \tau]$, we have:

$$\forall j \in \{1, N\}, \ \frac{S_i(t, \tau)}{S_j(t, \tau)} \geq \frac{\Phi_i}{\Phi_j} \qquad [1]$$

Summing equation(1) over all active sessions j , we obtain :

$$S_i(t,\tau) \geq \frac{\Phi_i}{\sum_j \Phi_j} C = r_{i,\min} \qquad [2]$$

Equation (2) means that each session i is guaranteed a minimum service rate $r_{i,\min}$ independently of the behavior of the other active sessions. Equation (1) further indicates that GPS has the ability to distribute excess bandwidth between the active sessions consistently with their weight assignment.

These features, namely isolation between sources and controlled distribution of the server bandwidth, explain why GPS is so attractive in the context of *Quality of Service* provisioning. See [ZHA 95] for a survey on the desirable features of a service discipline.

2.2. *Related Work*

Most studies concerning GPS have focused on implementation and end-to-end analysis issues.

GPS is only a model of procedure which is not really implementable since it assumes that each flow is infinitely divisible (fluid-flow model). A solution, called Packet Generalized Processor Sharing (PGPS) [PAR 94], has been proposed to emulate GPS in a packet network. It consists in emulating the behaviour of the GPS system and choosing among the eligible packets, the one which would have completed service first in the fluid system. This method is of course cumbersome and further works have focused on reducing the computational complexity of GPS emulations [STI 98, BEN 96].

A second major research topic concerning GPS is the derivation of end-to-end bounds. In [PAR 94], the authors provide an upper bound on the end-to-end delay for leaky bucket-constrained sources, for a special case of weight assignment called RPPS. This procedure is given further attention in the next section. These results were obtained assuming a deterministic framework. In [ZHA 94], the authors obtained similar results in the statistical case for exponentially bounded burstiness process.

At last, various studies are devoted to connection admission control procedures associated to GPS policy. In [ZHA 97], the authors have provided, using a statistical framework, a thorough study of the admission control procedure in the single server case. The QoS metrics considered is loss probability. In [AYA 99], the authors consider the RPPS policy. From the end-to-end delay formula, they derive the amount of resources required to provide the source its desired QoS, and study how to divide this resource requirement into local resource requirements on the servers of the flow's path.

In this paper, we first underline the limitations of RPPS and the need to improve the weight assignment process. To this purpose, a new weight assignment method is proposed for which a simple and scalable connection admission control procedure is derived. Throughout this study, a fluid-flow model is assumed and constant propagation delays are considered as negligible. Sources are assumed to be real-time leaky bucket constrained sources. A given source S_i is thus characterized by a maximum end-to-end delay constraint d_i and leaky bucket parameters (p_i, R_i, M_i) where p_i is the peak rate, R_i the average rate and M_i the maximum burst size of the source. We note $S_i \sim ((p_i, R_i, M_i), d_i)$. Results are obtained within a deterministic framework. The QoS criterion is the end-to-end delay.

3. RPPS

3.1. *RPPS networks*

RPPS stands for Rate Proportional Processor Sharing. It is a special case of GPS where each flow S_i is assigned a weight Φ_i equal to its mean rate R_i. End-to-end delay bounds have been provided in [PAR 94] for RPPS. More precisely, the results are provided for a more general class of networks called Consistent Relative Session Treatment(CRST) networks but final results are provided only for RPPS. This choice is based upon the fundamental result in [PAR 94] which states that CRST networks are stable. Stability means here that one is able to compute, at each router and for each session, a finite upper bound on the burstiness of the session. This relates to the work by Cruz [CRU 91b] where it is demonstrated that stability problems might occur in networks where the traditional stability constraint (utilization factor $\rho < 1$) is respected. This might happen only in feedback networks, that is networks with dependencies loops (even if, of course, no connection has a loop in its path).
Consider a source S_i crossing a network with n servers. Let Φ_i^j be the weight of S_i at server $j \in \{1, n\}$. With RPPS, $\Phi_i^j = R_i$, $\forall j \in \{1, n\}$. Let also $r_{i\min}^j$ be the minimum service rate offered by server j (obtained from equation (2). A bound on delay for a session i with the RPPS assignment, assuming a fluid-flow model and neglecting the constant propagation delays is [PAR 94]:

$$d_i = \frac{M_i}{\min\limits_{j \in \{1,n\}} r_{i,\min}^j} \qquad [3]$$

Note that this result is provided only for sources with infinite peak rate ($\forall i \in \{1, n\}$, $p_i = \infty$). Since this bound is obtained using only the property that the GPS server guarantees a minimum service rate equal to $r_{i,min} = \min_{j \in \{1,n\}} r_{i,\min}^j$, we can further refine it using Network Calculus [CRU 91a, CRU 91b, CRU 95] results (see Section 4) by taking into account that the peak rates are finite. We obtain (see Figure 1):

$$d_i = M_i \Big(\frac{1}{r_{i,min}} - \frac{1}{p_i} \Big) \qquad [4]$$

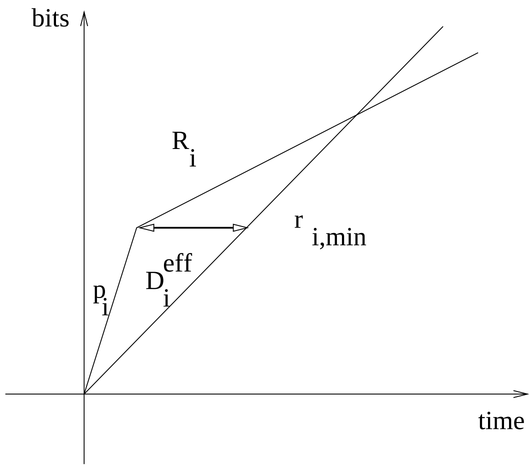

Figure 1. *RPPS delay bound for finite peak rate sources*

3.2. *Limitations of RPPS for QoS Provisioning*

We discuss here the efficiency of the RPPS assignment when performing the admission control procedure. The latter is done by computing the delay bound obtained from equation (3) and by checking whether it is compatible with the target value or not. With GPS, all the informations about a source are summarized in its weight Φ. As a consequence, from the admission control point of view, a RPPS server treats a source as a simple constant bit rate source, with a rate equal to its mean rate. This may of course be very inefficient, as we now illustrate with the following example. Consider 2 sources S_1 and S_2 with infinite peak rates and a server of fixed capacity C. We assume that:

$$S_1 \sim ((R_1, M_1), d_1) \text{ and } S_2 \sim ((R_2, M_2), d_2) \quad [5]$$

$$R_1 = R_2 = R \text{ and } M_1 = M_2 = M \quad [6]$$

$$d_1 = \frac{3M}{C} \quad [7]$$

$$d_2 = \frac{d_2}{2} \quad [8]$$

[9]

Let $\tilde{d}_i$ be the delay bound obtained from equation (3). We have:

$$\Phi_1 = \Phi_2 = R \quad [10]$$

$$r_{1,\min} = r_{2,\min} = \frac{C}{2} \quad [11]$$

$$\tilde{d}_1 = \tilde{d}_2 = \frac{2M}{C} = \frac{2}{3}d_1 \qquad [12]$$

Thus $\tilde{d}_1 < d_1$ and $\tilde{d}_2 > d_2$. RPPS will then lead to the acceptance of S_1 only. Now choosing $\Phi_2 = 2R$ (overestimating the mean rate of S_2) yields the following values:

$$r_{1,\min} = \frac{C}{3} \qquad [13]$$

$$r_{2,\min} = 2r_{1,\min} \qquad [14]$$

$$\tilde{d}_1 = \frac{3M}{C} \qquad [15]$$

$$\tilde{d}_2 = \frac{3M}{2C} \qquad [16]$$

As a consequence, $\tilde{d}_1 = d_1$ and $\tilde{d}_2 = d_2$. Under this weight assignment, the GPS server is able to accept both sources.
The previous example shows that the RPPS assignment may provide a quite inefficient admission control procedure leading to poor network performance. Especially, its weakness comes from the lack of correlation between the weight assignment method and the QoS requirement of the source. Further studies need thus to be made to find a better weight assignment method for GPS.

3.3. *An Admission Control Procedure for RPPS Scheme*

Here, we further study an admission control procedure for RPPS and emphasize its lack of scalability. Consider first the case of a single-server network with n connections already established and a new source, with leaky-bucket parameters (p, R, M). The admission control procedure, in a deterministic context, is as follows:

1. Assign a weight $\Phi = R$ to the new source S.
2. Compute the delay bound associated to all sources (using equation (3)), i.e. for S but also for the already established connections since the delay bound is based on the relative weight of each source which is affected by S.
3. Check the non-violation of the delay constraint of each of the $n + 1$ sources.

Thus, admitting a new source may potentially impact all the already established connections sharing the server. This phenomenon is accentuated in a real network where invoking the connection admission procedure leads to check the non-violation of the QoS of all the sources that have at least one server in common with the new source. This raises an obvious problem of scalability as the size of the network and the number of sources increase. Note however that this side effect does not propagate outside the path of the new source since the new source only affects the local weight of the sources. This can be checked easily on the network of Figure 2: the admission of the new source S affects S' but not S'' although S' meets S'' in server 6.

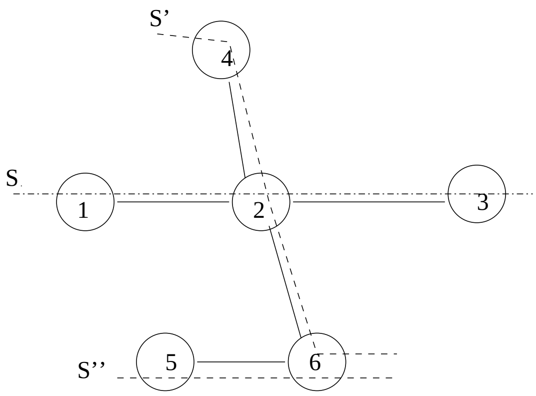

Figure 2. *Side effect due to the admission of a new source*

4. EBBPS: Effective Bandwidth Based Processor Sharing

4.1. *Deterministic Effective Bandwidth*

As seen above, the weight assignment method usually proposed for GPS, namely RPPS, suffers from a lack of correlation between weights and QoS requirements. In the framework of Network Calculus (see below), a deterministic effective bandwidth has been introduced [LEB 98]. The effective bandwidth captures in a single parameter both the source parameters and its QoS requirements. It is thus an appealing candidate to overcome the weakness of the RPPS scheme above mentioned. Thus, we propose a new weight assignment policy called EBBPS which makes use of the effective bandwidth as a weight Φ_i for source i.
Network Calculus is a set of methods that enable to obtain deterministic bounds on delays and backlogs. Within this framework, a source is modeled through an arrival curve which represents an upper bound on the traffic the source can emit on any time interval. For a leaky bucket constrained source with parameters (p, R, M), an arrival curve is (see [LEB 98]):

$$\alpha(\tau) = \min\left(p\tau, R\tau + M\frac{p-R}{p}\right),\ \forall\tau \geq 0 \qquad [17]$$

Servers are modeled through a service curve representing a lower bound on the service they are able to provide during each time interval. For instance, a service curve β for a FIFO server with a service rate C is $\beta(\tau) = C\tau$.
Consider now a flow characterized by an arrival curve α entering a server with a service curve β. An upper bound D on the delay (respectively Q on the backlog) experienced at the server, is given by the maximal horizontal (respectively. vertical) distance (see Figure 3) between the arrival curve and the service curve of the system (Theorems 1 and 2 of [CRU 95]).

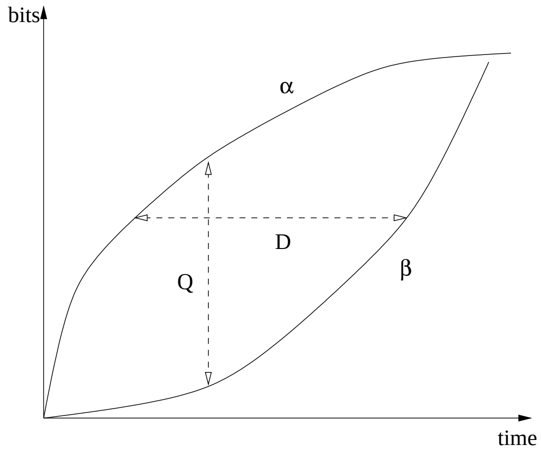

Figure 3. *Upper bound on backlog and delay*

From the network point of view, it is highly desirable to summarize the characteristics as well as the QoS constraints of a given source through a single parameter. This is the key idea behind the effective bandwidth. The deterministic effective bandwidth $e_d(\alpha)$ is the minimum required bandwidth such that the maximum delay experienced by S (with arrival curve α) is no greater than d. It is proved in [LEB 98] that:

$$e_d(\alpha) = \sup_{s \geq 0} \left(\frac{\alpha(s)}{s+d} \right) \qquad [18]$$

The deterministic effective bandwidth $e_d(\alpha)$ associated to a given source S is such that $R \leq e_d(\alpha) \leq p$. More precisely, depending on the value of the QoS requirement d:

$$e_d(\alpha) = \frac{M}{d + \frac{M}{p}} \text{ if } 0 \leq d \leq M\left(\frac{1}{R} - \frac{1}{p}\right) \qquad [19]$$

$$= R \qquad \text{if } d \geq M\left(\frac{1}{R} - \frac{1}{p}\right) \qquad [20]$$

Equations (19) and (20) indicate that not all the value of the delay requirement are significant. Beyond $d = M\left(\frac{1}{R} - \frac{1}{p}\right)$, the source must be granted a service rate equal to its mean rate to meet its QoS constraint, whatever it is.

Note that the deterministic effective bandwidth is not an approximation as it is the case in the stochastic setting (see for instance [ZHA 97]). However, this should not elude that an important task is the determination of the leaky bucket parameters, namely (p, R, M) [HéB 94].

EBBPS is thus a particular case of GPS for which a leaky bucket constrained source with a delay requirement d and an arrival curve given by equation (17) is assigned a weight $\Phi = e_d(\alpha)$. Moreover, we impose the following stability condition to admit a new source:

$$\sum_i e_{d_i}(\alpha_i) \leq C \qquad [21]$$

where C is the service rate of the server. If the source is to cross several servers, the stability condition must be met on each server. Note also that EBBPS is a CRST GPS assignment since the weight of a given session is the same at each node of its path (see [PAR 94]). This ensures the stability of EBBPS networks (Theorem 2 in [PAR 94]).

4.2. *Admission Control Procedure*

In this section, we derive a connection admission procedure for EBBPS. Let us adopt the following conventions:

– for a given source S with an arrival curve α and a delay constraint d, let $1, \ldots p$ be the index of the EBBPS servers crossed by S.

– $\Phi_S^j = e_d(\alpha)$ is the weight assigned to S at server j.

– I_j, for $j \in \{1, p\}$, the set of index of the sources crossing server j.

– C_j, for $j \in \{1, p\}$ the service rate of server j.

The minimum guaranteed rate for S at server j is:

$$r_S^j = \frac{\Phi_S^j}{\sum_{k \in I_j} \Phi_{S_k}^j} C_j.$$

We now use the following lemma (a proof can be found in [URV 99]):

Lemma 1 *Consider a source S crossing a network of p FIFO servers with constant service rates $(C_j)_{j \in [1,p]}$. The end-to-end delay of a bit from S is the same as if the network were restricted to one server with a service rate $\min_{j \in [1,p]}(C_j)$.*

Since a source S crossing a GPS network is guaranteed at server j a minimum guaranteed rate r_S^j, then, if $\min_{j \in \{1,p\}} r_S^j \geq e_d(\alpha)$, the QoS requirement of S is fulfilled. This comes from the definition of the deterministic effective bandwidth and Lemma 1. This is exactly what EBBPS performs. Indeed, assume that the local stability conditions are fulfilled at each server:

$$\sum_{k \in I_j \cup S} \Phi_k^j = \sum_{k \in I_j \cup S} EB(k) + e_d(\alpha) \leq C_j$$

Then, the minimum guaranteed rate for S at server j is:

$$r_S^j = \frac{\Phi_S^j}{\sum_{k \in I_j} \Phi_{S_k}^j + e_d(\alpha)} C_j \geq e_d(\alpha)$$

Thus, $\min_{j\in\{1,p\}} r_S^j = e_d(\alpha)$ and the delay condition for S is met by the network. The connection admission procedure for a new source consists thus simply in checking the local stability conditions for the new source. If these conditions are met, then:

– the QoS constraint of the new source is respected.

– the QoS constraint of the already established connections is not violated.

As a consequence, the admission procedure of EBBPS is perfectly scalable since it induces no side-effect. EBBPS thus exhibits two major advantages as compared to RPPS:

1. the QoS requirement of the source is taken into account in the weight assignment procedure.

2. the resulting admission procedure is simple and scalable (no side-effect)

4.3. ***Feasibility Tests***

In this section, we compare RPPS and EBBPS in terms of admission capacity. This study is performed in the single server case, and for the following three scenarios:

1. All the sources have the same characterization and the same delay constraint,

2. Two types of sources with the same characterization but different delay requirements,

3. Two types of sources corresponding to different characterizations and delay requirements.

We adopt the following notations:

– C is the service rate of the GPS server.

– n_j: number of sources of type j and $n = \sum_j n_j$

– for a given source S_i, α_i is the arrival curve of S_i given by equation (17), d_i its delay constraint and $\mathcal{D}_i^{\text{eff}}$ the delay provided by the GPS server.

We also assume that the delay constraints are significant. As explained in the previous section, this means that the effective bandwidth is greater than the mean rate of the source. Otherwise, EBBPS is strictly equivalent to RPPS.
Let us derive the admission conditions for the two policies. For RPPS, the following conditions must hold:

$$\begin{cases} \sum_{i=1}^n R_i \leq C \\ \mathcal{D}_i^{\text{eff}} \leq d_i, \ \forall i \in \{1,n\} \end{cases}$$

Using equation (4), the previous set of equations becomes:

$$\begin{cases} \sum_{i=1}^n R_i \leq C \\ M_i\left(\frac{\sum_{k=1}^n R_k}{CR_i} - \frac{1}{p_i}\right) \leq d_i, \ \forall i \in \{1,n\} \end{cases}$$

As explained above, the stability condition imposed by EBBPS also guarantee that the QoS constraints are met. Thus, the only condition to be checked in the EBBPS scheme is:

$$\sum_{i=1}^{n} e_{d_i}(\alpha_i) \leq C \qquad [22]$$

We can now study the three scenarios.

4.3.1. *Scenario 1:* $\forall i, \alpha_i = \alpha$ *and* $d_i = d$.

For all $i \in \{1, n\},\ R_i = R, p_i = p, M_i = M$. The admission conditions for RPPS may be rewritten as follows:

$$\begin{cases} nR \leq C \\ M\left(\frac{n}{C} - \frac{1}{p}\right) \leq d \end{cases}$$

Since, $\forall i \in \{1, n\}, e_{d_i}(\alpha_i) = e_d(\alpha) = \frac{M}{d+\frac{M}{p}}$, the set of equations becomes:

$$\begin{cases} nR \leq C \\ n \leq \frac{C}{e_d(\alpha)} \end{cases}$$

For EBBPS, one obtains from equation (22):

$$ne_d(\alpha) \leq C \qquad [23]$$

Thus, the admission condition for the two policies are the same. This is not surprising since if all the sources are equivalent in terms of characterization and QoS constraint, the two policies share evenly the available resources.

4.3.2. *Scenario 2:* $\forall i, \alpha_i = \alpha$ *and* $d_i \in \{d_1, d_2\}$

As in the first scenario, all sources are such that $R_i = R, p_i = p, M_i = M$. However, in this case, the two delay bounds requirements partition the sources in two sets, each one characterized by its own effective bandwidth:

$$e_{d_1} = \frac{M}{d_1 + \frac{M}{p}} \qquad [24]$$

$$e_{d_2} = \frac{M}{d_2 + \frac{M}{p}} \qquad [25]$$

The admission conditions for EBBPS is thus:

$$n_1 e_{d_1} + n_2 e_{d_2} \leq C \qquad [26]$$

For RPPS, we obtain the following set of equations:

$$\begin{cases} n_1R + n_2R \le C \\ M\left(\frac{(n_1+n_2)R}{CR} - \frac{1}{p}\right) \le d_1 \\ M\left(\frac{(n_1+n_2)R}{CR} - \frac{1}{p}\right) \le d_2 \end{cases}$$

which is equivalent to:

$$\begin{cases} nR \le C \\ M\left(\frac{n}{C} - \frac{1}{p}\right) \le \min(d_1, d_2) \end{cases}$$

The last equation may be rewritten using e_{d_1} and e_{d_2}. Finally, one obtains:

$$\begin{cases} nR \le C \\ n \le \min(\frac{C}{e_{d_1}}, \frac{C}{e_{d_2}}) \end{cases}$$

We can now represent the admission regions corresponding to RPPS and EBBPS. Without any loss of generality, we assume that $e_{d_1} \le e_{d_2}$. The admission regions are depicted in Figure 4. The results can be interpreted as follows. Since the sources

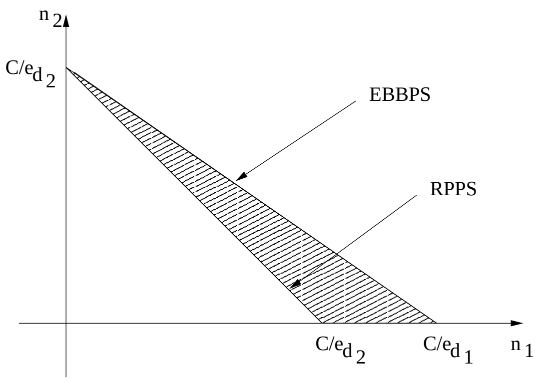

Figure 4. *Admission regions for RPPS and EBBPS*

have the same traffic descriptor, RPPS shares equally the service rates between the sources. But since they have different QoS requirements, RPPS shares the bandwidth with respect to the stringent QoS requirement, i.e. d_1. As compared to RPPS, EBBPS achieves better performances since it shares the bandwidth according to the effective bandwidth of the sources.

4.3.3. *Scenario 3:* $\forall i, (\alpha_i, d_i) \in \{(\alpha_1, d_1), (\alpha_1, d_1)\}$.

In this scenario, we assume that there are two kinds of sources with different characterization and delay requirements. This gives two different effective bandwidths:

$$e_{d_1} = \frac{M_1}{d_1 + \frac{M_1}{p_1}} \qquad [27]$$

$$e_{d_2} = \frac{M_2}{d_2 + \frac{M_2}{p_2}} \qquad [28]$$

The admission condition for EBBPS is, as before:

$$n_1 e_{d_1} + n_2 e_{d_2} \leq C \qquad [29]$$

For RPPS, we obtain the following set of equations:

$$\begin{cases} n_1 R_1 + n_2 R_2 \leq C \\ M\left(\frac{(n_1 R_1 + n_2 R_2}{C R_1} - \frac{1}{p_1}\right) \leq d_1 \\ M\left(\frac{(n_1 R_1 + n_2 R_2}{C R_2} - \frac{1}{p_2}\right) \leq d_2 \end{cases}$$

The set of equations may be rewritten using e_{d_1} and e_{d_2}. We obtain:

$$\begin{cases} n_1 R_1 + n_2 R_2 \leq C \\ n_1 R_1 + n_2 R_2 \leq \min(\frac{CR_1}{e_{d_1}}, \frac{CR_2}{e_{d_2}}) \end{cases}$$

If the second condition holds, then the first one is also fulfilled. As a consequence, the admission test for RPPS reduces to a single equation:

$$n_1 R_1 + n_2 R_2 \leq \min(\frac{CR_1}{e_{d_1}}, \frac{CR_2}{e_{d_2}}) \qquad [30]$$

Assume, without any loss of generality, that $\frac{CR_1}{e_{d_1}} \leq \frac{CR_2}{e_{d_2}}$. The admission test for RPPS may thus be rewritten as follows:

$$n_1 e_{d_1} + n_2 \frac{R_2 e_{d_1}}{R_1} \leq C \qquad [31]$$

Since $\frac{CR_1}{e_{d_1}} \leq \frac{CR_2}{e_{d_2}}$, we have $e_{d_2} \leq \frac{R_2 e_{d_1}}{R_1}$. As a consequence,

$$n_1 e_{d_1} + n_2 e_{d_2} \leq n_1 e_{d_1} + n_2 \frac{R_2 e_{d_1}}{R_1} \qquad [32]$$

The admission condition for EBBPS is thus fulfilled as soon as the admission test for RPPS is fulfilled. Once again, EBBPS outperforms RPPS.
The results obtained in the three previous scenarios, though not exclusive, show that EBBPS has a better capability to take the sources' QoS into account giving rise to larger admission regions.

5. Conclusion

Most of the studies concerning GPS have focused on extending or optimizing the delay bounds results, mainly in the particular case of RPPS.
In this paper, we have first discussed the weight assignment process used in GPS. We underline a major drawback of RPPS, which is that it is not able to fully take into account the QoS requirement of the source since it is based on the sources' traffic characterization only. To overcome this weakness, we propose another GPS policy called EBBPS, based on the deterministic effective bandwidth which aggregates in a single parameter the characterization as well as the delay constraint of a source.
A consequence of the weakness of the weight assignment process used in RPPS is that the admission procedure is not scalable. On the contrary, the EBBPS admission procedure is simple and efficient: if the local stability conditions are met, then the QoS requirements of the new source as well as the already established connections are also met, so that EBBPS enjoys scalability properties.
A last important feature of EBBPS is its efficiency. Indeed, we prove in the last part that for typical scenarios, EBBPS is more efficient than RPPS since it has larger admission regions.
Future work should address source grouping. Indeed, even if the admission procedure of EBBPS is clearly scalable, it still requires to serve each source individually. This may induce some scalability problem during the data-transmission phase as the number of sources increases. Extensions in a statistical framework should also be studied.

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