SSTF: A 'Shortest Setup Time First' Optical Connections Setup Management Approach with Quantifiable Success Rate

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Abstract— **The worldwide network domain tendency to evolve towards dynamic Quality of Service (QoS) enabled optical networks is imminent. In such an evolution, imporving connection setup conditions is considered to be one of the major requirements. This paper proposes a novel connection setup management approach. The rationale behind this proposal lies in considering the optical connection setup time requirement as a (timely increasing) priority indicator during the setup/provisioning process. From this viewpoint, we adapt the well known Earliest Deadline First (EDF) scheduling discipline to the particular case of optical connection setup management, which consists in giving highest priority to the connection request having the shortest setup time requirement. Another originality of this paper stems from the proposal of a computaional method for the assessment of *optical connection setup success probability* under the proposed management approach. The latter parameter, that is the *connection setup success rate*, is an important indicator for both optical operators and clients.**

Index Terms: **Optical networks, connection setup management, Earliest Deadline First (EDF) scheduling, performance evaluation, Markov chain modeling.**

I. Introduction

Optical fiber communication is now ubiquitous in the telecommunication infrastructure. Over the last two decades, extraordinary technological innovations in this field have consistently, delivered higher and higher bandwidth over longer and longer distances. Fiber optics and Wavelength Division Multiplexing (WDM) have significantly increased the transmission capacity of today's networks, and they are playing important roles in supporting the rapidly increasing data traffic. WDM divides the tremendous bandwidth of a fiber into many non-overlapping wavelengths (WDM channels), which can be operated at the peak electronic speed of several gigabits per second. The optical layer is however evolving not just in terms of raw capacity, but also in terms of functionality. The main trend is indeed to migrate from a "dumb" optical layer medium with static point to point connections towards a new era of dynamic, QoS-enabled, all-optical WDM optical networks [1]. This wavelength-routed all-optical WDM networking technology is a good candidate for the future wide-area backbone networks, allowing fast dynamic reconfiguration of network connections without the need for optoelectronic conversions at the data plane level. In wavelength-routed WDM networks, an Optical Cross-Connect (OXC) switches the optical signal on a WDM channel from an input fiber to an output fiber; thus a connection (lightpath) may be established from a source to a destination node. The connection setup process consists mainly in selecting a path of physical links between the source and destination edge nodes, and reserving a particular wavelength on each of these links for the lightpath. The resulting setup approach is referred to as *Routing and Wavelength Assignment (RWA)* [2]. The established lightpaths are mainly intended to provide circuit-switched services to end customers. A sequence of connection setup requests arrives over time, and each successful request results in network resources depletion for a certain connection holding time. When the network capacity becomes scarce, some lightpath requests may not be accepted, resulting in connection blocking. One of the primary design objectives in wavelength-routed optical networks is to minimize this blocking probability [3].

Previous studies (cf [4], [5], [6], [7]) on wavelength-routed networks have analyzed the request blocking probability under various Routing and Wavelength Assignment (RWA) schemes and wavelength router architectures. These studies are based on a key assumption that the blocked requests are immediately lost, and they do not consider the *connection setup time* in performance evaluation. In light of the emerging QoS-enabled and dynamic optical networks, the connection setup time is likely to become a common feature of the customers' service profiles. For instance, the authors in [8] presented the connection setup time as a potential service differentiator in Service Level Agreements (SLA) between optical operators and their customers. Furthermore, the agreed upon connection setup time represents a great opportunity for optical operators to reduce connection blocking probability. This is especially true since the connection setup time provides optical operators with a predefined period of time during which the blocked lightpath request tolerates being queued. This tolerance may be *firm* (i.e. the mismatch leads to connection drop) or *soft* (i.e. the request is maintained even if the tolerated period expired). There is thus a need to define new connection setup management approaches that take advantage of the connection setup time when dealing with blocked connection requests. To the best of our knowledge, there has been no dedicated

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work investigating the effects of considering the connection setup time during optical connection setup management in the context of wavelength-routed networks. Building on the previous analysis, this paper proposes a novel connection setup management approach, that we call *Shortest Setup Time First (SSTF)* strategy. The rationale behind this proposal lies in considering the optical connection setup time as a timely increasing priority indicator during the setup process. In this manner, it can be assimilated to a kind of *deadline*, for instance, a connection request arrived at instant a with a setup time of S will be assigned a deadline at $a + S$. Based on this observation, we adapt the well known *Earliest Deadline First (EDF)* scheduling discipline to the particular case of optical connection setup management. In other words, the connection requests which are blocked at a certain source node A will not be immediately dropped. But instead, they will be queued at A's level within an SSTF (EDF-like) queue according to an increasing order of their required connection setup times (deadlines). The first customer to be served will be the one having the smallest connection setup time.

Performance evaluation of this novel approach is of course a crucial issue. As our SSTF approach lies on the EDF discipline, it benefits and inherits the proprieties of the latter. The *Earliest-Deadline-First* (EDF) queueing discipline (proposed by Jackson in 1955 [9]) is one of the most efficient method to handle real-time systems. Applications of EDF policy can be found in various domains of computer science and industry (cf. [10], [11] for some of the earlier works, and [12], [13] for more recent works). Many efforts have been done for characterizing the EDF queue and assessing its main performance metrics, in particular the death probability. In [14] and [15] for instance, studies have been carried for a special version of the EDF, the $F/ML(n)$ queueing [14] which uses EDF only for the n *first* (or *last* in [15]) customers and the remaining are queued in First-In-First-Out (FIFO) manner. However, the general characterization of EDF (queue size distribution, stability condition, etc.) is still an open research issue. In particular, to the best of the authors' knowledge, the deadline miss ratio remains an open problem. This latter parameter is a major performance metric in our connection setup management approach, since it leads directly to the probability of setting up a connection in time. In this paper, we develop a computational method to assess this metric under the proposed SSTF management approach. This is the second contribution of this paper.

The rest of this paper is organized as follows. In Section II, we propose and describe the SSTF connection setup management approach, as well as the rationale of our computational approach. The computational framework aiming at the assessment of SSTF's performances is developed in Section III. Numerical results are presented in Section IV. Finally, Section V concludes this study and proposes future issues.

II. SSTF: Description and Modeling Rationale

Let us consider the simplified scenario presented in Figure 1(a) to describe the proposed SSTF setup management approach. In Figure 1(a), the Wavelength Router (WR) A is connected to the WR B through a fiber link which we suppose holding one wavelength. As such, when a connection t is

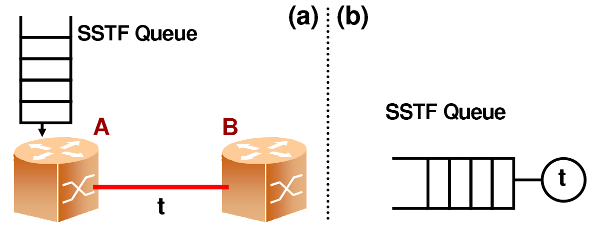

Fig. 1. A Sample SSTF Scenario.

established between A and B (occupying the sole available wavelength), future connection requests between A and B will be blocked as long as t occupies the wavelength on $A - B$. Based on our proposed SSTF approach, these blocked connections are queued at A's level in an SSTF queue according to an increasing order of their required setup times. Connections with stringent setup times are queued in front of those with longer setup times. We will be considering later this same scenario in our SSTF performance evaluation study. A queuing representation of the scenario is depicted in Figure 1(b). The *service* here is the offer of an optical connection (occupation of a λ during the connection). For sake of simplicity and to gain insight into this model, we suppose first that the connection service process is of constant duration; that is t for instance occupies the wavelength during a constant service time. In other words, each connection occupies a predefined time slot. In addition, the setup process is considered to be non preemptive, so once t is in-service the queued connections can not interrupt its service. Finally, we consider the case where a connection setup is provisioned even if its setup time is exceeded; that is its required service quality in terms of *connection setup time* is not met. This means that the setup time is considered here as a loose priority indicator, rather than a hard constraint.

In the next section, we will formally define the mathematical model allowing the computation of performance metrics. Now, we give rationale behind the model. We will use the vocabulary of customer instead of *connection setup request*, server instead of *optical connection providing*, laxity instead of *setup time*. As stated before, the evaluation of deadline mismatch ratio is an open problem, probably due to the fact that the deadline-based scheduling uses implicitly the *sojourn history*. Indeed, the position of a customer is determined by its urgency compared to the urgency of every other customer in the queue. Some of them may arrive after our target customer. The urgency of (and so the place taken by) a customer is not *fixed* upon its arrival, but is *timely increasing*. In this paper, we present our approach which takes the initial position of the customer as a parameter of the problem. This additional initial condition allowed us to develop a Markovian model, and, from which, calculate some of interesting performance metrics. The rationale behind our approach can be explained with the following observation: Let us move our view point from the queue to the arrival process. Consider a target customer which is queued at time t, with an initial laxity (margin before deadline expiration), say, L. Let us think about those customers who come *after* our target customer but will be served before our target customer. The EDF policy insures us that those customers *must* have their initial laxity smaller than the remaining deadline margin of our target customer at the time of their arrival. As time advances, the laxity of our target customer is getting smaller and smaller and these customers are getting rarer and rarer. Thus, we get the following observation for our target customer: *The EDF scheduler acts as a* filter *with the* residual *laxity as the filtering parameter, only the accepted customers are inserted* in front of *our target customer.* This observation is the basis of our approach. For technical reasons, we have also to deal with a slotted time axis and queues with limited buffers. As a customer eventually gets served or rejected, we obtain a transient Markov chain with absorbing states. We would like to point out that the additional condition we made, namely the knowledge of initial position and laxity, is readily available (for free) for our connection setup process.

III. The model

A. Definitions and Assumptions

- The time axis is slotted, *i.e.*, Time is divided into equal-length unit-slots. Customers arriving during one slot are considered at the beginning of the next slot.
- The service time is constant, assumed to be one slot time.
- Each customer comes with an initial *laxity* (denoted by L), which is the relative margin to its deadline expiration. The latter is defined related to the beginning of the service.
  - We assume that the initial laxities of customers are independent and identically distributed (i.i.d) integer random variables (r.v.). The CDF (Cumulative Distribution Function) of the initial laxity will be denoted by $F_L(.)$. For the purpose of numerical computability, we assume further that L is upper bounded by Λ. Thus, we have in particular

$$F(0) = 0, \quad \text{and} \quad F(l) = 1, \ \forall l \geq \Lambda.$$

  - Of course, the residual laxity of a customer decreases as time advances. For the sake of simplicity of formulation and without loss of generality, we consider a customer *alive* at a slot if in the *beginning* of this slot its residual laxity is *strictly* positive. In this paper, we do not consider the *tardiness*, *i.e.*, negative laxity. So, when a customer's laxity goes down to 0, it remains at 0.
- Services are non-preemptive and work conserving. This means in particular that *dead* customers (those having 0 residual laxity) are served as well.
- The queue has a capacity of K places, *i.e.*, it can accommodate $K-1$ waiting customers, in addition to the one being served. By convention, waiting places are numbered from 1 to $K-1$, the (virtual) position 0 will be later used to refer to a service completion situation, and the (virtual) position K refers to a rejection situation.
- The initial position of each customer is known. Customers move in the queue until being served (position 0) or being pushed out of the queue by customer having tighter laxity (position K).
- The overall arrival process is Poisson, denoted $\mathcal{P}$, with arrival rate λ_o. As the initial laxities are i.i.d integer variables, customers coming with an initial laxity strictly smaller than a particular laxity value, say l, form also a Poisson process $\mathcal{P}(l)$ with arrival rate $\lambda(l)$ given by $\lambda(l) = F_L(l-1)\lambda_o$ where $F_L(.)$ is the CDF of the initial laxity law. For a target customer $\mathcal{C}$ with residual laxity equal to l at the beginning of a slot, only those coming within the slot and having a initial laxity strictly smaller than l are to be inserted prior to $\mathcal{C}$. Note that $F_L(0) = 0$, this means $\lambda(1) = 0$, actually customers with residual laxity of 1 cannot be further delayed. For $l \geq 2$, let $A(l)$ denotes the number of customers arriving in a slot with initial laxity $d < l$. As such, $a(l,i)$, the probability of having i customers inserted before a target customer with residual laxity l, is given by

$$a(l,i) = Pr\{A(l) = i\} = e^{-\lambda(l)} \frac{[\lambda(l)]^i}{i!}. \tag{1}$$

B. A Markov Chain Model

Let us consider a target customer $\mathcal{C}$ arriving in a slot taken as time origin ($t = 0$) with an initial laxity L and initial queueing position N. The state of $\mathcal{C}$ at the i-th slot (S_i) can be described by a pair of random variables (r.v.) $S_i = (n_i, m_i)$ where

- the meaning of n_i depends on its value
  - For $1 \leq n_i \leq K-1$, n_i gives the queueing position occupied by $\mathcal{C}$, which is, in an equivalent manner, the number of customers which have to be served before $\mathcal{C}$, assuming that $\mathcal{C}$ is still in the queue at that slot.
  - By convention, $n_i = 0$ means $\mathcal{C}$ gets eventually served. Thus, once $\mathcal{C}$ enters a state with $n_i = 0$, it stays there forever.
  - By convention, $n_i = K$ means $\mathcal{C}$ is rejected without service. Thus, once $\mathcal{C}$ enters a state with $n_i = K$, it stays there forever.
- m_i gives the residual laxity. By convention, $m_i = 0$ means that there is no more residual laxity, thus $m_i = 0, \ldots, \Lambda$.

The $\{S_i\}_{i \geq 0}$ form a Markov chain. Indeed, the evolution of (n_i, m_i) is determined by the following relation:

$$m_{i+1} = \max(0, m_i - 1) \tag{2}$$

$$n_{i+1} = \text{minmax}\ (0, n_i - 1 + A(m_i), K) \tag{3}$$

where the function minmax (m, x, M) is a double limitation function

$$\text{minmax}\ (m, x, M) = \begin{cases} m, & x \leq m \\ x, & m < x < M \\ M, & x \geq M \end{cases}$$

and $A(m_i)$ is the number of customers arriving during the i-th slot with initial laxity strictly smaller than m_i, the law of $A(m_i)$ is given by Eqn. 1.

The evolution of S_i is thus totally forecastable from its current position. In addition, $P(A(m_i) = l)$ depends only on the values of the residual laxity m_i, and does not depend on the particular time position i. We obtain thus a transient homogeneous Markov Chain with absorbing states. Actually, the states $(0, m)$ and (K, m), $m = 0, \ldots, \Lambda$, are *absorbing* states by our convention.

- The states $(0, m)$ are those representing a customer eventually being served with laxity m,
- The states (K, m) are those representing a customer eventually being pushed out of queue with laxity m.

Theses absorbing states are of particular interest. With adequate interpretation (semantic), they provide estimation of useful performance metrics. In the following section, we present a framework for computing the probability of entering these states from a given initial position. We then define and compute some performance metrics of interest in section IV.

C. Computation

Assess the probability of entering one absorbing subset prior to the other one For a Markov chain is a classical problem. We recall the basic model here, then adapt it to our EDF queuing system for the estimation of SSTF performance metrics.

We consider a homogeneous Markov chain $X = \{X_i\}_{i \in \mathbb{N}}$ with a finite state space Ω, and transition probabilities $p_{ij} = Pr\{X_{n+1} = j/X_n = i\}$, $(i, j) \in \Omega^2$. Ω contains a subset of absorbing states $\mathcal{A}$, which is further divided into two subsets, respectively $\mathcal{G}$ and $\mathcal{B}$, *i.e.*, $\forall i \in \mathcal{G}, \forall j \in \Omega - \mathcal{G}, p_{ij} = 0$ (same statement for $\mathcal{B}$). Let $\mathcal{M} = \Omega - (\mathcal{G} \cup \mathcal{B})$, $\mathcal{M}$ is the non-absorbing subset. The triplet $(\mathcal{G}, \mathcal{M}, \mathcal{B})$ forms a partition of Ω.

If we attribute the semantic of good (living) places to $\mathcal{G}$, and bad (killing) places to $\mathcal{B}$. For our problem, $\mathcal{G}$ may be the event that the customer is served prior to its deadline, and $\mathcal{B}$ the event the customer is rejected (pushed out of queue) or it is served too late. Applications to SSTF case will be provided in section IV. We are interested by the probability of entering these absorbing states, *i.e.*, the probability of the event $G(i)$ that a chain which started at $X_0 = i$ enters eventually in $\mathcal{G}$ (and stays there forever).

$$G(i) = \{\exists n \geq 0, \exists j \in \mathcal{G}, X_n = j/X_0 = i\}$$

Let $g(i) = Pr\{G(i)\}$. Before drawing down the computation of $g(i)$, let us first notice that i) for $i \in \mathcal{G}$, $g(i) = 1$ and ii) for $i \in \mathcal{B}$, $g(i) = 0$. Thus, we only have to find formula for the cases $X_0 = i, i \in \mathcal{M}$. Let us first notice that, due to the memoryless property, and by assuming that $\{X_1 = j, X_0 = i\}$, $j \in \Omega$, does take place, we have

$$Pr\{G(i)/X_1 = j\} = Pr\{G(j)\}p_{ij} = g(j)p_{ij}.$$

We have

$$\begin{aligned} g(i) &= \sum_{j \in \Omega} Pr\{G(i)/X_1 = j\} \\ &= \sum_{j \in \mathcal{M}} g(j)p_{ij} + \sum_{j \in \mathcal{G}} 1 \times p_{ij} + \sum_{j \in \mathcal{B}} 0 \times p_{ij} \end{aligned}$$

Thus, we get the solution of all of the $g(i), i \in \mathcal{M}$ by solving a system of Card$\{\mathcal{M}\}$ linear equations with Card$\{\mathcal{M}\}$ unknowns, in the form of

$$\sum_{j \in \mathcal{M}, j \neq i} p_{ij} g(j) + (p_{ii} - 1) g(i) = -[\sum_{l \in \mathcal{G}} 1 \times p_{il}], \quad i \in \mathcal{M} \quad (4)$$

In conclusion, we get the following result.

Proposition 1: Consider a homogeneous transient Markov chain with state space Ω partitioned into the absorbing subset $\mathcal{A}$ and its complement $\mathcal{M}$, the non absorbing states. The subset $\mathcal{A}$ is further divided into $\mathcal{G}$ and $\mathcal{B}$. Giving the initial position $X_0 = i \in \mathcal{M}$, We can get $g(i)$, the probability of entering $\mathcal{G}$ starting from $X_0 = i \in \mathcal{M}$ by solving the system of linear equations specified by Eqn 4.

A similar result can be stated for $\mathcal{B}$ in the same manner. We omit it, since we don't need it in this paper.

We apply now the basic model to our specific EDF queueing system, the latter has been previously (subsection III-B) modeled as a transient homogeneous Markov chain with state descriptor (n, m) where $n = 0, \ldots, K, m = 0, \ldots, \Lambda$. For the sake of commodity, we denote the states by a scalar i, instead of the pair (n, m), with the relation

$$i(n, m) = n + m(K + 1) \quad (5)$$

Of course, this scalar indexing is useful only for computation.

IV. PERFORMANCE METRIC EVALUATION

A. Metrics definition

We take into account two phenomena : 1) deadline miss matching, 2) rejection due to buffer limitation. This leads to the following metrics, all of them are conditioned on the initial condition (inserted at position N with laxity L) of the target customer.

- conformed setup completion ($m > 0$) probability, denoted by $P_{cs}(N, L)$
- setup completion in late ($m = 0$) probability, denoted by $P_{ls}(N, L)$
- setup rejection ($m > 0$) probability, denoted by $P_{sr}(N, L)$
- reasonable rejection ($m = 0$) probability, denoted by $P_{rr}(N, L)$.

These metrics are obtained by computing $g(i(N, L))$ (cf. Eqn. 4 and Eqn. 5) with corresponding definition of $\mathcal{G}$ given below:

- For $P_{cs}(N, L)$, $\mathcal{G} = \{j(0, m)/j = m(K + 1), m = 1, \ldots, \Lambda\}$.
- For $P_{ls}(N, L)$, $\mathcal{G} = \{j(0, 0) = 0\}$.
- For $P_{sr}(N, L)$, $\mathcal{G} = \{j(K, m)/j = K + m(K + 1), m = 1, \ldots, \Lambda\}$.
- For $P_{rr}(N, L)$, $\mathcal{G} = \{j(K, 0) = K\}$.

We would like to point out that among the four metrics of the second group, P_{rr} is actually *identically* zero. In fact, due to our work-conserving hypothesis and the ML (minimum laxity) insertion rule, a customer with laxity $m = 0$ (or even $m = 1$) cannot be pushed toward the queue tail by new customers coming with a laxity at least equal to 1. Thus, once the laxity becomes 1, an already queued customer is surely to be served. Our computational results (cf. Table I), formally calculated according to our framework, confirm this theoretical deduction.

We can further define

- The setup completion probability $P_s(N,L) = P_{cs}(N,L) + P_{ls}(N,L)$ and
- The setup rejection probability $P_r(N,L) = P_{sr}(N,L) + P_{rr}(N,L)$.

B. Sample Results

The computation of metrics we proposed require mainly the solution of linear equations, according to previously established Proposition 1. Various *scenarii* have been tested. Due to space limitations, we choose to present one of them. Following the guidelines presented in [8] this scenario is defined as follows.

- the duration of each connection is 5 minutes. According to our model, it is normalized to 1 time slot.
- Buffer size $K = 20$, in other words, we accept to keep waiting up to 20 connection setup requests.
- There are two classes of customers :
  - Class C_2, with initial laxity set to 2 and arrival rate set to 0.25 customer/slot, this corresponds to a setup time of 10 minutes, with 1 request every 20 minutes.
  - Class C_{12}, with initial laxity set to $\Lambda = 12$ (a setup time of 60 minutes). We don't need to precise the arrival rate of C_{12} customers, since it has no impact on the metrics we want to compute.

We computed the various metrics for customers of class C_{12}, as function of their initial position. The results are given in Table I, only some sample values are given. We notice that the setup rejection ratio (P_{sr}) remains very low, whereas if the initial position is 11-th position or higher, then the probability of matching the setup time requirement vanishes.

N	P_{cs}	P_{ls}	P_s	P_{sr}	P_{rr}	P_r
5	0.987	0.013	1.000	0.000	0	0.000
8	0.758	0.242	1.000	0.000	0	0.000
9	0.544	0.456	1.000	0.000	0	0.000
10	0.287	0.713	1.000	0.000	0	0.000
11	0.082	0.918	1.000	0.000	0	0.000
18	0.000	0.996	0.996	0.004	0	0.004
19	0.000	0.963	0.963	0.037	0	0.037

TABLE I

SCENARIO: METRICS FOR CUSTOMERS COMING WITH INITIAL LAXITY SET TO 12, N GIVES THE INITIAL POSITION

V. CONCLUDING REMARKS AND FUTURE WORK DIRECTION

This paper proposes a novel optical connection setup management schema, namely the SSTF approach, which is based on the blocked connections' setup time values. The rationale behind this approach lies in the application of the EDF scheduling policy on the optical blocked connections to both increase the probability of connection success rate as well as to handle efficiently the time constraints of these connection requests.

For this approach, which benefits of advantages of the underlying EDF (Earliest Deadline First) scheduling algorithm, we presented also a numerical method for assessing some of the major performance metrics, such as the setup completion ratio. The latter is computed in function of the intensity of various requests with different specific time constraints (laxity), the buffer size, and finally the knowledge of initial conditions (laxity and position). The last condition is the basic assumption of this framework. As the problem of EDF miss ratio remains an open problem, we consider this computational approach as a second contribution of this paper.

We made our choice here not to reject the connection whose setup time is not met. This means that the setup time is used as a *soft* priority indicator, but not as a *hard* time constraint. Our framework cannot be used directly to deal with the latter case. Indeed, in the latter case, *dead* customers have to quit the queue, thus there is a double impact of the sojourn history on both the queueing position and the *death-and-departure* event. Our framework is intended to deal with the first issue by the knowledge of the initial position. The direct use of our framework would lead to a huge state space and so numerical computation difficulties. One direction of our future work is to find an alternate approach to deal with this non-work-conserving case.

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