Cost Minimisation for Optical Burst Switched Networks with Share-per-Node Fibre Delay Lines

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Abstract—In this paper, we present a cost minimisation problem for an optical burst switching network with share-per-node fibre delay lines. We solve the problem by means of a genetic algorithm and approximate non-Poisson traffic flows with a two-moment matching method. Emphasis is on the sensitivity of the network hardware cost to the offered traffic characteristics.

Index Terms—

I. INTRODUCTION

Fibre Delay Lines (FDLs) [1], [2] are used in Optical Burst Switching (OBS) networks to minimise burst losses that occur when different bursts contend for the same wavelength channel on a common output fibre link of a core node. In order to reduce the cost associated with the employment of FDLs and simultaneously satisfy a target performance in terms of burst loss probability, it is important to optimise the number of FDLs and their allocation in the OBS network. In this regard, we propose a method to determine a near-optimal FDL dimensioning for a buffered OBS network subject to performance constraints defined in terms of end-to-end burst blocking probability. Although research literature is rich with works related to optimisation problems for OBS networks [3], [4], we note that similar attention has not yet been devoted to the dimensioning of FDLs.

Our main contribution in the paper is in solving an FDL allocation problem for a buffered OBS network by means of a genetic algorithm. First of all, we consider the OBS Tune and Select (TAS) node architecture, where a dedicated input/output port of the switch is assigned to an FDL shared between the output ports in a feedback configuration (TAS-shFDL) [5]. Secondly, we approximate the deviations of burst traffic from being Poisson by employing the BPP method, a two-moment matching technique that has been successfully used in OBS network analysis [6], achieving better accuracy than standard Poisson analytic models. To the best of our knowledge, this is the first paper proposing a method to allocate FDLs in an OBS network with share-per-node buffers.

II. THE OBS NODE AND NETWORK UNDER STUDY

The OBS TAS-shFDL node architecture is illustrated in Fig. 1(a). The switch is equipped with \( P \) input/output ports, each one connected to an optical fibre link comprising \( W \) wavelength channels. We assume full wavelength conversion, that is each channel is supported by a wavelength converter.

Additionally, an extra input/output port is dedicated to an FDL comprising \( K \) wavelength channels. We refer to these channels as virtual buffers as described in [2]. The FDL is shared between the output links connected to the node in a feedback configuration. This means that a contention between two bursts will be resolved by directing one of the bursts to a free virtual buffer of the FDL and then re-offering it to a free wavelength channel of the output port. If this is not possible, the burst will be dropped and consequently lost from the system. It has extensively demonstrated in [5] that this architecture is more cost-efficient than a feed-forward architecture (where each output port has its own dedicated FDL). We consider an OBS network of such switches described by a graph \( G(\mathcal{N}, \mathcal{L}) \), where \( \mathcal{N} = |\mathcal{N}| \) denotes the number of nodes, \( \mathcal{L} = |\mathcal{L}| \) is the number of links. All links comprise the same number of wavelength channels \( W \). We assume that the network routing has already been determined, that is all traffic streams are routed over \( R \) different fixed paths. Every path is offered with the same burst traffic of load \( \rho_r \). We further define \( \rho = [\rho_1, \rho_2, \ldots, \rho_R] \) as the vector comprising the burst traffic loads offered to each path, where \( \rho_r \) represents the load of the traffic offered to path \( r \) (in Erlangs).

In general it is not possible to draw conclusions on the burst traffic characteristics at the output of a burst aggregator. The traffic may follow different distributions depending on the assembly procedure and on the nature of the traffic that is offered to the aggregator [7]–[9]. On the other hand, Gauger [5] has found from simulation that performance is relatively insensitive to burst length distribution. Rostami and Wolisz [10], through analysis, also show that burst length distribution has little impact on performance, concluding that assuming exponentially distributed burst lengths is appropriate in analysis. We further confirm this assumption by generating simulation results as illustrated in Figure 2. We show the burst
buffers of node $n$. Following Gauger in [5], the TAS-shFDL architecture equips $2(P_n + 1)$ Erbium-Doped Fibre Amplifiers (EDFAs), $P_n W + K_n$ Tunable Wavelength Converters (TWCs) and $(P_n + 1)(P_n W + K_n)$ Semiconductor Optical Amplifiers (SOAs), where $P_n$ and $K_n$ denote respectively the number of ports and the number of FDL virtual buffers of node $n$. Hence,  

$$C_n = 2(P_n + 1)c_E + (P_n W + K_n)c_T + ([P_n + 1](P_n W + K_n))c_S.$$  

(2)  

where $c_E$, $c_T$ and $c_S$ represent respectively the unit cost of an Edfa, a TWC and a SOA. Thus, the total hardware cost of the network can be expressed as $C(K) = \sum_{n \in N} C_n$, where $K = [K_1, \ldots, K_N]$ is a vector representing the FDL buffer allocation in the network. Let $P_{max}$ be the maximum tolerable end-to-end blocking probability for each path of the network. Furthermore, let us assume that each FDL can comprise a minimum and a maximum number of virtual buffers respectively indicated as $K_{min}$ and $K_{max}$ and that all virtual buffers must be expressed with an integer value. Thus, our problem is to find a near-optimal allocation of virtual buffers $K_{opt}$ that will minimise the cost $C(K)$ and satisfy the constraints previously defined. We express this problem as minimize  

$$C(K)$$  

subject to  

$$\begin{align*}
\max_r |P_r(K)| &\leq P_{max}, & r = 1, \ldots, R, \\
K_{min} &\leq K_n \leq K_{max}, & n = 1, \ldots, N, \\
K_n \in \mathbb{N}.
\end{align*}$$  

(3)  

The problem defined above falls into the category of mixed integer nonlinear programming problems, a branch of NP-hard problems that is particularly challenging to solve. In order to overcome this issue, we use a constraint handling Genetic Algorithm (GA) [12]. Due to its approach based on a search within a given population, the GA allows simultaneous search of different regions of the solutions space and potentially find multiple candidate near-optimal solutions of an optimisation problem in a single run [12]. In order to solve (3), each candidate solution (individual) representing a network buffer allocation is encoded into a vector $K$ of $N$ integer numbers $K_n$ with $K_{min} \leq K_n \leq K_{max}$. The algorithm starts by generating a population of $N_{pop}$ randomly generated individuals. The fitness $f(K)$, representing the “goodness” of individual $K$, is calculated as  

$$f(K) = \begin{cases} -C(K) & \text{if } K \text{ is feasible}, \\ -C(K^+) - D & \text{if } K \text{ is unfeasible}, \end{cases}$$  

(4)  

where $D = |\max_r |P_r(K)| - P_{max}|$ and where we have indicated with $K^+$ the feasible FDL allocation with the lowest fitness in the population (note that a solution is denoted feasible if it satisfies all the constraints of the optimisation problem). Candidate parents are selected according to the tournament selection strategy [12] and generate two new individuals with a two-point crossover [12] with probability $P_{rc}$. All children are finally mutated by randomly changing one their genes with a new value within the feasible range $[K_{min}, K_{max}]$ with probability $P_{rm}$. This process helps preserving the diversity in the population and prevents the GA to get stuck in a local minimum. We further adopt elitism by keeping the individuals...
TABLE I

Paths of the European Optical Network Topology.

<table>
<thead>
<tr>
<th>Path</th>
<th>Path hops</th>
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<tbody>
<tr>
<td>1</td>
<td>1 → 2</td>
<td>10</td>
<td>11 → 7</td>
</tr>
<tr>
<td>2</td>
<td>3 → 4</td>
<td>11</td>
<td>12 → 10</td>
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<tr>
<td>3</td>
<td>13 → 15</td>
<td>12</td>
<td>10 → 7</td>
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<tr>
<td>4</td>
<td>12 → 7</td>
<td>13</td>
<td>13 → 9</td>
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<tr>
<td>5</td>
<td>2 → 4</td>
<td>14</td>
<td>8 → 5</td>
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<td>6</td>
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<td>17</td>
<td>13 → 8</td>
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<tr>
<td>9</td>
<td>1 → 5</td>
<td>18</td>
<td>14 → 15</td>
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Fig. 3. Target values of $P_e$ obtainable with feasible allocations $K_{opt}$ yielding a near-optimal cost $C$ for $W = 16$ channels and offered load $\rho = 0.3$ Erlang per path. Simulation data is represented with 95% level confidence intervals.

Fig. 4. Target values of $P_e$ obtainable with feasible allocations $K_{opt}$ yielding a near-optimal cost $C$ for $W = 32$ channels and offered load $\rho = 0.35$ Erlang per path. Simulation data is represented with 95% level confidence intervals.

IV. RESULTS

We validate our model through comparison with data obtained from a discrete-event simulation of the OBS network. We consider the European Optical Network (EON) topology of Figure 1(b) comprising $N = 15$ nodes, $L = 26$ bidirectional links and $R = 18$ paths whose path hops are indicated in Table

we set the unit cost of a SOA as $c_S = 1$ and we decide to fix the unit cost of an EDFA at $3c_S$ and the unit cost of a TWC at $15c_S$. We run the GA for $G_{max} = 500$ generations with a population of $N_{pop} = 300$ individuals. The crossover and mutation probability are set respectively to $Pr_c = 0.9$ and $Pr_m = 0.05$.

Figures 3 and 4 illustrate the highest end-to-end blocking probability achieved with near-optimal cost $C(K_{opt})$. Each point corresponds to an instance of problem (3) solved with

I. All network links comprise the same number of wavelength channels $W$ and all paths are offered with burst traffic with the same value of average load $\rho$ and peakedness $Z$. Note that the proposed optimisation process is resolved during the phase of network planning, hence, although traffic demands are primarily dynamic, we allocate the network resources on the basis of static “peak-hour” offered traffic demands. We solve problem (3) multiple times by varying the maximum tolerable loss level $P_{max}$ in the range $[10^{-1}, 10^{-6}]$ and assuming that $K_{min} = 0$ and $K_{max} = W/2$ virtual buffers. We relate all unit costs to the one of a SOA, the SOA being a device currently less expensive than an EDFA and a TWC. Thus, we set the unit cost of a SOA as $c_S = 1$ and we decide to fix the unit cost of an EDFA at $3c_S$ and the unit cost of a TWC at $15c_S$. We run the GA for $G_{max} = 500$ generations with a population of $N_{pop} = 300$ individuals. The crossover and mutation probability are set respectively to $Pr_c = 0.9$ and $Pr_m = 0.05$.

Figures 3 and 4 illustrate the highest end-to-end blocking probability achieved with near-optimal cost $C(K_{opt})$. Each point corresponds to an instance of problem (3) solved with
the GA described in Section III. We first validate our analytic model by observing its very good accuracy compared to simulation data for a broad range of blocking probabilities. We also prove that the near-optimal network hardware cost varies considerably with the peakedness $Z$ of the traffic demands, an occurrence that, we believe, justifies the importance of approximating non-Poisson traffic. For example note that in Figure 4, the minimum hardware cost needed to reach a burst loss below $10^{-3}$ is $\approx 24000$ when $Z = 0.8$ whereas for $Z = 1.4$ it becomes $\approx 25200$.

Figure 5 illustrates an example of the distribution of the FDL virtual buffers in the OBS network. We observe that the FDL distribution changes considerably with $Z$, since congestion at nodes increases when traffic becomes peaked. Note that some nodes are not assigned with FDLs, regardless of the peakedness of their offered traffic demands. Thus, the GA is able to identify the nodes of the network for which adding an FDL does not add any contribution in lowering the end-to-end blocking probability value.

Finally, end-to-end blocking probabilities for each path are shown in Figure 6. We observe that the analytic method provides a quite accurate estimate of the blocking probability at the near-optimal point compared to simulation data. The graph additionally shows that each path blocking is below the maximum tolerable value given by $P_{\text{max}}$, thus satisfying the performance constraint of our optimisation problem.

V. CONCLUSIONS

We have proposed a method to find a near-optimal allocation of FDL buffers in an OBS network to minimise cost and satisfy performance constraints. Analytic results compare favourably to simulation data and illustrate how deviations from Poisson traffic can considerably influence the optimisation of FDL buffers in the network.

REFERENCES