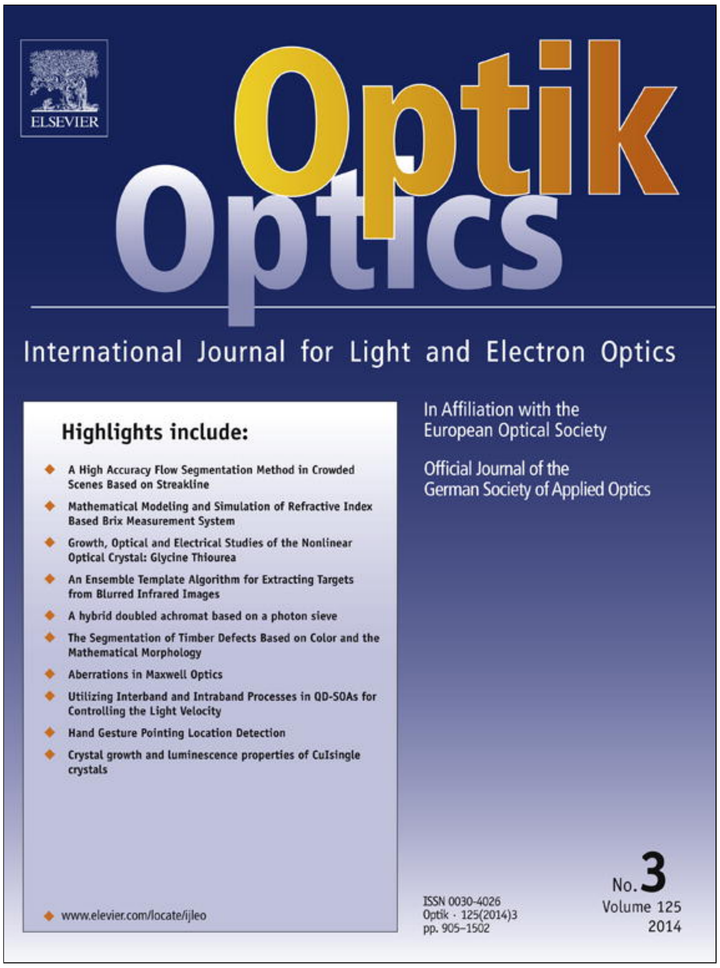
Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



ELSEVIER

Optik
Optics

International Journal for Light and Electron Optics

Highlights include:

- A High Accuracy Flow Segmentation Method in Crowded Scenes Based on Streakline
- Mathematical Modeling and Simulation of Refractive Index Based Brix Measurement System
- Growth, Optical and Electrical Studies of the Nonlinear Optical Crystal: Glycine Thiourea
- An Ensemble Template Algorithm for Extracting Targets from Blurred Infrared Images
- A hybrid doubled achromat based on a photon sieve
- The Segmentation of Timber Defects Based on Color and the Mathematical Morphology
- Aberrations in Maxwell Optics
- Utilizing Interband and Intraband Processes in QD-SOAs for Controlling the Light Velocity
- Hand Gesture Pointing Location Detection
- Crystal growth and luminescence properties of CuIsingle crystals

www.elevier.com/locate/ijleo

In Affiliation with the
European Optical Society

Official Journal of the
German Society of Applied Optics

ISSN 0030-4026
Optik · 125(2014)3
pp. 905–1502

No. 3
Volume 125
2014

This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

http://www.elsevier.com/authorsrights

Author's personal copy

Optik 125 (2014) 1002–1006

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A novel routing scheme in OBS network with sparse wavelength conversion capabilities

Tundong Liu[a,b], Tiane Fan[a,b], Binghui Zheng[a,b], Jiping Tao[a,b,*]

[a] College of Information Science and Technology, Xiamen University, Xiamen 361005, Fujian, China
[b] Center for Cloud Computing and Big Data, Xiamen University, Xiamen 361005, Fujian, China

ARTICLE INFO

Article history:
Received 19 March 2013
Accepted 21 July 2013

Keywords:
SWCC-OBS network
Routing scheme
Burst loss probability
Fictitious play
Random routing strategy

ABSTRACT

The overall burst loss probability is the primary metric of interest in an optical burst switching network with sparse wavelength conversion capabilities (SWCC-OBS). With the overall burst loss probability as the optimization objective, one has to solve an integer nonlinear programming (INLP) problem. In order to overcome the computational difficulties we propose a fictitious play method to approximately solve the INLP. Consequently, a randomized routing strategy can be achieved. The simulation results show that the proposed strategy can give a near-optimal route that avoids the conflict of burst data effectively and decreases the overall burst loss probability. At the same time it also performs well in balancing loads throughout the whole network under different kinds of burst traffic pattern.

© 2013 Elsevier GmbH. All rights reserved.

1. Introduction

Optical Burst Switching (OBS) has been proposed as a promising switching technology for the next generation of optical transport network [1]. OBS combines the advantages of optical circuit switching (OCS) and optical packet switching (OPS) scheme and avoids some drawbacks in many aspects [2,3]. One of the most important issues in OBS network is burst loss due to congestion caused by transient or permanent overload. As a kind of contention-resolution mechanism, wavelength conversion can effectively alleviate output port contention [4]. Recent studies have shown that even the most limited conversion range may reduce path blocking probabilities by several orders of magnitude, compared with no wavelength converter (WC) [5]. Moreover, OBS with full WC can achieve significantly lower blocking probabilities than OBS with limited WC. However, wavelength converters are very expensive and still immature technically. Due to these limitations in the implementation of full range WC, limited range WC is a more economical and practical solution for optical network [6]. Consequently new challenges arise for the routing strategy in the OBS network with sparse wavelength conversion capabilities.

In recent years, many routing algorithms have been presented to decrease the overall burst loss probability in the SWCC-OBS network. Teng and Rouskas [7] presented a traffic engineering approach to select paths for source routing to balance the traffic load across the network links. Thodime and Vokkarane [8] proposed a dynamic scheme for selecting routes at the burst sources. Belbekkouche [9] applied integral linear programming routing algorithm to reduce the contention between bursts, and so on [5,10,11]. Most of these routing algorithm adopt fixed or alternate routing mechanism, which can decrease the overall burst loss probability to some extent for OBS network with uniform traffic. They perform not very well for non-uniform traffic because most burst data choose the same routing path.

In this work, we propose a fictitious play method to solve the classical INLP model, from which a random routing strategy is derived. This paper is organized as follows. Section 2 describes the SWCC-OBS network and introduces INLP formulation for minimizing the overall burst loss probability. Section 3 presents the fictitious play method and the random routing strategy. Section 4 performs simulation comparison with other classical routing algorithms under different traffic patterns and validates the effectiveness of the strategy. Conclusion is given in Section 5.

2. SWCC-OBS network model

This section describes the SWCC-OBS network and introduces INLP formulation for minimizing the overall burst loss probability. Section 2.1 describes of the SWCC-OBS network; Section 2.2 introduces the switches blocking probability in the SWCC-OBS network; Section 2.3 describes INLP formulation for minimizing the overall burst loss probability.

---

[*] Corresponding author at: College of Information Science and Technology, Xiamen University, Xiamen 361005, Fujian, China.
E-mail address: taojiping@xmu.edu.cn (J. Tao).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.07.129

Author's personal copy

Table 1
Conversion capability matrix of WC with degree $d = 1$.

Wave length	1	2	3	...	...	$w-1$	w
1	√	√					
2	√	√	√				
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
$w-1$				√		√	√
w						√	√

2.1. A SWCC-OBS network

We use $G = (V, E, R, K)$ to denote the graph of a SWCC-OBS network. The set of switching nodes is represented as $V = (S_1, S_2, \ldots, S_N)$, $N = |V|$; the set of links is represented as $E = \{l_1, l_2, \ldots, l_M\}$, $M = |E|$. Each link is with the same number of wavelengths, let W denotes the total number of wavelengths, and the set of wavelengths is $\{\lambda_1, \lambda_2, \ldots, \lambda_W\}$. If a link l_k connects an output port of switching node S_i to an input port of switching node S_j, we will refer to S_i and S_j as the tail and head, respectively, of l_k. We define $R = 2d + 1$ as the conversion range of the nodes equipped with wavelength converters, where d is an integer in $[0, \lfloor W/2 \rfloor]$ and represents the conversion degree. For any in-progress burst arriving on ingoing wavelength λ_i, $1 \le i \le W$, it can only be converted to an outgoing wavelength λ_j in the range of $[\lambda_{\max(i-d,1)}, \lambda_{\min(i+d,W)}]$. In addition, for any in-progress burst arriving on λ_i, an aim conversion set $N^i = \{\lambda_j \,|\, j = (i + l)\mathrm{mod}(W),\ \ l = 0, \pm 1, \ldots, \pm d\}$ and $R = |N^i|$. Table 1 shows a WC capability matrix with the conversion degree $d = 1$, where each ingoing wavelength λ_i in rows can be converted to the corresponding wavelengths in columns.

Let $K (0 \le K \le W)$ denotes the number of WCs in a switching node, we assume that the core switching node be equipped with the same number of WCs. Specially, if $K = 0$, it represents an OBS network without wavelength converters; and if $K = W$, it means the network with full wavelength converters.

For OBS network with a limited number of WCs, one has to determine which core nodes to be equipped with WCs. This is usually done in terms of the node degree. The node degree indicates the importance extent of the corresponding node. Generally speaking, the larger the degree is, the greater the probability of the burst data conflict in the node. Therefore, the wavelength converters are allocated with preference to core nodes with larger degree to decrease the contentions among bursts.

2.2 The blocking probability in SWCC-OBS network

We assume that each photonic switch is with N input/output mono-fiber links each of which carries W wavelength channels $\lambda_1, \lambda_2, \ldots, \lambda_W$ in OBS network. Some assumptions are made for the traffic pattern in the switching nodes [12].

The arrival of bursts at each output port is a symmetric Poisson process, in other words, the burst internal arrival time is exponentially distributed and each burst arrives at any wavelength with the same probability.

There are W independent burst sources denoted by $\{s_0, \ldots, s_i, \ldots, s_{W-1}\}$, and each source s_i generates a burst flow to wavelength λ_i. The internal arrival time of burst is exponentially distributed with the mean of $1/\alpha$, the arrival rate of a port is $W \times \alpha$.

The burst length is exponentially distributed with expectation $1/\beta$. The arriving bursts will be served in a manner of first-come-first-served. The traffic intensity produced by each source s_i is α/β, and the traffic intensity of a port is $W\alpha/\beta$.

According to the definitions above, when a burst arises from s_i with a busy wavelength, the burst will be transmitted randomly to one of idle wavelengths in the aim conversion set N^i; if either no any wavelength converter is available or the wavelengths within the aim conversion set N^i are all occupied, the incoming burst will be dropped.

The system process at each output port can be described by a two-dimensional Markov process and the state transition diagram is shown in Fig. 1 [12]. The two-dimensional state (m,n) represents that m wavelengths and n converters are occupied by the bursts, where $0 \le n \le m \le W$, and $n \le K \le W$.

For simplicity, we only provide the transition rates for outgoing streams from a given state (m,n) since any incoming stream is also the outgoing one from other state (m',n'). We define $A_{m,n}$, $B_{m,n}$, $C_{m,n}$, $D_{m,n}$ as transition rates from state (m,n) to other states, respectively [12].

$A_{m,n}$: The system state transform from (m,n) to $(m+1,n)$, for $m+1 \le W$. This transition indicates that the incoming data burst can be directly scheduled on an unoccupied wavelength without using wavelength converter. Hence, input wavelength of the new burst must be one of the $(W - m)$ wavelengths that are not currently used. Thus, the current state transition rate is $A_{m,n} = (W - m)\alpha$.

$B_{m,n}$: The system transform from (m,n) to $(m+1,n+1)$, for $m + 1 \le W$, $n + 1 \le K$.This transition indicates that wavelength λ_i of the incoming burst belongs to one of the occupied wavelengths, and the aim conversion set N^i is not blocked completely. Consequently, an idle converter with conversion degree d is assigned for converting its input wavelength to other idle wavelength within the same aim conversion set. Thus, the transition rate is

$$B_{m,n} = \begin{cases} m\alpha & m = 1, \ldots, R-1 \\ \left(m - \sum_{i=r}^{m} (i - R + 1) n_m^i\right)\alpha & m = R, \ldots, W-1 \end{cases}$$

where n_m^i denotes average number of the successive occupied wavelength arrays [13].

$C_{m,n}$: The system transform from (m,n) to $(m-1,n)$, for $m - 1 \ge 0$, $m > n$.This transition indicates that a burst not using any wavelength converter has been terminated in this destination node. Currently there are $(m - n)$ bursts not using wavelength converters, therefore, the transition rate is $C_{m,n} = (m - n)\beta$.

$D_{m,n}$: The system transform from (m,n) to $(m-1,n-1)$. This transition indicates that a burst using one converter has just been terminated completely. As there are n bursts using wavelength converters, the transition rate is $D_{m,n} = n\beta$.

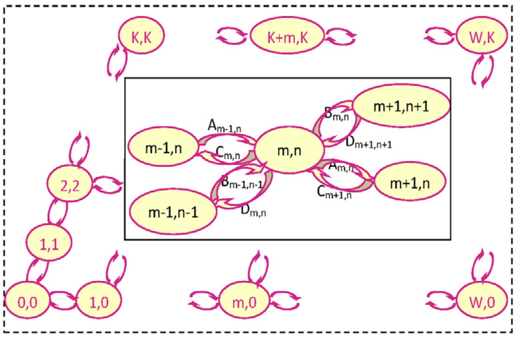


Fig. 1. System state transition diagram of Markov process.

Author's personal copy

Denote the stationary probability at the state of (m,n) by $p_{m,n}$. According to these transition rates above, we can derive the simultaneous equations as follows.

$$\begin{cases} \sum\limits_{m,n} p_{m,n} = 1 \\ (A_{m,n}+B_{m,n}+C_{m,n}+D_{m,n})p_{m,n} = A_{m-1,n}p_{m-1,n} + B_{m-1,n-1}p_{m-1,n-1} + C_{m+1,n}p_{m+1,n} + D_{m+1,n+1}p_{m+1,n+1} \end{cases} \tag{1}$$

Links in an OBS network can be divided into two kinds: E_1 which use the convertible core nodes as head node and E_2 which use the ordinary nodes as head node. P_{b1k} and P_{b2k} represent the blocking probability of these two links, respectively. The blocking probability of each link is composed of two terms below:

The blocking probability caused by having no idle output wavelengths at output port is $P_{b1k} = \sum_{i=0}^{K} p_{W,i}$.

The blocking probability caused by lacking limited wavelength converters is $P_{b2k} = \sum_{j=K}^{W-1} (j/w) p_{j,K}$.

Thus, the probability of each link in OBS network is

$$P_k = P_{b1k} + P_{b2k} = \sum_{i=0}^{K} p_{W,i} + \sum_{j=K}^{W-1} \frac{j}{W} p_{j,K} \tag{2}$$

To extend this point further, the blocking probability of

Combining (1) and (2), we can derive the blocking probability P_b^k as a nonlinear function with respect to the traffic intensity $W\alpha/\beta$ of the port. For ease of presentation, we denote the function by $p(\cdot)$, i.e.

$$P_k = p\left(\frac{W\alpha}{\beta}\right) \tag{3}$$

2.3. INLP formulation

In this work, we assume that the traffic pattern is described by a $N \times N$ matrix $\mathit{\Gamma} = [\gamma_{ij}]$, where γ_{ij} denotes the long-term arrival rate of bursts originating at node S_i and destined for node S_j. In practice, γ_{ij} can be obtained by experience or prediction regarding the long-term demands placed upon the network; while these values may be updated over time [14]. Let $1/U_{ij}$ denote the average length of bursts traveling from switch S_i to switch S_j, and $\{\rho_{ij}\}$ denote the load of bursts from S_i to S_j, where $\rho_{ij} = \gamma_{ij}/u_{ij}$. Let x_{ijk} denote the probability of burst traffic from node S_i to node S_j that travels over link l_k, and $0 \le x_{ijk} \le 1$. In this paper, we will restrict variables x_{ijk} to take only two values, 0 or 1. In this case, the solution will yield a single path for each source-destination pair, so it means we adopt a fixed routing mechanism at first. Denote the load along link l_k by ρ_k. Let P_k denotes the probability that a burst is dropped along link l_k. We make the reasonable assumption that $P_k \ll 1, \quad \forall k$. Then we can formulate an optimization problem in terms of the burst loss probability as follows [14]:

Minimize:

$$f_{obj} = \frac{\sum_{l_k \in E} \left(P_k \times \sum_{i \neq j} \rho_{ij} x_{ijk}\right)}{\sum_{i \neq j} \rho_{ij}} \tag{4}$$

Subject to:

$$\sum_{l_k \in tail(v)} x_{ijk} - \sum_{l_k \in head(v)} x_{ijk} = \begin{cases} 1 & v = i \\ -1 & v = j \\ 0 & \text{other} \end{cases} \tag{5}$$

$$\sum_{l_k \in tail(v)} x_{ijk} \le 1 \tag{6}$$

$$\sum_{l_k \in head(v)} x_{ijk} \le 1 \tag{7}$$

$$P_k = p(\rho_k) = p\left(\sum_{i \neq j} \rho_{ij} x_{ijk}\right) \tag{8}$$

where (5)–(7) represent the network flow constrains. Obviously, the objective function (4) is a nonlinear function with respect to x_{ijk} due to the nonlinearity of (8). In order to overcome the computational difficulties of solving the INLP, in this paper, we propose a fictitious play method to approximately solve the problem. Consequently we can achieve a randomized routing strategy.

3. Fictitious play

By investigating the INLP formulation above, we can find out that, if we omit the constrain (7) by assigning P_k as a given value (this can be done by predicting ρ_k), the original INLP would become a classical shortest path problem, which can be efficiently solved by many algorithms such as Dijkstra algorithm. Based on this observation, we propose the fictitious play method by iteratively updating the prediction about ρ_k.

The superscript (u) represents the u-th iteration. The fictitious play algorithm can be described below:

Step1: Initialize. Let $u = 1$, and $\rho_k^{(1)} = \sum_{i \neq j} \rho_{ij}/|E|$.

Step2: Compute the blocking probability with respect to the current prediction about the traffic load $P_k^{(u)} = p(\rho_k^{(u)})$.

Given the blocking probability $P_k^{(u)}$, solve (4) with constrains (5)–(7) by Dijkstra algorithm. Denote the corresponding optimal solution by $x_{ijk}^{(u)}$, and the optimal function value by $f^{(u)}$.

Step3: Check the stopping criteria by computing the changing value of the average optimal function value. If

$$\left| \frac{\sum_{s=1}^{u} f^{(s)}}{u} - \frac{\sum_{s=1}^{u-1} f^{(s)}}{u-1} \right| \le \varepsilon$$

where ε is a predetermined threshold, then stop, otherwise continue.

Step4: update the prediction

$$\rho_k^{(u+1)} = \left(1 - \frac{1}{k+1}\right) \rho_k^{(u)} + \frac{1}{k+1} \sum_{i \neq j} \rho_{ij} x_{ijk}^{(u)}$$

$u \leftarrow u + 1$. Go to Step2.

From proposition 2.2 and proposition 2.3 [15], we can guarantee that the fictitious play above converges.

Next we design a random routing strategy according to the solution of the fictitious play above. Let

$$\bar{x}_{ijk} = \frac{\sum_{u=1}^{U} x_{ijk}^{(u)}}{U},$$

where U is the total iteration number. $\bar{x}_{ijk}$ represents the probability with which the route from S_i to S_j pass l_k.

4. Simulation result

In this section, we perform simulation to corroborate the accuracy of the theoretical analysis results on the blocking performances (using Matlab software). We consider 16-node NSFNET topology derived from the 14-node NSF network as shown in Fig. 2, and assume that only two switches have wavelength converters and the convert degree $d = 3$. The number of limited capability

Author's personal copy

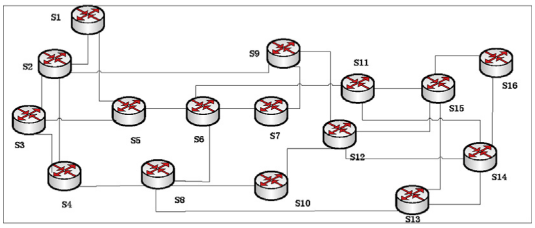


Fig. 2. The topology network based on 16-node NSFNET.

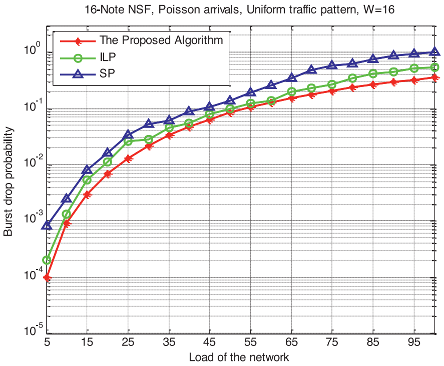
wavelength converters in one switch node is $K = 8$, and the number of wavelength channel is $W = 16$.

We assume that burst lengths are exponential distribution and arrival processes are Poisson distribution. Three different traffic flow patterns have been considered in our simulations: (i) *Uniform traffic pattern*: each switch generates the same traffic load, and the traffic from a given switch is uniformly distributed to other switches. (ii) *Positive-correlation traffic pattern*: the traffic load is positively correlated with the path hop count between two arbitrary nodes in OBS network. (iii) *Negative-correlation traffic pattern*: the amount of burst data has a negative correlation with the path hop count between two arbitrary nodes.

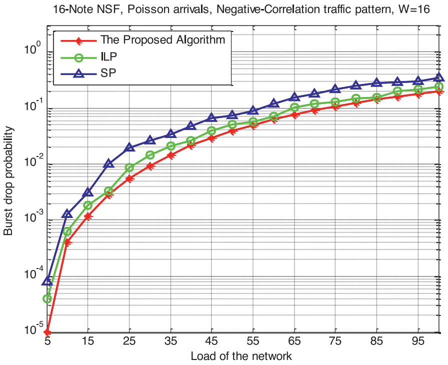
At the same time, we compare three different routing algorithms: (i) *SP routing*: bursts are routed over the shortest path (in terms of hops) between source and destination. (ii) *ILP routing*: linearizing the INLP formulation (6) and restricting $x_{ij}^{(k)}$ to take only two possible values, 0 or 1. Then solving the ILP formulation using MATLAB to obtain n sets of solutions about $x_{ij}^{(k)}$ and plugging them into B_N, minimizing B_N to get an approximate optimal path. (iii) *Proposed routing based on fictitious play*: build an INLP model, and then use fictitious play to calculate Nash equilibrium in mixed-strategy. The Nash equilibrium solution is the final path.

As shown in Fig. 3, it indicates that comparing with SP routing and ILP routing in NSFNET network topology with three different traffic patterns, the proposed algorithm based on fictitious play can obtain lower overall burst loss probability. And under the same normalized network conditions, this advantage shows little change with the increase of traffic load. This result is due to the fact that, with the load increasing the blocking probability of both SP routing and ILP routing shows non-linear growth as they use fixed routing mechanism, while the proposed algorithm adopt the random routing mechanism to randomly distribute the load in a certain probability. Under low loads, the blocking probability of proposed algorithm is almost under 10^{-4}, and is the lowest among three routing scheme. With the load increasing, shortest-path routing using the same set of paths regardless of the actual traffic pattern makes the big difference between links, therefore, a high link loading will lead to high burst drop probability, regardless of the burst arrival process. But the fictitious play algorithm can exploit the information regarding the actual traffic, which leads actual load to maintain relative balance.

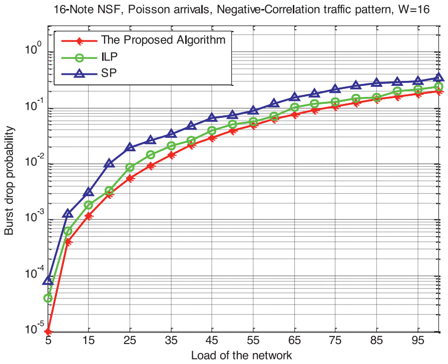
Fig. 3(a)–(c) indicates that under three different traffic patterns in NSFNET network topology, the performance of proposed algorithm is significantly better than SP routing and ILP routing. Under low loads, three different algorithms have a clear distinction and the burst drop probability changes quickly. In high loads, the burst loss probability of fictitious play algorithm is changing slowly with the load increasing. In the whole process of load increasing, the burst loss probability of proposed algorithm is always lower than SP and ILP routing. Furthermore, Fig. 3(d) reflects the performance of proposed algorithm in three different traffic patterns; it indicates that the negative-correlation traffic pattern performs better



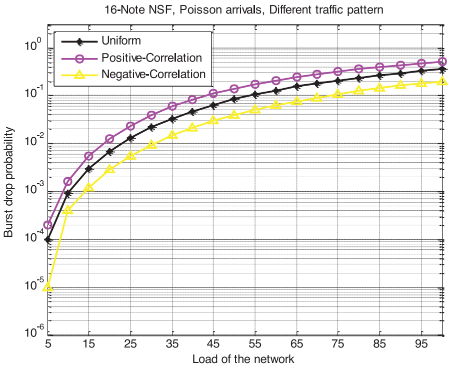
(a) Possion arrivals, Uniform traffic pattern



(b) Possion arrivals, Positive-Correlation traffic pattern



(c) Possion arrivals, Negative-Correlation traffic pattern



(d) Possion arrivals, Different traffic patterns

Fig. 3. The blocking probability of different algorithms. (a) Poisson arrivals, uniform traffic pattern. (b) Poisson arrivals, positive-correlation traffic pattern. (c) Poisson arrivals, negative-correlation traffic pattern. (d) Poisson arrivals, different traffic patterns.

Author's personal copy

than the other two patterns. Therefore, our algorithm is more suitable for the amount of burst data has a negative correlation with the path hop count between two arbitrary nodes.

The simulation results sufficiently indicate that the random routing model based on fictitious play in SWCC-OBS network performs significantly better than shortest path routing and ILP routing in burst loss probability, at the same time, it can obtain load balancing of whole network in different traffic patterns.

5. Conclusion

We have addressed the problem of selecting paths in practical SWCC-OBS network in order to minimize the overall burst loss probability. By establishing the INLP optimization formula, we propose a novel routing strategy based on fictitious play in OBS network to achieve a set of optimal routing paths for minimizing the burst loss probability. Our results indicate that, comparing with fixed routing, this approach is successful in obtaining paths that balance the load evenly, leading to a reduction in the burst loss probability for different traffic patterns in NSFNET network topology. Obviously, the randomized routing strategy can reduce network's blocking probabilities by several orders of magnitude, compared with most of the fixed routing mechanism.

Acknowledgments

This work was supported by China National Science Foundation (Grant No. 11201391) and Fujian Natural Science Foundation of China (Grant No. 2013J01103).

References

[1] C. Qiao, M. Yoo, Optical burst switching (OBS) – a new paradigm for an Optical Internet$\hat{1}$, J. High Speed Netw. 8 (1999) 69–84.

[2] J. White, Optical burst switching for next generation transport networks, Department of Electrical and electronic engineering, University of Melbourne, 2002, Masters-tophd conversion report.

[3] Y. Chen, H. Wu, D. Xu, C. Qiao, Performance analysis of optical burst switched node with deflection routing, in: Communications, 2003. ICC′03 IEEE International Conference on, 2003, pp. 1355–1359.

[4] L. Yang, G.N. Rouskas, Adaptive path selection in OBS networks, J. Lightwave Technol. 24 (2006) 3002.

[5] Z. Rosberg, A. Zalesky, H.L. Vu, M. Zukerman, Analysis of OBS networks with limited wavelength conversion, IEEE/ACM Trans. Netw. (TON) 14 (2006) 1118–1127.

[6] S.B. Yoo, Wavelength conversion technologies for WDM network applications, J. Lightwave Technol. 14 (1996) 955–966.

[7] J. Teng, G.N. Rouskas, Routing path optimization in optical burst switched networks, in: Proceedings of ONDM, 2005.

[8] G.R. Thodime, V.M. Vokkarane, J.P. Jue, Dynamic congestion-based load balanced routing in optical burst-switched networks, in: Global Telecommunications Conference, 2003. GLOBECOM′03. IEEE, 2003, pp. 2628–2632.

[9] A. Belbekkouche, A. Hafid, M. Tagmouti, M. Gendreau, A novel formulation for routing and wavelength assignment problem in OBS networks, in: Communications (ICC), 2010 IEEE International Conference on, 2010, pp. 1–6.

[10] Wang.F B.-Y., A.-H. Guan, A deflection routing mechanism based on priority in OBS networks, Opt. Commun. Technol. 1 (2011) 015.

[11] V.S. Puttasubbappa, H.G. Perros, Performance analysis of limited-range wavelength conversion in an OBS switch, Telecommun. Syst. 31 (2006) 227–246.

[12] Y. Xu, K.-Y. Shi, G. Fan, Performance analysis of optical burst switching node with limited wavelength conversion capabilities, J. Central South Univ. Technol. (Engl. Ed.) 16 (2009) 794–801.

[13] Z. Zhang, Y. Yang, Performance modeling of bufferless WDM packet switching networks with limited-range wavelength conversion, IEEE Trans. Commun. 54 (2006) 1473–1480.

[14] J. Teng, G. Rouskas, Traffic engineering approach to path selection in optical burst switching networks, J. Opt. Netw. 4 (2005) 759–777.

[15] D.A. Fudenberg, The Theory of Learning in Games, vol. 2, MIT press, 1998.