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# Ant algorithm for amplifier spontaneous emission (ASE)–aware routing

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**Abstract:** In this paper, we propose and demonstrate an Ant-based constraint-based routing for transparent optical networks based on ASE noise accumulation along the lightpath. Our proposed algorithm selects the route based on the minimum ASE noise, leading to lower blocking probability. The numerical results show that the proposed algorithm outperforms the traditional shortest path routing algorithm. The results show that these ASE have a significant impact on transparent networks. Careful gain choice, low noise figure are strongly desired for the accomplishment of efficient, cost-effective, high capacity WDM transparent optical networks.

**Keywords:** ASE, physical impairments, constraint based routing
**Classification:** Photonics devices, circuits, and systems

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## 1 Introduction

Most of the Routing and Wavelength Assignment (RWA) schemes assume that once the path and the wavelengths have been identified, the connection is feasible to be established [1]. This may not be true in transparent and managed reach networks, where the optical signal quality degrades during its transmission due to physical limitations and the impairments. For the light-path to be feasible, it is not only important to reserve the wavelengths on the path, but also to make sure that the signal quality is acceptable at the receiving end. The signal quality does degrade due to both linear and nonlinear effects. Impairments can be classified into two categories, linear and nonlinear. Linear effects are independent of signal power and affect wavelengths individually. Amplifier spontaneous emission (ASE), polarization mode dispersion (PMD) and chromatic dispersion are examples of physical impairments. Non-linearity is significantly more complex: they generate not only dispersion on each channel, but also crosstalk between channels. In this paper, we propose and demonstrate ant-based constrained routing algorithm for transparent optical networks based on physical layer impairments, including amplifier noise accumulation and losses along the path. Recently there has been an intensive on-going research on constraint based routing and on the way that physical constraints could be modeled and taken into account in the routing process in WDM optical networks. Some impairment that has been studied is: Polarization Mode Dispersion (PMD) [2], Amplifier Spontaneous Emission (ASE) Noise [1] and Crosstalk [3], Chromatic Dispersion (CD) and Filter Concatenation (FC) [4]. But none of them are using Ant Colony Optimization (ACO). ACO has been applied in many domains [5] including routing problem in optical network. [6] gives an extensive overview of the applications of ACO for routing and load-balancing. Most of the ant-based routing approaches in optical network are based on distance (shortest path, hop count, congestion information (available wavelengths) [7, 8] and others. None of them take into account the transmission impairments (ASE).

This paper is organized as follows. Section 2 presents implication of linear impairment of ASE as the consideration factor to evaluate the performance of the proposed algorithm. Section 3 describes the proposed ant-based impairment constrained routing design. Section 4 shows the numerical results on the studies considering ASE in terms of blocking probability. Finally, Section 5 concludes the paper.


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## 2 Implication of Linear impairment due to ASE noise

In this section we first outline how the key linear impairment ASE might be handled by a set of analytical formulate as additional constraints on routing and discuss the implication of such constraints on the network performance. Assume the lightpath from the transmitter to the receiver goes through M optical amplifiers, with each introducing some noise power and that each optical amplifier has the same power gain G. The upper bound on M, i.e., the maximum number of spans, given the OSNR constraint as [1]:

$$M \leq \frac{P_s}{2(G-1)n_{sp}hvB_0SNR_{\min}} \tag{1}$$

where $P_s$ is the average optical power launched at the transmitter, $\mathrm{n_{sp}}$ is the excess noise factor, h= $6.63{*}10^{-34}$ J/Hz is the Planck's constant, $v$ is the carrier frequency, $B_0$ is the optical bandwidth. When different types of optical amplifiers are used to account for different span loss, the amplifier gain and spontaneous emission factor may vary, denoted as $G(k)$ and $n_{sp}(k)$ respectively, $k = 1, 2, \ldots, M$. Assuming all amplifiers put out the same power, the constraint in this more general case becomes,

$$\sum_{k=1}^{M} n_{sp}(k)(G(k)-1) \leq \frac{P_s}{2hvB_0SNR_{\min}} \tag{2}$$

The route along the path considers feasible must satisfies the requirement that imposed by ASE above. Existing Impairment Constraint Based Routing (ICBR) schemes pay little attention to the overall efficiency of the network, since the metrics they incorporate refer only to aspects of the physical layer of the network (Bit Error Rate (BER), Optical Signal to Noise Ratio (OSNR), etc.) and do not take into account the performance in the network layer. Sometime a path is selected that does not necessarily have the best BER, but a BER within acceptable boundaries and its selection would be more suitable if it would cause less congestion in the upper layers, thus increasing the overall throughput of the network. For this reason, the metric we choose to use is blocking probability. So that we manage to tightly couple the constraints of the physical layer with the overall network performance as described by the blocking probability as shown in section 4.

## 3 Ant-based impairment constraint routing design

In ACO algorithm, each ant generates a complete tour by choosing next node according to a probabilistic state transition rule. The state transition rule used by ants is called a random proportional rule and is given by

$$P_{ij}(n) = \begin{cases} \dfrac{\tau_{ij}^{\alpha}(t)\eta_{ij}}{\sum \tau_{is}^{\alpha}(t)\eta_{is}} & , j, s \notin tabu_n, j, s \in adj_i \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$P_{ij}$ denotes the probability with which ant in node $i$ choose to move to next node $j$. We defined, $\tau_{i,j}(t)$ as the trace intensity (pheromone in the case of


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real ants) on the path $ij$ at time $t$ and $\eta_{ij}$ is the inverse of the length of path $ij$ (in our case it is the inverse of the span length from node $i$ to node $j$) and $\text{tabu}_n$ $(n = 1, 2, \ldots, m)$ is a list reporting nodes which ant n has visited. It is dynamically adjusted in evolutionary process and any node in the tabu list is disallowed to move in the later iterations. The more pheromone a path has, the larger the transition probability of the path is and more ants will chose the path according to the probabilistic state transition rule, and ants choose the node until forming a close tour. Once all ants have built their tours, that mean the ending of the current iteration, a global pheromones updating rule is applied. The process is repeated until the maximal iteration times or the maximal stagnation times are reached (End_Test). Pheromone trail are updated after all the ants have constructed their solutions.

The global updating rule is implemented as follows.

$$\tau_{ij}(t+n) = \rho.\tau_{ij}(t) + \Delta\tau_{ij} \tag{4}$$

where $\rho$ is a coefficient that represents the trace's persistence $(1-\rho)$ represents the evaporation and

$$\Delta\tau_{ij} = \sum_{n=1}^{m} \Delta\tau_{ij}(n) \tag{5}$$

$$\Delta\tau_{ij}(n) = \begin{cases} Q^{*}L_n & \text{if the n}^{\text{th}} \text{ ant use edge (i,j) in its tour} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

where $0 < \text{p} < 1$ is a coefficient which represents the residual pheromone of trail in the process ants search their closed tours, $Q$ is a constant; $L_n$ is the length of the tour performed by the $\text{n}^{\text{th}}$ ant (in our case is the maximum value of $\text{SNR}_{\text{min}}$ of the tour) given by equation (2); The parameters $Q$, $\alpha$ and $\rho$ can all be tested over different sets of values and finally determined their best combination.

The proposed Ant-based algorithm is as the following.

1. Initialize the trace matrix.

2. Upon the arrival of a connection request, the source node released m ants

   travel toward the destination node.

   For n=1: m(repeat)

      Choose, with probability given by equation (3), the adjacent node $(\text{ad}_{\text{ji}})$ as the next hop from those not yet chosen.

      Put the chosen node in the tabu list of the $n^{\text{th}}$ ant.

      Until the tabu list is full or reach the destination. (tabu list size equal to N). N is the number of node in the network

   End for.

3. For n=1:m


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Carry the solution and compute $L_n$.

Update the best permutation found. (The route has the highest SNR)

End for.

4. For each coupling (i,j), calculate $\Delta\tau_{ij}$ according to equation (5).

   Update the trace matrix according to equation (4).

5. If not (End_Test)

   Empty the tabu lists of all the ants.

   Goto 2

   Else

   Print the best permutation and Stop.

   End

## 4 Numerical results

In this section, we present results of the proposed ant-based algorithm compared with shortest path algorithm for two topologies: ring and mesh topologies as shown in figure 1 (a) and figure 1 (b). Our goal is to demonstrate the effectiveness of the proposed ant-based algorithm in terms of blocking probability when ASE noise is taken into consideration. The ACO parameters; $Q = 0.01$, $\alpha = 1$ and $\rho = 0.5$ are used in the experiment. The maximum hop length was restricted to 3 for both topologies in the shortest path algorithm for comparison and routes were constructed using minimum hop routing and number 15 routes in both topologies. The number of ants $m = 2$ is used in ring topology and $m = N$ ($N$ = number of nodes in the network) is used in mesh topology. The experiment results shown in figure 2 and figure 3 with $C = 32$ wavelength channels for the two different topologies.

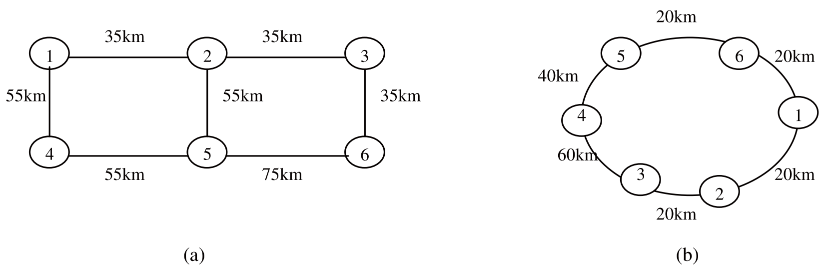


**Fig. 1.** The physical topologies of six nodes mesh and ring network

From the results shown in figure 2 and figure 3, as expected, the performance of the proposed Ant-based algorithm is always much better than those using shortest path algorithm for all the traffic loads when ASE noise is taken into consideration. The difference between the algorithm results is more apparent for low loads in mesh topology, whereas in the excessive high traffic case the results cannot be distinguished much. This is because there


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are not many more available routes in the network to establish new calls in high traffic loads. The blocking probability as shown in figure 2 and figure 3 for both cases (mesh and ring topologies) using Ant-based algorithm is higher than those without ASE noise (ideal case). However, the proposed ant-based algorithm still outperforms the shortest path algorithm in the presence of ASE noise for both topologies. The performance of the proposed algorithm is more obvious in mesh topology case as compared to ring topology. Furthermore, the overall results show that the proposed ant-based algorithm is more efficient and results in lower blocking probability in mesh topology than in ring topology for the same $SNR_{min}$ requirement. This is due to the fact that in a ring topology, there are less alternative routes compared to mesh topology.

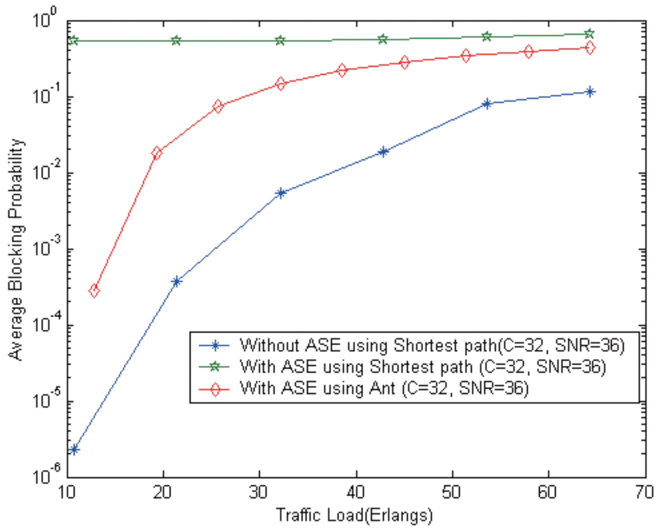


**Fig. 2.** Mesh topology

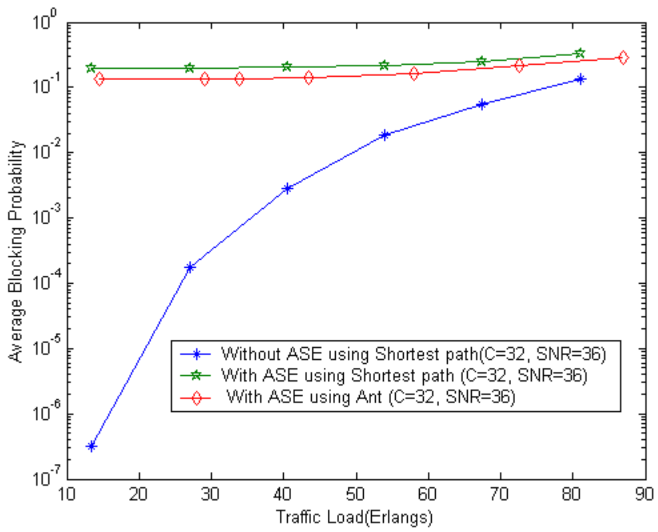


**Fig. 3.** Ring topology


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## 5 Conclusion

In this paper, we propose an Ant algorithm for Amplifier Spontaneous Emission–Aware Routing. Performance results show that the performance of the proposed Ant-based algorithm is better than that of the shortest path algorithm for all traffic loads when ASE noise is taken into consideration. Furthermore, the results show that the proposed ant-based algorithm is more efficient and results in lower blocking probability in mesh topology than in ring topology for the same SNR requirement. This is due to the fact that in a ring topology network, there are less alternative routes compared to the mesh topology network.


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