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JOINT SIGNALING AND DYNAMIC LIGHTPATH ESTABLISHMENT PERFORMANCE IN WAVELENGTH-ROUTED NETWORKS

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Joint Signaling and Dynamic Lightpath Establishment Performance in Wavelength-Routed Networks

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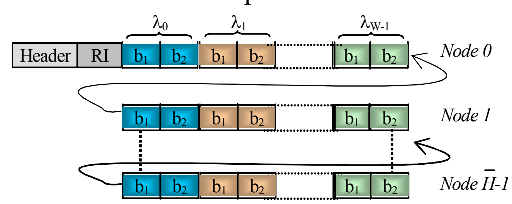
Abstract: We present a study and simulation on DLE for WDM-routed networks with/without conversion capabilities. A signaling scheme and a new wavelength assignment algorithm using single probe-packets are presented. The study includes realistic scenarios (delay, conflicts…).

1. Introduction

We address the problem of dynamic lightpath establishment (DLE), or dynamic routing and wavelength assignment (D-RWA). In [1], a signaling method and wavelength assignment (WA) scheme based on jointly signaling optical resources in a single probe-packet (ProbPac), constitutes an efficient D-RWA solution. We present an extensive simulation campaign comparing the performances of blocking, delay, conflict, and signaling overhead with those of the approach based on the well-known WA - the First-Fit (FF).



RI (route information): contain the list of the intermediate node IDs that the probe-packet will travel through.

Fig.1. Probe packet format for jointly signaling resources

2. Joint optical resource signaling and algorithms at OXC

Although the signaling scheme (we refer the interested reader to [1] for details) can be used with complex multi-path routing schemes, we limit the study here to a single fixed shortest-path (SP) routing for the sake of brevity. The solution is fully distributed and jointly, but solves two problems: routing and WA. We focus the attention on the signaling protocol and the applicable WA schemes.

2.1 Probe packet format and its usage in signaling

To setup a lightpath (LP) from *s* to *d*, *s* sends a ProbPac (Fig.1) where intermediate nodes append the route and WA information. ProbPac is forwarded by using a reliable control channel. ProbPac is extremely compacted, but still allows the transmission of the information to rebuild the complete state of all the wavelengths (WLs) and all the wavelength converters (WCs) along the route.

The joint state of any WL of the out-link of an optical cross-connect (OXC), to the WL of the in-link and either using WC or not, is coded by 2 bits (b_1b_2). For possible states are defined and they compose a complete set of state with the sum of probability is unit: {*Non-Idle* (00); *Continuously-Idle* (01); *Convertibly-Idle* (10); *Dually-Idle* (11)} (see details in [1]). With the capacity of W WL(s) per link, and the average route length of H hops, the packet size is proportional to $2HW$ bits. In Fig. 1, row j presents the state of all WL(s) of the link from node j-1 to node j, $j \in \{1,..,H\text{-}1=d\}$.

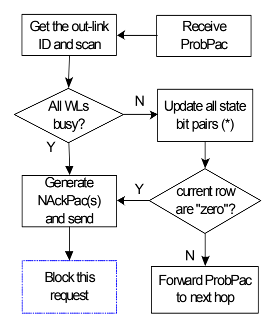


Fig.2. Processing ProbPac

2.2 Algorithm and behavior of OXCs to update probe packets

Every OXC maintains a database referring to all in/out-links (with all parameters) connected to it. Upon receiving a ProbPac, the OXC processes it as depicted in Fig.2, in which the detail of block (*) is given in Fig.3. The notation of $\lambda_i^{(j)}$ stands for the state bit pair of WL i at the out-link of node j.

When an OXC discards a ProbPac, it generates NAckPac to send upstream (to *s*) and downstream (to *d*) for reporting the probing phase failure. Two cases can lead to this situation: (1) all WL(s) at the out-link are busy; (2) no WL is *Continuously-Idle*, and no suitable WC is found. In the signaling scheme, it is simple to modify **if** clause (**) of the algorithm in Fig.3 so that a setup procedure is interrupted also in case some other physical constraint is violated, such as the power link budget or the cross-WL interference.

```
for (all WLs at the out-link)
{
  if (λi(j) at the out-link is busy)
    Set bit-pair of λi(j) = 00;
  else
  {
    if (state of λi(j-1) == 00)
    {
      if (found a converter to use(**))
        set bit-pair of λi(j) = 10;
      else
        set bit-pair of λi(j) = 00;
    }
    else
    {
      if (found a converter to use(**))
        set bit-pair of λi(j) = 11;
      else
        set bit-pair of λi(j) = 01;
    }
  }
}
```

Fig.3. Detail of block (*) in Fig.2

3. Joint-Signaling-based wavelength assignment and lightpath establishment procedure: practical issues

3.1 Joint-Signaling-based wavelength assignment scheme

When ProbPac arrives at *d*. it extracts all bit pairs to form a bit matrix, and triggers the WA module.

In [1] the detail of the WA algorithm based on joint signaling ProbPac was presented - hereafter, we name it as JS. The key element for running JS is a *Continuous-Segment* (*CS*). A *CS* is the continuous run of a WL through *k* hops, $k=\{1,2,..,H\}$. The JS WA module of *d* easily discovers every CS of every WL using the bit matrix. The best combination of *CSs* forms the LP from *s* to *d*. In the best case, only one *CS* running continuously from *s* to *d* forms a LP. Vice versa, when the WL usage along the route is most fragmented, the maximum number of *CSs* is $n_{\max}=(HW)/2$. JS orders possible LPs starting from the least possible use of *CSs*, therefore, in the worst case, the complexity of JS is $O(n_{\max}\log_2 n_{\max})$.

3.2 LP establishment with delay: reservation or not?

The conflict between multiple requests for occupying same optical resources is inevitable. State bit pairs collected by ProbPac can be out-of-date when node *d* triggers the WA module. Obviously, the more delay incurred by the LP establishment, the higher probability that conflicts occur.

To minimize the establishment delay and the probability of conflict, we implement the protocol without reservation phase. When the task of WA finishes at *d*, a setup packet (SetPac) is generated and sent back to *s* on the same route of the probing phase. The SetPac bears all necessary information to setup a LP. The behavior of an OXC when receiving a SetPac is described in Fig.4. If assigned resources are no more available, a NAckPac is sent upstream to notify *s* to block the corresponding request, and a release packet (RelPac) is sent downstream to tear down all already-set-up transceivers/switches;. The LP is successfully established only when the SetPac reaches *s*. Node *s*, then, register the service time for the LP and schedule the time for generating a RelPac to release the LP.

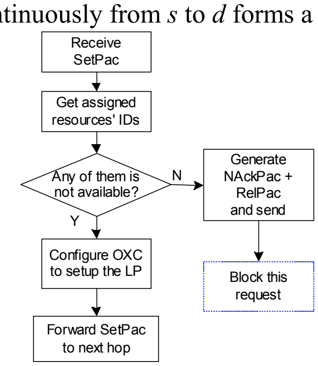


Fig.4. Processing SetPac

4. Performances

We implemented a simulation developed from the OMNet++ [5]. Performances are evaluated on three network topologies: a 12-node ring network, the 15-node PacNet with interconnected rings (Fig.5), and the 14-node NSFNet (Fig.6). Networks' configurations (nodes, links, and link lengths) are similar to those defined in [2,3]. The only modification is that we incorporate issues such as delay, the availability and distribution of wavelength converters ("share-per-node" configuration), impact of conflicts on performances. WA scheme is either JS or FF. In both schemes, procedures for LP establishment are identical - without reservation phase. With FF scheme, only WLs status is probe, as in [4].

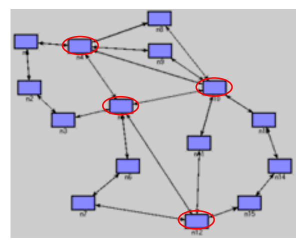


Fig.5. 15-node PacNet

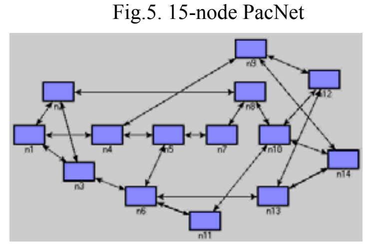


Fig.6. 14-node NSFNet

In all graphs, we denote with *D* results where delays are taken into account. Propagation delays are proportional to the link lengths. The delay for processing ProbPac, NAckPac, SetPac, RelPac at each OXC equals to *0.1ms*; $0.1\mu s$; *0.1ms*; *0.1ms*, respectively. And we denote with *I* the case when all delays are set to *zero*.

Every LP is bidirectional, thus, the number of WCs at each node - any must be an even number. In every graph, "n"WC identifies the number of WCs per node. 0WC means no WC at all, 2WC means that only 1 pair of WC is presented at each convertible node, and so on. The arrival rate of requests for setup LPs at each network node follows the Poisson process. The traffic load is distributed equally to all nodes. LP holding time follows the negative exponential distribution with the normalized mean. Simulations are run with different random generator seeds, obtaining the results that are within the confidence interval (it is so narrow to be distinguished on the graphs) with a confidence level of 95%.

For 12-node ring network, the link length is *10km* between any pair of adjacent nodes [3], $W = 16$. The blocking performance of this network is presented in Fig.7. Only every even node {2,4,6,8,10,12} has WCs, that is, the network is sparse conversion capability.

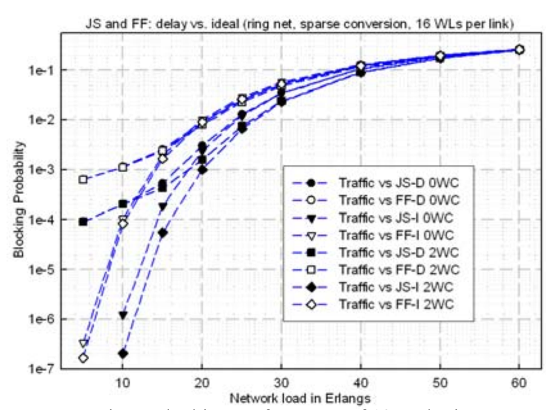


Fig.7. Blocking performance of 12-node ring

The blocking performance of the PacNet is reported in Fig.8. In the PacNet, the average link length is the order of hundreds of *km* [2], and $W = 32$. Nodes in circles are equipped with 2WCs or 8WCs for configuring the sparse conversion capability network. With 0WC, again, the network is constraint with WL continuity. For the NSFNet, we present the results for the network with full conversion capacity. Every network node has 0WC, 2WCs, or 8WCs, respectively. The average link length of the NSFNet is the order of thousands of *km* [2], and $W = 16$. The blocking performance of the NSFNet is reported in Fig.9.

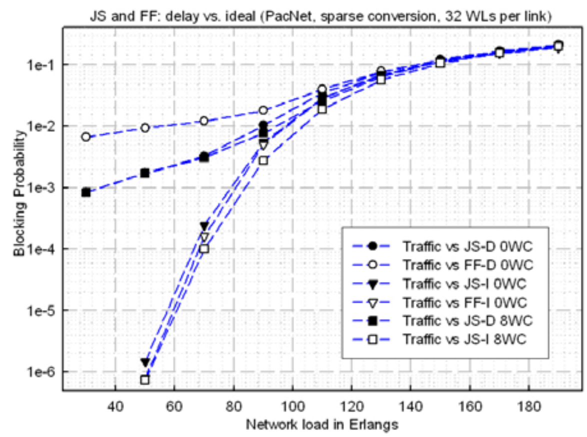


Fig.8. Blocking performance of PacNet

Some results of 2WC and 8WC are not presented, since they are relatively closed to each other due to reaching the saturation level of WCs. The average LP establishment delay in *ms* for each network is presented in Fig.10. Moreover, JS generates the same number of signaling packets as that of FF. There is only slight difference between the size of ProbPac (2 bits for one WL in JS, 1 bit for one WL in FF). Clearly, JS and FF approximately pay the same cost of delay for establishment LPs, and the cost of signaling overhead.

5. Remarks

In both JS and FF, results show how heavily the blocking performance depends on the delay parameters, especially in the operating range of the load (e.g. blocking probability ≤ 10^{-3}). The longer the delay is, the higher the probability of conflict is, incurring in worse blocking performances. When network load is high, the effect of delay disappears, because with high load, there is much higher probability that blocking comes from a global or local lack of resources, hence blocking at the probing phase. The results show that disregarding the delay when studying networks running distributed protocols in the control plane can lead to misleading results.

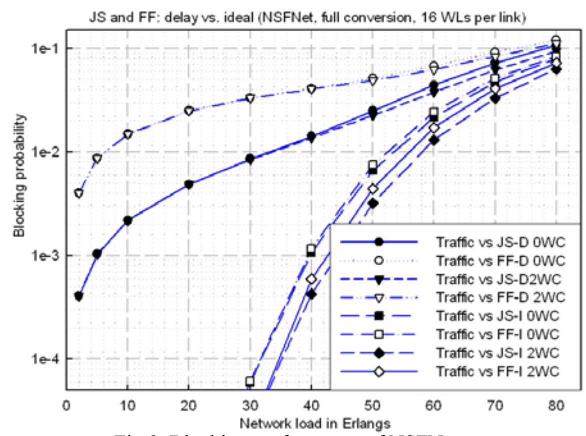


Fig.9. Blocking performance of NSFNet

As shown in all Fig.7,8,9, JS always outperforms FF when delay parameters present. The performance gain of JS is also proportional to the average hop length, since with long-hop routes, FF is more likely to fail. With both JS and FF, the present of WCs in the network does not mean that we gain the performance when the network load is low or moderate. This is explained by the fact that with moderate network load, we always finds at least one WL to run continuously from *s* to *d*. Even in case without delay (*I*), JS still perform slightly better than FF. Thus, we can conclude that FF itself contains the conflict element. Besides, simulation results with the single fixed-SP route make us doubt about how much conversion capability improves the blocking performance. To have a clear idea of this issue, further studies on different routing strategies (e.g. fixed-alternate-routing, adaptive routing) must be done.

Network	delay (*ms*)	
	FF	JS
Ring	0.84	0.98
PacNet	2.98	3.46
NSFNet	17.32	20.58

Fig.10. Average delay for LP establishment

The ODLE simulator [6] we developed allows parametric studies of JS and other WA procedures that we are actively carrying out.

6. References

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