Dynamic Routing and Spectrum Assignment in Flexible Optical Path Networks

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Abstract: We propose dynamic routing and spectrum assignment algorithms for bitrate-flexible lightpaths in OFDM-based optical networks. The novel algorithms enable dynamic spectrum assignment with more efficient resource utilization and less traffic blockings.

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1. Introduction

Fast and continuous development of widely-used high bitrate broadband internet services brings great challenge of not only the expansion of network capacity, but also heterogeneous and different granularities of bandwidth demand with diverse quality of service (QoS). Although traditional wavelength-division multiplexing (WDM) networking has obvious advantages to provide high-bit-rate transportation, it still has a significant drawback due to rigid grid and coarse bandwidth granularity. Such networks require full allocation of wavelength capacity even when the traffic demand is not sufficient to fill the entire wavelength capacity, which leads to inefficient optical spectrum utilization and significant granularity mismatch. Mixed-Line-Rates (MLR) networking using 10/40/100Gbps optical channels [1] is proposed to support traffic demands with different bandwidth, but the optical spectrum resources are still badly wasted because of rigid grid and still coarse granularities.

Optical orthogonal frequency-division multiplexed (OOFDM) [2,3] has been proposed as a promising candidate for high-bit-rate transmission in optical transport networks. Based on OOFDM technologies, a novel spectrum-sliced elastic optical path network (SLICE) [4-6] has been proposed. With the innovation of bandwidth-variable transponders (BV-transponders) and bandwidth-variable wavelength selective switches (BV-WSS), SLICE network demonstrate a spectrum-efficient elastic OFDM-based optical network. It is noticed that in the novel network wavelength-continuity constraint is transformed to spectrum-continuity constraint. The routing and spectrum assignment (RSA) algorithm becomes a key technology to enable OFDM-based flexible optical path networks. The static RSA researches for network planning with ILP/MIP models prove significant spectrum benefits compared with traditional WDM and MLR networks [7,8]. A dynamic RSA algorithm based on a depth-first search algorithm and first-fit (FF) algorithm under spectrum-continuity constraint for optical ring networks is also proposed [6]. However, efficient and scalable dynamic RSA algorithms for mesh networks have not been proposed so far.

In this paper, we focus on the dynamic RSA algorithm for mesh flexible optical path networks. Three different heuristic RSA algorithms are introduced and compared with traditional fixed-grid rigid-bandwidth WDM networks. Simulation results show that flexible networks with our algorithms outperform on lower blocking probabilities and more efficient spectrum utilization.

2. Dynamic Flexible Optical Path Networks and RSA problem

In the dynamic flexible optical path networks [4-6], OFDM-based real-time lightpaths with available bandwidth marching client layer requirement are generated by BV-transponders. It is needed to enable RSA technologies to find an optimal route and available contiguous optical spectrum for the lightpaths. If RSA returns available route and spectrum allocation, the lightpath is set and sustained until the duration time arrivals, otherwise the traffic is blocked. The lightpaths accepted to the network are established towards destination transponders through bandwidth-variable OXC (BV-OXC) employing BV-WSS with switching ability for contiguous spectrums.

Flooding of updating information is another important issue and out of scope of this paper. We assume that our RSA algorithms are implemented in an ideal central Path Computation Element (PCE) to calculate and return the optimal paths dynamically. We also assume that all the network status information including used and available spectrum in every fiber link is collected real-timely by PCE's Traffic Engineering Database and maintained all the time. As we focus on the optical domain RSA problem, we only consider the optical lightpath bandwidth. We ignore the influence of advanced modulation format in OFDM-based transmission. We also ignore the filter guard band and physical layer constraint which remain for further studies.

3. Dynamic Routing and Spectrum Assignment Algorithms

RSA can be designed as one- or two- step approach. In two-step approaches, RSA problem is divided into routing and spectrum assignment sub-problems. Three different heuristic dynamic RSA algorithms are proposed.

1) KSP-based RSA (KSP) is a two-step approach. Different from [6], we use Yen's KSP algorithm to calculate *K*-Shortest-Paths. This Algorithm is described in Table 1.
2) Modified Dijkstra Shortest Path (MSP) is a one-step approach. We add a set to restore available spectrums of intermediate node. Every time we add physical links, we check whether the links have enough contiguous available spectrums with the previous node available spectrum. The algorithm is shown in Table 2.
3) Spectrum-Constraint Path Vector Searching (SCPVS) is also a one-step approach. We build a path vector tree with spectrum constraint to search the global optimal route. The procedure is described in Table 3.

Table 1. KSP Algorithm

a) Use Yen's KSP algorithm and calculate *K*-Shortest-Paths, the result set has k ordered paths
b) **if** k=0, **return ROUTING FAIL**
  else $i \leftarrow 1$
  end if
  while $i \leqslant k$
    if *i*th shortest path can been assigned an available contiguous spectrum
    return RSA SUCC
    else $i \leftarrow i+1$
    end if
  end while
  if $i=k$, **return SPECTRUM ASSIGN FAIL**

Table 2. MSP Algorithm

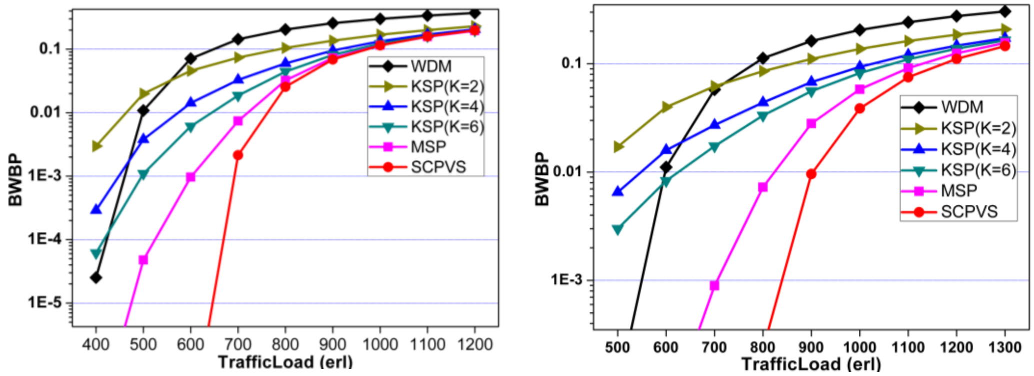
a) In $\boldsymbol{G}(\boldsymbol{N},\boldsymbol{E})$, Node set $\boldsymbol{M} \leftarrow \{S\}$, routing cost $C_S \leftarrow 0$,
  any node i connected with Source S, $C_i \leftarrow e_{Si}$,
  other node $C \leftarrow$INF
  node available spectrum $T_S \leftarrow$ {full spectrum}
  $T_i \leftarrow$ {available spectrum on link e_{Si}}
  shortest path $P_i \leftarrow (S,i)$
b) **while** Destination D is not in $\boldsymbol{M}$
    if we can find minimum cost C_w of node $w \in (\boldsymbol{N}-\boldsymbol{M})$ AND C_w<INF
      $\boldsymbol{M} \leftarrow \boldsymbol{M} + \{w\}$
      Check any node $n \in (\boldsymbol{N}-\boldsymbol{M})$ connected with w
      if $C_n > C_w + e_{wn}$ AND T_w has enough contiguous available spectrum with link e_{wn}
        $P_n \leftarrow P_w + (w,n)$
        $T_n \leftarrow$ available spectrum of both T_w and link e_{wn}
      end if
    else return RSA FAIL
    end if
  end while
c) P_D is the route and assign optical spectrum on spectrum T_D **return RSA SUCC**

Table 3. SCPVS Algorithm

a) Result route vector $R \leftarrow$NULL, routing cost $CR \leftarrow$INF
b) Searching Tree Root Node $N_0 \leftarrow S$ (*level*=0)
  add leaves N^i_1 (*level*=1) if another node linked with source and the link has available continual spectrum
  spectrum $T^i_1 \leftarrow$ *available spectrum* of link S-N^i_1
  routing cost is $C^i_1 \leftarrow$ *cost* of link S-N^i_1
  path vector $P^i_1 \leftarrow$ link S-N^i_1
  previous node $V^i_1 \leftarrow S$
  (i = 1, 2, 3… K_1)
  K_1 is the number of leaves in *level* 1
c) **for** each level *level*=L (L=1, 2, 3…|N|-1)
  for each leaves N^i_L in *level*=L
      if N^i_L is destination AND route $C^i_L < CR$
        update result path:
        $R \leftarrow P^i_L$, $CR \leftarrow C^i_L$
      end if
      if N^i_L has other nodes B connected without route-loop AND connected link N^i_L-B has available continual spectrum with T^i_L AND C^i_L + *cost* of link N^i_L-$B < CR$
      add leaves B as N^j_{L+1} to new level (*level*=L+1)
      spectrum $T^j_{L+1} \leftarrow$ *available spectrum* of both link N^i_L-B
      routing cost $C^j_{L+1} \leftarrow C^i_L$ + *cost* of link N^i_L-B
      path vector $P^j_{L+1} \leftarrow P^i_L + (N^i_L$-$B)$
      previous node $V^j_{L+1} \leftarrow N^i_L$
      end if
  end for
  end for
d) **if** CR <INF AND R is available
      return R and its spectrum, **RSA SUCC**
  else return RSA FAIL

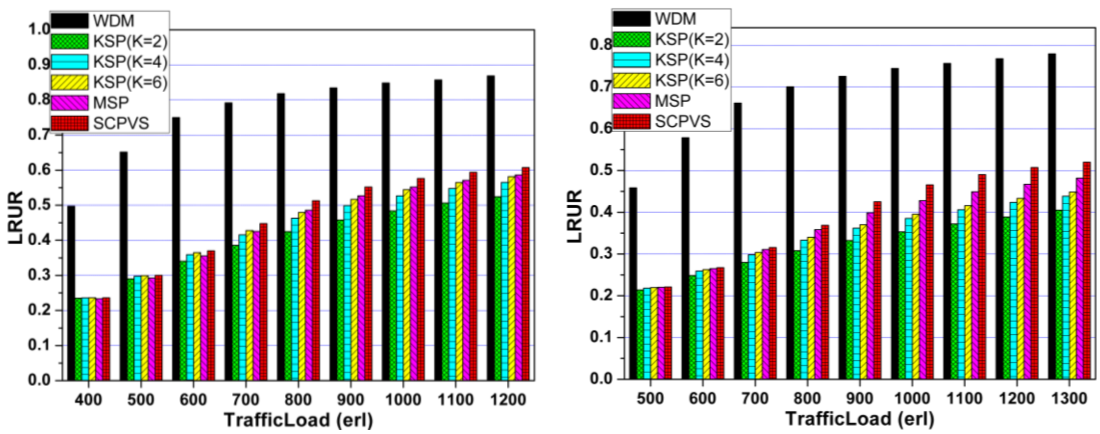
4. Simulations and Results

We use Bandwidth-Weighted Blocking Probability (BWBP) to represent the dynamic performance in flexible optical path networks. We also introduce a novel Bandwidth-Distance-Product Weighted Link Resource Used Ratio (LRUR) to describe the network resource status. This radio calculate product of link distance and used bandwidth for every link represent the total link resource unitization ratio.We assume that the link spectrum pool has 4000GHz and spectrum-flexible lightpaths have a spectrum demand from 1GHz to 100GHz with uniform distribution. As a comparison, we also implement of WDM RWA algorithm with 40 wavelength and 100GHz grid for each wavelength. We use two topologies in our simulations, 14-node, 22-link NFSNET and 24-node 43-link US-NET. BWBP and LRUR are shown in Fig.1 and Fig.2. Simulations indicate that in flexible optical path networks, the proposed dynamic RSA algorithms obtain lower blocking probabilities and more efficient spectrum utilization.



(a) NFSNET (b) US-NET

Fig.1 Bandwidth-Weighted Blocking Probabilities



(a) NFSNET (b) US-NET

Fig.2 Bandwidth-Distance-Product Weighted Link Resource Used Ratio

5. Conclusions

Three different heuristic RSA algorithms are introduced. Simulation results show that flexible networks with our algorithms outperform on lower blocking probabilities and more efficient spectrum utilization.

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References

[1] A. Nag et al., "Transparent Optical Network with Mixed Line Rates," IEEE ANTS, art. no. 4937771, 2008.
[2] A.J. Lowery et al., "Performance of optical OFDM in ultralong-haul WDM lightwave systems," JLT, vol. 25, pp. 131-138, 2007
[3] W. Shieh et al., "Transmission experiment of multi-gigabit coherent optical OFDM systems over 1000km SSMF fibre," Electronics Letters, vol. 43, no. 3, pp. 183-185, 2007
[4] M. Jinno et al., "Spectrum-Efficient and Scalable Elastic Optical Path Network: Architecture, Benefits, and Enabling Technologies," IEEE Commun. Mag., vol. 47, no. 11, Nov. 2009, pp. 66–73.
[5] M. Jinno et al., "Demonstration of Novel Spectrum-Efficient Elastic Optical Path Network with Per-Channel Variable Capacity of 40 Gb/s to over 400 Gb/s," ECOC'08, 2008, paper no. Th.3.F.6.
[6] M. Jinno et al., "Distance-Adaptive Spectrum Resource Allocation in Spectrum-Sliced Elastic Optical Path Network," IEEE Commun. Mag., vol. 48, no. 8, Aug. 2010, pp. 138–145.
[7] K. Christodoulopoulos et al., "Spectrally/Bitrate Flexible Optical Network Planning," ECOC'10, 2010, paper no. We.8.D.3.
[8] W. Zheng et al., "On the Spectrum-Efficiency of Bandwidth-Variable Optical OFDM Transport Networks," OFC/NFOEC'10, 2010, paper no. OWR5.