Crosstalk-Aware Spectrum Defragmentation based on Spectrum Compactness in SDM-EON

Yongli Zhao

State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications (BUPT), Beijing 100876, China
Tel: +86-10-61198108; Email: yonglizhao@bupt.edu.cn; Web: ipoc.bupt.edu.cn

Group Meeting, 27th May 2016
Outline

1. Background of SDM-EON
2. Problem description
3. Spectrum compactness in SDM-EON
4. Crosstalk-aware RSCA in SDM-EON
5. Spectrum defragmentation in SDM-EON
Multi-dimensional resource in optical networks

(a) PMM
(b) WDM/EON
(c) SDM
(d) OTDM

Yongli Zhao, Jie Zhang, et al., Mode and Wavelength Allocation in Multi-Dimensional Optical Networks, ACP2014, Shanghai, China, Nov.2014
Switch fabric of SDM-EON with multi-mode fiber

Yongli Zhao, Jie Zhang, et al., Mode and Wavelength Allocation in Multi-Dimensional Optical Networks, ACP2014, Shanghai, China, Nov.2014
The transceiver resources consist of a transceiver pool, supplying the appropriate sub-transceivers according to the traffic requirement.
Core and spectrum switching with spectrum continuity

In the switch fabric, different spectrum slots can be switched between different cores, but must follow spectrum continuity and spectrum contiguity.
Crosstalk between adjacent cores

\[ h = \frac{2k^2r}{\beta w_{th}} \]  \( (1) \)

\[ XT = \frac{n-n\cdot\exp[-(n+1)\cdot2hL]}{1+n\cdot\exp[-(n+1)\cdot2hL]} \]  \( (2) \)

\( h \) denotes the mean increase in crosstalk per unit length. \( k, r, \beta, \) and \( w_{th} \) are the relevant fiber parameters, representing the coupling coefficient, bend radius, propagation constant, and core-pitch, respectively. In formulation (2), \( n \) is the number of the adjacent cores and \( L \) represents the fiber length.

(a) Crosstalk between adjacent cores

(b) Schematic of trench-assisted seven-core fiber

(c) Schematic of a core with index trench
Outline

1. Background of SDM-EON
2. Problem description
3. Crosstalk-aware RSCA in SDM-EON
4. Spectrum compactness in SDM-EON
5. Spectrum defragmentation in SDM-EON
Spectrum fragments in SDM-EON

But when? How to evaluate it?

- The issue of spectrum defragmentation will be more serious compared with simple EON, because the spectrum status in SDM-EON becomes more complex.
- Crosstalk is another factor to be considered with setting a certain threshold value of inter-core crosstalk.
Benefits model of spectrum defragmentation

- **Improve SE**
  - Increase the number of services
  - Reduce the BBR

- **Reduce OEO**
  - Reduce the number of transponders

- **Interrupt Service**
  - Quality of Service

- **Increase the Delay**

The value of Q represents the benefits of operator
- Q<0, Spectrum Defragmentation should not be taken;
- Q>0, Spectrum Defragmentation should be taken.

\[
Q = \sum_{n=1}^{N} (\Delta F_n * C_F + \Delta E_n * C_E) + \sum_{i=1}^{M} \Delta D_i * C_D - \sum_{i=1}^{M} (T_i * C_T + P_i * C_P)
\]

- Spectrum
- Energy
- Delay
- Interrupt
- Cost
Outline

1. Background of SDM-EON
2. Problem description
3. Spectrum compactness in SDM-EON
4. Crosstalk-aware RSCA in SDM-EON
5. Spectrum defragmentation in SDM-EON
Spectrum compactness in SDM-EON

\[ SC_{c,l} = \frac{S_{\text{max}}^{c,l} - S_{\text{min}}^{c,l} + 1}{\sum_{i=1}^{P} B_i^{c,l}} \times \frac{\sum_{j=1}^{G^{c,l}} g_j^{c,l}}{G^{c,l}} \]

\[ SC^l = \sum_{c=0}^{6} SC^{c,l} \]

\[ S_{\text{max}}^{c,l} \text{ and } S_{\text{min}}^{c,l} \text{ represent the maximum and minimum occupied spectrum in the core } c \text{ of link } l \text{ respectively. } B_i^{c,l} \text{ represents the spectrum occupied by the } i\text{th connection in the core } c \text{ of link } l. \]

\[ l.G^{c,l} \text{ is the number of available spectrum blocks in the core } c \text{ of link } l, \text{ and } g_j^{c,l} \text{ denotes the spectrum resources of the } j\text{th available spectrum block in the core } c \text{ of link } l. \]

Outline

1. Background of SDM-EON
2. Problem description
3. Spectrum compactness in SDM-EON
4. Crosstalk-aware RSCA in SDM-EON
5. Spectrum defragmentation in SDM-EON
Crosstalk-aware RSCA

Request R

Calculate k-shortest path

For each candidate path, SCs of 7 cores are calculated along each link

For each link, sort SC of each core in a descending order

Select the core with the maximum SC of each link

Spectrum satisfied?

Y

ΔSC = \sum_{c \in C, l \in path} SC_{before}^{l} - \sum_{c \in C, l \in path} SC_{after}^{l}

N

Block the request R

R is established successfully

Select the minimum ΔSC and its corresponding path, core and spectrum segment as RCSA method

Calculate ΔSC

XT < Threshold

Y

N

SC^{l} = \sum_{c=0}^{6} SC^{c, l}
Outline

1. Background of SDM-EON
2. Problem description
3. Spectrum compactness in SDM-EON
4. Crosstalk-aware RSCA in SDM-EON
5. Spectrum defragmentation in SDM-EON
**Network model**

- $G(V,E,C)$: a SDM-EON network with bidirectional graph...
- $V$: a set of physical nodes in $G(V,E,C)$...
- $E$: a set of physical links in $G(V,E,C)$...
- $C$: a set of cores in $G(V,E,C)$...
- $R$: a set of connections in $G(V,E,C)$ at the comment...
- $M$: the number of links in the networks topology $G(V,E,C)$...
- $N$: the number of nodes in the networks topology $G(V,E,C)$...
- $T$: the number of cores in each line...
- $P$: the number of connections in the network at the comment...
- $S_{\text{max}}^{c,d}$: the maximum occupied spectrum in the core $c$ of link $d$...
- $S_{\text{min}}^{c,d}$: the minimum occupied spectrum in the core $c$ of link $d$...
- $B_{i}^{c,d}$: the spectrum occupied by the $i$th connection in the core $c$ of link $d$...
- $G_{c,d}$: the number of available spectrum blocks in the core $c$ of link $d$...
- $g_{j}^{c,d}$: the spectrum resources of the $j$th available spectrum block in the core $c$ of link $d$...
- $L_{l}$: the length of link $l$...
- $L_{R_{i}}$: the length of the $i$th connection in the network...
- $SC_{c,l}$: the spectrum compactness in the core $c$ of link $l$...
- $SC_{l}$: the spectrum compactness of link $l$...
- $SC_{\text{threshold}}$: the threshold of spectrum compactness for spectrum defragmentation...
- $XT_{R_{i}}$: the crosstalk for connection $R_{i}$...
- $XT_{\text{threshold}}$: the threshold of crosstalk for the connection...
The main idea of CASD-SS-DC is to move the connection to another core on the same link with the same spectrum slots to increase the spectrum compactness.
Algorithm 1: CASD with Same Spectrums and Different Cores (CASD-SS-DC)

**Input**: network topology \(G(V, E, C)\), current connections...

**Output**: new connections distribution...

1: **For** \(m = 1; m \geq 1; m + +\)\]
2: Calculate all \(SC^{i-1}\) for the network;
3: Sort them in an ascending order, and select the first connection from the ordered list;
4: **If** the first \(SC^{i-1} < SC_{threshold}\)
5: **For** all the connections on link \(l\),
6: Search the available spectrum for the connection in the other cores of link \(l\);
7: If there are available spectrum for the connection \(R_l\) on \(n\) cores \((n>1)\),
8: **For** \(j = 1; j < n + 1; j + +\),
9: Calculate the \(SC^{i-1}\) of the original core and the \(jth\) oriented core;
10: **If** \(SC^{i-1}\) of both original core and the \(jth\) oriented core > \(SC_{threshold}\)
11: Calculate the crosstalk of the affected connections \(R_s\) (may be more than one);
12: **If** \(XT_{R_s} < XT_{threshold}\)
13: Move the spectrum to the oriented core;
14: Break;
15: **Else** do nothing;
16: **End if**;
17: **Else** do nothing;
18: **End if**;
19: **End for**;
20: **Else** do nothing;
21: **End if**;
22: **End for**;
23: Break;
24: **Else** break;
25: **End if**;
26: **End for**.
Different from CASD-SS-DC, if there is no available spectrum resources on other cores or the crosstalk exceeds the threshold, the connection can be moved to other available spectrum on the same core along the lightpath.
Algorithm 2: CASD with Different Spectrums and Same Cores (CASD-DS-SC)$^v$

Input: network topology $G(V, E, C)$, current connections.$^v$
Output: new connections distribution.$^v$

1: For $(m = 1; m \geq 1; m + +)$.$^v$
2: Calculate all $SC^{c, l}$ for the network.$^v$
3: Sort them in an ascending order, and select the first connection from the ordered list.$^v$
4: If the first $SC^{c, l} < SC_{threshold}$.$^v$
5: For all the connections on link $l$.$^v$
6: Search the available spectrum for the connection in the other cores of link $l$.$^v$
7: If there are available spectrum for the connection $R_i$ on $n$ cores $(n \geq 1)$.$^v$
8: For $(j = 1; j < n + 1; j + +)$.$^v$
9: Calculate the $SC^{c, l}$ of the original core and the $jth$ oriented core.$^v$
10: If the $SC^{c, l}$ of both original core and the $jth$ oriented core $> SC_{threshold}$.$^v$
11: Calculate the crosstalk of the affected connections $R_x$ (may be more than one)$^v$
12: If $XT_{R_x} < XT_{threshold}$.$^v$
13: Move the spectrum to the oriented core.$^v$
14: Break.$^v$
15: Else do nothing.$^v$
16: End if.$^v$
17: Else do nothing.$^v$
18: End if.$^v$
19: End for.$^v$
20: Else Search the available spectrum for the connection in the same core along the lightpath.$^v$
21: If there are available spectrum for the connection $R_i$ on $q$ spectrum blocks $(q \geq 1)$.$^v$
22: For $(j = 1; j < q + 1; j + +)$.$^v$
23: Calculate the $SC^{c, l}$ of the original spectrum block and the $jth$ spectrum block.$^v$
24: If $SC^{c, l}$ of both original spectrum block and the $jth$ spectrum block $> SC_{threshold}$.$^v$
25: Calculate the crosstalk of the affected connections $R_x$ (may be more than one)$^v$
26: If $XT_{R_x} < XT_{threshold}$.$^v$
27: Move the spectrum to the oriented spectrum block.$^v$
28: Break.$^v$
29: Else do nothing.$^v$
30: End if.$^v$
31: Else do nothing.$^v$
32: End if.$^v$
33: End for.$^v$
It is assumed that each fiber has 7 cores and each core has 50 spectrum slots. The fiber parameters $k$, $r$, $\beta$, $w_{th}$ in formulation 1 are set as $3.16 \times 10^{-5}$, $55mm$, $4 \times 10^6$, $45\mu m$, respectively, and the threshold for the crosstalk is -32dB. The service requests are generated randomly between any node pairs. The arrivals of service requests follow Poisson process, and the required spectrum of each request is randomly generated between 1 and 5 spectrum slots. The results are obtained from 10,000 service requests. The normal RSA (Nor-RSA) and crosstalk-aware RSA (XTA-RSA) algorithms are simulated as the base algorithms. First fit strategy is adopted in Nor-RSA and XTA-RSA algorithms. The performance is verified in terms of blocking probability, spectrum utilization, spectrum moving times, spectrum defragmentation latency.
Thank you for your attention!

Yongli Zhao

State Key Laboratory of Information Photonics and Optical Communications (IPOC), Beijing University of Posts and Telecommunications (BUPT), Beijing 100876, China
Tel : +86-10-61198108; Email: yonglizhao@bupt.edu.cn; Web: ipoc.bupt.edu.cn