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

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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

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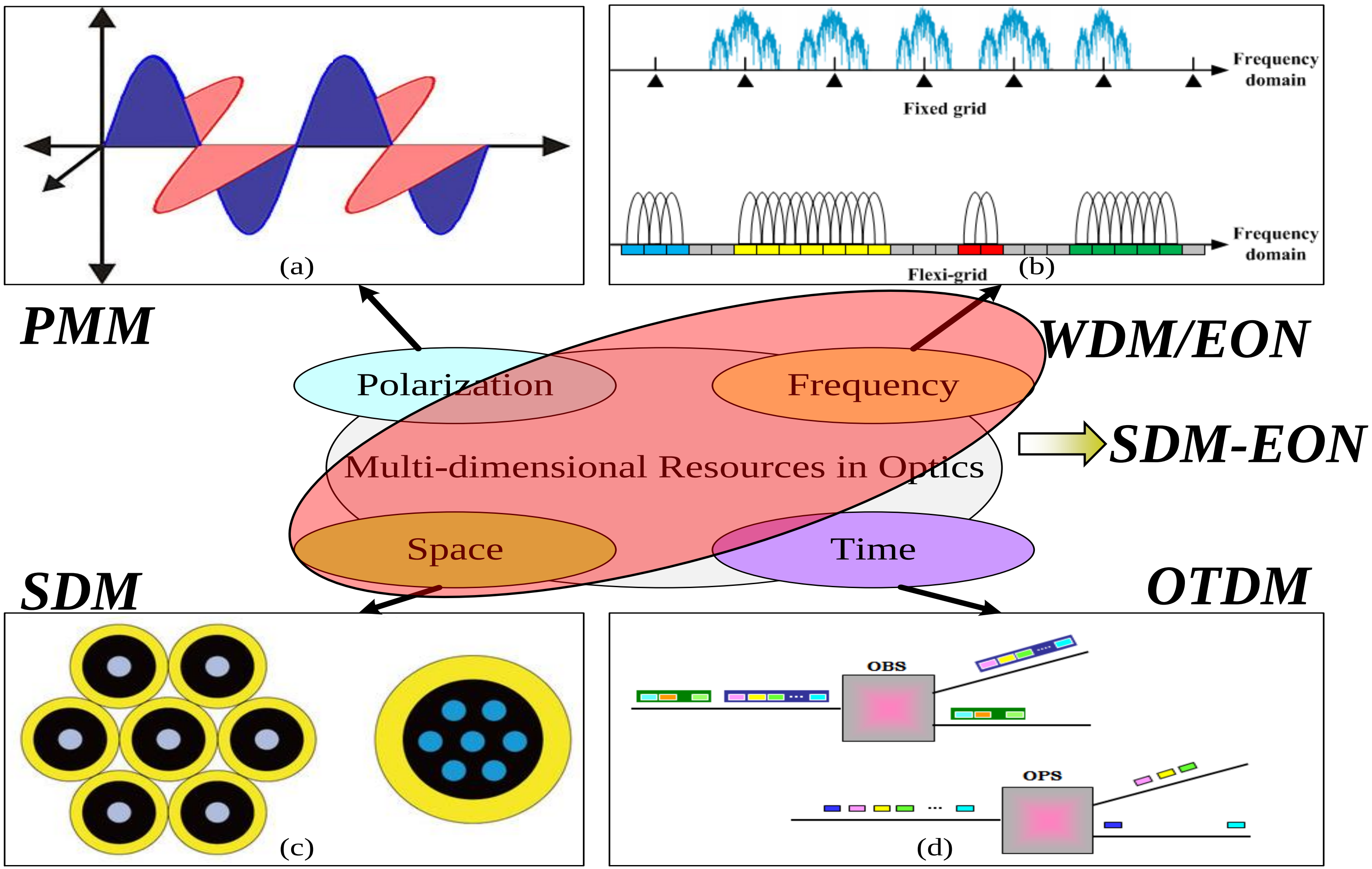
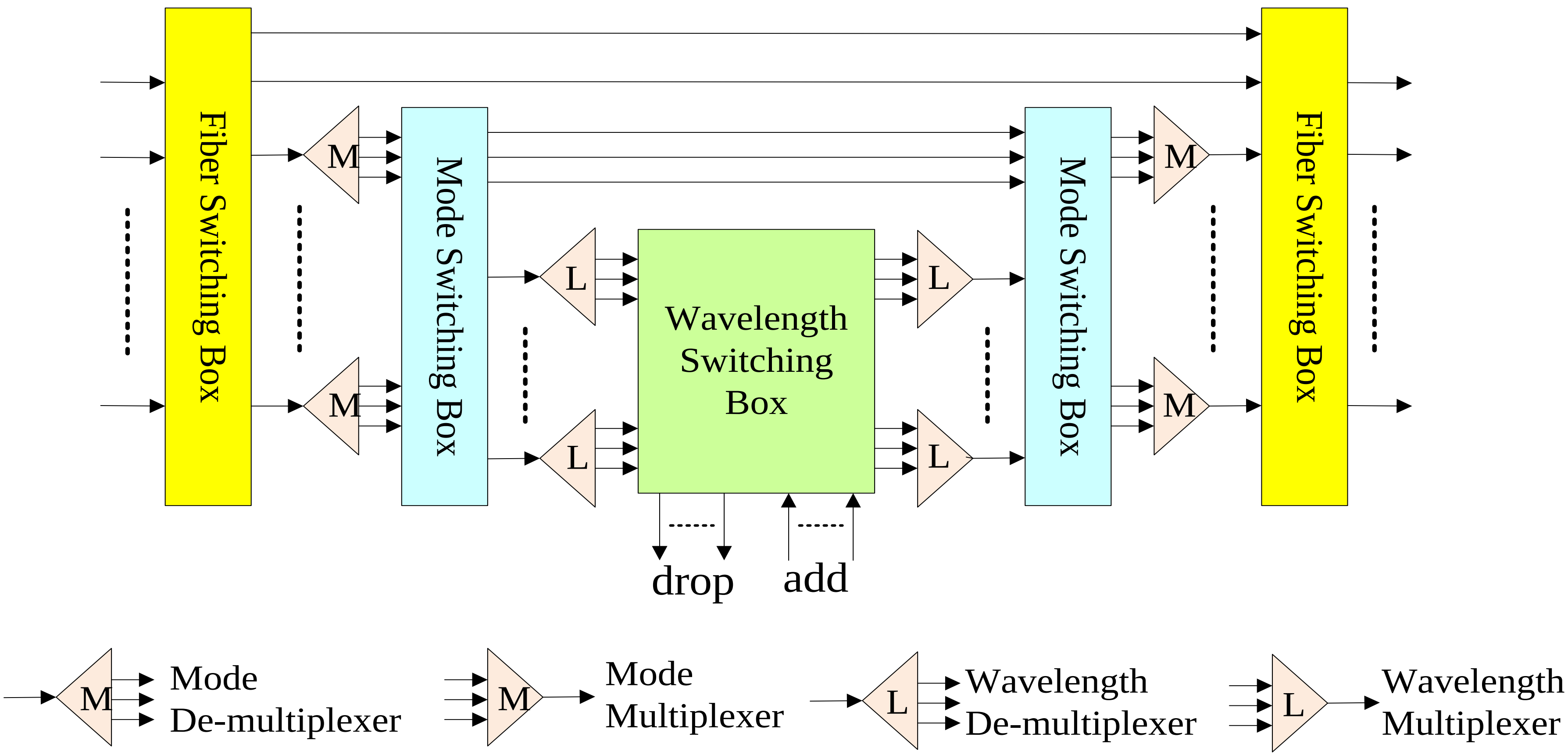
Multi-dimensional resource in optical networks



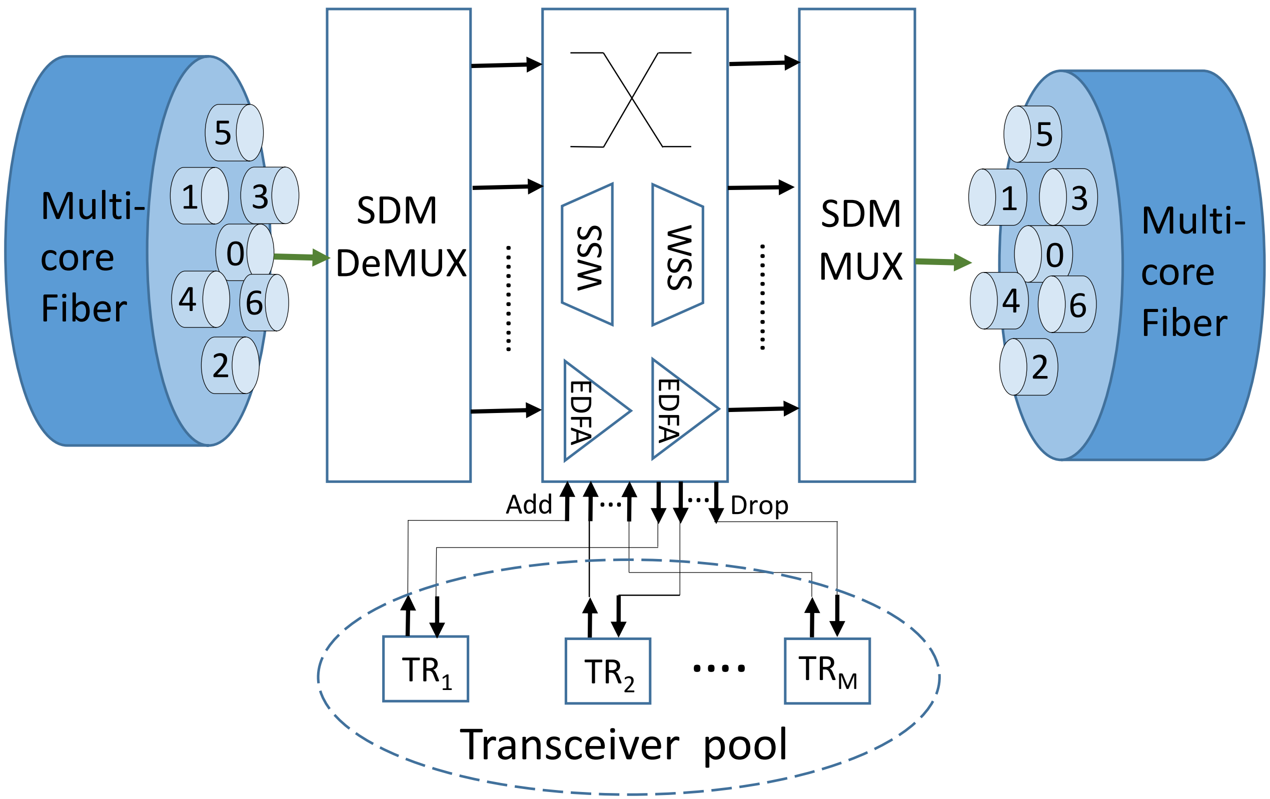
Yongli Zhao, Jie Zhang, et al., Mode and Wavelength Allocation in Multi-Dimensional Optical Networks, ACP2014, Shanghai, China, Nov.2014

Switch fabric of SDM-EON with multi-mode fiber



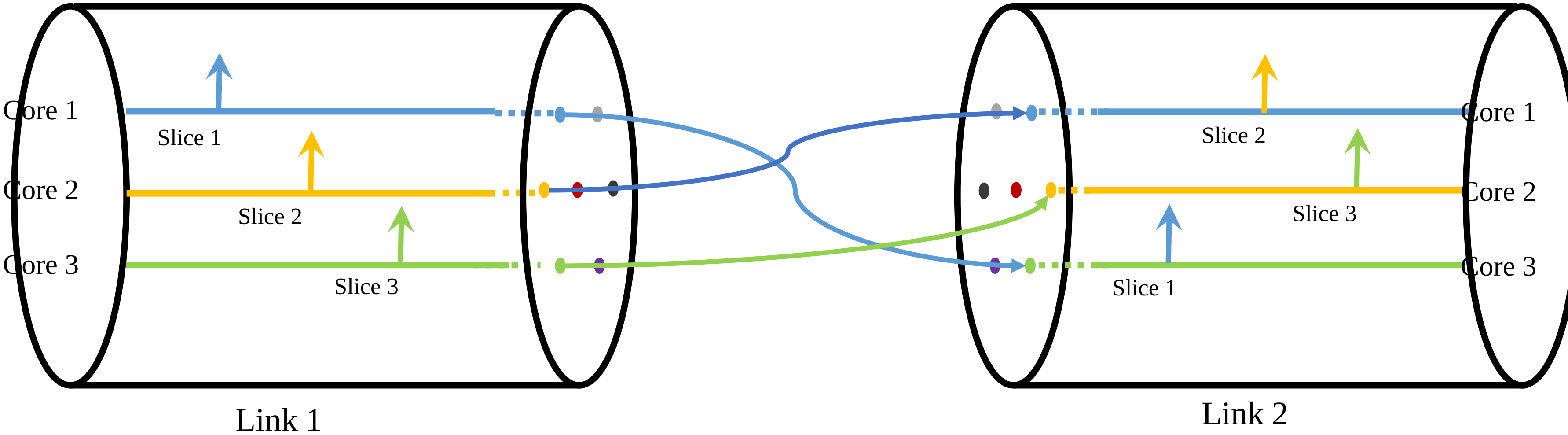
Yongli Zhao, Jie Zhang, et al., Mode and Wavelength Allocation in Multi-Dimensional Optical Networks, ACP2014, Shanghai, China, Nov.2014

Switch fabric of SDM-EON with multi-core fiber



The transceiver resources consist of a transceiver pool, supplying the appropriate sub-transceivers according to the traffic requirement.

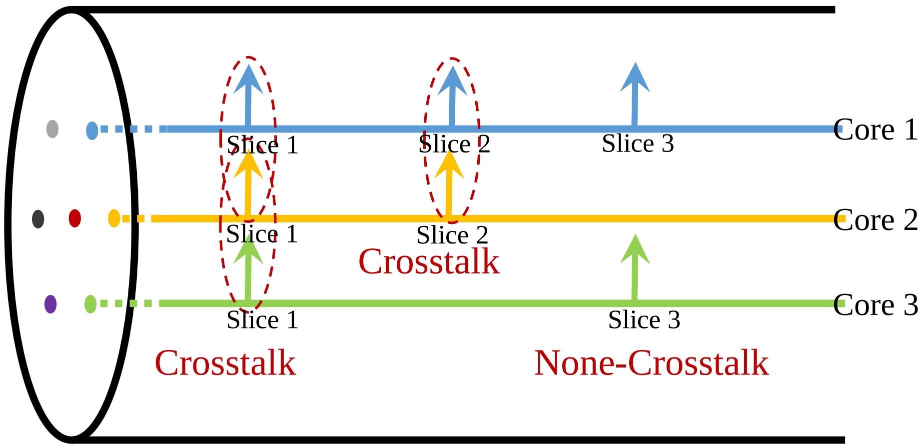
Core and spectrum switching with spectrum continuity



Core and spectrum switching

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

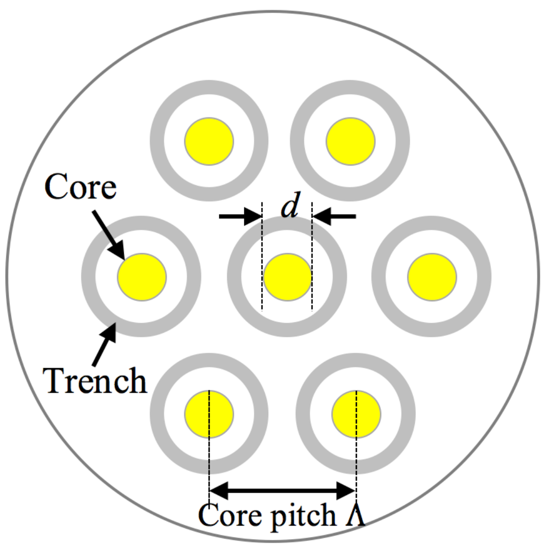


(a) Crosstalk between adjacent cores

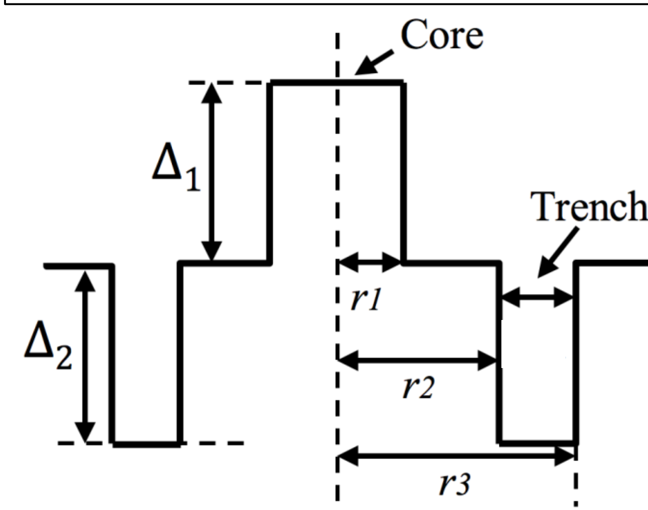
$$h = \frac{2k^2 r}{\beta w_{th}} \quad (1)$$

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

h denotes the mean increase in crosstalk per unit length. k, r, β, 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.



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



(c) Schematic of a core with index trench

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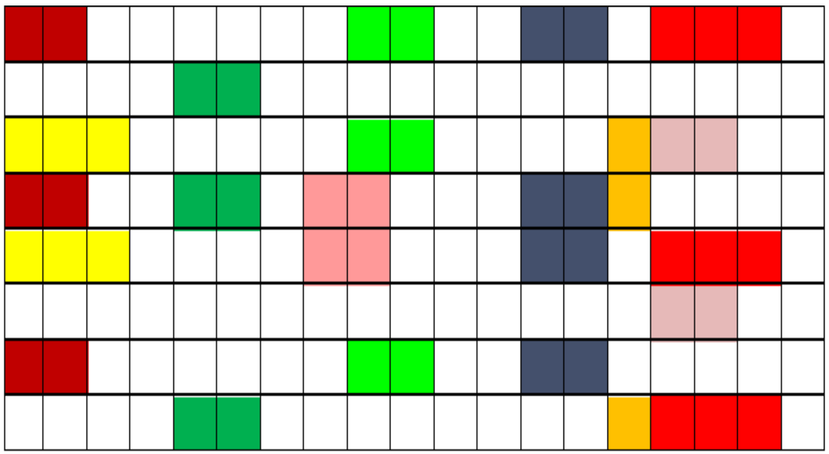
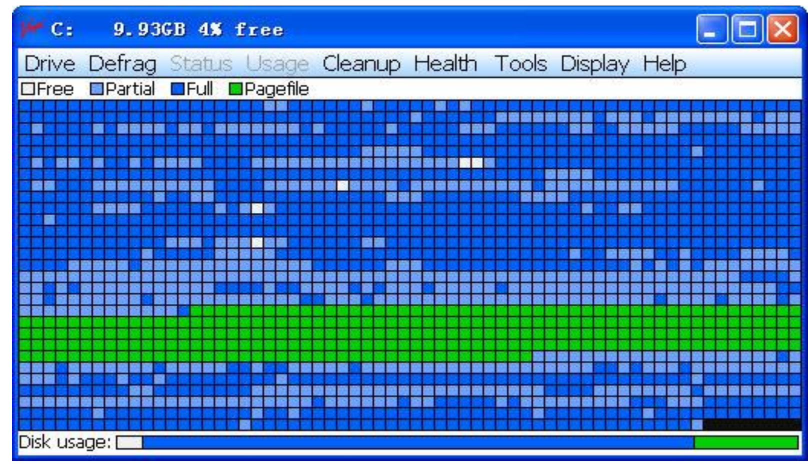
Spectrum fragments in SDM-EON

But when? How to evaluate it?



Spectrum fragmentations



Memory fragmentations

- 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.

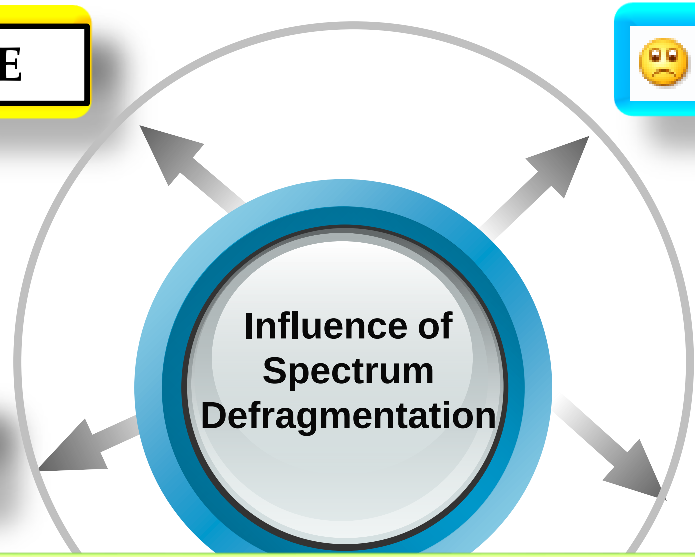
Benefits model of spectrum defragmentation

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 been taken;
- Q>0, Spectrum Defragmentation should be taken.

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

Spectrum Energy Delay Interrupt Cost

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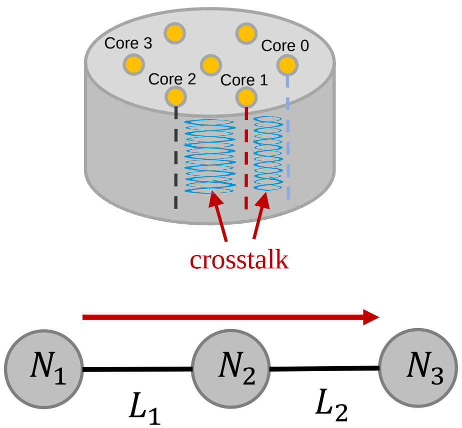
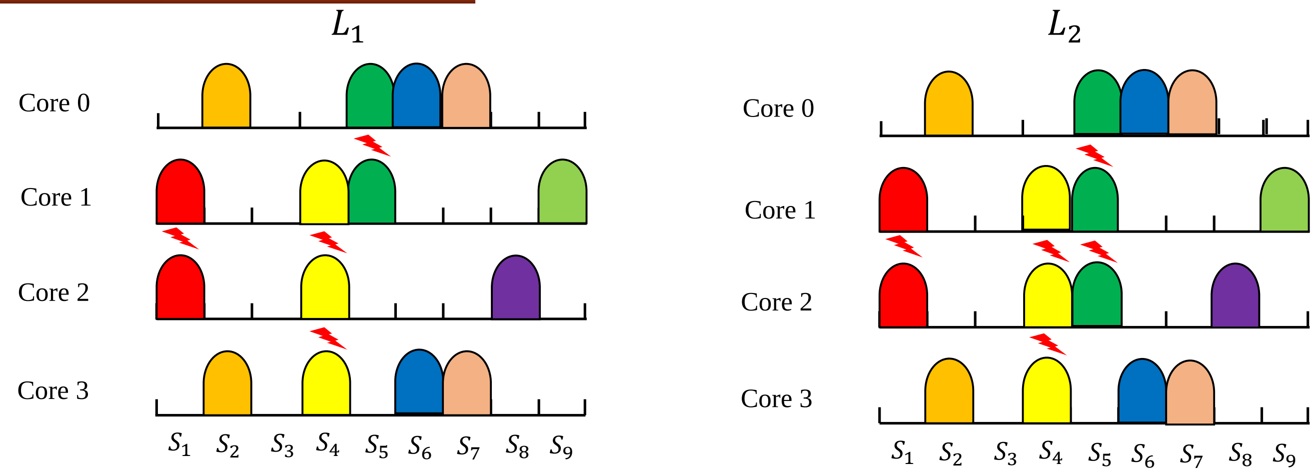
Spectrum compactness in SDM-EON





$$SC^{c,l} = \frac{S_{max}^{c,l} - S_{min}^{c,l} + 1}{\sum_{i=1}^{P} B_i^{c,l}} \times \frac{\sum_{j=1}^{G^{c,l}} g_j^{c,l}}{G^{c,l}}$$

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

$$SC^{0,1} = \frac{7-2+1}{4} \times \frac{1+2+2}{3} = 2.5$$

$$SC^{1,1} = \frac{9-1+1}{4} \times \frac{2+3}{2} = 5.625$$

$$SC^{2,1} = \frac{8-1+1}{3} \times \frac{2+3+1}{3} = 5.333$$

$$SC^{3,1} = \frac{7-2+1}{4} \times \frac{1+1+1+2}{4} = 1.875$$

$$SC^{0,2} = \frac{7-2+1}{4} \times \frac{1+2+2}{3} = 2.5$$

$$SC^{1,2} = \frac{9-1+1}{4} \times \frac{2+3}{2} = 5.625$$

$$SC^{2,2} = \frac{8-1+1}{4} \times \frac{2+2+1}{3} = 3.333$$

$$SC^{3,2} = \frac{7-2+1}{4} \times \frac{1+1+1+2}{4} = 1.875$$

$S_{max}^{c,l}$ and $S_{min}^{c,l}$ represent the maximum and minimum occupied spectrum in the core c of link l respectively. $B_i^{c,l}$ represents the spectrum occupied by the ith connection in the core c of link l. $G^{c,l}$ is the number of available spectrum blocks in the core c of link l, and $g_j^{c,l}$ denotes the spectrum resources of the jth available spectrum block in the core c of link l.

Xiaosong, Jie Zhang, Yongli Zhao, Jie Zhang, et al., Spectrum compactness based defragmentation in flexible bandwidth optical networks, OFC2012, Los Angeles, CA, USA, Mar.2012.

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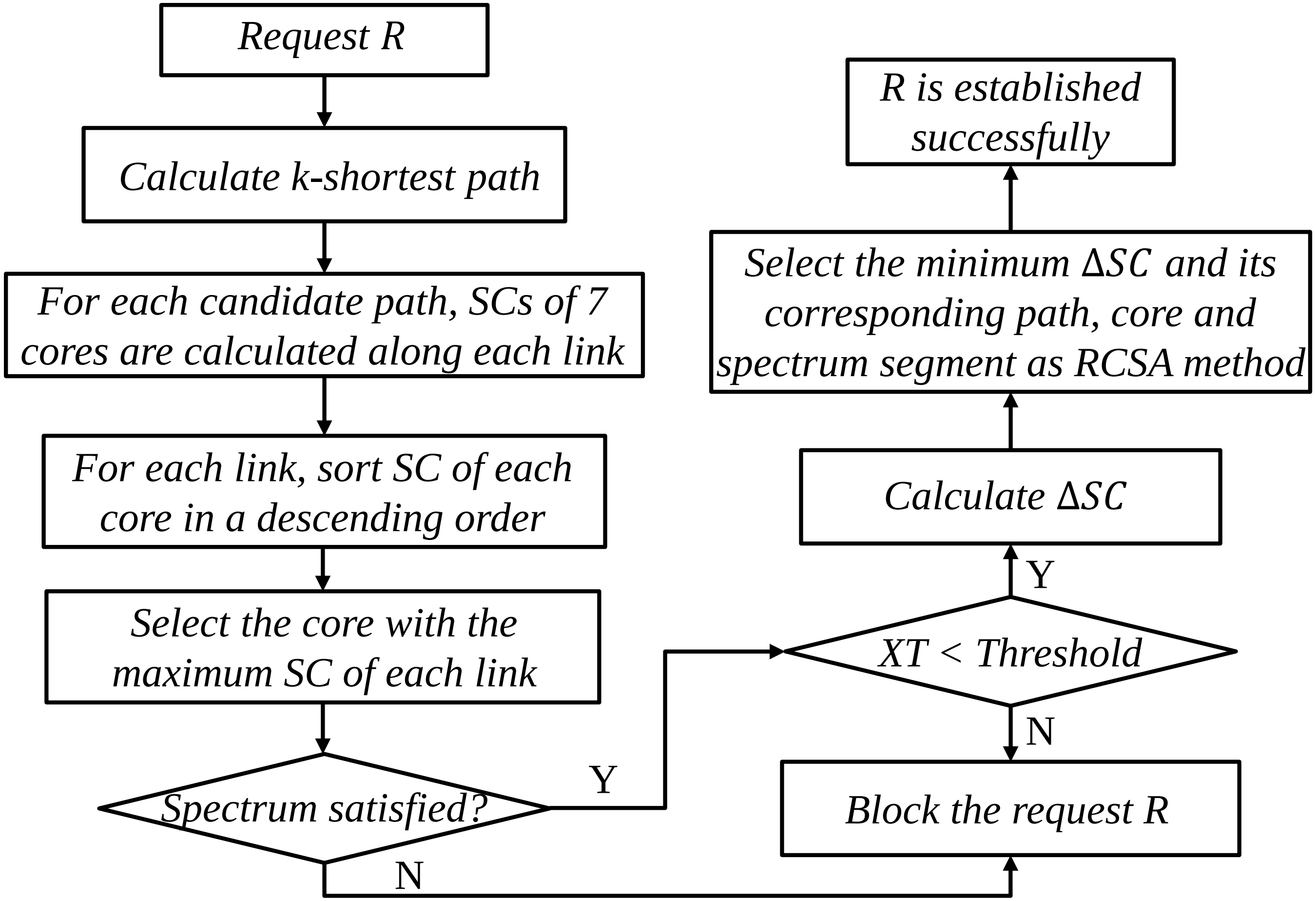
Crosstalk-aware RSCA



$$SC^{l} = \sum_{c=0}^{6} SC^{c,l} \qquad \Delta SC = \sum_{c \in C, l \in path} SC_{before}^{l} - \sum_{c \in C, l \in path} SC_{after}^{l}$$

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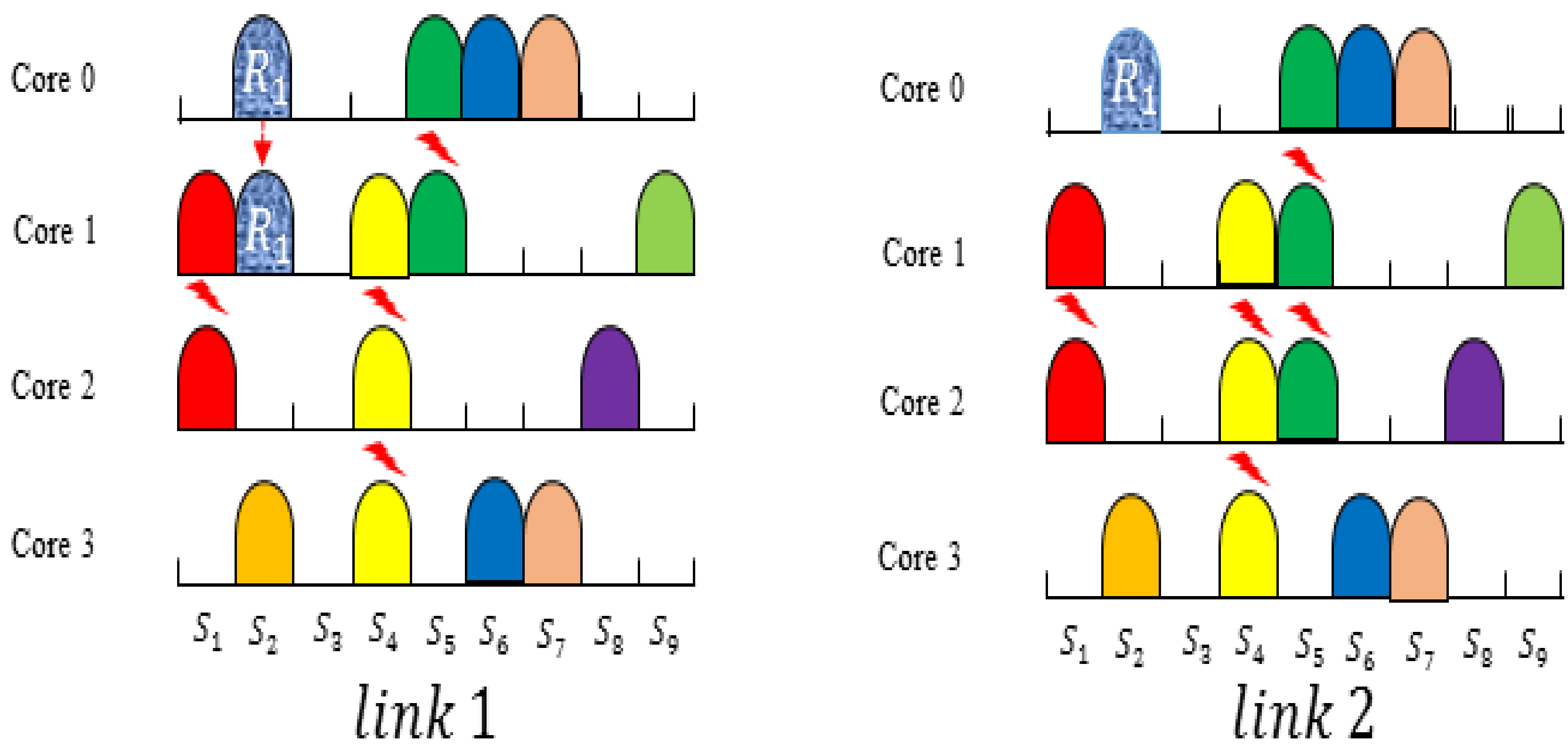
Network model

- $G(V, E, C)$: 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.
- $S_{max}^{c,l}$: the maximum occupied spectrum in the core c of link l.
- $S_{min}^{c,l}$: the minimum occupied spectrum in the core c of link l.
- $B_i^{c,l}$: the spectrum occupied by the ith connection in the core c of link l.
- $G^{c,l}$: the number of available spectrum blocks in the core c of link l.
- $g_j^{c,l}$: the spectrum resources of the jth available spectrum block in the core c of link l.
- L_l: the length of link l.
- L_{R_i}: the length of the ith 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.
- $SC_{threshold}$: the threshold of spectrum compactness for spectrum defragmentation.
- XT_{R_i}: the crosstalk for connection R_i.
- $XT_{threshold}$: the threshold of crosstalk for the connection.

CASD with Same Spectrums and Different Cores



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.

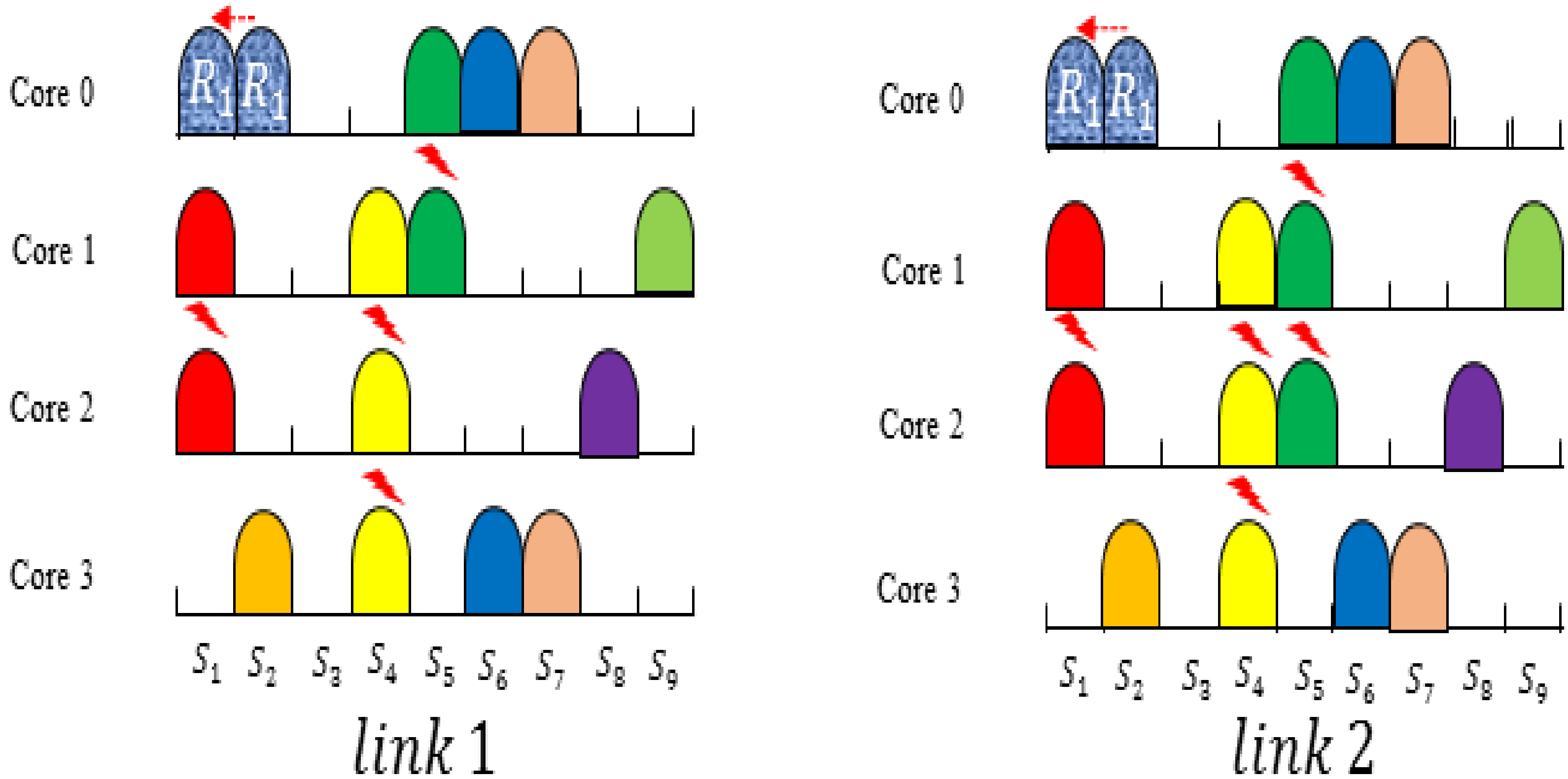
CASD with Same Spectrums and Different Cores

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.

For $(m = 1; m \geq 1; m++)$
Calculate all $SC^{c,l}$ for the network;
Sort them in an ascending order, and select the first connection from the ordered list;
If the first $SC^{c,l} < SC_{threshold}$
For all the connections on link l.
Search the available spectrum for the connection in the other cores of link l;
If there are available spectrum for the connection R_l on n cores (n>=1)
For $(j = 1; j < n + 1; j++)$
Calculate the $SC^{c,l}$ of the original core and the jth oriented core;
If $SC^{c,l}$ of both original core and the jth oriented core > $SC_{threshold}$
Calculate the crosstalk of the affected connections R_x (may be more than one);
If $XT_{R_x} < XT_{threshold}$
Move the spectrum to the oriented core;
Break;
Else do nothing;
End if
Else do nothing;
End if
End for
Else do nothing;
End if
End for
Break;
Else break;
End if
End for

CASD with Different Spectrums and Same Cores



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.

CASD with Different Spectrums and Same Cores

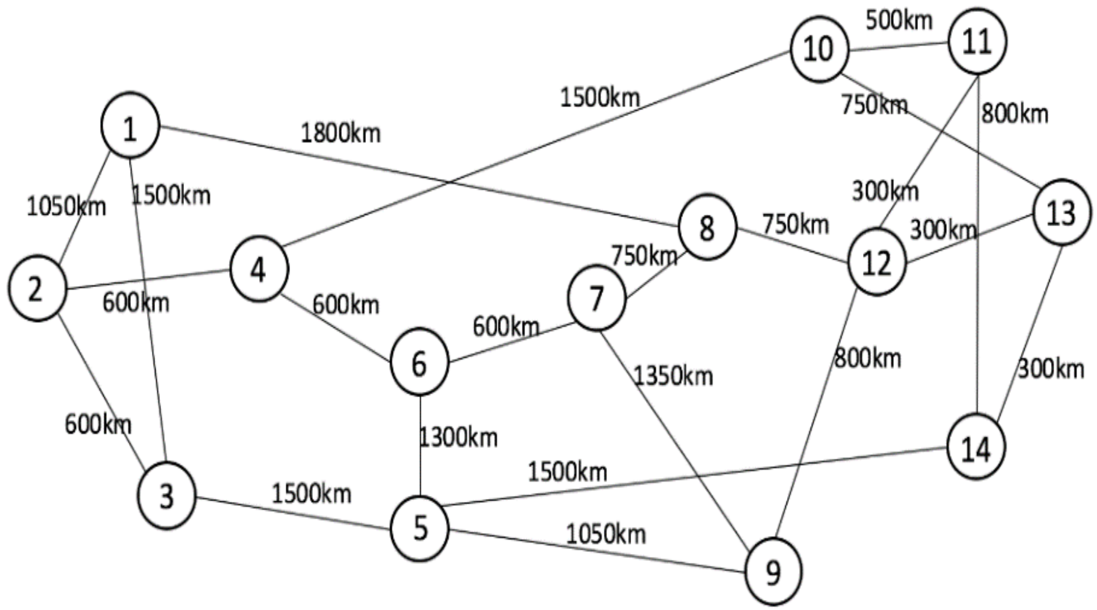
Algorithm 2: CASD with Different Spectrums and Same Cores (CASD-DS-SC)

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

Output: new connections distribution.

For $(m = 1; m \geq 1; m++)$
  Calculate all $SC^{c,l}$ for the network;
  Sort them in an ascending order, and select the first connection from the ordered list;
  If the first $SC^{c,l} < SC_{threshold}$
    For all the connections on link l
      Search the available spectrum for the connection in the other cores of link l;
      If there are available spectrum for the connection R_i on n cores (n>=1)
        For $(j = 1; j < n + 1; j++)$
          Calculate the $SC^{c,l}$ of the original core and the jth oriented core;
          If the $SC^{c,l}$ of both the original core and the jth oriented core > $SC_{threshold}$
            Calculate the crosstalk of the affected connections R_x (may be more than one);
            If $XT_{R_x} < XT_{threshold}$
              Move the spectrum to the oriented core;
              Break;
            Else do nothing;
            End if
          Else do nothing;
          End if
        End for
      Else Search the available spectrum for the connection in the same core along the lightpath;
        If there are available spectrum for the connection R_i on q spectrum blocks (q>=1)
          For $(j = 1; j < q + 1; j++)$
            Calculate the $SC^{c,l}$ of the original spectrum block and the jth spectrum block;
            If $SC^{c,l}$ of both original spectrum block and the jth spectrum block > $SC_{threshold}$
              Calculate the crosstalk of the affected connections R_x (may be more than one);
              If $XT_{R_x} < XT_{threshold}$
                Move the spectrum to the oriented spectrum block;
                Break;
              Else do nothing;
              End if
            Else do nothing;
            End if
          End for
        Else do nothing;
        End if
      End if
    End for
    Break;
  Else break;
  End if
End for

Simulation works to be done



It is assumed that each fiber has 7 cores and each core has 50 spectrum slots. The fiber parameters k, r, β, 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!

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