Multi-Layer versus Single-Layer MG-OXC for WBS

Xiaojun Cao

In collaboration with

Vishal Anand and Chunming Qiao
Outline

- Concept of Waveband Switching (WBS)
- Multi-Layer MG-OXC and Single-Layer MG-OXC architecture
- Offline WBS algorithms
- Reconfigurable MG-OXC for Online case
- Online WBS algorithms
- Conclusions
The Optical Cross-connect (OXC)

- Called Ordinary-OXC here
- DeMux/Mux: split/combine the wavelengths in a fiber
- Switch: connects the wavelengths to one another using ports
- requiring one port for each wavelength
- As the number of wavelength or fiber increase, it also brings up
  - Size, management complexity, cost …
Waveband Switching (WBS)

- Up to 60%~80% of the total traffic in the backbone is bypass (i.e. transit) traffic

- Waveband: a group of several wavelengths

- All the wavelengths in a band will be switched as a single entity (port)

- Major merits of WBS
  - reduce port count
  - simplify network management
  - reduce complexity
  - better scalability

- Need new cross-connects architecture: Multi-Granularity optical cross-connect (MG-OXC)
MG-OXC Architecture

- A new switching hierarchy with multiple granularities
  - Fiber, band, wavelength
- Three layer, three switching fabric
- Advantage:
  - flexible

Three-Layer MG-OXC
Single-Layer MG-OXC

- One common switching fabric, includes three logical divisions
- Only designated fibers/bands can be demuxed/muxed
- Advantage:
  - Simple
  - Better signal quality
In WBS networks with Single-Layer MG-OXC, an appropriate WBS algorithm needs to make sure that dropped lightpath will be assigned wavelengths belong to a designated fiber/band.

In the following, Consider Fixed band size as well as fixed set of wavelengths per band
Offline WBS

Given static traffic, network topology, the number of wavelength etc, how to satisfy the demands while minizing the size of MG-OXCs.

Optimal ILP model, BPHT appeared in InfoCom’03 and OptiComm’02
  – Too time-consuming

Near-Optimal ILP model (Off-ILP)
  – Limit the number of possible routing
  – To reduce the computation complexity
Off-ILP model

- **Primary Notation:**
  - $I_n, O_n, A_n, D_n$: set of incoming/outgoing fibers
  - $B, W, L_b$: number of band/wavelength, set of $\lambda$ in band $b$.
  - $P, T[p], K, R_{k,p}$: traffic matrix and K-shortest path set

- **Variables:**
  - $V, S, W, B, F$: lightpaths going through which switching fabric
  - $FTB/BTF, BTW/WTB$: describe which demux/mux to use

- **Objective:** minimize the total MG-OXC ports in the network

\[
\minimize \left[ \sum_{n} WXC_n + \sum_{n} BXC_n + \sum_{n} FXC_n \right]
\]
Constraints

- Traffic flow constraints
  - Satisfy all the traffic demands

- Waveband switching
  - Appropriately switch the lightpaths through the switch fabrics at a node

- Mux/Demux
  - Appropriately Mux/Demux the lightpaths at a node

Detailed formulations refer to Papers
Performance Metrics

- Total port number ratio \( T \):

\[
T = \frac{\text{Total}(FXC_n + BXC_n + WXC_n) \cdot u \cdot \sin g \cdot MG - OXC}{\text{Total}(OXC_n) \cdot u \cdot \sin g \cdot \text{ordinary} - OXC}
\]

- Max port number ratio \( M \):

\[
M = \frac{\text{Max}(FXC_n + BXC_n + WXC_n) \cdot u \cdot \sin g \cdot MG - OXC}{\text{Max}(OXC_n) \cdot u \cdot \sin g \cdot \text{ordinary} - OXC}
\]

- Used wavelength-hop ratio \( WH \):

\[
WH = \frac{\lambda - \text{hop used by WBS algorithm}}{\lambda - \text{hop used by optimal RWA without WBS}}
\]
Numerical Results

14-node Network with random traffic, K=3

![Graph 1: Ratio T vs Number of Wavelength per Band](image1)

![Graph 2: Ratio M vs Number of Wavelength per Band](image2)
Summary for Offline case

- Near-optimal ILP model perform better
- Single-Layer MG-OXC requires up to 20% fewer ports than Multi-Layer MG-OXC
- With appropriate wavelength granularity (W=4), MG-OXC can achieve more than 50% ports reduction when compared to ordinary OXCs
  - The maximum size of a node over all the nodes also has similar reduction
- Tradeoff between wavelength-hops and port count
Online WBS

- Given MG-OXC and network topology, how to process lightpath request without knowledge of any future requests.
  - Incremental, non-rearrangeable

- Unlike offline case, which can have as many port as needed to guarantee all demands

- In online case, MG-OXCs may have a predetermined limited port count
  - How to minimize request blocking probability
  - How to efficiently use the network resources (e.g. minimize active ports)
Reconfigurable MG-OXC

- $X$: the number of incoming fibers
- $\alpha (\leq 1)$: the ratio of fibers can be demuxed to bands
  - Any $\alpha \cdot X$ fibers can be demuxed to bands
- $Y$: the number of BXC ports from FTB demux
- $\beta (\leq 1)$: the ratio of bands can be demuxed to $\lambda$s
  - Any $\beta \cdot Y$ bands can be demuxed to $\lambda$s

Total number of ports:

$$MG - OXC_n = (1 + \alpha) \cdot X + (1 + \beta) \cdot Y + \beta \cdot Y \cdot W + W_{\text{add/drop}}$$
T for Reconfigurable MG-OXC

- **T₃**: ratio of the port count in a Three-Layer MG-OXC to the port count in an ordinary-OXC

\[ T₃ = \frac{MG - OXC}{OXC} \approx \beta \cdot \alpha + \frac{(1 + \beta) \cdot \alpha}{W} \]

- Similarly, **T₁**: the ratio for Single-Layer MG-OXC

\[ T₁ \approx \beta \cdot \alpha + \frac{(1 - \beta) \cdot \alpha}{W} \]

- For single-fiber systems, it’s necessary to set \( \alpha = 1 \), otherwise the blocking is too high
Online ILP model (On-ILP)

- Additional constraints for Three-Layer MG-OXC
  - \( \delta \): node degree

\[
\sum_{o,b} WTB_{o}^{n,b} \leq \delta \cdot \beta \quad \forall n \quad \sum_{i,b} BTW_{i}^{n,b} \leq \delta \cdot \beta \quad \forall n
\]

- Additional constraints for Single-Layer MG-OXC
  - The choice of the designated bands is critical: the traffic carried by a designated band at one node may bypass at another node.
  - EWTB/EBTW: the setting of designated bands: randomly select \( \beta \cdot Y \) bands as designated bands.

\[
WTB_{o}^{n,b} \leq EWTB_{o}^{n,b} \quad \forall n, o, b \quad BTW_{i}^{n,b} \leq EBTW_{i}^{n,b} \quad \forall n, i, b
\]

- Since \( \alpha=1 \), no constraint on the number of FTB/BTF ports
Online heuristics

- **Random-Fit**
  - Combine the K-shortest path routing with random wavelength assignment

- **First-Fit**
  - Use K-shortest path routing and assign the wavelength sequentially

- **Maximum Overlap Ratio (MOR)**
  - Model a WBS network as a band-graph having B layers
  - Find K-shortest path in each layer corresponding to band b
  - Intuitively, to minimize the blocking coming with limitation of ports and wavelength resource
    - Route along the path that has max links in common with existing lightpaths
    - Avoid the wastage of wavelength resources
  - Set the weight of each (k,b) pair as $Q_k^b = \sum_{H} \frac{L}{H}$ where L is the overlap length, H is the number of hops, choose the maximum weight to route the new demand
MOR example

- New demand: $0 \rightarrow 7$
- Compute weight
  
  $Q_{k_2}^{b_2} = \frac{3}{4}$  
  $Q_{k_1}^{b_0} = \frac{1}{4}$  
  $Q_{k_3}^{b_1} = \frac{3}{5}$

- New lightpath: $0 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7$ ($\lambda_5$)
Results of Three-Layer MG-OXC

- For medium load, MOR is better than First-Fit, On-ILP, much better than Random-Fit.
  - MOR takes waveband grouping into consideration
  - On-ILP minimize additional ports, random λs assignment to the initial traffic set hurts its performance

- When $\beta \approx 0.45$ (i.e. $T_3 \approx 0.60$), MOR achieves the lowest blocking probability
  - One may build 45% (but not more) BTW ports
  - 40% savings on port count
Results of Three-Layer MG-OXC cont.

- For high load, First-Fit is the best when $T_3 > 0.75$
  - Assign $\lambda$s sequentially
  - Prefer to use shortest path

- MOR consumes more wavelength resources, experience more blocking due to the lack of wavelength resources
Results of Single-Layer MG-OXC

The designated bands are allocated randomly at different nodes, greatly reduces the chance of wavebanding and hence increase the blocking

- At low loads, noneligible blocking
- At high loads, blocking probability close to 1
Three-Layer versus Single-Layer

- Under medium load, the blocking probability using Three-Layer MG-OXC is much lower
  - Three-Layer MG-OXC is more suitable for online traffic
Conclusion

- Proposed feasible ILP model for offline case and efficient heuristics for online case

- Compared Three-Layer MG-OXC and Single-Layer MG-OXC for both online case and offline case
  - For the offline case, Single-Layer MG-OXC is better in terms of reducing port count when building network from scratch
  - For the online case, Three-Layer MG-OXC is more flexible and results in lower blocking probability
  - The ratio ($\beta$) and waveband granularity have a great effect on the performance of WBS networks