

Improved Block-Based Wavelength Assignment Strategies for DWDM Networks with All-Optical Wideband Converters

Denise Sagbo, Chisom Ezegebe, Luiz Bonani

Abstract—Block-based wavelength assignment heuristics have been proposed for DWDM optical networks with all-optical wideband wavelength converters to mitigate the wavelength continuity constraint. The Longest Block First (LBF) algorithm selects the longest contiguous available wavelength block, thereby reducing blocking probability, but its first-fit expansion strategy generates excessive wavelength conversions. This paper proposes and evaluates two improved strategies: All Longer Blocks First (aLBF) and Longest Block Last Edge Blocks (LBLEB). Both retain the longest-block selection of LBF but employ alternative left and right-subrange covering policies. The aLBF uses an optimal greedy expansion that minimizes the start node (leftward) and maximizes the end node (rightward) of each covering subblock, while LBLEB adopts a passive last-valid-block strategy. Simulations on the CORONET continental topology with incremental traffic and fiber augmentation show that aLBF-B and LBLEB-B approach the blocking performance of the OEOWC reference while achieving significantly better converter utilization. In particular, aLBF-B provides the best trade-off, reducing conversions by 23.6% and converters by 21.8% relative to LBF-B while approaching the OEOWC reference in blocking performance. In contrast, LBLEB shows more modest improvements over LBF.

Keywords—DWDM networks, RSA, wavelength conversion.

Resumo—Heurísticas de alocação de comprimentos de onda baseadas em blocos têm sido propostas para redes óticas DWDM com conversores de comprimento de onda totalmente óticos de banda larga para mitigar a restrição da continuidade do comprimento de onda. O algoritmo *Longest Block First* (LBF) seleciona o maior bloco de comprimento de onda contínuo disponível, reduzindo assim a probabilidade de bloqueio, mas sua estratégia de expansão *first-fit* gera conversões excessivas de comprimento de onda. Este artigo propõe e avalia duas estratégias melhoradas: *All Longer Blocks First* (aLBF) e *Longest Block Last Edge Blocks* (LBLEB). Ambos os algoritmos mantêm a mesma seleção do bloco mais longo que o LBF, mas empregam políticas alternativas de cobertura de subfaixas esquerda/direita. O aLBF usa uma expansão gulosa ótima que minimiza ativamente o nó inicial (para a esquerda) e maximiza o nó final (para a direita) de cada bloco de cobertura, enquanto o LBLEB usa uma estratégia passiva de último bloco válido. Simulação com a topologia continental CORONET com tráfego incremental e aumento de fibras demonstram que tanto aLBF-B quanto LBLEB-B se aproximam da eficiência da referência OEOWC em termos de probabilidade de bloqueio, ao mesmo tempo que alcançam uma utilização de conversores significativamente melhor que a OEOWC. O aLBF-B, em particular, alcança o melhor compromisso, reduzindo as conversões em 23,6% e os conversores em 21,8% em relação ao LBF-B, enquanto se aproxima da referência OEOWC no desempenho de bloqueio.

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Em contraste, o LBLEB mostra melhorias mais modestas em relação ao LBF padrão.

Palavras-chave—Redes DWDM, RSA, conversão de comprimento de onda.

I. INTRODUCTION

The relentless growth of bandwidth-intensive applications, cloud services, and hyperscale data centers continues to drive the demand for high-capacity optical transport networks. Dense Wavelength Division Multiplexing (DWDM) technology remains a fundamental enabler for ultra-high-capacity communications, but efficient spectrum management in dynamic traffic scenarios remains an open challenge.

In wavelength-routed optical networks, the Routing and Spectrum Assignment (RSA) problem must be solved for each incoming connection request. Under dynamic or incremental traffic, where connections are established progressively and never released, spectrum fragmentation [9] becomes a critical issue: spectral resources become increasingly fragmented over time, leading to higher blocking probabilities.

All-optical wideband wavelength converters (AOWWCs) have recently emerged as a promising technology to mitigate fragmentation by enabling wavelength conversion over contiguous spectral ranges [2], [4], [6], [7]. Several block-based heuristics have been proposed to exploit these capabilities. Among them, the Longest Block First (LBF) algorithm [4] identifies all maximal contiguous available spectral segments (blocks) along a path and selects the longest one as the primary assignment segment. The remaining uncovered path portions are then recursively covered using additional spectral blocks.

While LBF achieves competitive blocking probability, its covering strategy for left/right subranges relies on a first-fit selection that picks the first valid block encountered during iteration and generates unnecessary wavelength conversions. To address this limitation, this paper first provides a detailed analysis of the LBF covering mechanism, identifying its first-fit expansion as the root cause of excessive wavelength conversions. Based on this analysis, we propose two improved block-based strategies: the *All Longer Blocks First* (aLBF) and the *Longest Block Last Edge Blocks* (LBLEB), which introduce better covering policies. Their performance is comprehensively evaluated on the CORONET topology under incremental traffic with fiber augmentation. The obtained

results demonstrate that both aLBF and LBLb approach the OEOWC reference in terms of blocking probability while achieving more efficient converter management, with aLBF offering the best overall trade-off.

This paper is organized as follows: Section II reviews related work on RSA and wavelength conversion. Section III presents the block-based wavelength assignment framework, including the availability matrix definition and the proposed aLBF and LBLb strategies, along with an illustrative example. Section IV outlines the simulation setup. Section V discusses the results in terms of blocking probability, wavelength conversions, and converter deployment. Finally, Section VI concludes the paper.

II. RELATED WORK

The Routing and Spectrum Assignment (RSA) problem in dynamic optical networks has been extensively studied. Classical approaches, such as First-Fit (FF) wavelength assignment, are known for their simplicity and low complexity but suffer from spectrum fragmentation [9] under sustained traffic load.

The min-cost path selection algorithm for DWDM networks with wideband converters was first proposed in [3] and later extended in [8], addressing the economics of converter placement. Following this line of research, the Longest Block First (LBF) algorithm was developed to mitigate spectrum fragmentation by prioritizing long contiguous spectral segments. LBF identifies all maximal available blocks along a path and selects the longest one as the primary assignment. The remaining uncovered segments are then recursively covered using a first-fit search across the remaining blocks.

Other related work addresses the wavelength conversion problem through alternative frameworks, such as cloud-native conversion architectures [2] and multi-objective optimization for regenerator placement [5].

The present work identifies and addresses a specific inefficiency in the LBF covering mechanism. Rather than proposing a fundamentally new algorithm, we demonstrate that simple modifications to the subrange covering strategy (replacing first-fit with optimal greedy expansion) yield substantial improvements in conversion efficiency. As shown in Section V, the proposed aLBF reduces wavelength conversions by 23.6% and deployed converters by 21.8% relative to standard LBF-B, while improving identical blocking probability.

III. BLOCK-BASED WAVELENGTH ASSIGNMENT

A. Availability Matrix and Wavelength Blocks

We define a wavelength block as a tuple $\langle w, s, e, l \rangle$, where w is the wavelength index, s is the start node index, e is the end node index, and l is the block length (number of links covered). The availability matrix $M \in \mathbb{B}^{h \times F}$ is constructed such that $m_{l,w} = 1$ if wavelength w is free on link l and 0 otherwise. An illustrative example of the matrix and the resulting wavelength paths is provided in Section III-F after the algorithm descriptions.

B. The Original LBF Algorithm

The Longest Block First (LBF) algorithm operates in three phases:

a) Phase 1: Block Discovery: For a given path with h links and F wavelengths, all maximal contiguous available blocks are extracted from the availability matrix. Each block is characterized by its wavelength λ , start node s , end node e , and length (number of links covered).

b) Phase 2: Sorting and Selection: All discovered blocks are sorted in descending order by size (length). The longest block $B_{\max} = B(\lambda^*, s^*, e^*)$ is selected as the primary assignment segment.

c) Phase 3 (Left/Right Covering): The remaining uncovered segments, $[0, s^*)$ (left) and $[e^*, h)$ (right), are recursively covered by searching for valid blocks. For the left subrange, LBF iterates through all wavelengths in natural spectral order, and for each wavelength, scans its blocks until finding the first block that covers the current uncovered position. This First-Fit expansion picks the first valid block encountered, with no optimization regarding how far left the block extends. The covering procedure is shown in the algorithm 1.

Algorithm 1 Standard LBF Covering (First-Fit Expansion)

Require: Block map $\mathcal{B}$, subrange $[s, e)$, ref. λ_r

Require: *canBreak* flag

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1: result  $\leftarrow \emptyset$ , link  $\leftarrow s$  (or  $e$  depending on direction)
2: while link uncovered do
3:   chosen  $\leftarrow$  null
4:   outer: ▷ Label for break loop
5:   for each wavelength  $\lambda$  in  $\mathcal{B}$  do
6:     if  $|\lambda - \lambda_r| > S_{\max}$  then
7:       continue
8:     end if
9:     for each block  $b \in \mathcal{B}[\lambda]$  do
10:      if  $b$  overlaps uncovered position then
11:        chosen  $\leftarrow b$  ▷ First-fit, no comparison
12:        break outer
13:      end if
14:    end for
15:  end for
16:  if chosen = null then
17:    return failure
18:  end if
19:  Add chosen to result, update link and  $\lambda_r$ 
20: end while
21: return result

```

C. The aLBF algorithm

The All Longer Blocks First (aLBF) algorithm preserves Phases 1 and 2 of LBF but replaces the first-fit covering in Phase 3 with an *optimal greedy expansion*. For each uncovered subrange, aLBF evaluates *all* valid candidate blocks and selects the one that maximizes coverage:

- *Leftward covering (Right-to-Left):* Among all valid blocks overlapping the left subrange $[0, s^*)$, aLBF selects the

block with the *minimum start node* $s_{\min}$, i.e., the block that extends furthest toward the source node.

- *Rightward covering (Left-to-Right)*: Among all valid blocks overlapping the right subrange $[e^*, h)$, aLBF selects the block with the *maximum end node* $e_{\max}$, i.e., the block that extends furthest toward the destination node.

The comparison logic is shown in Algorithm 2.

Algorithm 2 aLBF Covering (Optimal Greedy Expansion)

Require: Block map $\mathcal{B}$, subrange $[s, e)$, ref. λ_r

Require: *canBreak*, *direction*

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1: result  $\leftarrow \emptyset$ , link  $\leftarrow s$  or  $e$ 
2: while link uncovered do
3:   chosen  $\leftarrow$  null
4:   for each  $\lambda$  in  $\mathcal{B}$  do
5:     if  $|\lambda - \lambda_r| > S_{\max}$  then
6:       continue
7:     end if
8:     for each  $b \in \mathcal{B}[\lambda]$  do
9:       if  $b$  overlaps uncovered position then
10:        Compute candidate  $c$  from  $b$ 
11:        if direction = LEFT and (chosen = null
or  $c.s < \text{chosen}.s$ ) then
12:          chosen  $\leftarrow c$  ▷ Min start node
13:        else if direction = RIGHT and (chosen =
null or  $c.e > \text{chosen}.e$ ) then
14:          chosen  $\leftarrow c$  ▷ Max end node
15:        end if
16:      end if
17:    end for
18:  end for
19:  if chosen = null then
20:    return failure
21:  end if
22:  Add chosen to result, update link,  $\lambda_r$ 
23: end while
24: return result
    
```

D. The LBLLeB algorithm

The Longest Block Last Edge Blocks (LBLLeB) algorithm also preserves Phases 1 and 2, but uses a *last-valid-block* covering strategy. Unlike aLBF's optimal comparison, LBLLeB simply overwrites the chosen block with each new valid candidate, ultimately selecting the last valid block encountered during iteration. This effectively produces a random-like selection whose outcome depends on the HashMap iteration order of the block data structure.

This passive strategy can be understood as a variant of aLBF (Algorithm 2) where the comparison step is replaced by simple overwriting. While its pseudo-random behavior may seem less robust, it serves as an important comparative baseline in this study to demonstrate the necessity of the active, controlled comparison employed by aLBF.

E. Complexity Analysis

For a path of length h with F wavelengths, discovering all spectral blocks requires $O(F \cdot h)$ operations. The sorting step in LBF, aLBF, and LBLLeB is identical: $O(N \log N)$ where N is the number of discovered blocks.

The difference lies in the covering step:

- *LBF*: For each uncovered position, the first-fit search examines blocks until finding the first valid one, requiring $O(N)$ in the worst case per subrange.
- *aLBF*: For each uncovered position, all valid candidates are evaluated to find the optimal one, also $O(N)$ per subrange, but with a constant-factor overhead for the comparison.
- *LBLLeB*: For each uncovered position, all valid blocks are examined and the last one is selected, also $O(N)$ per subrange, with the same worst-case complexity as first-fit.

Thus all three algorithms have the same asymptotic complexity $O(F \cdot h + N \log N + N \cdot h)$, but aLBF performs slightly more comparisons per subrange iteration.

F. Illustrative Example

Figure 1 shows an example of the availability matrix with $W = 5$ wavelengths and $L = 12$ links (13-node path). Table I presents the wavelength paths produced by the three algorithms with breaking (B) for this matrix.

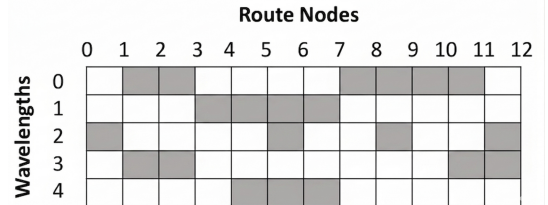


Fig. 1: Example of an availability matrix for a 13-node (12-link) path with 5 wavelengths. White zones represent free wavelengths (available blocks), and shaded zones represent busy wavelengths (unavailable links). The blocks extracted are used to determine the best wavelength assignment strategy.

TABLE I: Wavelength Paths Produced by Each Algorithm. Each segment corresponds to a block $\langle w, s, e, l \rangle$.

Algorithm	Wavelength Path	Conv.
LBF-B	$\langle 0, 0, 1, 1 \rangle, \langle 1, 1, 3, 2 \rangle, \langle 3, 3, 10, 7 \rangle, \langle 1, 10, 12, 2 \rangle$	3
aLBF-B	$\langle 4, 0, 3, 3 \rangle, \langle 3, 3, 10, 7 \rangle, \langle 1, 10, 12, 2 \rangle$	2
LBLLeB-B	$\langle 4, 0, 3, 3 \rangle, \langle 3, 3, 10, 7 \rangle, \langle 4, 10, 12, 2 \rangle$	2

The longest block $\langle 3, 3, 10, 7 \rangle$ (length = 7) is selected by all three algorithms in Phase 2. The differences lie in Phase 3 (left/right covering), where each algorithm employs a distinct strategy:

IV. SIMULATION SETUP

The proposed algorithms were evaluated using the discrete-event simulator on the CORONET optical topology [1]. The simulation parameters are summarized in Table II.

TABLE II: Simulation Parameters

Parameter	Value	Description
Topology	CORONET	75 nodes, 99 links
n_{events}	4000	Connection requests
n_{reps}	200	Simulation replications
F	80	Wavelengths per fiber
S_{max}	80	Maximum conversion shift (slots)
M_{conv}	4	Max conversions per path
N_{fibers}	4	Max fiber pairs per link
ρ_{th}	0.9	Fiber augmentation threshold
Converter type	AOWC	All-optical wideband converter
Traffic model	Incremental	Connections never leave

The following algorithms were compared:

- *LBF-B / LBF-NB*: Standard LBF with first-fit expansion
- *aLBF-B / aLBF-NB*: Proposed - optimal greedy expansion
- *LBLeB-B / LBLeB-NB*: Proposed - last-valid-block expansion
- *MinCost*: Minimum-cost path selection with wideband converters (max 4 conversions per path)
- *OEOWC*: Full OEO wavelength conversion (unlimited conversions per path)
- *NoWC*: No wavelength conversion

For each algorithm, the suffix *-B* indicates that *breaking* is allowed: meaning a wavelength block can be broken mid-link if no continuous block covers the entire remaining subrange. The suffix *-NB* (*no breaking*) requires each block to cover its subrange continuously without fragmentation.

V. RESULTS AND DISCUSSION

Table III summarizes the final cumulative values at the last request of the simulation.

TABLE III: Final Cumulative Results at the last Request

Algorithm	Blocks (%)	Conversions	Converters
aLBF-B	9.35%	494.3	431.7
aLBF-NB	10.79%	391.3	354.4
LBF-B	9.36%	646.8	552.4
LBF-NB	10.84%	471.0	421.3
LBLeB-B	9.35%	671.7	554.0
LBLeB-NB	11.11%	447.1	383.2
MinCost	9.36%	673.4	86.8
OEOWC	9.34%	404.4	404.4
NoWC	32.15%	—	—

Blocking probability: All block-based algorithms: LBF, aLBF, and LBLeB achieve nearly identical blocking probability, regardless of the covering strategy employed. This convergence is expected because all three algorithms share the same longest-block selection criterion; the covering strategy only affects how remaining subranges are filled, not whether a valid assignment can be found. MinCost and OEOWC achieve marginally lower blocking due to their more flexible conversion policies, while NoWC exhibits substantially higher

blocking since it cannot resolve spectrum conflicts through conversion.

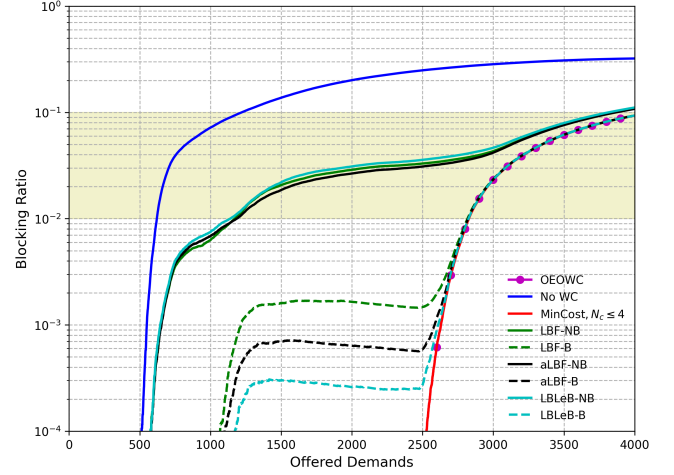


Fig. 2: Blocking probability on the CORONET topology.

Wavelength conversions: The most significant differences emerge in conversion efficiency, where the choice of covering strategy becomes the dominant factor. aLBF approaches the OEOWC reference baseline most closely, requiring the fewest conversions among the block-based algorithms. This demonstrates that the optimal greedy expansion effectively minimizes conversion events compared to the suboptimal first-fit expansion of standard LBF. For the no-breaking variants, the same relative ordering is preserved, although the differences are less pronounced because the constraint already limits the available covering options.

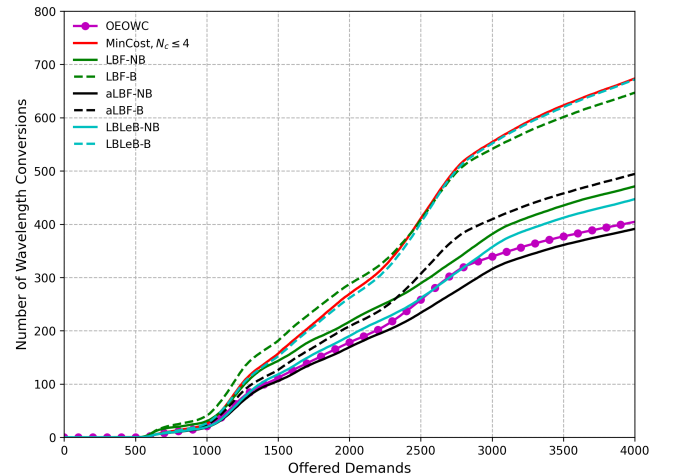


Fig. 3: Wavelength conversions on the CORONET topology.

Converter deployment: Converter deployment patterns directly reflect conversion behavior. aLBF achieves the most efficient converter utilization among the block-based strategies, closely approaching the OEOWC reference where each conversion deploys exactly one converter. This efficiency means that aLBF manages a high number of conversions with proportionally fewer deployed converters. LBF requires substantially more converters, while LBLeB shows a similar

pattern. MinCost installs the fewest converters overall, as it explicitly minimizes converter placement cost by reusing existing converters, but at the expense of a higher conversion count than aLBF.

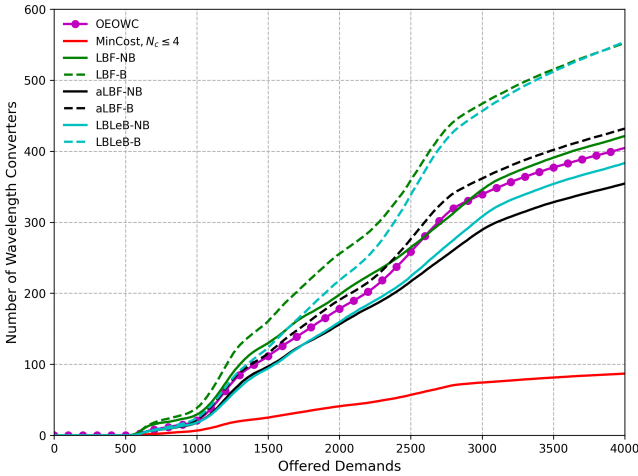


Fig. 4: Placed converters on the CORONET topology.

The results establish a clear hierarchy among the three block-based strategies when measured against the OEOWC reference. aLBF stands out as the algorithm that most closely approaches OEOWC in both conversion count and converter efficiency, achieving a near one-to-one conversion-to-converter ratio. LBF incurs a significant conversion overhead, while LBLB performs comparably, confirming that active candidate comparison is essential for meaningful conversion reduction. The practical significance is that network operators can closely approach OEOWC-level performance by adopting aLBF, while requiring fewer converter resources than standard LBF. This improvement comes at no additional computational complexity, as all three algorithms maintain the same asymptotic complexity, reinforcing the finding that the covering strategy, not the block selection criterion, determines conversion efficiency in block-based wavelength assignment.

Furthermore, these results have significant practical implications for hardware deployment. In real-world [3], DWDM networks, placing all-optical wideband converters is constrained by high hardware costs and physical space limitations at the optical nodes. The ability of aLBF to drastically reduce the number of required converters without sacrificing blocking performance makes it highly attractive for practical implementations, directly translating to reduced capital expenditures and simplified network management.

VI. CONCLUSION

This paper presented two improved block-based wavelength assignment strategies for DWDM optical networks equipped with all-optical wideband wavelength converters. The All Longer Blocks First (aLBF) algorithm replaces the first-fit covering mechanism of standard LBF with an optimal greedy expansion that actively minimizes start-node distance (leftward) and maximizes end-node distance (rightward) during subrange covering. The Longest Block Last Edge Blocks (LBLB) algorithm uses a passive last-valid-block strategy.

Simulation results on the CORONET continental topology under incremental traffic with fiber augmentation demonstrate that both aLBF and LBLB approach the OEOWC reference in blocking performance while achieving efficient converter management. aLBF in particular achieves only 494.3 cumulative conversions with 431.7 deployed converters, significantly outperforming LBF. LBLB shows more modest improvements, confirming that active candidate comparison is essential for significant conversion reduction.

The key insight is that the covering strategy, not the block selection criterion, is the primary determinant of conversion efficiency in block-based wavelength assignment. This finding opens several directions for future work. First, we will conduct further validation under alternative network topologies and dynamic traffic models (with connection releases) to reinforce the generalizability of these conclusions. Additionally, reporting detailed statistical confidence measures will strengthen the interpretation of performance differences. Other future directions include adaptive covering strategies that dynamically adjust the comparison criterion based on network load, and extensions to elastic optical networks with flexible grid allocation.

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