

Efficient Placement of Splitters in Optical WDM Network

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Research Article

Keywords: Multicast routing, Wavelength division multiplexing, Splitter placement problem, Optical networks, Tree structure

Posted Date: April 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-328737/v1>

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Efficient Placement of Splitters in Optical WDM Network

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Received: date / Accepted: date

Abstract In this paper, we investigate the splitter placement problem in an optical WDM network. The goal is to select a given number of MC nodes in the network such that the overall link cost of a multicast session is minimized. We present an exact formulation in integer linear programming (ILP) to find a set of trees that connects a source to a set of destination nodes. Then, four algorithms based on network topology metrics are proposed to select a given number of MC nodes in the network such that the overall link cost of a multicast session is minimized. The efficiency of the proposed algorithms is verified by simulation results.

Keywords Multicast routing · Wavelength division multiplexing · Splitter placement problem · Optical networks · Tree structure

1 Introduction

A WDM optical network is a set of nodes linked together by optical links. In such a network, an optical link supports multiple optical channels and each channel uses a specific wavelength [1-3]. The optical nodes may connect any channel on one of its input ports to any channel on one of its output ports [4-5]. In an optical network, an optical path is defined by a succession of links and nodes between a source node and a destination node in which a single wavelength is used from end to end [6, 7]. For a given multicast session (i.e., a source node and a set of destination nodes), a request for that session in an

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optical network requires the establishment of an optical structure that interconnects the source and the destinations. In an all-optical network, an optical structure must be established to serve a multicast request [8-10].

A wavelength converter is a special device that shifts a wavelength arriving at an input switch port to another wavelength [11]. Thanks to this wavelength converter, different wavelengths can be used along a single optical path, and thus the wavelength continuity constraint is relaxed. If no wavelength converters are used in the WDM network, the same wavelength must be used on all the optical links of each optical structure [12, 13]. In this paper, the communications are considered to be established in core (or metropolitan) networks using active optical switches (passive optical network which is used to provide fiber to the end consumer is not considered) and both the transmission and the switching are performed in the optical domain.

Multicasting is an important research topic. It allows a good use of the bandwidth in a WDM optical network. This mode of transmission enables sending data from a source node to several destination nodes [14, 15, 16]. To support the WDM multicasting function, a switch (optical cross-connects, OXCs) node should be equipped with an optical splitter (thus a switch equipped with an optical splitter becomes a multicast capable node, MC)[17, 18]. An optical splitter divides the incoming signal into multiple outputs, which makes it possible to establish an optical path toward multiple destinations [19-21, 22]. When an optical signal passes through an optical splitter, the input optical signal power of the optical splitter decreases as a function of its number of output links [23]. To maintain the power level of the signal, a costly active amplification device is required. Therefore, a multicast capable node is more expensive than an incapable multicast (MI) node (nodes that do not have the capability of splitting) [24].

Adding more optical splitters to the network increases the cost of the hardware because they are expensive and because it requires a large number of expensive amplification devices to maintain the signal power level. Therefore, an optical network where all nodes are equipped with optical splitters (full splitting network) is expensive. In practice, only a subset of nodes is equipped with optical splitters also known as sparse splitting network [25, 26]. These optical nodes are called "multicast capable" (MC) nodes; the rest of the optical nodes are called "incapable multicast" (MI) nodes (nodes that do not have the capability of splitting) [25]. In [25, 26], authors showed that sparse splitting can achieve most benefit of full optical splitting. In an optical network, establishing communication between the optical nodes requires first determining the path to be taken, then assigning the wavelength on each optical link. This problem is called Routing and Wavelength Assignment (RWA) [27-28]. In this paper, we studied the routing and wavelength allocation problem with sparse splitting using a tree structure. An ILP formulation is presented where the objective is to minimize the overall link cost constituting the optical structure required by a multicast session. The problem of selecting a limited number of MC nodes such that certain performance measures (number of wavelengths, the blocking probability, the delay ... etc.) are optimized is called the splitter placement

problem [26, 29-33]. In an optical network, some MC nodes reduce the overall link cost of a multicast session better than other MC nodes. Efficient selection of a small number of MC nodes can provide a better reduction in the overall link cost than a large number of poorly selected MC nodes. The question is how the MC nodes can be selected into the network in order to minimize the overall link cost of a multicast session.

In this paper, we study the splitter placement problem in an optical WDM network. The goal is to select a given number of MC nodes in the network such that the overall link cost of a multicast session is minimized. Our main contribution consists in introducing several criteria based on the topology of the network to select a given number of MC nodes such as the criterion based on the cost of the optical links of these neighboring nodes, the criterion of the uniform distribution of MC nodes and the criterion of MI node degree. In addition, we propose four algorithms to select a given number of MC nodes in the network such that the overall link cost of a multicast session is minimized. The rest of the paper is organized as follows. In Section 2, we present the related works. In Section 3, we propose an ILP formulation of the problem. Section 4 describes the criteria for selection of MC nodes and algorithms. Section 5 presents the simulation results and Section 6 presents the conclusion.

2 Related Works

As the problem of where to optimally place the multicast capable nodes in the network is an NP-complete problem [29, 30], heuristic algorithms that give approximate solutions are the most used in practice. The main heuristics [26, 29-33] for efficient placement of splitters in optical network are described in the following. In [26], authors proposed two heuristics, called k-maximum Degree (kmaxD) and k-maximum Wavelength Reduction (WR). K-maximum Degree selects a node with a larger degree of connectivity; a node with a more neighbor nodes is more likely to be equipped with splitter. However, this criterion is not enough to determine the order of precedence in selecting nodes to be splitter since many nodes in a network may have the same degree of connectivity. K-maximum Wavelength Reduction consists to place a splitter at a node that yields more reduction on the wavelength resource usage.

In [31], several criteria of selecting multicast capable nodes (Smallest total cost (node with a smaller total link cost to reach all other nodes), multicast capable connectivity (number of MC nodes directly connected to it), etc.) are given. Authors propose placement algorithms that are based on network topology and the relative importance of a node in routing multicast sessions which is measured by the proposed metrics. At each time, the placement algorithms begin to select MC nodes according to their highest degree of node and if several nodes have the same node degree; the algorithms applies one of the criterion. In [32], the goal is to select a given number of MC nodes in the network for delivering packets among the nodes on a small multicast tree. Heuristic algorithms are proposed for minimizing the number of wavelength with minimum

transmission delay as required by a given multicast session. In [33], authors consider the case where only some nodes of the network are equipped with wavelength converter and optical splitter, also known as sparse wavelength conversion and sparse splitting [33]. The optical splitter and wavelength converter placement problem is considered jointly and the combined placement is realized, trying to find the optimal configuration of optical splitter and wavelength converter. It has been shown that sparse splitting can achieve most benefit of full optical splitting [25-26].

Unlike [26, 29-33] which aims to select a given number of MC nodes such that the number of wavelengths or the probability of blocking a multicast session is minimized, the goal of our proposed algorithms is to select a number given MC nodes in the network such that the overall link cost of a multicast session is minimized. In addition, in comparison with the research works [26, 32, 33], we have introduced several criteria such as the criterion of the cost of the optical links of its neighboring nodes directly connected to it, the criterion of the uniform distribution of MC nodes and the MI node degree criterion which consists of distributing MC nodes over a larger number of MI nodes in the network.

3 Problem definition and formulation

An optical WDM network is modeled as a connected undirected graph $G(V, E)$, where V is the set of nodes (optical cross connects), and E is the set of bidirectional optical links representing the physical connectivity between the nodes. Each fiber supports a set of wavelengths W . In the first part, we studied the splitter placement problem in an optical WDM network. The goal is to select a given number of MC nodes in the network such that the overall link cost of a multicast session is minimized. Four algorithms based on network topology metrics are proposed to select the preference order of optical nodes that become MC nodes in the network such that the overall link cost of a multicast session is minimized. In the second part, we studied the routing and wavelength allocation problem with sparse splitting using a tree structure. Given a multicast session denoted by $ms = (s, D)$ and the MC nodes, the problem consists to find a set of optical trees that connect a source s to a set of destination nodes D . An ILP formulation is presented where the objective is to minimize the overall link cost constituting the optical structure required by a multicast session. The question is how the MC nodes can be selected into the network in order to minimize the overall link cost of a multicast session. To check the efficiency of the proposed algorithms, we vary the number of MC nodes and calculate the overall link cost of a multicast session. The mathematical model to generate the set of optical trees in the WDM optical network is set out below.

3.1 Notations and network parameters

Parameters are:

G : Graph of the optical network, formed on V and E

V : Set of optical nodes

E : Set of optical links

W : Set of wavelengths in any optical link

$MI_{(G)}$: Set of nodes of G that do not own a splitter, included in V

$MC_{(G)}$: Set of nodes of G that own a splitter, included in V (and $MC_{(G)} = V - MI_{(G)}$)

$ms(s, D)$: Multicast request from the source node s to the set of destination D

$C_{m,n}$: The cost of the optical link $E_{m,n}$

$L_{m,n}(\lambda)$: Equals 1 if the multicast request $ms(s, D)$ uses the wavelength λ in the optical link $E_{m,n}$ and equals 0 otherwise

Notations are:

$F_{m,n}(\lambda)$: This variable indicates the number of destinations served by the optical link $E_{m,n}$ for wavelength λ

$S(\lambda)$: Equal to 1 if wavelength λ is used in the optical tree and equals 0 otherwise

$In_{(m)}$: Set of incoming links to the node m

$Out_{(m)}$: Set of outgoing links of node m

3.2 ILP Formulation

The solution of this problem is to find an optimal set of optical trees covering a multicast session and minimizing its cost. The objective function is defined as follows: $\text{Min} (\sum_{\lambda \in W} \sum_{n \in In(m)} L_{n,m}(\lambda) \times C_{n,m})$
The objective function is to minimize the overall link cost of the set of optical structures.

3.2.1 Tree structure

- Connectivity constraints of the tree structure

Source constraint:

$$\sum_{\lambda \in W} \sum_{n \in Out(s)} F_{s,n}(\lambda) = |D| \quad (1)$$

Constraint (1) indicates that the value of the set of optical flows emitted by the source must be equal to the number of destinations $|D|$ in the multicast session.

Destination constraints:

$$\sum_{\lambda \in W} \sum_{n \in In(d)} F_{n,d}(\lambda) = \sum_{\lambda \in W} \sum_{n \in Out(d)} F_{d,n}(\lambda) + 1, \forall d \in D \quad (2)$$

$$\sum_{n \in \text{Out}(d)} F_{d,n}(\lambda) \leq \sum_{n \in \text{In}(d)} F_{n,d}(\lambda), \forall d \in D, \forall \lambda \in W \quad (3)$$

$$\sum_{n \in \text{Out}(d)} F_{d,n}(\lambda) \geq \sum_{n \in \text{In}(d)} F_{n,d}(\lambda) - 1, \forall d \in D, \forall \lambda \in W \quad (4)$$

Equations (2)to(4)ensure that only the terminal nodes consume an optical flow. When the destination is not a terminal node, the flow enters and exits to power one or more other destinations.

Non-member node constraint:

$$\sum_{n \in \text{In}(m)} F_{n,m}(\lambda) \doteq \sum_{n \in \text{Out}(m)} F_{m,n}(\lambda), \forall m \in V \setminus (S \cup D), \forall \lambda \in W \quad (5)$$

Equation (5) ensures the conservation of flows at the intermediate nodes, excluding the destination node and the source node.

$$F_{m,n}(\lambda) \geq L_{m,n}(\lambda), \forall m, n \in V, \forall \lambda \in W \quad (6)$$

$$F_{m,n}(\lambda) \leq |D| \cdot L_{m,n}(\lambda), \forall m, n \in V, \forall \lambda \in W \quad (7)$$

Equations (6) and (7) ensure that if a link $E_{m,n}$ is used in the optical structure, the number of flows $F_{m,n}(\lambda)$ that go through this link is not equal to zero and should not exceed the total number flows emitted by the source node.

– Constraints of the tree structure

Source constraints:

$$\sum_{\lambda \in W} \sum_{n \in \text{In}(s)} L_{n,s}(\lambda) = 0 \quad (8)$$

$$1 \leq \sum_{\lambda \in W} \sum_{n \in \text{Out}(s)} L_{s,n}(\lambda) \leq |D| \quad (9)$$

Constraint (8) ensures that the number of incoming links to the source node is equal to 0. Constraint (9) ensures that the number of outgoing links from the source node must be greater than or equal to 1 and less than or equal to the number of destinations $|D|$.

Destination constraint:

$$1 \leq \sum_{\lambda \in W} \sum_{n \in \text{In}(d)} L_{n,d}(\lambda) \leq |D|, \forall d \in D \quad (10)$$

Constraint (10) ensures that each destination node must be reached at least once and at most $|D|$ optical structures are used.

$$S(\lambda) \geq L_{m,n}(\lambda), \forall m, n \in V, \forall \lambda \in W \quad (11)$$

Equation (11) shows that the wavelength λ is used by the optical structure if the multicast request $ms(s, D)$ uses the wavelength λ in the optical link $E_{m,n}$.

Non-member node constraint:

– $MC_{(G)}$ node

$$\sum_{n \in In(m)} L_{n,m}(\lambda) \leq 1, \forall \lambda \in W, \quad (12)$$

$\forall m \in MC_{(G)}, \text{ and } m \text{ is not s}$

$$\sum_{n \in Out(m)} L_{m,n}(\lambda) \leq Out(m) \times \sum_{n \in In(m)} L_{n,m}(\lambda), \quad (13)$$

$\forall \lambda \in W, \forall m \in MC_{(G)}, \text{ and } m \text{ is not s}$

Constraint (12) ensures that the number of incoming links to an optical splitter must be less than or equal to 1. Equation (13) indicates that if an optical splitter without wavelength conversion participates in the optical structure, the number of outgoing links of this optical splitter must be between 1 and $Out(m)$.

– $MI_{(G)}$ node

$$\sum_{n \in In(m)} L_{n,m}(\lambda) \leq 1, \forall \lambda \in W, \forall m \in MI_{(G)}, \text{ and } m \text{ is not s} \quad (14)$$

For all $MI_{(G)}$ nodes other than the source node, constraint (14) ensures that the number of incoming links is equal to or less than 1.

$$\sum_{n \in Out(m)} L_{m,n}(\lambda) \leq 1, \forall m \in V, \text{ and } m \text{ is not an element of D} \quad (15)$$

Apart from the destination nodes, constraint (15) ensures for all the other $MI_{(G)}$ nodes that the number of outgoing links is equal to or less than 1. Equations (14) and (15) ensure that the tree structure does not allow a cycle.

4 MC nodes placement algorithms

In this section, we describe the node selection criteria and the MC nodes placement algorithms.

4.1 Node selection criteria

$ND(m)$: Node degree

The idea of this criterion is that a node with a larger degree of connectivity (more neighbor nodes) is more likely to be equipped with splitter. However, this criterion is not enough to determine the order of precedence in selecting nodes to be MC nodes, since many nodes in a network may have the same degree of connectivity. $ND(m)$ is given by $ND(m) = |In(m)|$.

MCND(m): MC node degree (number of MC nodes directly connected)

The idea of this criterion is to distribute the MC nodes as evenly as possible so that a situation where one node may have many MC nodes neighbors and another may have few or no MC nodes neighbors at all, can be prevented. *MCND(m)* is given by $MCND(m) = \sum_{n \in In(m)} MC(n)$. The node with the least MC node degree is more likely to be equipped with splitter.

COLN(m): Cost of the optical links neighborhood

When you minimize the cost of a set of optical links in an optical network, the optical links with the highest cost are avoided and the optical links with the lowest cost are the most sought after. For this, we introduce a new criterion favoring the optical links with the lowest cost. This criterion essentially selects a node to be MC node on the basis of the cost of the optical links of its neighboring nodes directly connected to it. The node with the highest *COLN(m)* is more likely to be equipped with splitter. *COLN(m)* is given by $COLN(m) = \sum_{n \in In(m)} \frac{1}{C_{n,m}}$

MIND(m): MI node degree

The idea of this criterion is to distribute the MC nodes about a larger number of MI nodes in the network. The node with more neighboring MI nodes (MI node degree) is more likely to be equipped with a splitter. *MIND(m)* is given by $MIND(m) = \sum_{n \in In(m)} MI(n)$.

4.2 MC nodes placement algorithms

4.2.1 MI node degree (*MIND*)

The algorithm selects the MC nodes one by one sequentially. At each step of the selection, the node with more neighboring MI nodes is more likely to be equipped with a splitter. If p splitters must be placed, then the p nodes with the highest *MIND(m)* value are selected to be equipped with splitter. We consider that G is the graph in which we want to place p splitters. The algorithm is described below.

Algorithm *MIND(G, p)*

- 1: Int p ;
- 2: Graph G ;
- 3: Set of nodes $MC = \{\}$;
- 4: **for** ($i = 1; i \leq p; i++$) **do**
- 5: insert(in MC the node m of G with the highest *MIND(m)* value);
- 6: $G = G - \{m\}$;
- 7: **end for**
- 8: Return (MC);

4.2.2 Cost of the optical links neighborhood(*COLN*)

The algorithm selects the MC nodes in decreasing order according to their *COLN(m)* values. The node with the largest *COLN(m)* value is more likely

to be equipped with splitter. We consider that G is the graph in which we want to place p splitters. The algorithm is described below.

Algorithm $COLN(G, p)$

```

1: Int  $p$ ;
2: Graph  $G$ ;
3: Set of nodes  $MC = \{\}$ ;
4: for ( $i = 1; i \leq p; i++$ ) do
5:   insert(in  $MC$  the node  $m$  of  $G$  with the highest  $COLN(m)$  value);
6:    $G = G - \{m\}$ ;
7: end for
8: Return ( $MC$ );

```

4.2.3 MI node degree with cost of the optical links neighborhood (MINDCOLN)

The algorithm selects the MC nodes one by one sequentially. At each step of the selection, the node with the largest $(M_1 \times MIND(m) + COLN(m))$ value are selected to be equipped with splitter and M_1 an upper bound of $COLN(m)$. We consider that G is the graph in which we want to place p splitters. The algorithm is described below:

Algorithm $MINDCOLN(G, p)$

```

1: Int  $p$ ;
2: Graph  $G$ ;
3: Set of nodes  $MC = \{\}$ ;
4: for ( $i = 1; i \leq p; i++$ ) do
5:   insert(in  $MC$  the node  $m$  of  $G$  with the highest  $(M_1 \times MIND(m) + COLN(m))$  value);
6:    $G = G - \{m\}$ ;
7: end for
8: Return ( $MC$ );

```

4.2.4 Node degree with MC node degree (NDMCND)

The criterion $ND(m)$ is not enough to determine the preference order to select the MC nodes, since many nodes in a network may have the same node degree. So, we added the criterion $MCND(m)$ to select the efficient placement for the nodes which have the same node degree. The algorithm selects the MC nodes one by one, sequentially. At each step of the selection, the node with the largest $(M_2 \times ND(m) + MCND(m))$ value are selected to be equipped with splitter and M_2 an upper bound of $MCND(m)$. We consider that G is the graph in which we want to place p splitters. The algorithm is described below.

Algorithm $NDMCND(G, p)$

```

1: Int  $p$ ;
2: Graph  $G$ ;
3: Set of nodes  $MC = \{\}$ ;
4: for ( $i = 1; i \leq p; i++$ ) do

```

```

5:   insert(in  $MC$  the node  $m$  of  $G$  with the largest  $(M_2 \times ND(m) + MCND(m))$  value);
6:    $G = G - \{m\}$ ;
7: end for
8: Return ( $MC$ );

```

4.2.5 Node degree(ND)

The algorithm selects the MC nodes in decreasing order according to their $ND(m)$ values. The node with the largest $ND(m)$ value is more likely to be equipped with splitter. We consider that G is the graph in which we want to place p splitters. The algorithm is described below.

Algorithm $ND(G, p)$

```

1: Int  $p$ ;
2: Graph  $G$ ;
3: Set of nodes  $MC = \{\}$ ;
4: for ( $i = 1; i \leq p; i++$ ) do
5:   insert(in  $MC$  the node  $m$  of  $G$  with the largest  $ND(m)$  value);
6:    $G = G - \{m\}$ ;
7: end for
8: Return ( $MC$ );

```

5 Simulation results

In this section, we evaluate the performance of the MC nodes placement algorithms via simulations. The proposed algorithms were also compared with the node degree method. The results are obtained by considering the well-known COST-239 and the USA Longhaul networks. We assume each fiber supports an infinite set of wavelengths, the links are bidirectional (each link is made of two fibers; each fiber is used in one direction), and wavelength converter is not present in the network. For the implementation of the ILP model, we use the C++ language with Cplex package. The number of destinations and the source are drawn randomly (uniform distribution) and we randomly generate 200 multicast sessions. Then, we run the model to find the optimal solution generated for each session. Then, we compute, over the 200 sessions, the average values of the overall link cost constituting the optical structure. The following metrics are taken into account:

- The cost of the set of optical links constituting the optical structure (overall link cost): $CL = \sum_{\lambda \in W} \sum_{n \in In(m)} L_{n,m}(\lambda) \times C_{n,m}$.
- The number of wavelengths used by the tree structure: $NWU = \sum_{\lambda \in W} S(\lambda)$.

Based on the experimental results obtained from the well-known COST-239 and USA Longhaul networks, we make the following observations. Figure 3 presents the overall link cost as a function of the number of MC nodes in

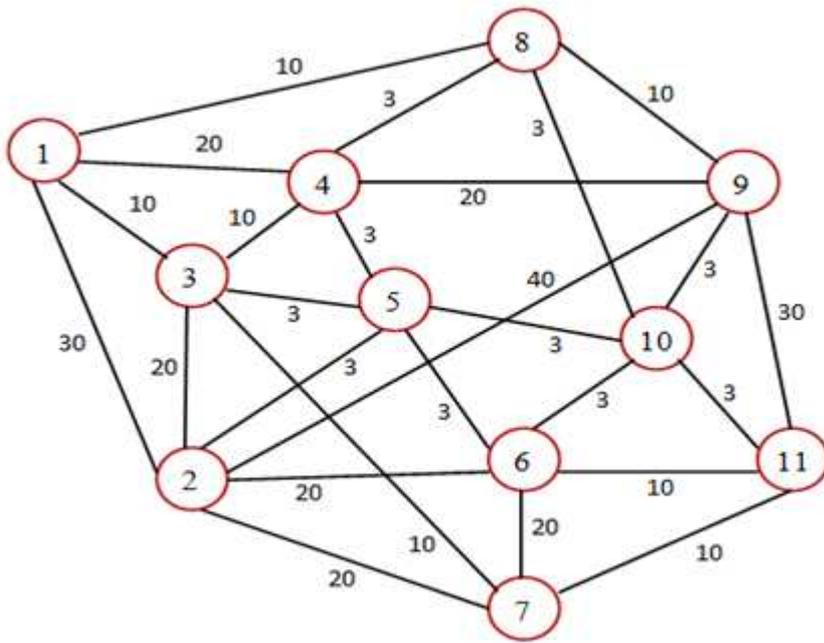


Fig. 1 COST-239 topology

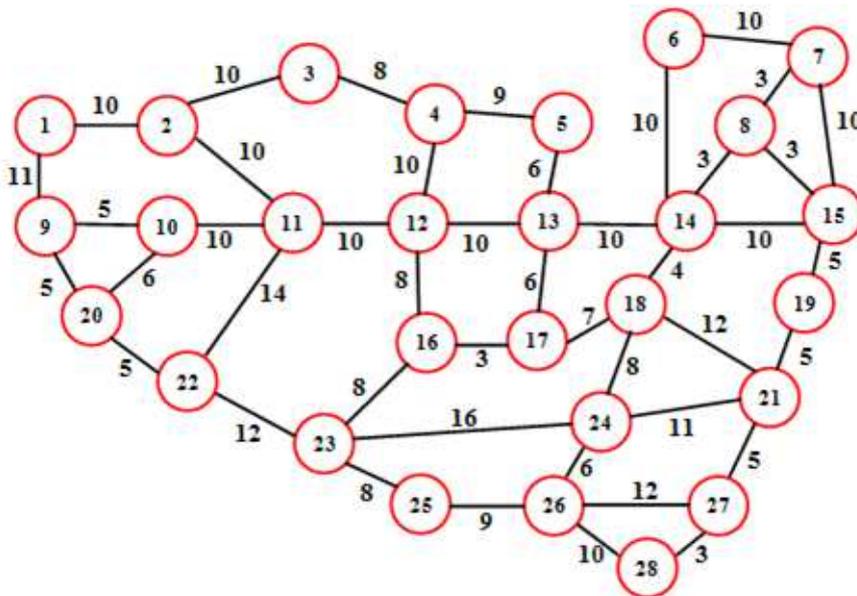
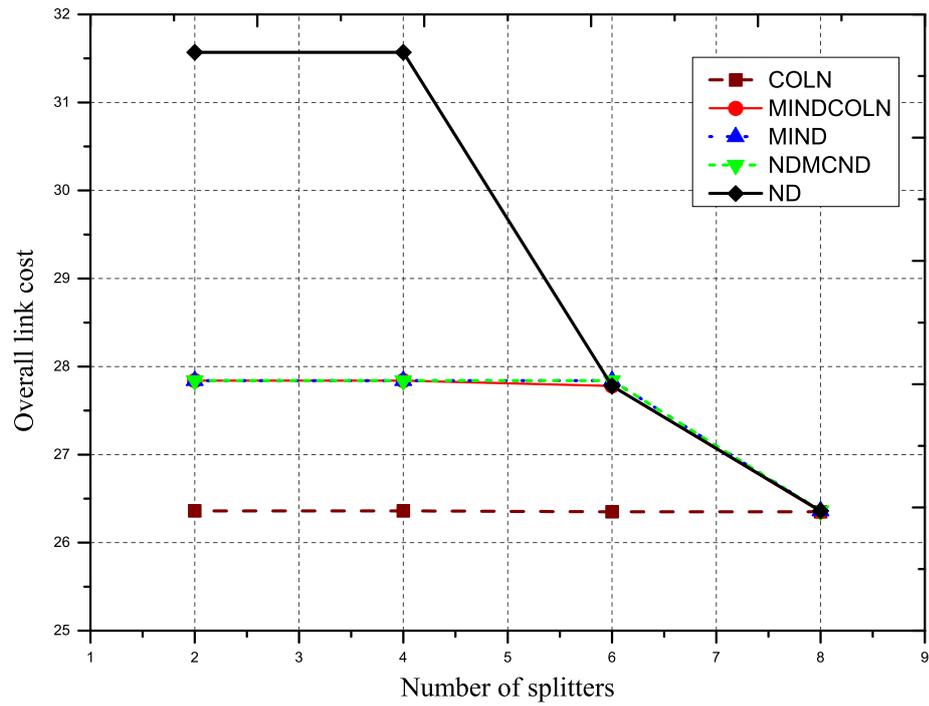
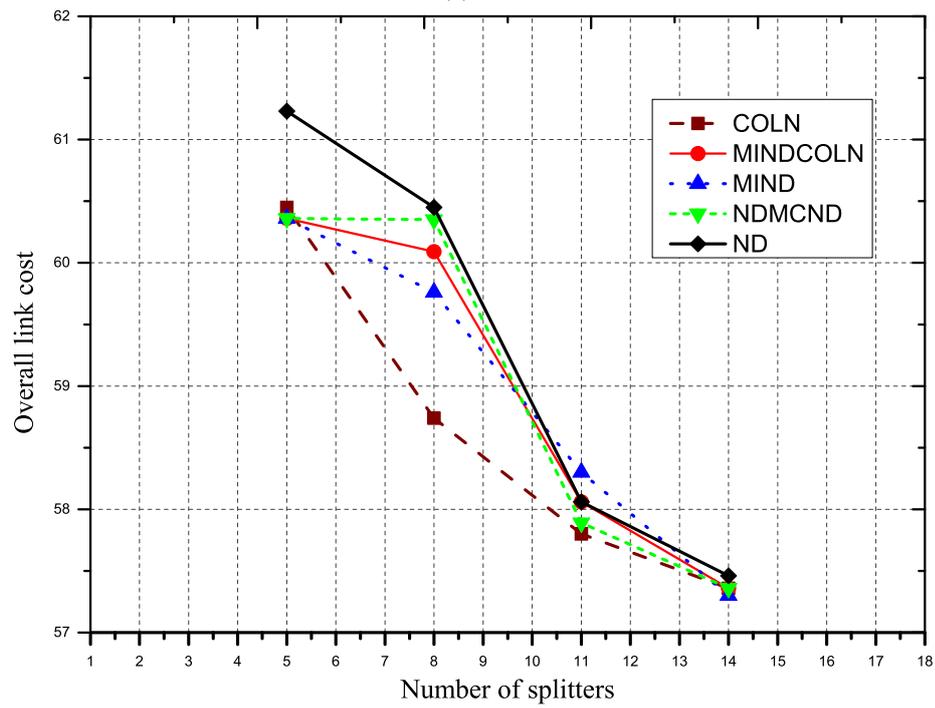


Fig. 2 USA Longhaul topology



(a)



(b)

Fig. 3 Overall link cost as a function of the number of splitters: (a) COST-239; (b) USA Longhaul

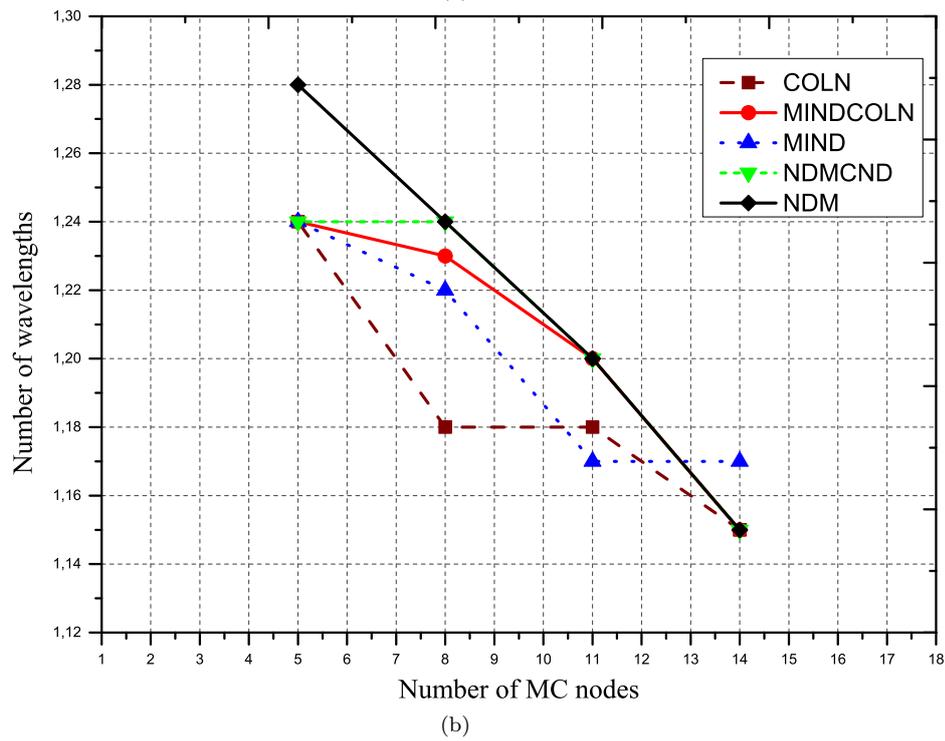
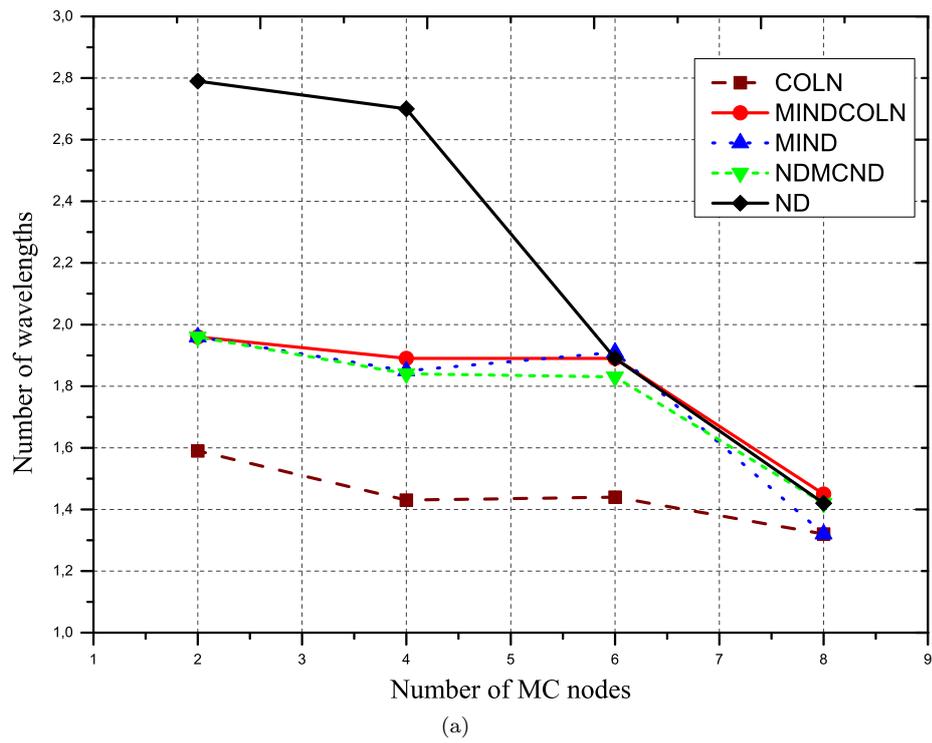


Fig. 4 Number of wavelengths as a function of the number of splitters: (a) COST-239; (b) USA Longhaul

COST-239 and USA Longhaul networks. The horizontal axis describes the number of MC nodes (nodes that have the capability of splitting) and the vertical axis describes the overall link cost. The overall link cost is the cost of the set of optical links constituting the optical structure. Figure 4 presents the number of wavelengths as a function of the number of MC nodes in COST-239 and USA Longhaul networks. The horizontal axis describes the number of MC nodes and the vertical axis describes the number of wavelengths.

Figure 3 shows that the absence of MC nodes in the network leads to a high overall link cost, compared to the case where the MC node exists in the network. In addition, Figure 3 shows that a small percentage of MC nodes in the network provide a significant decrease in overall link cost and the number of wavelengths. In general, the result of simulations shows that increasing the number of MC nodes decreases the overall link cost and the number of wavelengths. However, when the number of MC nodes reaches a certain percentage, increasing MC nodes can't decrease more the overall link cost and the number of wavelengths.

The simulation result also shows that the MC nodes placement algorithms proposed are significantly better than the degree of node method in terms of overall link cost and number of wavelengths. The improvement in the performance of the proposed algorithms over the node degree method is mainly due to the fact that the proposed algorithms determine the appropriate nodes to be MC nodes using the information that becomes available after routing the multicast sessions such as the cost of the optical links of the neighboring nodes and the uniform distribution of the MC nodes in the network. In the case of the COST-239 topology, MINDCOLN algorithm gives slightly decrease compared to the MCND and MIND algorithms. However, in the case of the USA Longhaul topology, the MIND algorithm that gives slightly decrease compared to the MCND and MINDCOLN algorithms. In the case of the MIND and MCND algorithms, the reduction of the overall cost of the link and the number of wavelengths compared to the node degree method is due to the uniform distribution of the MC nodes in the network.

Figure 3 and figure 4 show that the COST-239 topology needs less percentage of MC nodes to achieve most benefit of full optical splitting compared to the USA Longhaul topology. This is due to the nature of the topology such as the degree of the nodes and the number of optical links. In COST-239 topology, the nodes are very connected to each other and therefore it is easier to reach all of the destinations compared to the USA Longhaul topology.

Figure 3 and Figure 4 indicate that the COLN algorithm is the best of the MC nodes placement algorithms in terms of overall link cost and number of wavelengths. In the case of the COST-239 topology, the COLN algorithm provides a significant decrease compared to other MC nodes placement algorithms in terms of overall link cost and number of wavelengths for all number of MC nodes. In fact, if 20% of nodes in the Cost-239 topology are MC nodes, then it performs as if 99.81% are MC nodes. In the case of the USA Longhaul topology, COLN algorithm provides also a significantly decreasing compared to other MC nodes placement algorithms in terms of overall link cost and

number of wavelengths. In fact, if 40 % of the nodes in the USA Longhaul topology are MC nodes, then it performs as if 80 % are MC nodes. The reason is because the COLN algorithm selects the MC node on the basis of the cost of the optical links of its neighboring nodes which are directly connected to it. It is better to perform splitting when the node has optical links at lower cost. This allows more choices to reach all destinations at a lower cost. When you minimize the overall link cost of a multicast session, the optical links with the highest cost are avoided and the optical links with the lowest cost are the most sought after.

Figure 3 and figure 4 show that the COST-239 topology needs less percentage of MC nodes to achieve most benefit of full optical splitting compared to the USA Longhaul topology. In the case of the COST-239 topology, the COLN algorithm shows that if 20% of nodes is MC nodes, then it performs as if 99.81% is MC nodes. However, in the case of the USA Longhaul topology, the COLN algorithm shows that if 40 % of the nodes are MC nodes, then it performs as if 80 % are MC nodes. This is due to the nature of the topology (the number of nodes, the number of optical links, the degree of the nodes, the costs of the optical links, etc.). In COST-239 topology, the nodes are very connected to each other and therefore easy to reach all of the destinations compared to the USA Longhaul topology.

Table 1 and table 2 present the standard deviation of the overall link cost and the number of wavelengths in the COST-239 and USA Longhaul topology. Thus, we verify that the average values computed over 200 sessions are significant because the relative standard deviation of each value is lower than 10% for the two topologies (COST-239 and USA Long Haul).

MC	Standard deviation of the overall link cost					Standard deviation of the number of wavelengths				
	COLN	MINDCOLN	MIND	NDMCND	ND	COLN	MINDCOLN	MIND	NDMCND	ND
2	2.36	2.61	2.61	2.61	3.04	0.63	0.89	0.89	0.89	0.9
4	2.36	2.61	2.61	2.61	3.04	0.54	0.91	0.81	0.85	0.98
6	2.35	2.59	2.61	2.61	2.36	0.58	0.9	0.9	0.86	0.53
8	2.35	2.35	2.36	2.36	2.36	0.55	0.55	0.5	0.53	0.56

Table 1 Standard deviation of the overall link cost and the number of wavelengths in the COST-239 topology.

MC	Standard deviation of the overall link cost					Standard deviation of the number of wavelengths				
	COLN	MINDCOLN	MIND	NDMCND	ND	COLN	MINDCOLN	MIND	NDMCND	ND
5	5.91	3.45	3.47	3.46	3.85	0.52	0.51	0.51	0.51	0.6
8	5.7	3.16	3.59	3.45	3.66	0.46	0.55	0.5	0.56	0.53
11	5.67	3.42	2.4	3.25	2.56	0.47	0.49	0.48	0.47	0.41
14	5.5	2.49	2.69	2.49	2.52	0.4	0.37	0.4	0.37	0.42

Table 2 Standard deviation of the overall link cost and the number of wavelengths in the USA Longhaul topology.

6 Conclusion

In this paper, four algorithms based on network topology metrics are proposed to select a given number of MC nodes in the network such that the overall link cost and the number of wavelengths of a multicast session is minimized.

The result of the simulation shows that the MC nodes placement algorithms proposed are significantly better compared to the node degree method in terms of the overall link cost and the number of wavelengths. The result of the simulation shows also that the COLN algorithm is better than the other MC nodes placement algorithms. In fact, if 20% of nodes in the Cost-239 topology are MC nodes, then it performs as if 99.81% are MC nodes. In the case of USA Longhaul topology, if 40 % of the nodes in the USA Longhaul topology are MC nodes, then it performs as if 80 % are MC nodes.

The best factor to take into account when selecting a limited number of MC nodes such that the overall link cost of a multicast session is minimized is the cost of the optical links of neighboring nodes.

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Figures

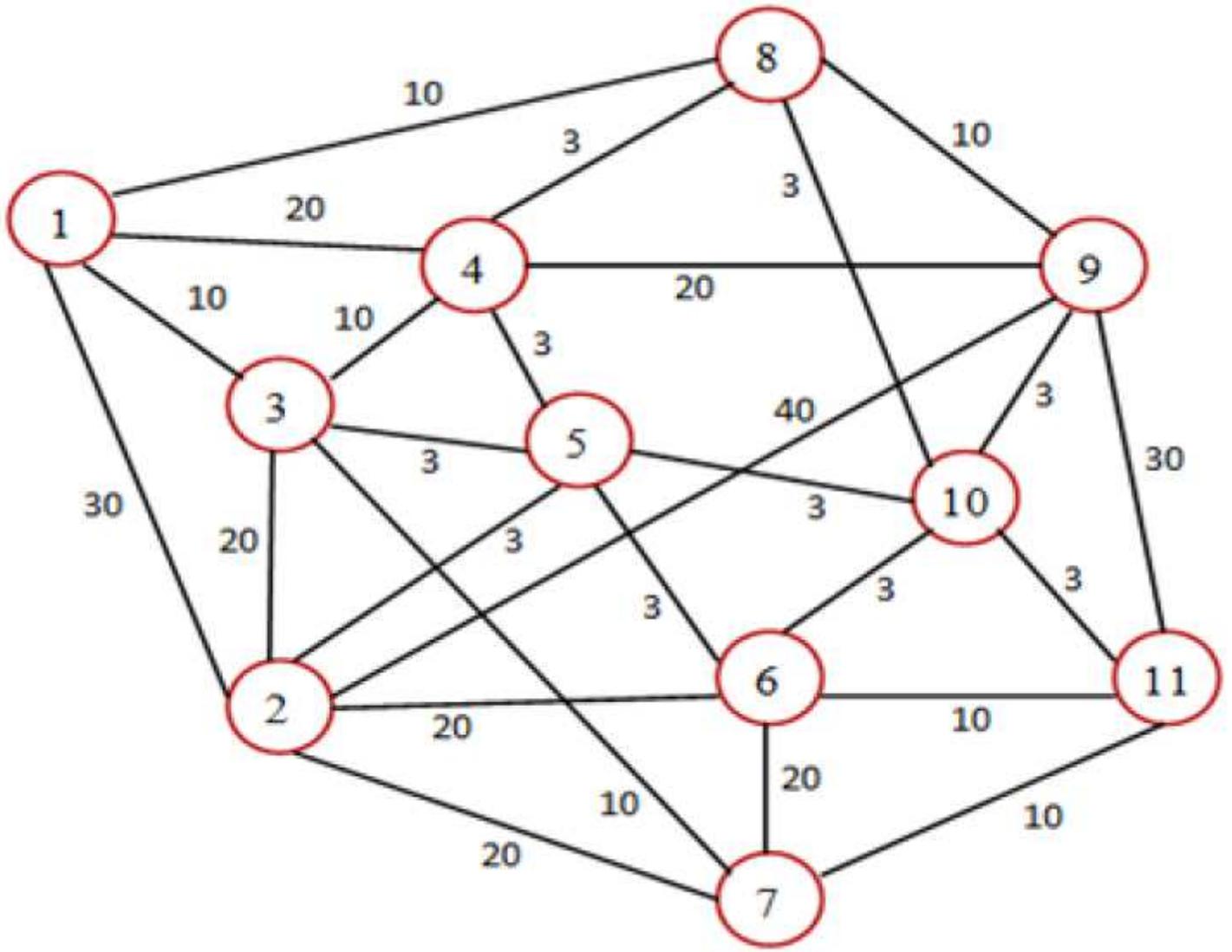


Figure 1

COST-239 topology

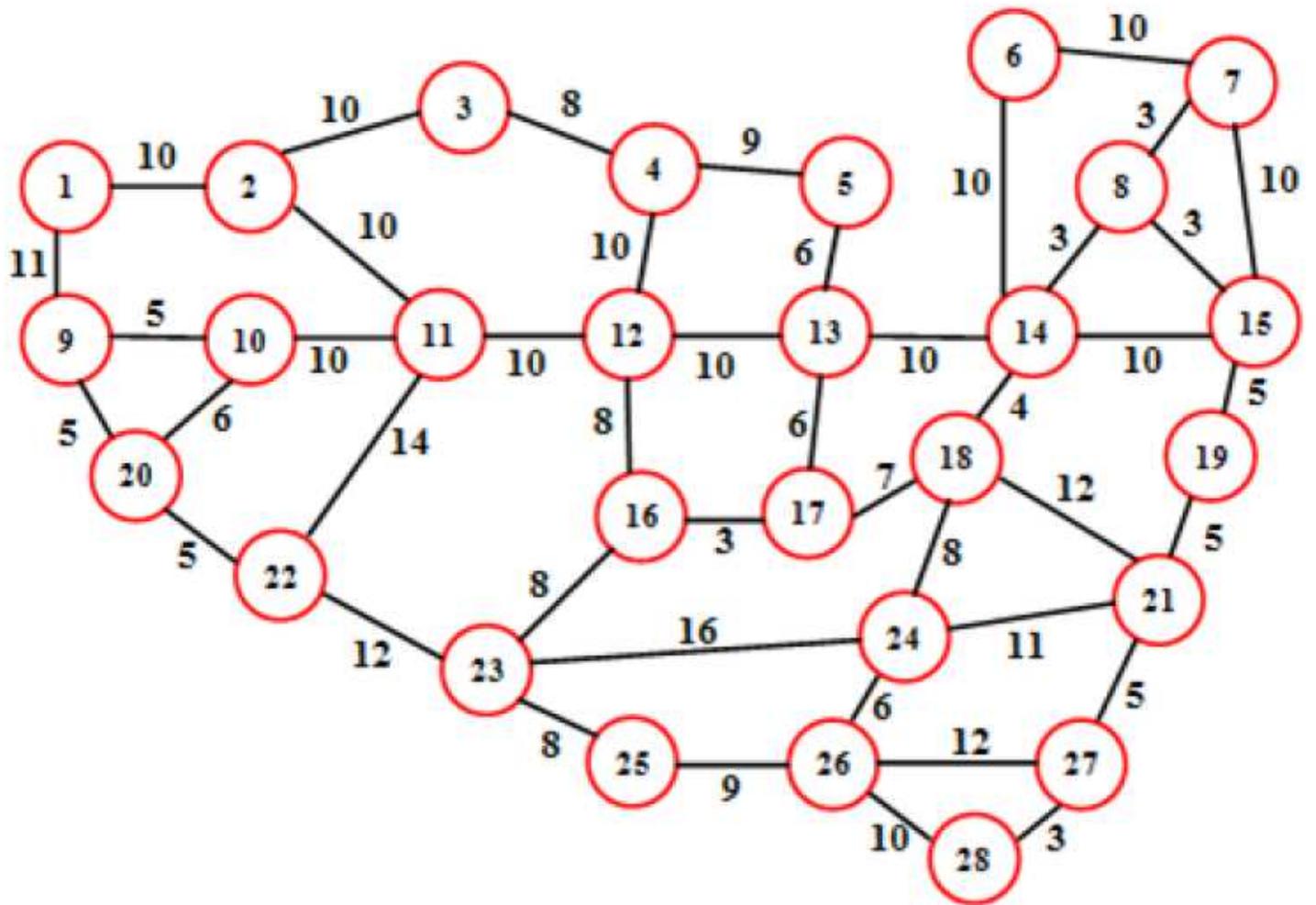


Figure 2

USA Longhaul topology

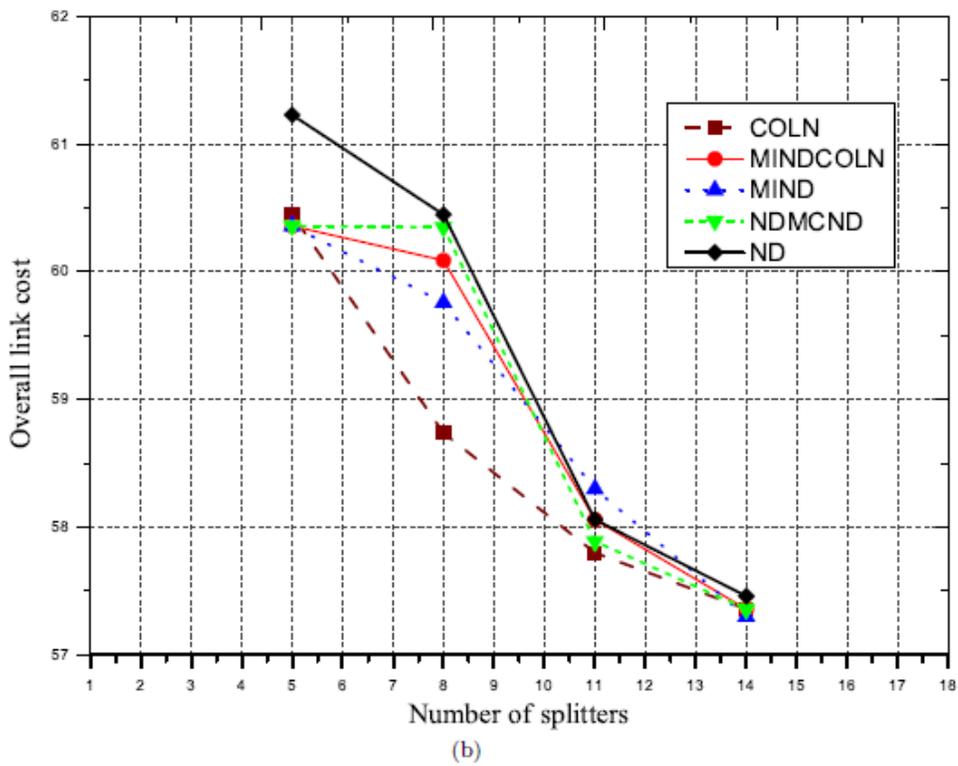
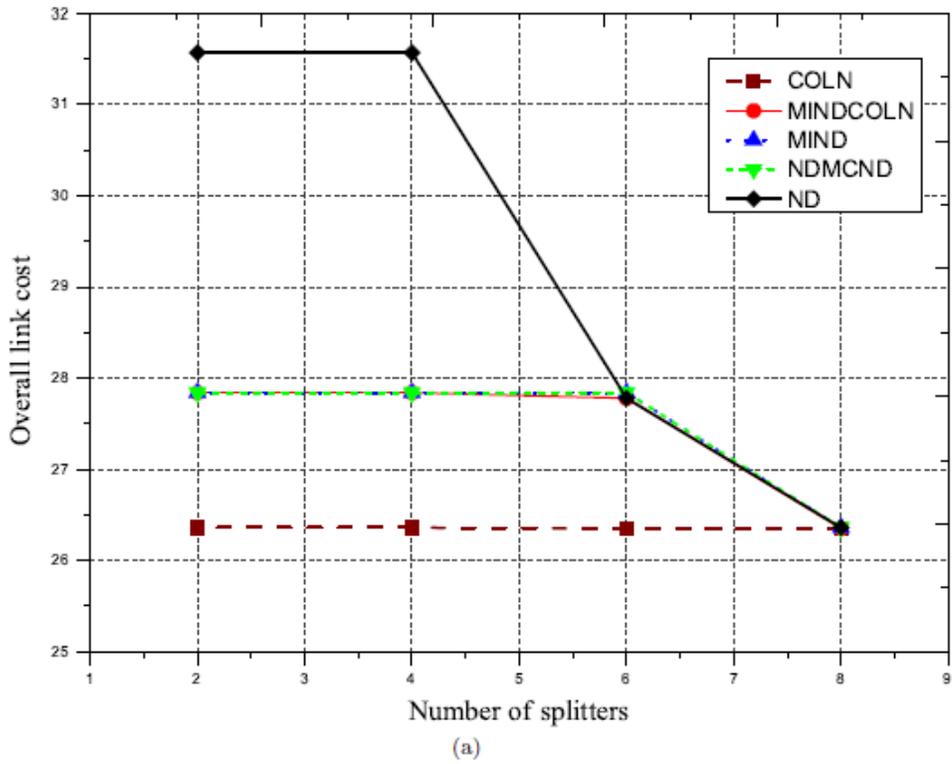


Figure 3

Overall link cost as a function of the number of splitters: (a) COST-239; (b) USA Longhaul

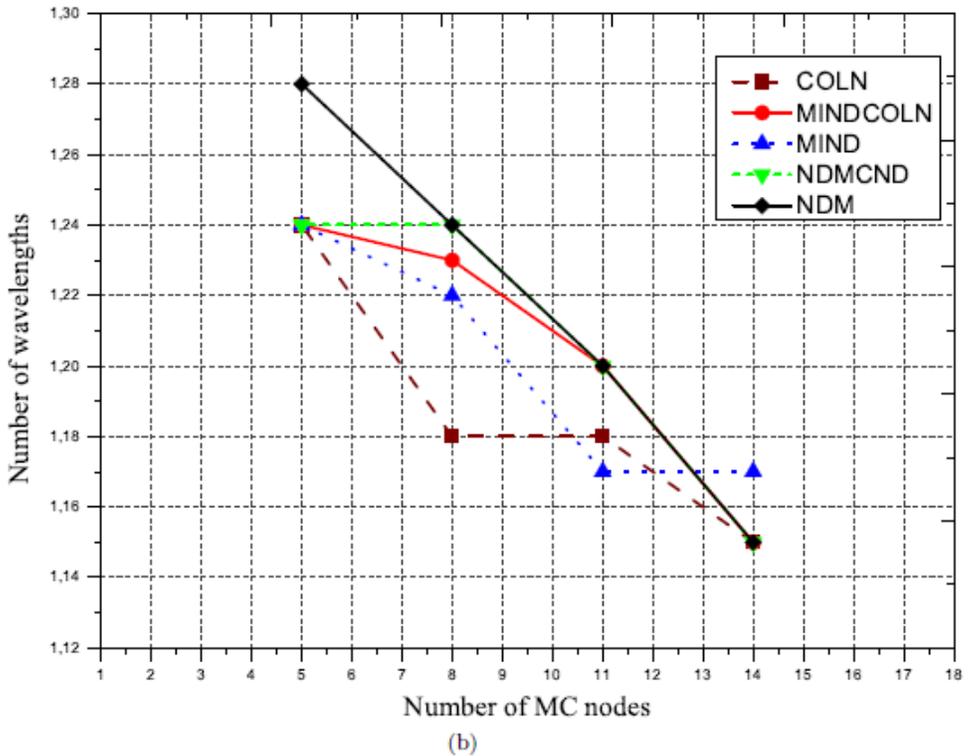
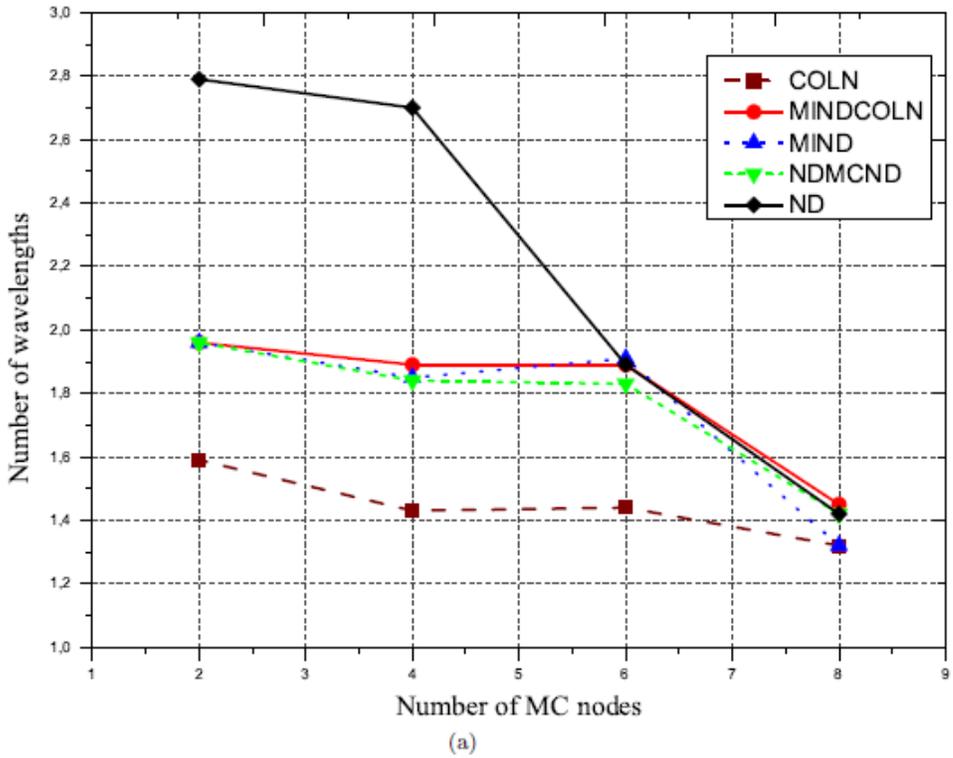


Figure 4

Number of wavelengths as a function of the number of splitters: (a) COST-239; (b) USA Longhaul