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Resource allocation strategies for survivability in WDM optical networks

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Abstract

WDM optical networks are high speed networks and provide enormous capacity. Survivability is very important issue in these networks. Survivability requires resources for handling the failures. So, efficient resource allocation strategy is required for survivability. In this paper, we have presented two resource allocation strategies for survivability. These strategies reserve the resources for the primary lightpaths and backup lightpaths. Then extensive simulations are done on different networks to evaluate the performance in terms of blocking probability. The results show that the second strategy performs better than first strategy.

Keywords: Blocking probability; Survivability; Request acceptance rate; Failure recovery rate

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1. Introduction

Optical networks provide enormous capacity and a common infrastructure over which a variety of services can be delivered. Wavelength division multiplexing (WDM) is the most important technique that allows for expanding the inherent great capacity of optical fibers [1]. It modulates multiple information signals (optical signals) at different wavelengths; the resulting signals are combined and transmitted simultaneously over the same optical fiber. It establishes communication between pairs of network nodes by establishing paths and assigning wavelength to each path. No two paths going through the same fiber link use the same wavelength at the same time to observe wavelength continuity constraint [2].

Survivability is the ability of the network to continue providing service in the presence of failure. It is the process of reconfiguration and reestablishment of connections upon failure [3]. Providing survivability is an important requirement for high speed networks because in case of a failure, a tremendous amount of information can be lost, affecting a huge number of requests. The resource allocation strategy deals with the allocation of resources for the connections. It is also known as provisioning. The main aim of it should be to utilize the resources efficiently. It greatly affects the number of connections accepted. If the strategy is efficient, then more free resources will be available to accommodate more connection requests to increase request acceptance rate. The increased request acceptance rate will result in reduced blocking probability.

Survivability is greatly affected by the resource allocation strategy. It is because survivability requires resources to handle the failures and resource allocation strategy provides the resources.

Lightpath is a connection in all optical networks, which is totally optical except at the end nodes. There are two types of lightpaths: primary lightpath and backup lightpath. Primary lightpaths are those lightpaths upon which data transmission takes place under normal conditions. Backup lightpaths are those lightpaths which carries the data when primary lightpath cannot be used due to failure occurrence. The survivability techniques can be categorized in various ways. They can be categorized as link based and path based. In link based approach, a new path is selected between end nodes of failed link only. In path based approach, a new path is searched between the source and the destination. The path based survivability can be further categorized as failure dependent and failure independent. In failure dependent method, associated with each failure, a backup lightpath is there. The backup lightpath need not to be

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link and node disjoint with the primary lightpath. In failure independent approach, there is only one backup lightpath. In it, both lightpaths need to be link and node disjoint. The control mechanism can be either centralized or distributed. In centralized control, there is a central controller to keep track of the state of the network. It is also responsible for selecting the path for data transmission. Distributed control strategy requires exchange of control messages among nodes.

Many terms are associated with restoration such as request acceptance rate, blocking probability, failure recovery rate, resource requirement. Request acceptance rate gives the ratio of the connection requests accepted out of all the connection requests. Blocking probability is the ratio of number of connections rejected and total number of connection requests. Failure recovery rate represents the ratio of traffic affected that has been reestablished by the amount of the total traffic affected. Resource requirement gives the resources required to accommodate all the connection requests.

In this paper, two resource allocation strategies for survivability have been presented which reserve the resources for the primary and backup lightpaths. Then simulations are done on different networks to evaluate the performance in terms of blocking probability and results are compared. This paper is organized as follows. Section 2 explains the system model. In Section 3, we have presented two resource allocation strategies for survivability in WDM optical networks. Section 4 focuses on results and discussion and evaluates the performance of the strategies in terms of blocking probability. Conclusions are drawn in Section 5.

2. System model

2.1. Problem formulation

2.1.1. Notations

A	Set of nodes in the network
B	Set of links in the network
C	Set of connections
D	Set of wavelengths
N	Total number of wavelengths numbered from $W1$ to WN
M	Total number of connection requests numbered from 1 to M
n	Total number of nodes in the network numbered from 0 to $n-1$
lw_{ij}	The weight associated with link ij
s	The source for a connection
d	The destination for a connection
p_{sd}	Total number of links along the primary lightpath for s–d connection
b_{sd}	Total number of links along the backup lightpath for s–d connection
$sd[j]$	jth connection
Pr	The route of primary lightpath for the connection request numbered r
Br	The route of backup lightpath for the connection request numbered r
Rp_{tu}	The primary route for the connection when $s=t$ and $d=u$
Rb_{ij}	The backup route for the connection when $s=i$ and $d=j$
Wp_{ij}	The wavelength assigned to the primary lightpath for connection when $s=i$ and $d=j$
Wb_{tu}	The wavelength assigned to the backup lightpath for connection when $s=t$ and $d=u$
sh(h)	The shortest route for hth connection request which is to be used for primary lightpath establishment
ash(h)	The route for alternate shortest path that is to be used for backup lightpath of hth connection request
rejconn	Total number of connections rejected
acconn	Total number of connections accepted
wp_{ij}^{sd}	$=0$, if primary lightpath for s–d connection does not use link ij $=1$, otherwise
wb_{ij}^{sd}	$=0$, if backup lightpath for s–d connection does not use link ij $=1$, otherwise
$m_{ij,k}^{sd}$	$=0$, if s–d connection does not use wavelength k on link ij $=1$, otherwise
qp_{sd}^{k}	$=1$, if primary lightpath for s–d connection is established on wavelength k $=0$, otherwise
qb_{sd}^{k}	$=1$, if backup lightpath for s–d pair is established on wavelength k $=0$, otherwise.

2.1.2. Mathematical formulations

Total number of connection requests with permutation routing (M) (if s–d pairs when $(s=d)$ included), $\forall(s,d\in A)$

$=(n(n-1)/2)+n$, if $(Rp_{ij}=Rp_{ji}$ and $Wp_{ij}=Wp_{ji})$ and $(Rb_{ij}=Rb_{ji}$ and $Wb_{ij}=Wb_{ji}),\forall ij\in A$

$=n\times n$, otherwise.

Total number of connection requests with permutation routing (M) (if s–d pairs when $(s=d)$ excluded), $\forall(s,d\in A)$

$=n(n-1)/2$, if $(Rp_{ij}=Rp_{ji}$ and $Wp_{ij}=Wp_{ji})$ and $(Rb_{ij}=Rb_{ji}$ and $Wb_{ij}=Wb_{ji}),\forall ij\in A$

$=n\times n$, otherwise.

Blocking probability $=\text{rejconn}/M=(M-\text{acconn})/M$.

Objective function $=$ minimize (blocking probability) for fixed number of wavelengths or minimize (N) for zero blocking probability.

2.2. Constraints

1. $\sum_{sd} wp_{ij}^{sd}+\sum_{sd} wb_{ij}^{sd}\leqslant N,\quad \forall s,d\in C,\ \forall ij\in B.$
   Wavelengths assigned on a link for all the connections should not exceed N, i.e., number of wavelengths on a link.
2. $wp_{ij}^{sd}+wb_{ij}^{sd}\leqslant 1,\quad \forall s,d\in C,\ \forall ij\in B.$
   A link will either be not used by the s–d pair under consideration for connection establishment or it will be used by only one lightpath for that connection, i.e., for primary

lightpath or backup lightpath but not by both of the lightpaths for the *s–d* pair.

3. $$\begin{aligned} \sum_{ij} m^{sd}_{ij,k} &= p_{sd} + b_{sd}, \quad \text{if } qp^k_{sd} = 1 \text{ and } qb^k_{sd} = 1 \\ &= p_{sd}, \quad \text{otherwise, if } qp^k_{sd} = 1 \\ &= b_{sd}, \quad \text{otherwise, if } qb^k_{sd} = 1 \\ &= 0, \quad \text{otherwise, } \forall sd \in C,\ ij \in B, \text{ and } \forall k \in D. \end{aligned}$$

   For any wavelength k and for any connection corresponding to the connection for *s–d* pair, left side of the equation represents the number of channels with wavelength k used by the connection. If both the lightpaths use wavelength k then the total number of channels used will be equal to the addition of channels used by primary and backup lightpaths. If only primary lightpath is on wavelength k and backup lightpath is on any other wavelength then the total number of channels used will be equal to channels used by primary and similar is the case when wavelength k is used only for backup lightpath and not for primary lightpath. If none of the lightpaths use the wavelength k then the number of channels (on wavelength k) used for the connection under consideration will be zero.

4. $$\begin{aligned} m^{sd}_{ij,k} &= 1, \quad \text{if } wp^{sd}_{ij} = 1 \text{ and } qp^k_{sd} = 1 \\ &\quad\ \ \text{or } wb^{sd}_{ij} = 1 \text{ and } qb^k_{sd} = 1 \\ &= 0, \quad \text{otherwise, } \forall sd \in C,\ ij \in B, \text{ and } \forall k \in D. \end{aligned}$$

   The left side of the equation shows whether the wavelength k on link ij is used by the connection for *s–d* pair or not. It will be 1, only if any of the lightpaths for the *s–d* pair under consideration is using the channel, i.e., the lightpath uses the link ij and also the lightpath is established on wavelength k.

5. $wp^{sd}_{ij} \times wb^{sd}_{ij} = 0, \quad \forall s, d \in C,\ \forall ij \in B.$

   A link can't be used by both primary lightpath and backup lightpath of a connection request because primary lightpath and backup lightpath are link disjoint.

6. $$\sum_{ij} \left(lw_{ij} \times wp^{sd}_{ij}\right) \leqslant \sum_{ij} \left(lw_{ij} \times wb^{sd}_{ij}\right), \quad \forall s, d \in C,\ \forall ij \in B.$$

   The weight of primary lightpath according to the links along the route and the link weights will never be greater than the weight of backup lightpath as shortest path algorithm is applied and the shortest path according to the weight is taken as the route for primary lightpath.

7. $$\begin{aligned} m^{sd}_{ij,k} + m^{sd}_{wv,k} &= wp^{sd}_{ij} + wp^{sd}_{wv}, \quad \text{if } qp^k_{sd} = 1 \\ &= wb^{sd}_{ij} + wb^{sd}_{wv}, \quad \text{if } qb^k_{sd} = 1 \\ &= 0, \quad \text{otherwise, } \forall ij, wv \in B,\ \forall k \in D, \\ &\qquad \text{and } \forall sd \in C. \end{aligned}$$

8. $$\begin{aligned} m^{sd}_{ij,k} \times m^{sd}_{wv,x} &= 1, \quad \text{if } k = x \text{ and } wp^{sd}_{ij} = 1 \\ &\qquad \text{and } wp^{sd}_{wv} = 1 \\ &\qquad \text{or } k = x \text{ and } wb^{sd}_{ij} = 1 \\ &\qquad \text{and } wb^{sd}_{wv} = 1 \\ &= 0, \quad \text{otherwise, } \forall ij, wv \in B,\ \forall k, x \in D, \\ &\qquad \text{and } \forall sd \in C. \end{aligned}$$

   Constraints 7 and 8 are for wavelength continuity constraint.

3. Resource allocation strategies for survivability

Survivability is one very important issue for critical applications. These applications require the reservation of resources for primary and backup lightpaths at the time of connection acceptance, so that 100% failure recovery rate can be achieved and no time is wasted in searching for a new lightpath on the occurrence of failure [4]. Resource allocation strategy employed greatly affects the blocking probability as it has to provide the resources for primary and backup lightpaths. If the resource allocation strategy uses the resources efficiently, then more free resources will be available. It will lead to increase in request acceptance rate and so will result in reduced blocking probability. The resource allocation strategy should aim at minimizing the blocking probability. Two resource allocation strategies for survivability have been presented below. These strategies support path based failure independent proactive survivability and can be used for 100% failure recovery rate. The strategies work with centralized control system.

3.1. Dedicated resources (DR) strategy

The wavelengths are divided into two sets according to the proportionate of resources considered. One set of wavelengths can be used for primary lightpaths and another set can be used for backup lightpaths.

Let $e{:}f$ represents the proportionate of resources allocated for primary and backup lightpaths. It means that the wavelengths that can be used by primary lightpaths are $((e/(e+f)) \times$ total number of wavelengths in the system). The wavelengths for the backup lightpaths are the remaining $((f/(e+f)) \times$ total number of wavelengths in the system) wavelengths.

Whenever wavelength is required for any primary lightpath, it is searched from the wavelength set for primary lightpaths and not from the set for backup lightpaths. Similar is the case with backup lightpaths.

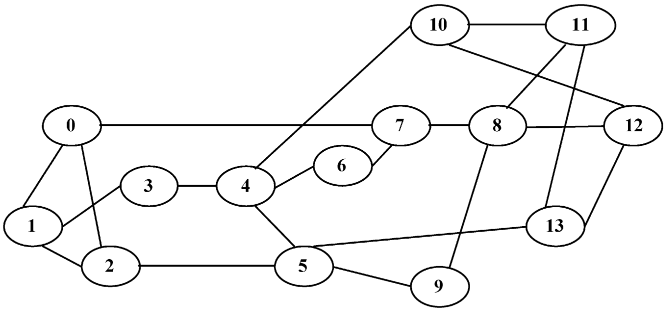

Fig. 1. NSFNET network model.

3.2. Shared resources (SR) strategy

All wavelengths are treated as single set. Both primary and backup lightpaths can use all the wavelengths in the network.

It may be the scenario that any wavelength is being used by some primary and some backup lightpaths simultaneously. In it, first of all the primary lightpath of first *s*–*d* pair is tried. Then the backup lightpath of the same *s*–*d* pair is tried. The same process is repeated for all the connection requests. Whenever any lightpath is tried, the free wavelength is searched from all the wavelengths. This strategy will result in reduced blocking probability as compared to the *DR* strategy for the

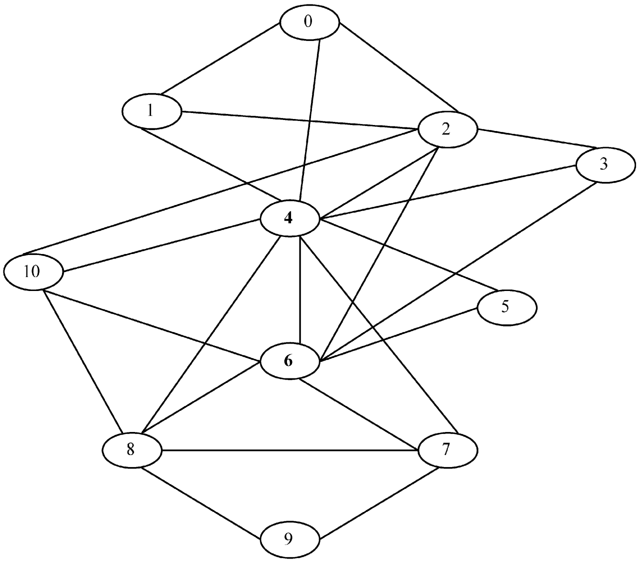

Fig. 2. NJ LATA network model.

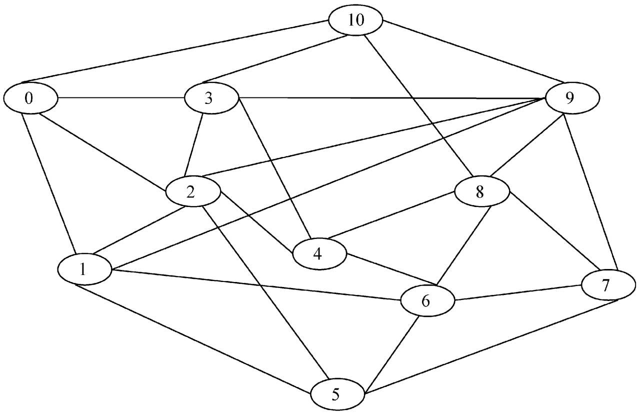

Fig. 3. EON network model.

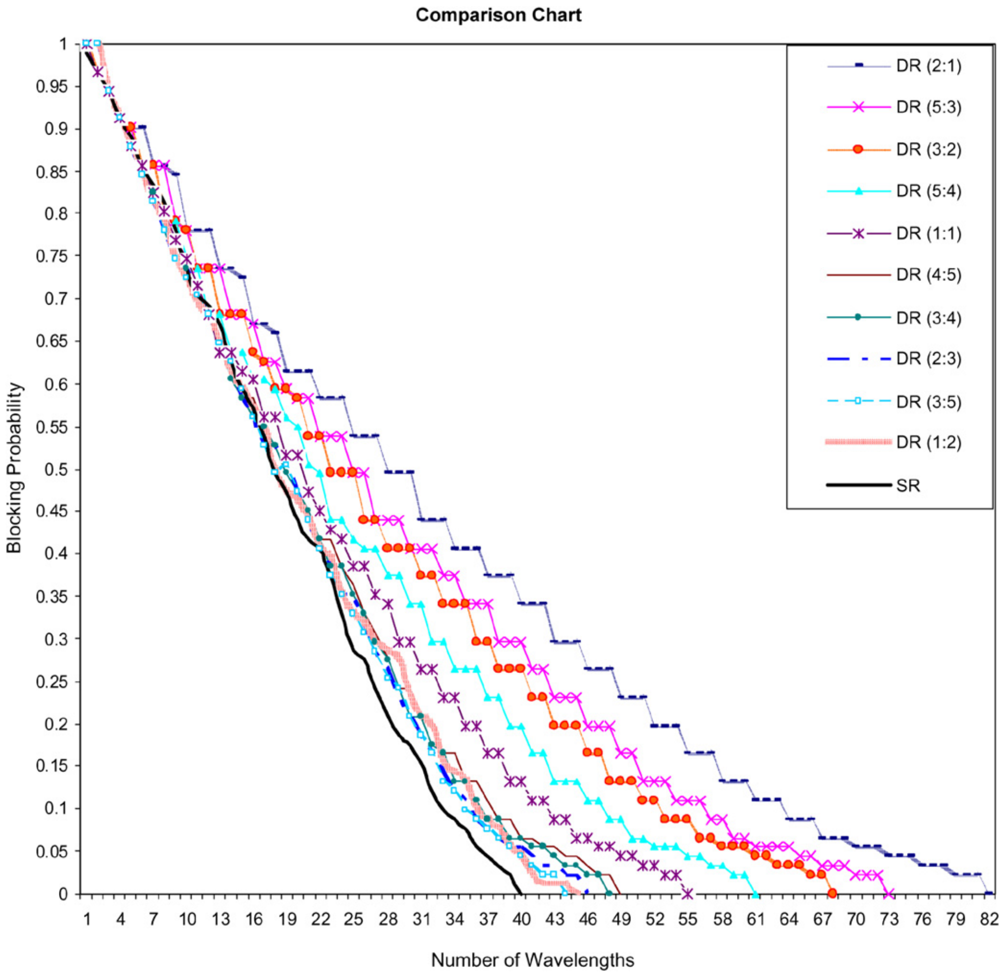

Fig. 4. Comparison chart for NSFNET.

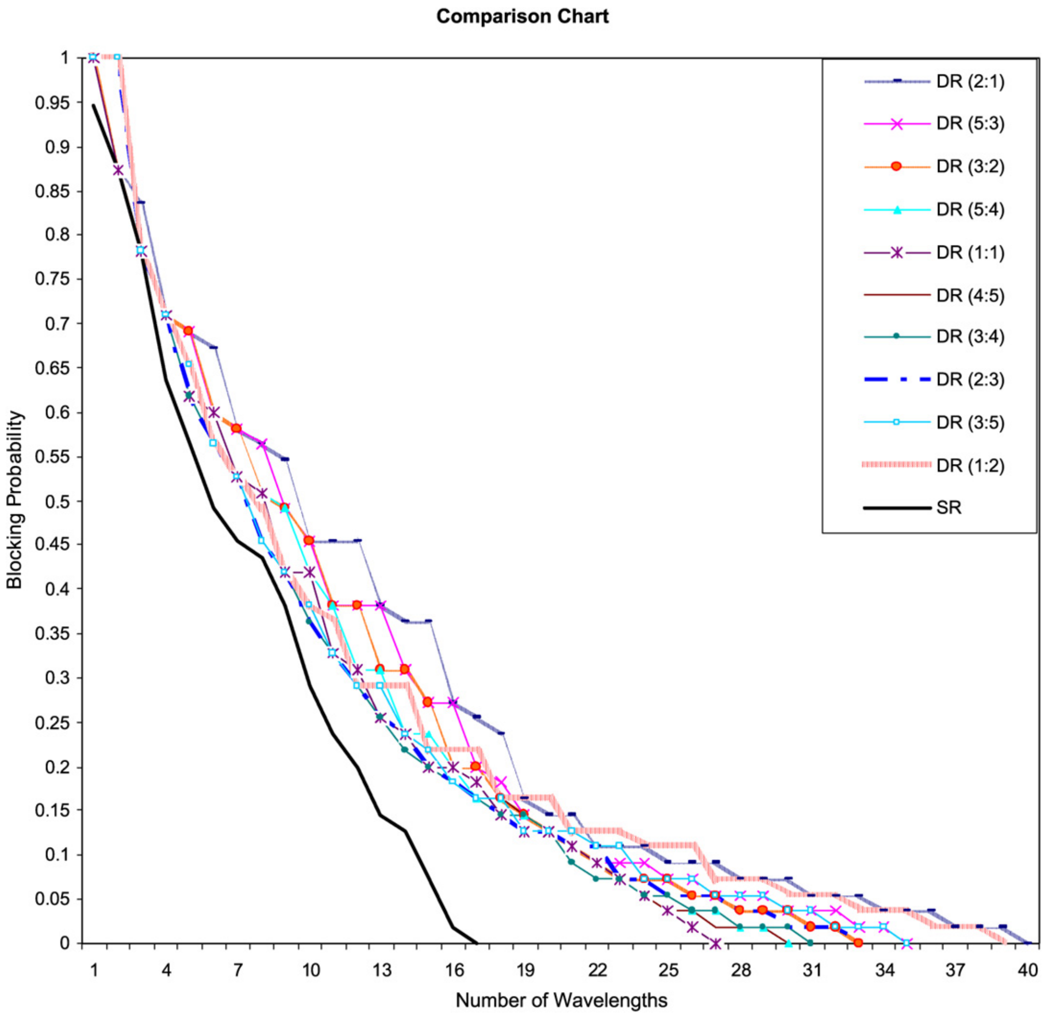

Fig. 5. Comparison chart for NJ LATA.

same network configuration, connection requests and the resources.

In *DR* strategy, it may be case at any time for a connection request that no wavelength is free along the route from the set of wavelengths for backup lightpath, but at least one wavelength is free from the set for primary lightpaths. Obviously the connection will be rejected because the resources for primary lightpaths cannot be used for backup lightpath. Although the resources were available for backup lightpath, but as those resources were for primary lightpaths only, the backup lightpath could not be established. The same case may also arise for any primary lightpath. In critical applications, if the any of the lightpaths is not established, the connection will be dropped. With *SR* strategy, this connection will be accepted as all the free resources are made available for the lightpaths irrespective of the fact whether they are primary or backup. If any of the wavelength is free along the route that can be used for connection establishment.

4. Results and discussion

No strategy could be validated until that is supported by practical results. In order to demonstrate that *SR* strategy performs better than *DR* strategy and to investigate the performance of the strategies, we must resort to simulations. Not able to find a suitable simulator that could support the strategies, we designed and developed a simulator to implement resource allocation strategies for survivability in optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link weight information, number of wavelengths per fiber, connection requests and the wavelength assignment strategy, etc. All these parameters can be initialized before running the simulations or at the execution time to obtain results. Some of the calls may be blocked because of the unavailability of free wavelength on links along the route from source to destination. The ratio of the total number of calls blocked to the total number of connection requests in the network is defined as the blocking probability. The output of the simulator is the blocking probability for the specified parameters along with the detailed information of connections for given resources. Another output of the simulator is minimum number of wavelengths required per fiber to accept all the connection requests. Extensive simulations are then carried out and the results are obtained.

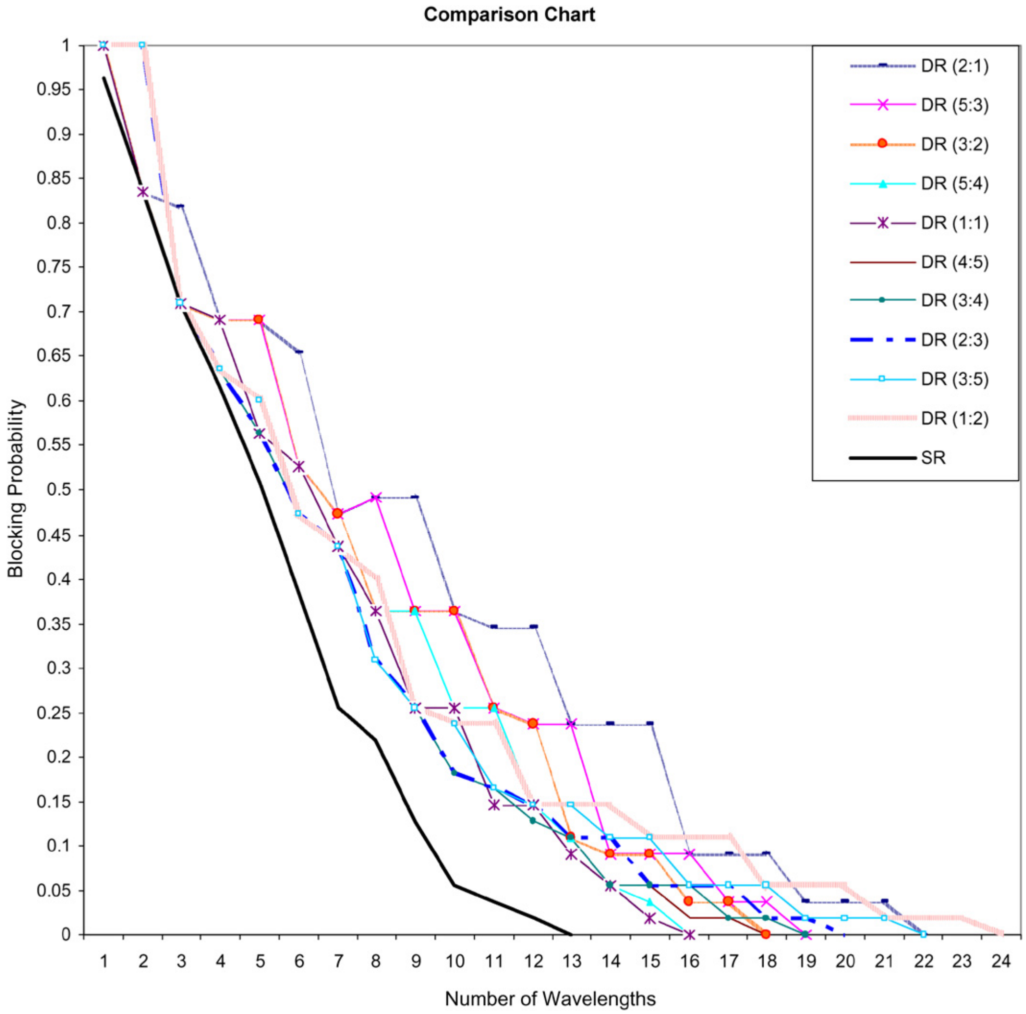

Fig. 6. Comparison chart for EON.

Figures 1, 2, and 3 show the 14 nodes with 21 links NSFNET [5,6], 11 nodes with 23 links NJ LATA [7,8], and 11 nodes with 26 links EON [5] standard networks, respectively, taken as sample networks. The nodes are connected together with undirected links and the information on links can flow in both directions. Let t and u are two different nodes in the network. Due to undirected links, the primary routes for t (source) to u (destination) and u (source) to t (destination) will be same. It will also be the case for their backup lightpaths. Permutation routing has been taken for finding out the sample source destination pairs in which every node in the network acts as the source to every other node in the network simultaneously with unicasting approach. Total number of source destination pairs in permutation routing depends upon the number of nodes. Shortest path algorithm is applied to find the route for primary lightpath because it efficiently utilizes the resources. The weight of each link is taken as unity. Alternate shortest path, which is link and node disjoint with primary lightpath, is used for backup lightpath. The backup lightpath will be able to handle all types of failures. First-fit wavelength assignment strategy has been employed to find the wavelength. If primary lightpath and backup lightpath for a connection are established, only then the connection is accepted. So the connections accepted are those which lead to 100% failure recovery rate in the event of failure and can be used for critical applications.

Figures 4, 5, and 6 show the comparison of the resource allocation strategies: *DR* strategy (with different proportionate of resources) and *SR* strategy when applied on NSFNET, NJ LATA, and EON networks, respectively in terms of blocking probabilities. The wavelengths are shown along the X-axis and the blocking probabilities are shown along the Y-axis in the figures. The proportionate of resources taken are mentioned in the brackets with the *DR* strategy. For example, *DR* (5:3) shows that first $((5/(5+3))^{*}N)$ wavelengths are for primary lightpaths and the remaining $((3/(5+3))^{*}N)$ wavelengths are for the backup lightpaths. With *DR* strategy, ten proportionate of resources have been considered to evaluate the performance. The proportionate that results in minimum resource requirement is also considered. For example, the 1:1 proportionate results in minimum resource requirement with NJ LATA. If the proportionate is changed such that more proportionate of resources is given to primary and lesser to backup lightpaths, then more primary and lesser backup lightpaths may get established. As both of the lightpaths are required for connection acceptance, lesser connections may be accepted. It may increase the blocking probability and the resource requirement to accommodate all the connection requests. For example, for the proportionate (5:4), the wavelengths for primary lightpaths are more and the wavelengths for backup lightpaths are less as compared to the case for (1:1) proportionate with the NJ LATA. Now more number of primary lightpaths and lesser backup lightpaths are established for (5:4) proportionate as compared to (1:1) proportionate, in many cases with the given resources. As both type of lightpaths are required to accommodate a connection request, so lesser number of connections are accepted in many cases. It has lead to increased blocking probability and increase in resource requirement to accommodate all connection requests. The wavelengths required to accommodate all the connection requests with (5:4) proportionate are 30 as compared to 27 wavelengths for (1:1) proportionate. Similar will be the case when more proportionate of resources is given for backup and lesser for primary lightpaths. If more asymmetric proportionate is taken, the performance will further degrade. Simulation results show that for the applications that require 100% failure recovery rate, *SR* strategy performs better than *DR* strategy in terms of blocking probability, because it efficiently utilizes the resources.

5. Conclusion

In this paper, we have discussed the importance of survivability in optical networks. Then the need of efficient resource allocation strategy for survivability is described. Two resource allocation strategies have been presented for survivability for critical applications. Simulations are performed on different networks with permutation routing. Results are obtained for dedicated resources strategy (with different proportionate of resources for primary and backup lightpaths) and for shared resources strategy. Results show that shared resources strategy performs better than dedicated resources strategy in terms of blocking probability, because it utilizes the resources more efficiently.

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