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ScienceDirect
Optik 120 (2009) 497–503
Optik Optics
www.elsevier.de/ijleo

# Survivability strategies with backup multiplexing in WDM optical networks

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Received 22 May 2007; accepted 13 December 2007

## Abstract

In this paper, we have presented four variations of applying the same routing algorithm for primary and backup lightpaths, wavelength assignment strategy for survivability. The simulation results show that although everything is the same, yet how and when they are applied leads to variations in results in terms of number of connections accepted. The backup multiplexing technique has been incorporated to reduce the blocking probability in all the strategies. The results have been calculated both for the systems that require 100% degree of survivability, i.e. critical, and for those that do not. The variation to be used depends upon whether the application is critical or not.


*Keywords:* WDM; Survivability; Permutation routing; Backup multiplexing; Blocking probability

## 1. Introduction

Optical networks are very high-speed networks and carry a huge amount of traffic. The service interruption even for a short duration can result in huge data loss and the survivability strategy should try to provide almost continuous service in the case of failure. These networks are also increasingly becoming capable of delivering bandwidth in a flexible manner where and when needed. The reliability of a network is directly affected by the survivability strategy used. A key technology behind optical networks is wavelength-division multiplexing (WDM). While the bandwidth of an optical fiber reaches nearly 50 Tb/s, electronic data rates are in the order of Gb/s. WDM is the same as the frequency-division multiplexing (FDM) technique used in traditional systems and, in addition, allows for bridging the opto-electronic mismatch. In WDM networks, data can be simultaneously transmitted at multiple wavelengths over the same fiber [1]. Each wavelength can be used for a separate connection. So, many connections can simultaneously use the same fiber, thus exploiting the huge bandwidth that a fiber offers.

In case of a failure, a tremendous amount of information can be lost, affecting a huge number of requests. In this scenario, network survivability becomes an important issue. Provisioning and survivability are related issues in WDM optical networks [2]. Provisioning is important due to the fact that it deals with resource allocation with the aim to minimize the resource requirement. The resources required depend upon the resource allocation strategy, i.e. provisioning. Provisioning also greatly affects the number of connections accepted.

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0030-4026/$ - see front matter 
doi:10.1016/j.ijleo.2007.12.008

In this paper, we have discussed four survivability strategies. These can be used for critical applications that provide 100% degree of survivability and very low restoration time. The strategies can also work for non-critical applications. This paper is organized as follows. Section 2 introduces the survivability in WDM networks. Section 3 explains the four survivability strategies. In Section 4, we explain about the simulator setup to evaluate the performance of *s* restoration strategies. This section will also focus on the performance evaluation of the strategies in terms of blocking probability. Conclusions are drawn in Section 5.

## 2. Restoration in optical networks

Providing resilience against failure, i.e. survivability, is an important requirement for high-speed networks. The amount of disruption caused by a network-related outage becomes more significant because these networks carry more and more data. A single outage can disrupt millions of users and results in millions of dollars of lost revenue to users and operators of the networks [3,4]. Survivability is the ability of the network to continue providing service in the presence of failure. It is greatly affected by the provisioning. Lightpath is a connection in all optical networks, which is totally optical except at the end nodes. There are two types of lightpaths: primary lightpaths and backup lightpaths. Primary lightpaths are those lightpaths upon which data transmission takes place under normal conditions. Backup lightpaths are those lightpaths that carry the data when the primary lightpath cannot be used due to failure occurrence. There can be three provisioning approaches for resource allocation for survivable networks [5]:

(i) *Dedicated backup (DB)*: In this, there is a DB lightpath for each source destination pair. The resources, i.e. channels, are not shared. A channel is a wavelength on a link. A channel is reserved at any time for at the most one lightpath.
(ii) *Primary backup (PB) multiplexing-based allocation*: A primary lightpath and one or more backup lightpaths can share a channel. It does not warrant 100% survivability degree.
(iii) *Backup multiplexing (BM)-based allocation*: In this, two or more backup lightpaths can share a channel if the corresponding primary lightpaths do not fail simultaneously, i.e. primary lightpaths need to be link and node disjoint. Two or more paths are said to be link disjoint if there is no common link between any two paths. Two or more lightpaths are said to be node disjoint if the there is no common intermediate node between any two lightpaths.

With the BM-based allocation technique, resources among backup lightpath can be shared and it greatly reduces the resource requirement. Also, as there is resource sharing among backup lightpaths only, it can provide 100% degree of survivability. For the critical applications, we require 100% degree of survivability. A PB multiplexing-based scheme does not warrant 100% survivability degree, so DB and BM-based allocation are the only solutions. Mostly a backup lightpath requires more channels as compared with a primary lightpath. So sharing the channels among multiple backup lightpaths results in very good results in terms of resource utilization.

Many terms are associated with restoration such as blocking probability, degree of survivability, resource utilization and restoration time. Blocking probability is the ratio of the number of connections rejected and the total number of connection requests. Degree of survivability is the ratio of traffic affected that has been restored by the amount of the total traffic affected. Resource utilization gives the ratio of utilized resources and total resources. Restoration time is the time taken by the system for restoration after failure.

## 3. Proposed fault tolerance strategies

This section covers four different variations of applying the survivability giving four strategies. Centralized control has been assumed, i.e. there is one central controller to manage all the activities such as routing, wavelength assignment, etc. These can work with all the routing algorithms that can be used for finding the routes of primary and backup lightpaths. These can be used when no wavelength converters are considered to observe wavelength continuity constraint and also when wavelength conversion is used to establish a lightpath. These can work for both failure-dependent and failure-independent survivability approaches as well as for link-based and path-based survivability approaches. A static traffic model is assumed. A single failure model is taken. These strategies can work for the systems that require 100% degree of survivability for all the connections accepted as well as for those systems that do not require 100% degree of survivability and backup lightpaths are established if possible. In the first type of systems, a connection is accepted only if both its lightpaths are established, but in the second type of systems a connection is accepted if its primary lightpath is established although an attempt is made to establish the backup lightpath. The strategies can be used with all wavelength assignment strategies.

In all of these strategies, the primary lightpath corresponding to each connection request is established before its backup lightpath. The same routing algorithm is used for finding out the route for the primary lightpath for all the connection requests. The same is the case for backup lightpaths. The same wavelength assignment strategy is used to allocate the wavelengths for lightpaths. The same sequence of connection requests is taken. The backup lightpath corresponding to a connection request is tried only if its primary lightpath has been established. The same network configuration is taken. BM is used to efficiently utilize the resources and to reduce the blocking probability. The differences in the results of the strategies in terms of number of connections accepted or blocking probability are due to the difference when and how all the activities are performed.

### 3.1. Strategy 1

In this, first of all the primary lightpath corresponding to all the connection requests is tried on all the wavelengths before the backup lightpath.

It tries to establish the primary lightpath for the first connection request on the first wavelength. If the primary lightpath not established, it tries the same lightpath on the second wavelength and so on till the primary lightpath is established or the last wavelength is tried. Then an attempt is made to establish the primary lightpath for the second connection request in the same way as for the first connection request and so on for all the connection requests. The above-mentioned procedure is then followed for the backup lightpaths.

**Algorithm**

For $h = 1$ to $M$
For $q = 1$ to $N$
Try to establish *sh*(*h*) on *Wq* if not already established.
End loop for *q*
End loop for *h*
For $h = 1$ to $M$
For $q = 1$ to $N$
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *q*
End loop for *h*

**OR**

On the first wavelength in the sequence, the primary lightpath corresponding to first connection request is tried for establishment; now the primary lightpath corresponding to the second connection request is tried for establishment and so on for all the connection requests. After this, the same steps are repeated for the second wavelength and so on up to the last wavelength.

The steps in the above-mentioned paragraph are then followed for backup lightpaths of all the connection requests.

**Algorithm**

For $q = 1$ to $N$
For $h = 1$ to $M$
Try to establish *sh*(*h*) on *Wq* if not already established.
End loop for *h*
End loop for *q*
For $q = 1$ to $N$
For $h = 1$ to $M$
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *h*
End loop for *q*

These two strategies give the same results because in both of these strategies, primary lightpaths corresponding to all the connection requests are tried on all the wavelengths and only after this backup lightpaths are considered, resulting in the same number of connections accepted.

### 3.2. Strategy 2

The primary lightpath for the first connection request is tried on the first wavelength, then on the second wavelength and so on up to the last wavelength. Now the backup lightpath establishment for this connection request is attempted, starting from the first to the last wavelength. The same procedure is followed for all the connection requests.

**Algorithm**

For $h = 1$ to $M$
For $q = 1$ to $N$
Try to establish *sh*(*h*) on *Wq* if not already established.
End loop for *q*
For $q = 1$ to $N$
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *q*
End loop for *h*

### 3.3. Strategy 3

The backup lightpath corresponding to a connection request is tried immediately after its primary lightpath is tried and that also on the same wavelength.

On the first wavelength, try the primary lightpath for the first connection request and then its backup lightpath is tried on the same wavelength. Repeat the same process for the same wavelength for all other connection requests in the sequence. Follow the same steps for the second wavelength and so on up to the last wavelength.

**Algorithm**

For $q = 1$ to $N$
For $h = 1$ to $M$
Try to establish *sh*(*h*) on *Wq* if not already established.
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *h*
End loop for *q*

**OR**

Try to establish the primary lightpath of the first connection request on the first wavelength; now try the backup lightpath of the same connection request on the same wavelength. Repeat this process for the same connection request on the second wavelength and so on up to the last wavelength. Follow the procedure mentioned in the above paragraph for all other connection requests.

**Algorithm**

For $h = 1$ to $M$
For $q = 1$ to $N$
Try to establish *sh*(*h*) on *Wq* if not already established.
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *q*
End loop for *h*

These two strategies give the same results in terms of connections accepted for the same sequence of requests because in both of these strategies always on every wavelength, the backup lightpath corresponding to each connection request is tried immediately after its corresponding primary lightpath. As the concept is the same in both of the strategies, there will be an equal number of connections accepted for the same connection request sequence and the same resources.

### 3.4. Strategy 4

On the first wavelength, try to establish the primary lightpath for the first connection request, then try the primary lightpath for the second connection request and so on for all the connection requests on the same wavelength. Now the backup lightpaths for the same sequence of requests is tried on the first wavelength. The same steps are followed for the second wavelength and so on up to the last wavelength.

**Algorithm**

For $q = 1$ to $N$
For $h = 1$ to $M$
Try to establish *sh*(*h*) on *Wq* if not already established.
End loop for *h*
For $h = 1$ to $M$
Try to establish *ash*(*h*) on *Wq* if not already established and if lightpath on *sh*(*h*) is established.
End loop for *h*
End loop for *q*

## 4. Performance analysis

Figs. 1 and 2 show the 14 nodes with 21 links NSFNET [6,7] and 11 nodes with 26 links EON [6] 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. 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 a unicasting approach. The total number of source destination pairs in permutation routing depends upon the number of nodes. BM has been used so that more backup lightpaths can be established with fewer resources. It will lead to reduced blocking probability.

Tables 1 and 2 show the link information for NSFNET and EON networks, respectively. There is one row in the table corresponding to each link. The first column shows the connecting nodes of the link and the second column represents the weight taken for that link. The shortest path algorithm is applied to find the route for the primary lightpath because it efficiently utilizes the resources according the weights of the links. An

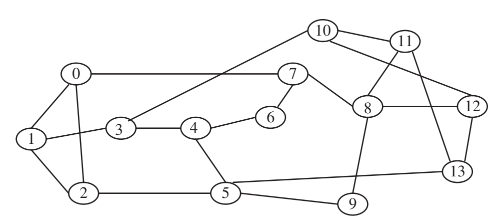


**Fig. 1.** NSFNET network model.

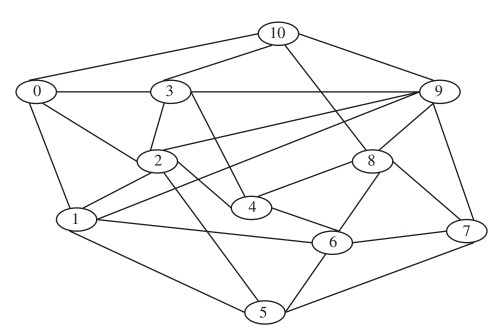


**Fig. 2.** EON network model.

**Table 1.** Link information for NSFNET network

| Link | Weight | Link | Weight |
|---|---|---|---|
| 0–1 | 67 | 5–13 | 114 |
| 0–2 | 100 | 6–7 | 43 |
| 0–7 | 173 | 7–8 | 39 |
| 1–2 | 38 | 8–9 | 55 |
| 1–3 | 61 | 8–11 | 25 |
| 2–5 | 118 | 8–12 | 27 |
| 3–4 | 42 | 10–11 | 38 |
| 3–10 | 130 | 10–12 | 49 |
| 4–5 | 91 | 11–13 | 29 |
| 4–6 | 40 | 12–13 | 14 |
| 5–9 | 58 | | |

**Table 2.** Link information for EON network

| Link | Weight | Link | Weight |
|---|---|---|---|
| 0–1 | 10 | 3–9 | 50 |
| 0–2 | 12 | 3–10 | 20 |
| 0–3 | 11 | 4–6 | 25 |
| 0–10 | 28 | 4–8 | 17 |
| 1–2 | 9 | 5–6 | 18 |
| 1–5 | 45 | 5–7 | 40 |
| 1–6 | 42 | 6–7 | 35 |
| 1–9 | 80 | 6–8 | 24 |
| 2–3 | 8 | 7–8 | 14 |
| 2–4 | 7 | 7–9 | 19 |
| 2–5 | 50 | 8–9 | 15 |
| 2–9 | 55 | 8–10 | 30 |
| 3–4 | 15 | 9–10 | 18 |

alternate shortest path that is link and node disjoint with the primary lightpath is used for better provisioning for the backup lightpath. The backup lightpath will be able to handle all types of failures. Let $t$ and $u$ be 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 the same. It will also be the case for their corresponding backup lightpaths.

Figs. 3 and 4 show the comparison of the four strategies for the systems that require 100% degree of survivability when applied on NSFNET and EON networks, respectively, with BM. The connections accepted in this case are those that lead to 100% degree of survivability in the event of failure so these can be used for critical applications. Simulation results show that for the applications that require 100% degree of survivability, strategies 2 and 3 perform better than 1 and 4 in terms of blocking probability. So 2 and 3 should be used for critical applications of the network that does not have sufficient resources, i.e. wavelengths on a fiber. It is due to this reason that in these strategies the backup lightpath corresponding to any s–d pair is tried to be established immediately after the establishment of its primary lightpath as the connection is

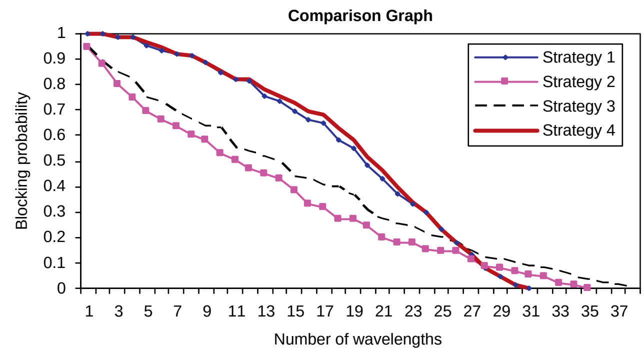


**Fig. 3.** Comparison graph for NSFNET (critical applications).

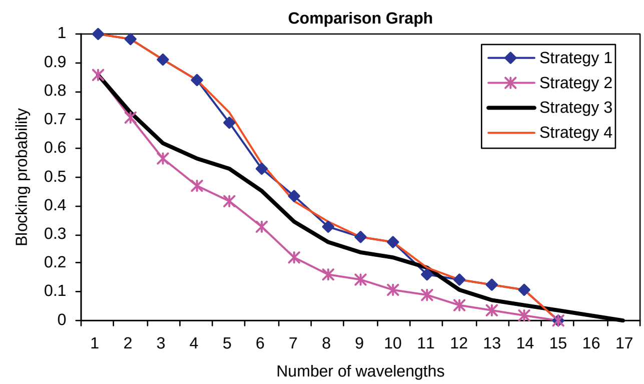


**Fig. 4.** Comparison graph for EON (critical applications).

established only if both its lightpaths are established. But in the case of strategies 1 and 4, first of all the primary lightpaths of all the connections are tried on the available resources, then those resources are made available for backup lightpaths. In this way, more primary lightpaths and less backup lightpaths have resources allocated, resulting in lesser connections accepted (because both lightpaths are required) as compared with 2 and 3 for limited resources. But if we have sufficient resources, then all the strategies give almost similar results because for all the connections to be accepted, we need all the primary and backup lightpaths, i.e. almost the same resource requirements.

Figs. 5 and 6 represent the comparison of the strategies in terms of blocking probability for non-critical data when applied on NSFNET and EON networks, respectively, with BM. For the non-critical applications, in which a connection can be accepted if the primary lightpath is established but the backup lightpath is desired and not compulsory, strategies 1 and 4 perform better than 2 and 3 because first of all on the available resources primary lightpaths are tried, then the resources are given to backup lightpaths. So more primary lightpaths are established, resulting in more number of connections accepted for limited resources.

Figs. 7–10 show the advantage of incorporating the BM technique to reduce the blocking probability. The

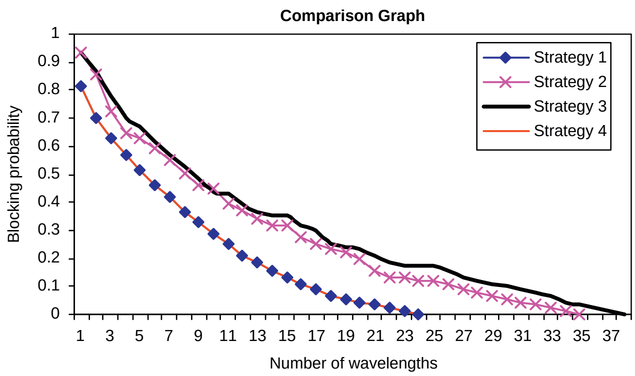


**Fig. 5.** Comparison graph for NSFNET (non-critical applications).

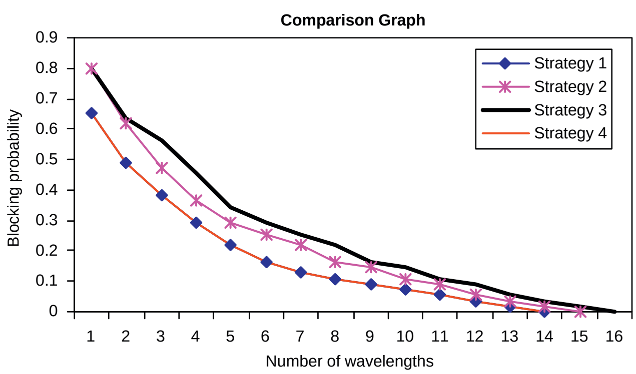


**Fig. 6.** Comparison graph for EON (non-critical applications).

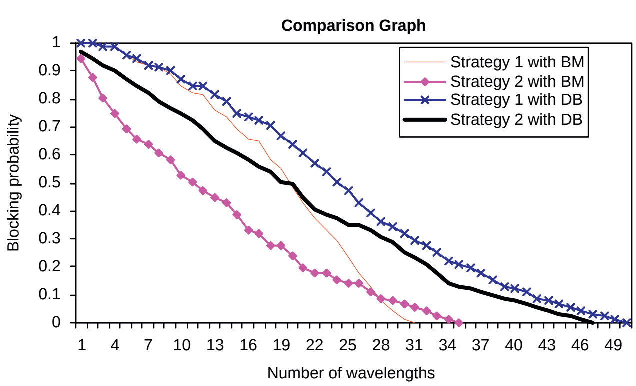


**Fig. 7.** Comparison graph for NSFNET (critical applications) for strategies 1 and 2.

data taken for plotting are of NSFNET. Figs. 7 and 8 are for the systems that require 100% degree of survivability. Figs. 9 and 10 are for the systems that do not require 100% degree of survivability. Figs. 7 and 9 show blocking probabilities for strategies 1 and 2, and Figs. 8 and 10 show the results for strategies 3 and 4. The simulation results show that for the critical systems where backup lightpath establishment is compulsory, BM gives much reduced blocking probability as compared with the DB technique as shown in Figs. 7 and 8. BM gives good results as compared with the

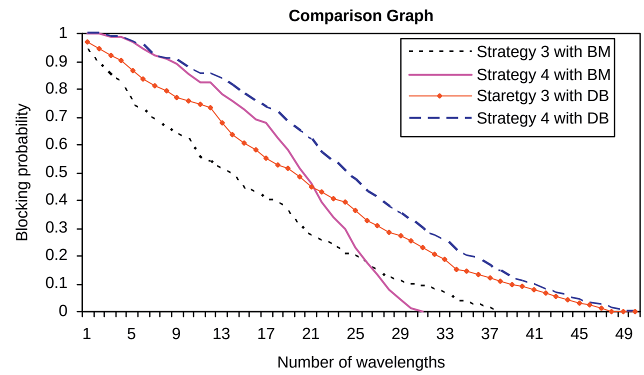


**Fig. 8.** Comparison graph for NSFNET (critical applications) for strategies 3 and 4.

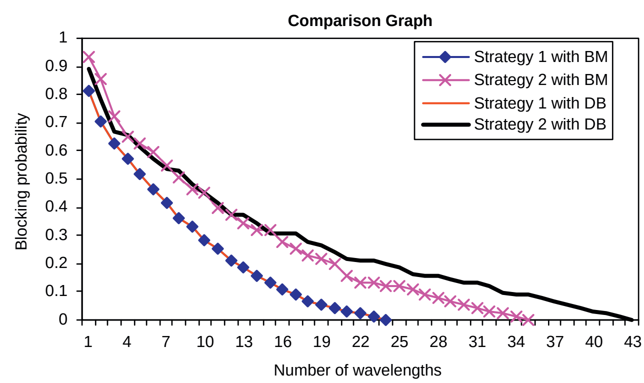


**Fig. 9.** Comparison graph for NSFNET (non-critical applications) for strategies 1 and 2.

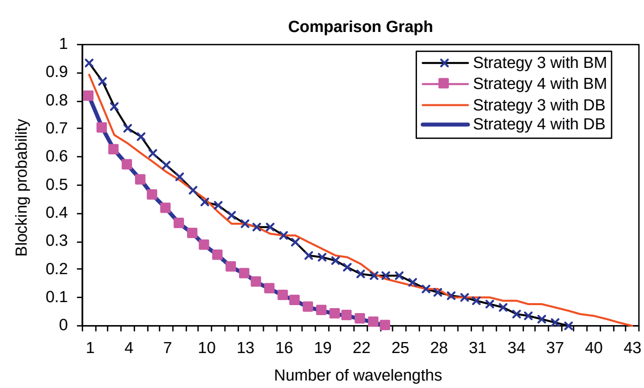


**Fig. 10.** Comparison graph for NSFNET (non-critical applications) for strategies 3 and 4.

dedicated technique for non-critical systems in many cases as shown in Figs. 9 and 10.

## 5. Conclusions

In WDM optical networks, the BM technique has been employed for the backup lightpath to accept more number of connections. It will directly reduce blocking probability. In this paper, we presented four different variations of applying the same routing algorithm for primary and backup lightpaths, wavelength assignment strategy and the survivability approach. In the simulation, we have applied the shortest path algorithm for the route of primary lightpath, an alternate shortest path (node and link disjoint with primary path) for backup lightpath and first-fit wavelength assignment strategy for wavelength assignment. The results show that everything else remaining the same, the variations of when these strategies and algorithms are applied lead to the variations in the number of connections accepted. The blocking probability has been plotted corresponding to the number of wavelengths. For the critical applications that require 100% degree of survivability, strategies 2 and 3 perform better than strategies 1 and 4 and reverse is the case for non-critical applications in the case of fewer resources. The strategy that should be used depends upon whether the applications are critical or non-critical.

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