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A New Recovery Scheme for Single and Multiple Link Failures in Crossbar Networks

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Abstract: The handling of instability due to link failures in a network is an important problem while handling typical large scale networks. This issue is particularly more challenging in optical networks operating under the wavelength continuity constraint where the same wavelength must be assigned on all links in the selected path. Hence, a fast and reliable Fault Recovery System is essential in survivability design of very high bandwidth networks. The Generalized Loop Back Recovery (GLBR) Method provides a solution for this kind of problem but it handles only single link failure. Though the pre-configuration cycle accomplishes multiple link failures, the length of restoration path provided by p-cycles is longer and applicable for only small networks. This problem is alleviated in the Star-Block algorithm but involves redundant procedures. In this study, a new recovery scheme is proposed for single and multiple link failures which eliminate the redundancy involved in Star-Block algorithm. A crossbar network is used for the analysis and results are improved in reducing the length of restoration path and number of iterations involved. Further, this scheme avoids redundancy.

Key words: Link failures, GLBR, p-cycles, star-block, crossbar network, k-means

INTRODUCTION

Many emerging networking applications such as data browsing in the world wide web, video conferencing, video on demand, e-Commerce and image distributing, require very high network bandwidth. Optical networking is a promising solution to this problem because of the nearly unlimited bandwidth of optics. To fully use the bandwidth, a fiber is divided into a number of independent channels with each channel on a different wavelength. This is referred to as Wavelength-Division Multiplexing (WDM) (Zhang and Yang, 2006).

The very high capacity of an optical fiber (e.g., the data rate of an OC-768 fiber channel is 40 Gb sec^{-1} and a single fiber strand may carry upto 320 wavelength channels) may cause heavy data loss (of the order of terabits per second) due to any failure of a part of the network (e.g., fiber cut). Several approaches have been proposed for implementing survivable optical networks (Gautam and Chaudhayr, 1995; Dommetry *et al*., 1995; Yang and Masson, 1995; Han and Kamber, 2007; Houlahan *et al*., 1996; Du and Masson, 1999). Duato *et al.* (2003) discussed the basic concept of interconnection networks, switches and different types of links. These approaches are classified in two categories: protection and restoration (Zhou and Yang, 2002). In protection, backup resources are preconfigured (i.e., reserved during connection setup) while in restoration, backup routes are discovered dynamically after a failure. Restoration schemes typically have longer recovery times than protection schemes.

The protection or dedicating spare resources in anticipation of faults and rapid restoration of traffic upon detection of a fault are also becoming increasingly important (Gerstel and Ramaswami, 2000a) in the networks. Gerstel and Ramaswami (2000b) analysed factor affecting the complexity of implementing different protection schemes in optical layer. The performance of rapid restoration using minimum resources (to minimize the cost) is to be considered as the main objective in the design of survivable networks. The mechanism in which redundant capacity or protection capacity is preallocated for use when a link fails is called protection. Since, link failures are by far the most common failures in optical networks, the research in this study is restricted only to the link failures.

Protection mechanisms are broadly classified as path protection or link protection, depending on where protection switching is done (Ellinas and Stern, 1996). In link protection (also called loop back protection), alternate paths (distinct paths for each wavelength, in general), called backup or protection paths between the end points

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of each link are pre-computed. Upon the link's failure, all of the light-paths using the link (called primary or working light paths) are switched at the end-nodes of the link to their corresponding backup light-paths. A light-path is a connection setup from source to destination through intermediate nodes by using the same wavelength. The portion of the working light-paths excluding the failed link remains the same. In contrast, path protection entails the end to end rerouting of all working light-paths that use the failed link along pre-computed backup light-paths. Here, the entire route of the working light-paths may be changed. In order to save cost, the protection capacity can be shared between paths (or links, in link protection) that are known to not fail simultaneously. However, capacity sharing also leads to increased switching times because the switches on the backup path must be configured after the failure happens.

The flexibility of rerouting a light path on an end to end basis in path protection could lead to a lower protection capacity requirement. However, it may require the end-nodes of all failed light-paths to be notified of a link's failure, if the end to end rerouting is failure dependent. On the other hand, link protection may require more protection capacity because of reduced flexibility in rerouting but can be much faster as it uses only local knowledge around the failed link and can perform the switching at a lower layer (the link layer as opposed to the path layer) thus reducing the amount of signalling performed after a failure occurs and providing the potential for much faster recovery than shared path protection schemes.

There are various classes of protection such as protection from two or more failures, protection from single failures and no protection. This ensures that light-paths services with differentiated protection guarantees are likely to be offered.

The protection from the more common failures of fiber cuts in optical networks is completed within a few milliseconds to a few seconds, depending on the mechanism used for recovery. However, the time, it takes to repair the cut may be a few hours to a few days. It is certainly possible for one (or even more) cut (s) to happen in this duration, thus requiring protection from multiple failures.

In the approach, researchers consider the elimination of multiple link failures by using new recovery scheme. This scheme makes use of the combination of mathematical induction method for identifying the number of blocks, edge deletion for finding the initial centre, k-means for identify the faces of the network, direction assignment for producing working subnet and protection sub-net for achieving single and multiple failure.

LITERATURE REVEIEW

The major challenge in survivable networks is the design of resource allocation algorithms that allocate network resources efficiently while at the same time being able to quickly recover from failure by rerouting the broken connection using the reserved spare capacity. This issue is particularly more challenging in optical networks operating under the wavelength continuity constraint where the same wavelength must be assigned on all links in the selected path (Eshoul and Mouftah, 2009).

WDM loop-back recovery: Medard *et al.* (1999) verified the WDM-based loop-back recovery and algorithms for performing WDM-based loop-back on link and node-redundant networks. Loop-back recovery scheme is further extended to WDM-based loop-back recovery where protection paths are reserved at wavelength level. It requires only two fibers.

Figure 1 illustrates WDM based recovery. Primary traffic is carried by fiber 1 on λ_1 and by fiber 2 on λ_2. Back up is provided by λ_1 on fiber 2 (for λ_1 on fiber 1) and by λ_2 on fiber 1 (for λ_2 on fiber 2). The main advantage of WDM based loop back recovery system over fiber based system is that only two fibers are require in the former whereas at least four fibers are required in the latter.

Generalized loop-back recovery in optical mesh networks: Medard *et al.* (2002) verified several algorithms to perform recovery for link failure and node failure. They prove their validity and present a network management protocol algorithm which enables distributed operation for link or node failure. They have also presented three different applications of generalized loop-back.

This method is applicable to arbitrary two link redundant and two node redundant networks to restore services after the failure of a link or a node, respectively. A two-link (node) redundant network remains connected after the failure of a link (node). In this method, the network is represented by graphs and failure of a link (node) is mapped to the disappearance of an edge (vertex)

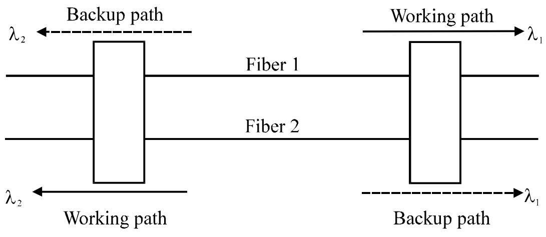

Fig. 1: WDM-based loop-back recovery

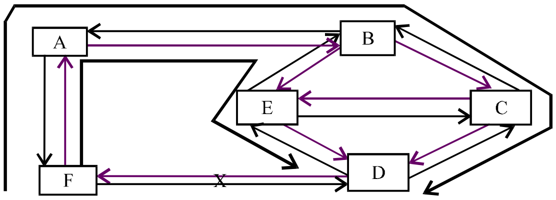

Fig. 2: Generalized loop-back recovery

in the corresponding graph. In generalized loop back, pair of conjugate digraphs are used for routing primary path and reservation of protection path, respectively. Traffic flows in the primary digraph and protection is provided through the use of its conjugate, the backup digraph. These digraphs are calculated only once before the network is put on line for the first time. In the event of failure, nodes adjacent to the failure simply flood the pre-established backup digraph with traffic of the failed link.

For simplicity, only unidirectional conjugate digraph is chosen which is shown in Fig. 2. The primary digraph is shown in solid lines and backup digraph is shown in dashed lines. Suppose when there is failure in link FD, the traffic is switched over to backup digraph. The backup digraph is flooded with the backup traffic by node F and the backup traffic finds its way to node D. There can be two possible backup paths (F A B E D) and (F A B C D) for the traffic. The protocol ensures that only the traffic which arrives at a node first is forwarded to the output ports. Traffic which arrives subsequently is simply discarded and the node that sends out this traffic is notified by means of a Negative Acknowledgement Message (NACK). After receiving a NACK, the node stops forwarding traffic to the corresponding output port. Therefore, only one of the two possible paths is actually established.

The gist of this approach is to eliminate the use of rings. Instead, a primary (secondary) digraph (corresponding to a set of unidirectional fibers or wavelengths) is backed up by another secondary (primary) digraph (corresponding to a set of unidirectional fibers or wavelengths in the reverse direction of the primary (secondary) digraph). After a failure occurs, broadcast the stream carried by the primary (secondary) digraph along the failed link onto the secondary (primary) digraph. Finally, a protocol ensures that only a single connection arrives to each node on the back-up path. When the back-up path reaches the node that lost its connection along the primary (secondary) digraph because of the failure, the traffic is restored onto the primary (secondary) digraph. However, this scheme can only accommodate single faults.

Survivability approach using p-cycles in WDM mesh networks: Schupke *et al.* (2002) proposed preconfigured protection cycle (p-cycle) for achieving fast protection speed and mesh like high efficiency of spare capacity for multiple link failures. This is possible, because a p-cycle can provide protection not only for on-cycle span but also for straddling span (Choi *et al.*, 2004).

Ellinas *et al.* (2000) introduced the concept of p-cycles and developed algorithms to obtain the cycles in networks with planar, non-planar and Eulerian topologies. Asthana *et al.* (2010) named the various p-cycles discussed in the literature on the basis of their structural relationship with the network and the type of protection provided by them.

The major advantages of p-cycles protection schemes over the diverse routing protection schemes are their ability to achieve both good resource efficiency and fast restoration times simultaneously. It is possible to achieve fast restoration time because the only real time switching required upon link failure is between the end nodes of the failed link.

Moreover, p-cycles can reach good resource redundancy compatible to that of conventional survivable schemes used in mesh networks. In WDM wavelength-routed optical mesh networks, p-cycle techniques can be applied to ensure survivability against span failures (fiber cuts) under static and dynamic traffic environments (Eshoul and Mouftah, 2009). However, the length of restoration path provided by p-cycles is longer and applicable for only small networks.

Star-Block design in two-level survivable optical networks: An algorithm designated as star-block is used to reduce the length of the restoration path. This algorithm simplifies the original topology to a 2 connected graph and partition the graph into multiple blocks where each block contains a centre node and the minimum number of neighbouring nodes that collectively form a complete cycle.

The simplified graph is then restored to the original topology using conventional graph rules. The block selection algorithm is then used to assign the edges belonging to multiple blocks to an appropriate block for fault recovery purposes. In their approach, the given physical topology is converted into logical topology and the spoke connection formed by the centre node in the star block provide a restoration during the failure of any online or offline link. However, the main disadvantage of this method is that the failure of centre node may forbid the restoration of link failure and cause total disaster (Li *et al.*, 2011). In the approach, a new recovery framework is suggested by eliminating the centre node proposed by star-block. The proposed method is used for achieving the single and multiple failures in a given network.

The complexity involved in identification of faces, generating dual face, direction assignment for finding protection subnet by Face Dual Algorithm (FDA) using many steps are simplified in single step. A crossbar network is taken for the consideration. The new recovery scheme using crossbar switching network is discussed in the study.

Software fault prediction using tree-based k-means clustering algorithm: Quad-tree-based k-means algorithm (QDK) (Bishnu and Bhattacherjee, 2012) has been applied for predicting faults in program modules. QDK are applied for finding the initial cluster centers for k-means algorithm. A Quad-tree in two dimensional spaces is a 4 way branching tree that represents recursive decomposition of space using separators parallel to the coordinate axis.

At each level a square subspace is divided into four equal size squares. If the number of data points in any bucket is less than threshold then the Quad-tree consists of a single leaf. In case the user intends to form a desired number of clusters for k-Means algorithm, the QDK algorithm can give k initial cluster centers to be used as input to the simple k-Mean algorithm (Han and Kamber, 2007). This is facilitated by varying the value of the threshold parameter which is input to the Quad-tree algorithm.

NEW RECOVERY SCHEME

Crossbar switching network: A crossbar switching network which is the simplest type of switching network is considered for the analysis. A switching network which consists of one or more stages of switches can be used to provide various connections between inputs and outputs.

A crossbar provides full connectivity, i.e., any permutation can be implemented using crossbar. A N×N crossbar is shown in Fig. 3 which is implemented as a rectangular array with N inputs (rows) and N outputs (columns) as shown in Fig. 4.

In general, the number of cross-points is used as a representative measure of the hardware complexity of switching circuits. An N×N crossbar network has N^2 cross-points. The crossbar network is a connected network in which for each node $i = 2n$ ($n = 1, 2, ...$) there exists a path to every other node $j = 2n$ ($n = 1, 2, ...$) with $i \neq j$.

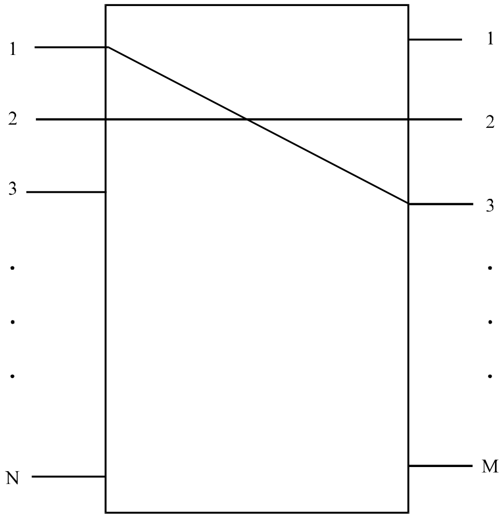

Fig. 3: N×N crossbar network

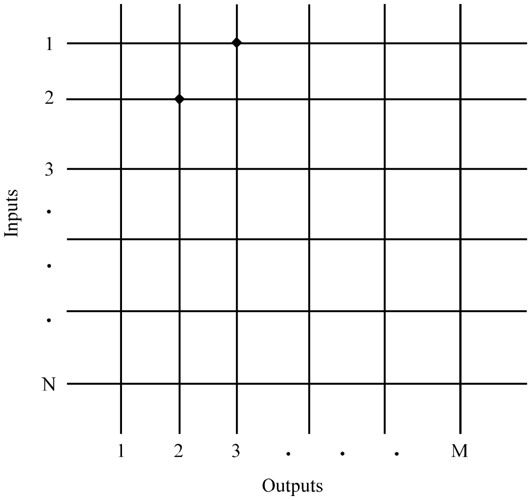

Fig. 4: Rectangular array switch connections

Researchers divide the network into different disjoint blocks with each blocks contains only four nodes. The blocks are formed by using k-Means algorithm with a marked difference (Han and Kamber, 2007). In k-Means algorithm, the initial centre node is selected arbitrarily and the numbers of blocks are not selected known in advance (Bishnu and Bhattacherjee, 2012). In the case, the centre node is chosen by edge deletion method and the number of blocks can be easily predicted.

Block selection: The blocks from the chosen network are selected based on the following principles:

- A minimum square is taken for each block. This can be achieved with just four nodes

- The blocks formed are disjoint and independent. The procedure for forming blocks and the proof for choosing four nodes as well as block independency are as follows:

Algorithm for block selection:

```
Input: n (a positive integer)
    Step 1: Get n
  Step 2: Calculate $N = n×n$
  Step 3: Determine N/4. If the reminder is 0, number of
      blocks $g = N/4$; otherwise $n = n+1$ & goto Step 2.
  Step 4: If the number of nodes in all blocks are same,
      goto Step 5; otherwise stop
  Step 5: If all the formed blocks are independent, store g;
      stop.
Output: Number of blocks, g.
```

Proof for the number of nodes in a block and independency (Lemma 1): Let G be connected network and there are g blocks where g is $n^2/4$ then:

- G contains a sub-block with 4 nodes
- $2 \leq d(N) \leq 4$
- All the blocks are independent

Proposition 1: Let G be connected network with N nodes if n is a natural even number then n^2 is always divisible by 4 for all $n \geq 4$ [n^2 gives total number of nodes in the network and 4 is number of nodes in a block].

Proof: If any number is divisible by 4 it can be written as 4r for all r. Assume , $n = k \Rightarrow k^2 = 4r$. By induction method, $n = k+2 \Rightarrow (k+2)^2 = 4(r+k+1)$ is also divisible by 4. Hence, the proof.

The above proposition1 is used to identify the number of nodes and blocks of given network.

Proposition 2: If g and h are the number of inner and outer blocks, respectively all with same size, drawn from the given network then the mean value (i.e., the number of edges associated with each node) of all the respective blocks (whether inner or outer) will be the same.

Proof: Researchers take the null hypothesis as $H_0: \overline{A} = \overline{B}$ (There is no significant difference between mean values of blocks) and alternative hypothesis as $H_1: \overline{A} \neq \overline{B}$ (There is significant difference between mean values of blocks). For using testing statistic with degree of freedom $\upsilon = 2g-2$ (Montgomery, 2008):

$$t = \frac{\overline{A}-\overline{B}}{\sqrt{\frac{S_1^2+S_2^2}{g-1}}}$$

Where:

$S_1^2 = 1/g \times \sum A^2 - (A)^2$
$S_2^2 = 1/g \times \sum B^2 - (B)^2$

For the level of significance are at 10, 5, 2 and 1%, it is evaluated that H_0 is accepted and both the blocks A and B are same.

Proposition 3: Any two blocks in the network are independent.

Proof: Let A and B be two blocks. Assume both are random variables then $COV(A, B) = E(AB)-E(A)E(B)$, $E(AB) = 36/4$, $E(A) = 3$, $E(B) = 3$, $COV(A, B) = 0$. Therefore, A and B are independent.

Determination of initial centre values: In this study, researchers determine the initial centre value for all the blocks with the help of scatter plot and edge deletion algorithm.

Algorithm for initial centre values:

```
Input : No. Of nodes and edges.
Step 1: Determine the coordinate values of the each node using
        scatter plot.
Step 2: Initialize the row and column by 1.
Step 3: Start the traverse from node1and fix the first initial value
       as node1.
Step 4: Delete the alternate link from the starting edge .
Step 5: Assign the every selected link first node value as initial
       value of the each block.
Step 6: Increase row and column by 2.
Step 7: This process continues both row wise and column wise.
Step 8: Finaly store all the initial values and considered as centre
        point of the each block.
Output: Centre point for the each block.
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Example of the center selection: The 4×4 cross bar network shown in Fig. 5 contains 16 nodes starting from

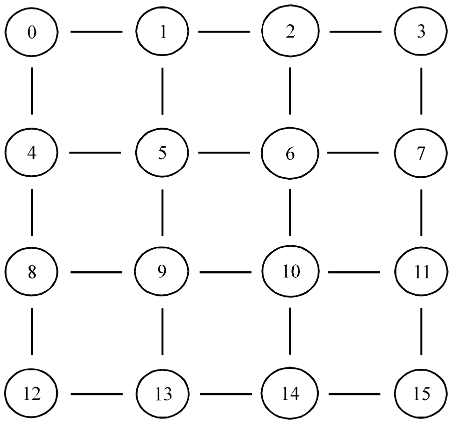

Fig. 5: 4×4 crossbar network

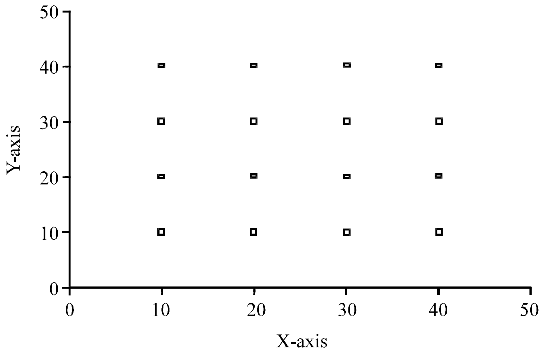

Fig. 6: Scatter graph of 4×4 crossbar network

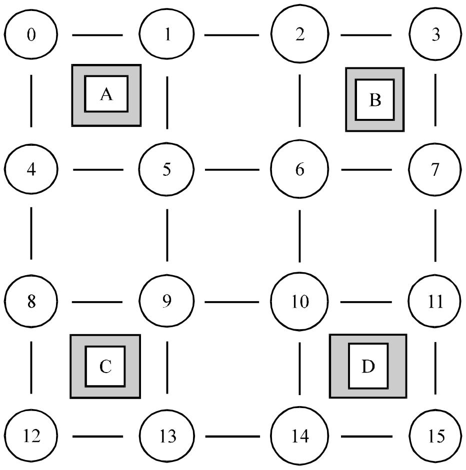

Fig. 7: 4×4 crossbar network with four blocks. Block A: [0 1][1 5][5 4][4 0]; Block B: [2 3] [3 7] [7 6] [6 2]; Block C: [8 9] [9 13] [13 12] [12 8]; Block D: [10 11] [11 15] [15 14] [14 10]

Table 1: Initial centre values of all blocks

	Blocks			
Values	1	2	3	4
X	10	40	40	10
Y	10	10	40	40

0-15 and Fig. 6 contains 16 points starting from 0-15. The initial centre values and the corresponding required blocks are determined by the algorithms given in study. The example network has 4 blocks, hence researchers need 4 initial values as given in Table 1.

Decomposition of the network: As mentioned earlier, the k-Means algorithm assumes the initial centre values and the number of blocks arbitrarily. Then, this algorithm separates the blocks by measuring the squared Euclidean distance. In the analysis, the centre values and the blocks are determined systematically by using the algorithms given in study. The block separation is done in the same manner as in the k-Means algorithm. However, the method is considered only the neighbouring node to form a block which is used to reduce the number of iterations in a k-means. As per the example given the study.

The centre point will change the derived initial centre point. In the iteration process for one single point the centre point will remain constant. So, the centre point is considered as actual centre point for each block. It is decomposed into 4 blocks named as A to D, respectively. Each block contains a set of nodes defined by the following Fig. 7. The mean value of the nodes and centre point of the all blocks are same for large network.

RECOVERY OF MULTIPLE FAILURES

The generalized loop-back recovery is applicable for only single-link failure since the direction of assignment is done only in either clockwise or anticlockwise direction. The star block algorithm achieves both single and multiple failures using Face Decomposition Algorithm (FDA). There are 4 steps involved in FDA viz., faces in block, face dual graph, two colorable consolidation and direction assignment to determine the working of sub-network and protection of sub network in case the original sub-network fails. The algorithm used in the analysis to decompose the network eliminates the first three steps involved in Star-Block algorithm. Hence, the approach simplifies the Star-Block algorithm by reducing the four steps into one single step.

Researchers may now formalize the approach. By defining an undirected graph G = (N, E) to be a set of nodes N and edges E. With each edge [x, y] of an undirected graph, reseachers associate two directed arcs (x, y) and (y, x). Researchers assume that if an edge [x, y] fails then arcs (x, y) and (y, x) both fail. A directed graph P = (N, A) is a set of nodes N and a set of directed arcs A. Given a set of directed arcs A, define the reversal of A to be $\underline{A} = \{(i, j) \mid (j, i) \varepsilon A\}$. Similarly, given any directed graph P = (N, A), define $\underline{P} = (N, \underline{A})$ to be the reversal of P.

In this method, researchers initially define the working path in a given network and form the directions for the blocks. The directions for the links belonging to the blocks are assigned in clockwise direction and for the remaining links in anti-clockwise direction and vice versa for protection sub-network.

For instance, there are 16 nodes in a network which form blocks designated as A-D. Each block consists of 4 nodes. The block A has nodes 0, 1, 4 and 5, block B contains 2, 3, 6 and 7, block C has 8, 9, 12 and 13 and the block D has 10, 11, 14 and 15. The directions are assigned for these blocks as follows. The links belonging to the blocks are assigned in clockwise direction; the remaining

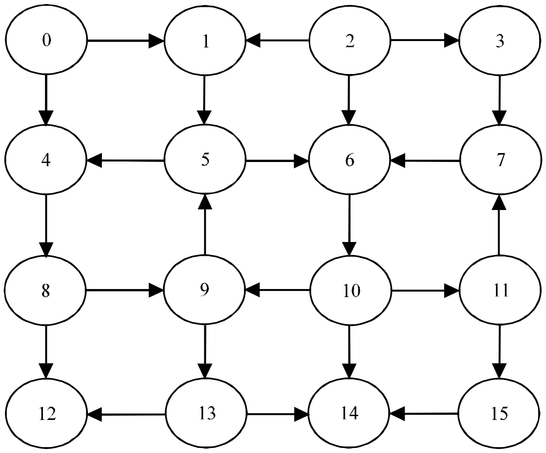

Fig. 8: Working sub-network

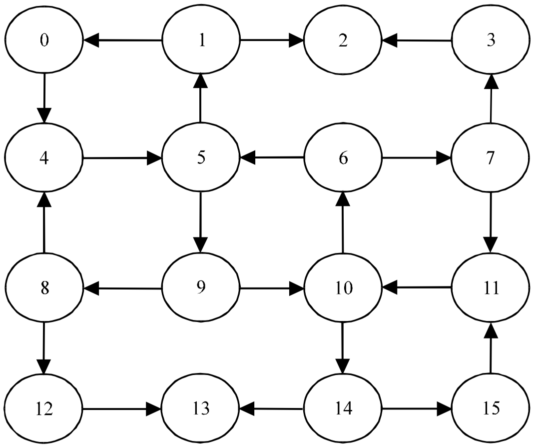

Fig. 9: Protection sub-network

links are assigned in anti-clockwise direction for working sub-network and vice versa for protection sub-network as shown in Fig. 8 and 9.

CONCLUSION

A new recovery scheme for handling single and multiple link failures is proposed in this study. This scheme has employed a crossbar network for the analysis. The k-Means algorithm is used for global grouping of a given network. In this algorithm, the initial centre node is selected arbitrarily and the numbers of blocks selected are not known in advance.

In the scheme proposed, the initial centre node is chosen by Edge Deletion Method and the number of blocks can be easily predicted. The method not only eliminates the redundancy involved in Star-Block algorithm but also proves to be better than GLBR and p-cycles Methods. As a future work, researchers suggest that this scheme can be extended for any other network.

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