Node Reliability in WDM Optical Network

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Abstract

The Wavelength Division Multiplexing (WDM) technology has significantly enhanced the performance and reliability of optical components. Still failures occur. Due to the massive increase of bandwidth supported by fiber networks it becomes extremely important to identify the impact of individual failures may have on the network performance. Node failures in a WDM optical network result in a very high value of Call Drop Probability (CDP). In a backbone network, a node usually carries a huge amount of data and a low CDP is desirable. This paper focuses on understanding the different parameters that affect the reliability of optical networks with emphasis on failures caused due to the optical components comprising the network infrastructure. One algorithm has been developed for calculation of node reliability in WDM optical network. The algorithm is implemented in NSFNET (National Science Foundation Network), Ring and Mesh topology. The parameters affecting the Node Reliability of the optical network are presented, discussed and compared. The different scenarios under study are based on a national USA network topology i.e. NSFNET.

Keywords: *Node Reliability, WDM, NSFNET*

1. Introduction

1.1 Optical Network

Optical networks are high-capacity telecommunications networks based on optical technologies and components that provide routing, grooming, and restoration at the wavelength level as well as wavelength-based services. As networks face increasing bandwidth demand and diminishing fiber availability, network providers are moving towards a crucial milestone in network evolution: the optical network. Optical networks, based on the emergence of the optical layer in transport networks, provide higher capacity and reduced costs for new applications such as the Internet, video and multimedia interaction, and advanced digital services [1]. Optical networking allows for fantastic speeds in the transmission of voice and data. Conventionally speaking, electrical WANs make use of T-1 (1.544 Mbps) and T-3 (45 Mbps) connections. In a LAN environment, speeds are peppier, clocking in at 100 Mbps and even 1 Gbps. Most optical networks are enjoying WAN speeds of 10 Gbps, though many can go as fast at 40 Gbps. In the labs, speeds of 1.6 Tbps are being fine-tuned [2].Optical networks use two different technologies to transmit data across the miles. There must be some way to turn data in electrical form into light. This is accomplished by a laser or an LED. Once converted into light, the data is transmitted across a silken fiber smaller than a human hair. The fiber is made out of extremely pure glass, which allows the light to traverse vast distances. [3].

Attenuation and dispersion are the two main culprits that can keep your optical network from achieving the long hauls of a metropolitan area network (MAN) or a WAN. However, using an amplifier can help resolve some of these problems. It’s also important to recognize that optical networking is not a panacea. Optical networking can work just great inside an Internet service provider or as part of the Internet’s backbone, for example. That functionality, however, hits a huge speed bump when it encounters the Last Mile problem. Additionally, though costs are coming down, the expense involved in an optical network means that one can’t just build one on a whim [4].

1.2 Reliability

In a fiber optical network, 80 percent of outages can be attributed to cable damage. This can happen in an office building if someone unwittingly trips over a length of cable, or even in an industrial environment, where a backhoe slices through underground fiber. In a bus or ring topology, the entire network goes down if the cable is damaged. In these topologies, the nodes aren’t able to operate as isolated units. The ring is designed to send signals clockwise and counter-clockwise by adding another ring of fiber and transmitters/receivers at each node. Both cables can be collocated in the same conduit, because even if both cables are cut, the network will go on functioning. Similarly, if a node goes offline, the rest of the ring will continue following a switch over that will go unnoticed by users. Using a modular fiber optic design can reduce the cost of a ring topology [5]. Rather than duplicating the modem, you only need to add a transmitter/receiver module and a self-healing ring module to each modem. In a bus topology, if modems are already present, the network can be given self healing attributes by connecting the two ends and inserting additional modules, essentially creating a ring topology. Because you would be adding modules, rather than modems, installation time and costs are reduced. Different applications with varying reliability needs can use different network topologies. For extremely critical environments, nodes can be arranged in a self-healing ring. Less critical environments can use a bus, star, collapsed backbone, or hybrid topology [6].

2. Problem Definition and Description

Nodes are computer systems that are connected through optical fibers. The nodes may also be switches, hubs or any other network components comprising the LAN or WAN. Optical networks running on fiber technologies have enabled us to reach data rates much higher than alternative technologies can support [7]. However, when supporting streams of terabits, efficient and reliable data transfer becomes critical. A downtime of minutes could be extremely costly for service providers, massive financial losses, customer inconvenience, and loss of critical data, could occur. Therefore, most current network solutions offer what is known as 5-nines availability (0.99999). This corresponds to a downtime of no more than 5 minutes per year [8].

There are so many causes of failure, from physical failure to failures caused by environment (e.g. extreme heating, earthquakes etc) and other external effects (e.g. cable cuts) to software failures [9]. However, due to the increased bandwidth supported by fiber networks it is crucial to ensure that the network infrastructures used to support this amount of bandwidth can provide high enough network availability and can offer differentiation in the degree of availability for different types of traffic [10]. Due to the massive increase of bandwidth supported by fiber networks it becomes extremely important to identify the impact individual failures may have on the network performance. In the literature, limited studies have been reported to date about how the reliability of components, affects the traffic distribution and behavior in the network. The European Union project COST270 studied the reliability of optical components and devices in communications systems and networking [11].The objective here is to measure the node reliability in a WDM optical network. This paper focuses on understanding the different parameters that affect the reliability of optical networks with emphasis on failures caused due to the optical components comprising the network infrastructure. One algorithm has been developed for calculation of node reliability in WDM optical network. The algorithm is implemented in NSFNET, Ring and Mesh topology. The parameters affecting the Reliability of the optical network are presented, discussed and compared. As part of this study the reliability parameter associated with individual optical components is associated with the reliability of node. Several reliability-scenarios and their relevant results are presented.

2.1 Network Reliability

Reliability is the probability of failure free operation. The different parameters that affect the network reliability are described below.

2.2 Failure Rate (FR)

Failure rate is the number of failures experienced or expected for a device divided by the total equipment operating time. The Failure rate varies with time period. It is shown in the following figure.

2.3 Mean Time To Repair (MTTR)

The MTTR is the amount of time spent performing all corrective maintenance repairs divided by the total number of these repairs.

2.4 Mean Time Between Failures (MTBF)

The MTBF is the mean time expected between failures, measured in hours. For constant failure rate systems, MTBF is the inverse of the Failure Rate.

$$MTBF = 1/FR$$

2.5 Mean Time To Failure (MTTF)

The MTTF is the mean time expected before the first failure of a piece of equipment. It is meant to be the mean over a long period of time and a large number of units.

2.6 Reliability (R)

Reliability is the probability of failure-free operations over a period of time.

$$\text{MTBF} = \int_0^\infty R(T)dt$$

$$\text{R(T)} = e^{(-T/MTBF)}, \textit{where } T \textit{ is the number of hours}$$

2.7 MTBF and R for multiple components

As

$$MTBF = 1/FR$$

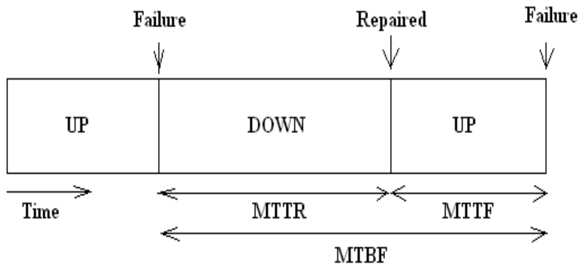
MTBF=1 / (FR_1+FR_2+FR_3+……+FRn), where 'n' is the number of components in the system.

Therefore, $R(T) = \prod_{i=1}^{n} R_i(T)$

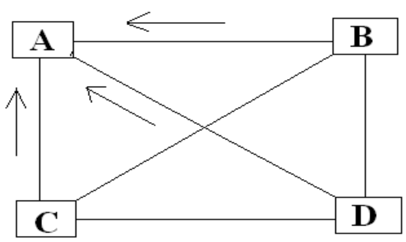
2.8 Availability

Availability is the probability that a system will be operational when called upon to perform it's function.

$$A = MTBF/(MTBF + MTTR)$$



3. Determination of the Node Reliability & Network Reliability of a Mesh Topology



(Mesh Topology)

Failure Rate (FR) =Number of failures experienced or expected / Total equipment operating time (in hours)

MTBF=1/FR or 1/ (FR1+FR2+FR3+……. +FRn)

$$R(T) = e^{(-T/MTBF)}, \textit{where } T \textit{ is the number of hours}$$

For which reliability is to be calculated.

Here, failure is the number of failures encountered while sending a packet from N1 to N2 or N1 to N3 etc. Suppose, R(T) of the mesh topology is to be determined. For this purpose first we have to find out whether packets send to N1 from N2, N3 & N4 are received or not and so on. The Mean Time Between Failures (MTBF) has to be calculated using the following formula.

MTBF=1/FR (N1) +FR (N2) +FR (N3) +FR (N4)

Finally, the Reliability is calculated using the following formula.

$$R(T) = e^{(-T/MTBF)}$$

OR

$$R(T) = \prod_{i=1}^{n} R_i(T)$$

4. Algorithm for Calculation of Node-Reliability in WDM Optical Network

Input: - Failures Experienced or Expected (FAIL_EXP), Equipment Operating Time (EOT), The Time Period (T) for which Reliability is to be calculated.

Output: -Node Reliability of Each Node & The Node Reliability of Entire Topology in WDM Optical Network.

1. The number of failures experienced or expected (FAIL_EXP) for a node during Total Equipment Operating Time (EOT), which is in hours (hrs) is checked.
2. The Failure Rate (FR) of the node can be calculated using the formula,

FR= FAIL_EXP / EOT

3. The Mean Time Between Failures (MTBF) can be calculated using the formula,

MTBF= 1 / FR

4. Node-Reliability of each node can be calculated using the formula

$$R(T) = e^{(-T/MTBF)}$$

Where T is the time period for which Reliability is to be calculated in hours and T>=EOT.

5. The Node-Reliability of the entire network can be calculated by multiplying Reliability values of each node i.e.

$$R(T) = \prod_{i=1}^{N} Ri(T), where\ 0 \le R(T) \le 1$$

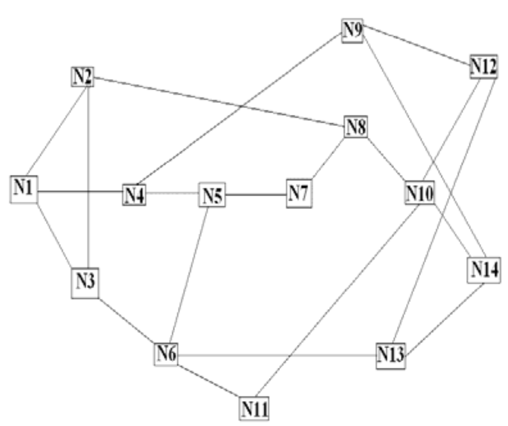
6. Exit

5. Experimental Results and Discussion

In order to study the performance of the algorithm, we have coded the algorithm in C language to run on a 1.7 GHz Pentium IV machine under Borland C++ environment. For carrying out experiments, we have taken a standard NSFNET network having 14 nodes and 21 links. The network is described below.

5.1 National Science Foundation Network (NSFNET)

The NSFNET is a loosely organized community of networks funded by the National Science Foundation to support the sharing of national scientific computing resources, data and information. NSFNET consists of a large number of industry and academic campus and experimental networks, many of which are interconnected by a smaller number of regional and consortium networks. The NSFNET Backbone Network is a primary means of interconnection between the regional networks. The NSFNET Backbone Network, called simply the Backbone in the following, includes switching nodes located at six supercomputer sites: San Diego Supercomputer Center (SDSC), National Center for Supercomputer Applications (NCSA) at the University of Illinois, Cornell National Supercomputer Facility (CNSF), Pittsburgh Supercomputer Center (PSC), John von Neumann Center (JVNC) and the National Center for Atmospheric Research (NCAR). The six nodes are interconnected by 56-Kbps inter node trunks. By the early 1980's, there was going concern that the lack of access to large-scale computing resources and the inability of the researchers to easily share and exchange information was jeopardizing U.S. technological and economic leadership. In response to those concerns the National Science Foundation (NSF) created the office of Advanced Scientific Computing (OASC) which initiated two programs. The first was designed to make supercomputing "cycles" available to researchers; the second was to develop a national computer network NSFNET. The NSFNET is shown below.



(14-Node 21-Link NSFNET)

5.2 Graphs

Graphs are plotted against the values obtained by "different parameters affecting reliability" versus "node reliability". The values are obtained by giving different input values and finding out their corresponding reliability values by running the program iteratively. The values and their corresponding graphs are presented below.

5.2.1 "Number of failures experienced or expected" versus "Node Reliability"

Here, the Equipment Operating Time is taken as 1hour and the time period for which reliability is calculated is also taken as 1 hour. These two parameters (EOT & T) are kept constant.

Table-1

Number of failures experienced or expected	**Node Reliability**
0	1.00000
1	0.36788
2	0.13534
3	0.04979
4	0.01832
5	0.00674
6	0.00248
7	0.00091
8	0.00034
9	0.00012
10	0.00005
11	0.00001
12	0.00000

The corresponding graph is shown below.

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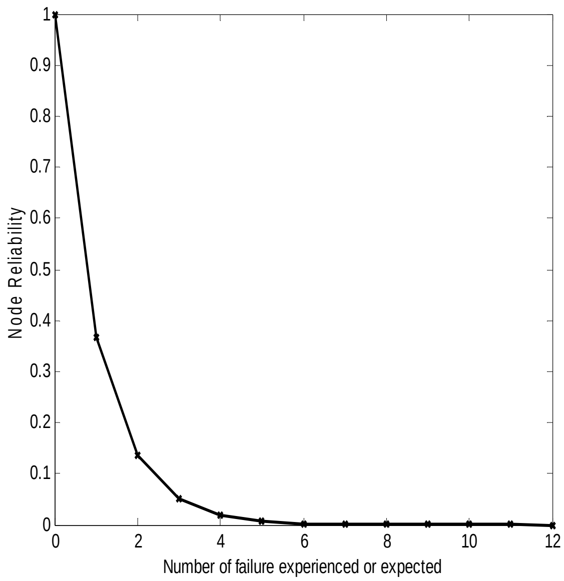


Graph-1

From the above graph it is found that the Node Reliability gradually decreases with increase of the number of failures experienced. It is maximum i.e. 1 when there is zero number of failures and reliability becomes 0 when 12 numbers of failure occurred at each node keeping the value of Equipment Operating Time & Time period constant.

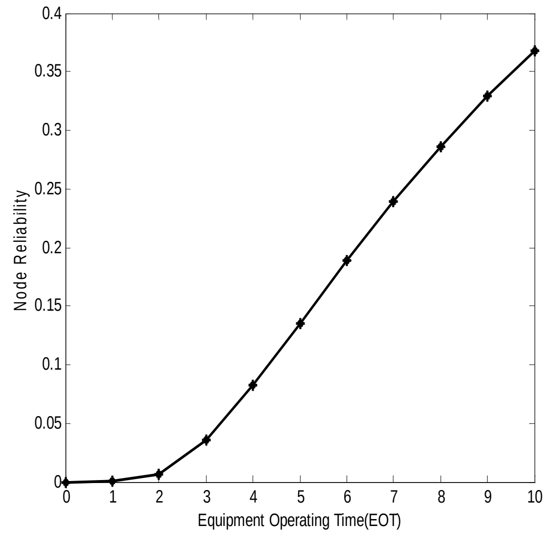
5.2.2 "Equipment Operating Time" versus "Node Reliability"

Here, the number of failure experienced is taken as 1 and the time period for which reliability is calculated is taken as 10 hours. These two parameters (fail_exp & T) are kept constant.

Table-2

Equipment Operating Time	Node Reliability
0	Idle
1	0.00005
2	0.00674
3	0.03567
4	0.08208
5	0.13534
6	0.18888
7	0.23965
8	0.28650
9	0.32919
10	0.36788

The corresponding graph is shown below.



Graph-2

From the above graph it is found that the Node Reliability gradually increases as the Equipment Operating Time increases keeping the values of number of failures experienced & Time period constant.

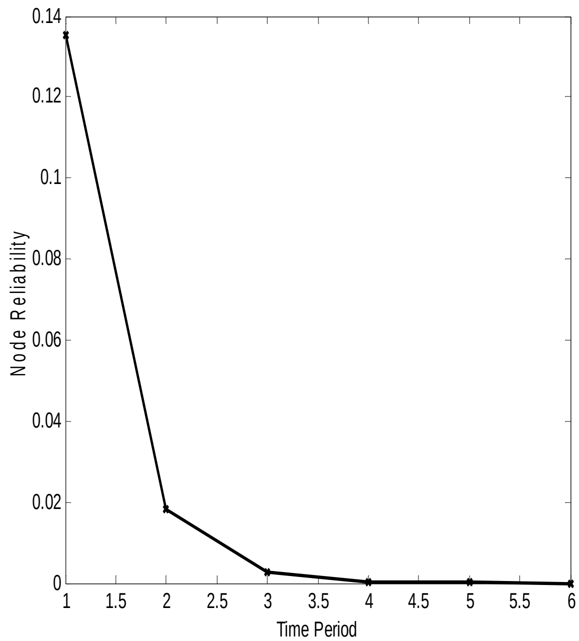
5.2.3 "Time Period" versus "Node Reliability"

Here, the number of failures experienced is taken as 1 and the Equipment Operating Time is taken as 1hour. These two parameters (fail_exp & EOT) are kept constant

Table-3

Time Period	Node Reliability
1	0.13534
2	0.01832
3	0.00248
4	0.00034
5	0.00005
6	0.00000

The corresponding graph is shown below.



Graph-3

From the above graph it is found that the Node Reliability gradually decreases as the Time Period increases keeping the values of number of failures experienced & Equipment Operating Time constant.

6. Conclusion

Although recent advancements in WDM technology have significantly enhanced the functionality, improved the performance and increased the reliability of optical components and systems, failures still occur in any realistic network environment. Causes of failure can span within a wide range, from physical failures, to failures caused by environmental (e.g. extreme heating, earthquakes etc) and other external effects (e.g. cable cuts) to software failures. This paper focuses on understanding the different parameters that affect the reliability of optical networks with emphasis on failures caused due to the optical components comprising the network infrastructure. One algorithm has been developed for calculation of node reliability in WDM optical network. The algorithm is implemented in NSFNET, Ring and Mesh topology. The parameters affecting the Reliability of the optical network are presented and discussed. From experiments it is found that,

(1) The Node Reliability gradually decreases with increase of the number of failures experienced.
(2) The Node Reliability gradually increases as the Equipment Operating Time increases.
(3) The Node Reliability gradually decreases as the Time Period increases.

References

[1] S. Mandal, S. Bera, and D. Saha COST – ESF, Cost Action 270, "*Reliability of Optical Components and Devices in Communications Systems and Networks*" in Progress Report, May 2003 - April 2004.

[2] Mohan G., Samani A.K. "*Routing Dependable Connections with Specified Failure Restoration Guarantees in WDM Networks"* in Proc. IEEE INFOCOM, March, 2000.

[3] Hjalmtysson G. Yates, J., Choudhury S. "*Restoration Services for the Optical Internet"* in Photonics East, November, 2000.

[4] Rammamurthy, S. Mukherjee, "*Survivable WDM Mesh Network.Part 1- Protection*" in proc. IEEE INFOCOM, 1999, pp. 744–51.

[5] Mohan G., Murthy, C.S.R. "*Routing and Wavelength Assignment for Establishing Dependable Connections in WDM Networks"* in Proc. IEEE Int'l Symp. Fault-Tolerant Comp. June, 1999, pp. 94–101.

[6] Ramamurthy S., Mukherjee "*Survivable WDM Mesh Network s, Part-II – Restoration"* in Proc. ICC, 1999.

[7] Mandal S., Jana S., and Saha, D *"A Heuristic Search for Dynamic Lightpath Establishment in WDM Optical Networks with Limited Wavelength Conversion Capability"* in IEEE ICCT, April, 2003.

[8] L. Wosinska, M. Held "*Optimization of optical networks: price and value of reliability*", in Proc. of 6th International Conference on Transparent Optical Networks, July 2004, vol. 1 pp 53-58.

[9] R. Ramaswami, K. Sivarajan, "*Optical Networks, A Practical Perspective*" in second edition. Morgan Kaufmann Publishers, 2002.

[10] S. Chalasani, V. Rajaravivarma "*Survivability in Optical Networks*", in Proc. of the 35th Souteastern Symposium, March 2003, pp. 6-10,

[11] Doshi, B.T "*Optical Network Design and Restoration"*. Bell Labs Tech., January-March 1999, pp. 58–84.