Link Reliability in WDM Optical Network

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Abstract
The 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. Contemporary link failures in a WDM optical network results in a very high value of call drop probability (CDP). In a backbone network, a link 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 links comprising the network infrastructure. One algorithm has been developed for calculation of link reliability in WDM optical network. The algorithm is implemented in NSFNET, Ring and Mesh topology. The parameters affecting the Link 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: 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 [5].

The combination of optics and networking creates unique capabilities, but it also creates unique challenges. 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 [9].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. As much an improvement as fiber is over copper wire, it is not without its own roadblocks [10].

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 [6].

1.2. *Reliability*

In a fiber optic 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 link 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 [7]. 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, links can be arranged in a self-healing ring. Less critical environments can use a bus, star, collapsed backbone, or hybrid topology [8].

2. PROBLEM DEFINATION 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 [11]. 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 [3].

Although recent advancements in WDM technology have significantly enhanced the performance and reliability of optical components and systems it remains inevitable that failures occur. 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 [2]. 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 [4]. 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 links, 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 [1].

The objective here is to measure the link 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 links comprising the network infrastructure. One algorithm has been developed for calculation of link reliability in WDM optical network. The algorithm is implemented in NSFNET, Ring and Mesh topology. The parameters affecting the Link Reliability are presented, discussed and compared. As part of this study the reliability parameter associated with individual optical components is associated with the reliability of link. Several reliability-scenarios and their relevant results are presented. The different scenarios under study are based on a national USA network topology i.e. NSFNET.

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, $MTBF = 1/FR$

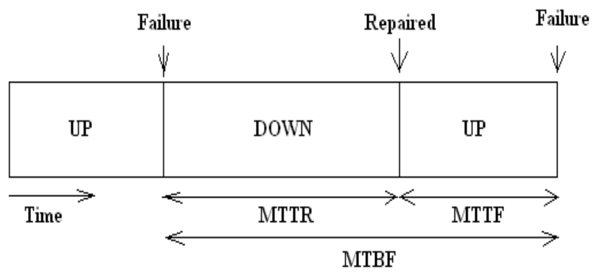
MTBF=1/(FR$_1$+FR$_2$+FR$_3$+……+FRn), where 'n' is the number of components in the system.
Therefore,

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

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. Derivation of Link Reliability

To map the reliability of network components to the reliability of links in the network three different parameters were used: (1) component failure in time (FIT) rate, which is measured in 10^9 operating hours of the component, typical values vary from few tens (simple coupler) to few thousands (complex switch), (2) mean time between failures (MTBF) which can be derived from the FIT rate and (3) mean failure time (MFT), which determines how long on average a failed component remains off-line.

On a link, any 2 components can fail independently in time. Therefore individual failures can be modeled as statistically independent events. We note that a link with 2 amplifiers for example, fails if any of the amplifiers fails. This also holds for *n* amplifiers, or components. Thus the probability of success (i.e. non-failure) of a link is the product of the probabilities of success of all individual components. From [1], we assume that fibers have FIT rates of 500 per km. We also assume that each 100 km of fiber requires an Amplifier, and we use erbium doped fiber amplifiers with FIT = 2850. We consider the MFT of fiber to be 1 hour and the MFT of an amplifier to be 2 hours. The Fiber and Amplifier availability (or Reliability) can be found as follows:

Fiber unavailability= (Length*FIT*MFT) / (1*10^9)

=> Fiber availability=1- Fiber unavailability … (1)

Amp unavailability= (FIT * MFT) / (1*10^9)

=>Amp availability=1- Amp unavailability ... (2)

From equations (1) & (2)

Link availability=Fiber availability*(Amp availability)^N… (3)

N in equation (3) is the number of Amplifiers in that link. We note that components other than amplifiers can be also considered and the link's reliability can be calculated in a similar manner. Applying equation (3) in the network topology under study, the reliability values calculated for any link across the network topology were found to be always above 0.999. This implies that some of the links across the network do not satisfy the 5 9s availability requirement that most operators have. The value of link availability, or reliability, which we derived, can be set as a link parameter in the VPI tool.

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

Input : - Length of the fiber, fail_exp, MFT
Output: - Link Reliability in WDM Optical Network

1. Find out the length of a fiber (Length) connecting two nodes in a topology.

2. The Component Failure in Time (FIT) rate can be calculated using the formula,

$$FIT = fail\_exp / 10^9,$$

Where "fail_exp" is the number of failures experienced or expected during 10^9 operating hours.

3. The Mean Failure Time (MFT), which determines how long on average a failed component, remains Off-line can be determined using the formula

$$MFT=MTBF-MTTF,$$

Where MTBF is Mean Time Between Failures & MTTF is Mean Time To Failure.

4. Fiber unavailability is calculated as

$$\text{Fiber unavailability} = (Length*FIT*MFT) / (1*10^9)$$

=> Fiber availability=1- Fiber unavailability

5. Amplifier unavailability is calculated as

$$\text{Amp unavailability} = (FIT * MFT) / (1*10^9)$$

=> Amp availability=1- Amp unavailability

6. Link availability is calculated as

Link availability=Fiber availability*(Amp availability) ^{N} ,

Where N is the number of amplifiers in the link, Components other than amplifiers can also be considered and the link's reliability can be calculated in a similar manner.

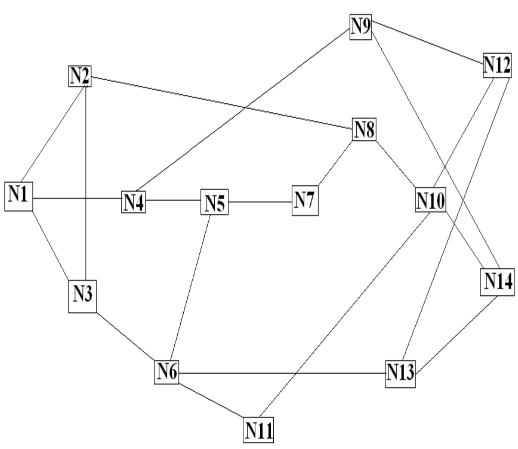
7. Exit.

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. *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 “link 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.

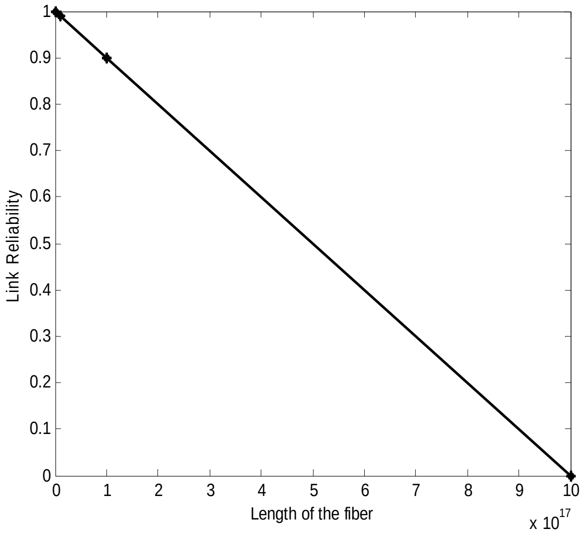
5.2.1. “Length of the Fiber” versus “Link Reliability”

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

Length of the Fiber in meter	**Link Reliability**
10	1.00000
10^2	1.00000
10^4	0.99999
10^6	0.99999
10^8	0.99999
10^{10}	0.99999
10^{12}	0.99999
10^{13}	0.99999
10^{14}	0.99990
10^{15}	0.99899
10^{16}	0.98999
10^{17}	0.90000
10^{18}	0.00000

(Table-1)

The corresponding graph is shown below.



(Figure-1)

From the above graph it is found that the Link Reliability gradually decreases as the length of the fiber increases keeping the values of number of failures experienced & MFT constant.

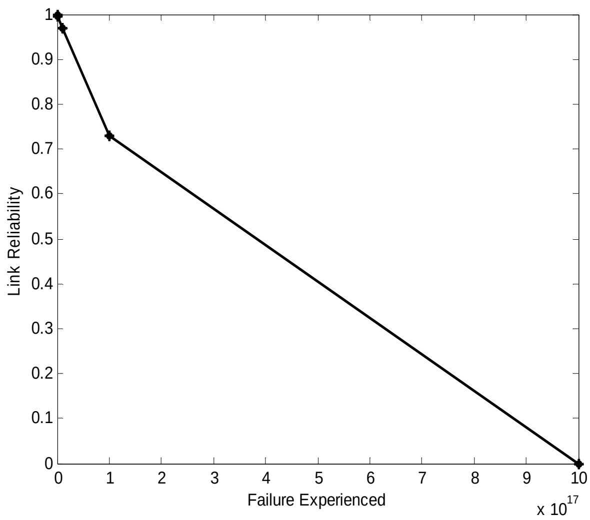
5.2.2. "Number of failures experienced" versus "Link Reliability"

Here, the length of the fiber is taken as 1km and the Mean Failure Time (MFT) is taken as 1hour. These two parameters (Fiber length & MFT) are kept constant.

Number of failures experienced	Link Reliability
10	1.00000
10^2	0.99999
10^4	0.99999
10^6	0.99999
10^8	0.99999
10^{10}	0.99999
10^{12}	0.99999
10^{13}	0.99997
10^{14}	0.99970
10^{15}	0.99700
10^{16}	0.97030
10^{17}	0.72900
10^{18}	0.00000

(Table-2)

The corresponding graph is shown below.



(Figure-2)

From the above graph it is found that the Link Reliability suddenly falls as the number of failures goes on increasing & then gradually decreases as the number of failures increases keeping the values of length of the fiber & Mean Failure Time constant.

6. CONCLUSION

With millions of wavelength-miles laid out in typical global and nationwide networks, fiber optics cable in a WDM optical network is the most failure prone component. Survivability in a WDM network usually refers to the ability of the network to reconfigure and reestablish communication upon 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 link 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. From experiments it is found that,

(1) The Link Reliability gradually decreases as the length of the fiber increases and

(2) The Link Reliability suddenly falls as the number of failures increases.

Here, higher survivability ensures higher reliability. It is very important for backbone network as each link carries a huge amount of data. Thus, failure to reestablish communication on a link failure may cause retransmission of large amount of data, thereby, causing a revenue loss for a network operator. Hence, low call drop probability (CDP) is a desirable feature of a WDM optical backbone network. To ensure low CDP, a network requires redundant capacity to survive a failure.

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