Performance Evaluation of fiber optic communication Using Boolean Function Approach

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Abstract: In this paper a mathematical model has been formulated to assess reliability of a fiber optic communication system using Boolean algebra technique. This technique is simple and convenient than other methods when there are more complexities in a system. The model has been solved and some special cases have been considered to evaluate different reliability parameters. A comparison of decline in reliability with respect to time has been made under those special cases. Another comparison of decrease in MTTF with increase in failure rate has been done.

Keywords - Reliabilty modeling, Weibull distribution, Exponential distribution, Boolean Algebra, Fiber optic communication.

1. Introduction

The process of fiber optic communication involves various steps. Fiber optic communication system is used by telecommunication companies and internet service providers to transit the signals, which could be sound (mobile voice calls, music) and data (e-mail, messages). In such cases electric cabling cannot used because signal transmission require high-bandwidth for transfer of heavy data files, long distance transmission, high speed and immunity to electromagnetic interference. Under these circumstances, Optical fiber is best suitable.

Many researchers have undertaken reliability analysis of various complex systems under different types of failure modes [1]. Researchers have also considered single unit standby redundancy and three unit standby system with common cause failure mode [2] [3] in their models to increase the reliability of systems. In common cause failure mode failure of several units or components is due to single cause [2]. Herein some internal and external factors are attribution of common cause failure, where internal factors such as designing, fabrications, etc and externals ones are like environmental conditions (humidity, temperatures, dust) , earth quake , flood , humidity , power failure , fire etc . Common cause failure needs to be considered in understanding reliability parameters of a system, otherwise reliability will over-estimated.

To maintain reliability experiment is repeated many times under same conditions on number of test sample and then result is compared with control sample to obtain accurate result.

2. How does a fiber optic communication works

The optic fiber communication system contains two circuitry one for transmitting the data from source and another for receiving the signal and transmitting it to destination. In the transmitting circuitry, the data from source is converted into electrical signals which are then converted into light signals. These light signals are emitted by LED or Laser Diodes and they pass through optic fiber cables to travel long distances. The receiving circuitry contains phto-detectors which receive the light signal and converts it into electrical signal. These electrical signals are subsequently converted back to data format which was original transmitted [4].

The optic fiber cables use principle of total internal reflection to enable the light beams to travel through the cables without any loss of signal. The core of these cables is made up of high quality, highly flexible extruded glass or plastic. The cladding of core is done in such a manner that it does not allow the light source to pass through, thus causing total internal reflection. Since, the data travels for long distances, these optic fibers are connected to various amplifiers, switches and cables on its way to boost the signal strength. LED is used to emit light if data is required to travel for short distance. However, Laser Beam Transmitter or Laser Diode is used when the data is required to travel for long distance and at high speeds. The photo-detector present in receiving circuitry has ability to measure frequency, phase and magnitude of emitted light. PN photo diode and avalanche photo diode are two types of photo detector are used for optical receiver in optic communication system. Some of the prominent benefits of using optic fiber cables are: (1) small size (2) light weight (3) flexibility (4) negligible transmission loss, (5) large bandwidth etc. [5]

The Boolean variable based math system essentially comprises of following steps [6]:

1. Determine different working paths of system.

2. Define Boolean expression corresponding to the paths
3. Determine a disjoint expression comparing to the Boolean expressions.
4. Substitute the corresponding values of reliability to different Boolean units in order to obtain the reliability

3. Assumptions

- At time t=0 all components are in up-state.
- State of each component is either working or fail.
- Repair facility is unavailable
- The state of all the components is statistically independent of each other
- The failure time of all components is arbitrary.
- The supply between components is fully reliable.

Notations:

X_1,X_2: Input data

X_3: Transmitter

X_4, X_5 : capacitor of light source

X_6 :Fiber optic cable

X_7: Detector

X_8 : Receiver circuitry

| | : This is used to represent logical matrix.

Ri : Reliability of the ith component, ∀ i = 1,2,..17.

Rs : Reliability of the system , ∀ i = 1,2,..17.

Asw: Reliability of system when failure rate follows Weibull distribution with respect to time

Ase: Reliability of the system when failure rate follows exponential distribution with respect to time

4. Formulation of mathematical model

Using Boolean function technique, in a terms of logical matrix the condition of capability of successful operation of the system are expressed.

$$F(X_1, X_2, \dots X_8) = \begin{vmatrix} X_1 & X_3 & X_4 & X_6 & X_7 & X_8 \\ X_1 & X_3 & X_5 & X_6 & X_7 & X_8 \\ X_2 & X_3 & X_4 & X_6 & X_7 & X_8 \\ X_2 & X_3 & X_5 & X_6 & X_7 & X_8 \end{vmatrix}$$

5. Solution of model

By using logic algebra , we can write equation as:

$$F(X_1, X_2, \dots \dots . X_8) = |(X_3\ X_6 X_7 X_8) \wedge Ꚍ(X_1, X_2, \dots \dots . X_8)|$$

$$[\,X_3 X_6 X_7 X_8] \wedge \begin{vmatrix} X_1 & X_4 \\ X_1 & X_5 \\ X_2 & X_4 \\ X_2 & X_5 \end{vmatrix}$$

$$Ꚍ(X_1, X_2, \dots \dots . X_8) = \begin{vmatrix} X_1 & X_4 \\ X_1 & X_5 \\ X_2 & X_4 \\ X_2 & X_5 \end{vmatrix}$$

Where, $M_1 = |X_1 \quad X_4|$

$M_2 = |X_1 \quad X_5|$

$M_3 = |X_2 \quad X_4|$

$M_4 = |X_2 \quad X_5|$

Using Orthogonalization we can rewrite algorithm as

$$\text{Ʈ}(X_1, X_2, \ldots\ldots X_8) = \begin{vmatrix} M_1 & & & \\ M_1' & M_2 & & \\ M_1' & M_2' & M_3 & \\ M_1' & M_2' & M_3' & M_4 \end{vmatrix}$$

we get , $\begin{vmatrix} X_1 & X_2 & & \\ X_1 & X_4' & X_5 & \\ X_1' & X_2 & X_4 & \\ X_1' & X_2 & X_4 & X_5 \end{vmatrix}$

$(X_3X_6X_7X_8) \wedge \begin{vmatrix} X_1 & X_2 & & \\ X_1 & X_4' & X_5 & \\ X_1' & X_2 & X_4 & \\ X_1' & X_2 & X_4 & X_5 \end{vmatrix}$

Now putting all values in orthogonalization as

we get, $\begin{vmatrix} X_1 & X_2 & & \\ X_1 & X_4' & X_5 & \\ X_1' & X_2 & X_4 & \\ X_1' & X_2 & X_4 & X_5 \end{vmatrix}$

$(X_3X_6X_7X_8) \wedge \begin{vmatrix} X_1 & X_2 & & \\ X_1 & X_4' & X_5 & \\ X_1' & X_2 & X_4 & \\ X_1' & X_2 & X_4 & X_5 \end{vmatrix}$

=

$R_3R_6R_7R_8R_1R_2 + R_3R_6R_7R_8R_1R_4'R_5 + R_3R_6R_7R_8R_1'R_2R_4 + R_3R_6R_7R_8R_1'R_2R_4R_5$

= $[R^6 + R^6 - R^7 + R^6 - R^7 + R^7 - R^8]$

Where $R_i(i = 1,2,3, \ldots .8)$ $is\ reliability\ of\ section\ rate\ of X_i(\ i = 1,2,3, \ldots .8)$ respectively.

6. Some typical cases

Case 1: Reliability of each component is same (=R) then equation becomes:

$R_s = 3R^6 - R^7 - R^8$

Case 2: Failure rate of each component follows Weibull distribution with respect to time:

Suppose k_i is failure rate corresponding to section rate X_i, for all i = 1,2,3,….8 then reliability of optic fiber communication method at an instant 's' is given by:

A_{sw}(t) = 3 exp (-6kt^s) – exp (-7 kt^s) – exp (-8 kt^s)

Where s = positive integer.

Case 3: Failure rate of each component follows exponential distribution with respect to time

In Weibull distribution if shape parameter s = 1, then it becomes exponential distribution and in practical problem purpose it is very useful. The reliability of system in this case is

A_{SE} (t) = $3e^{-6kt} - e^{-7kt} - e^{-8kt}$

MTTF is given by

MTTF = $\int_0^\infty A(t)$ dt = 0.23214286/k

7. RESULT AND CONCLUSION

Table 1: Reliability of system for exponential and Weibull failure rate distribution with increase in time

T	A_{Sw}	A_{SE}
0	1	1
0.2	0.98	0.9899
0.4	0.94	0.9665
0.6	0.904	0.94554
0.8	0.8773	0.9028
1.0	0.8474	0.8474

1.2	0.8173	0.7835
1.4	0.7884	0.7065
1.6	0.7578	0.623
1.8	0.7295	0.5432

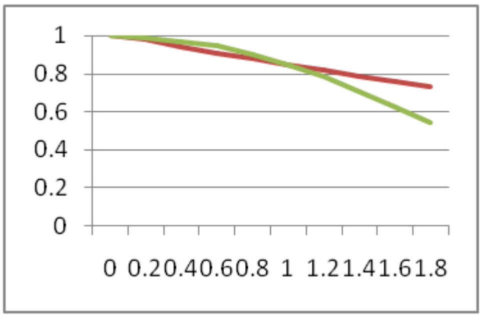

Figure 1. Reliability (Exponential and Weibull distribution) vs time

Table 2: Failure Rate vs MTTF

K (Failure Rate)	MTTF
0.1%	232.14286
0.2%	116.07143
0.3%	77.3809533
0.4%	58.035715
0.5%	46.428572
0.6%	38.6904767
0.8%	29.0178575
0.9%	25.7936511
1%	23.214286

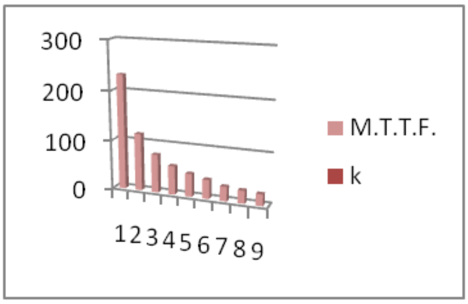

Figure 2 Failure Rate vs. MTTF

In this paper a fiber optic communication system has been considered for studying various reliability parameters by employing Boolean function techniques and algebra of logics. Table 1 compares decrease in reliability of system with respect to time under condition when failure rate of each component follows exponential and Weibull time distributions. This comparison is depicted by Fig 1 in which it can be observed that reliability of system shows uniform decline with increase in time if failure rate follows exponential distribution. However, this decline is steeper when failure rate follows Weibull distribution. Table 2 and Figure 2 represents effect in values of MTTF with increase in failure rate from 0.1% to 1% (Fig 2) It can be observed that initial decline in MTTF is rapid with increase in failure rate but later on this decline becomes uniform.

Future Work will be to assess reliability of fiber optic communication system using Neural Network [7].

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