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Modeling and Availability Analysis of Computer Networks using Fuzzy Reliability Approach

Anju*Pooja**
*Phd Scholar, Department of Mathematics, BMU, Rohtak
**Assistant Professor , Department of Mathematics, BMU, Rohtak

Abstract:
The traditional theory of reliability is based on the Bernoulli trials, i.e., either success or failure. However, itseems unrealistic for enormous complex systems like computer networks. To overcome this issue, in the present study, an effort has been made regarding the development of a mathematical model for a computer network system and analysis of fuzzy availability of the same. The concepts of constant failure, constant repair and coverage factor have been used for the development of the model. The impact of coverage factor, repair rates and failure rates of components has been analyzed on the fuzzy availability of the system. Markov birth-death process has been used for the development of Chapman-Kolmogorov differential equations. Theleading differential equations have been simplified by Runge–Kutta method of order four using MATLAB (Ode 45 function).

Keywords: Computer Network, Markov Process, Fuzzy Availability, Runge-Kutta Method, Coverage Factor.

Introduction

During the last few decades, computer networks become the integral part of human society as most of the infrastructural systems like power plants, communication systems, commercial systems, healthcare and academic system has become censoriously contingent on these. With the shifting of life critical and necessary facilities on internet, it becomes important to ensure the reliability and availability of these networks. Because, failure of these networks significantly affect the performance of network service and have disastrous results. Reliability and availability are the key attributes of the system performance. In literature, the traditional reliability theory approach has been extensively used for evaluation of performance measures of systems. The traditional theory of reliability is based on the Bernoulli trials, i.e., either success or failure. However, it seems unrealistic for enormous complex systems like computer networks. The assumption of Bernoulli states has been replaced by the technique of fuzzy reliability theory developed by Zadeh (1965). Fuzzy reliability theory provides the chance of studying all possible states that falls between operative and down states. This approach is known as profust reliability. Though, both the profust and traditional reliability approached have their own importance and no one can replace or dominant each other. But in current age, the performance of industrial systems based on computer networks can be efficiently analyzed by using profust reliability approach.

Literature Review:

Fratta and Montanari (1973) developed Boolean algebra methodology for computing the terminal reliability in a communication network. Ball (1980) discussed the complexity of network reliability computations.Dhillon and Singh (1981) applied the Markovian approach for availability analysis using constant repair and failure rates. Performance evaluation of sugar plant has been done by Kumar et al. (1989) using Markovian approach. Kumar and Singh (1989) derived the expression for availability of a washing system in paper industry. Singer (1990) established a new procedure to find out various reliability measures using fault tree and fuzzy set approach. Ghafoor et al. (1991) performed the reliability analysis of a fault-tolerant multi-bus multiprocessor system.The effect of fluctuating environment on the reliability of a system has been studied by Dayal and Singh (1992).Fuzzy system reliability using confidence interval has been discussed by Cheng and Mon (1993). Chen (1994) offered a new scheme for investigating system reliability using fuzzy number arithmetic operations.Utkin and Gurov (1995) articulated a universalrecognizedmethod for fuzzy reliability analysis.Lin and Chen (1997) discussed the computational complexity of reliability problem on distributed systems. Singh and Mahajan (1999) obtained long-run availability of a utensils manufacturing plant.The concept of imperfect repairs in maintained systems has been discussed for availability evaluation by Biswas and Sarkar (2000). Selvam et al. (2001) carried out the reliability evaluation of distributed computing networks using 2-mode failure. Knezevic and Odoom (2001) projected Petri nets methodology as an alternative of fault trees approach. Loman and Wang (2002) done reliability modeling and analysis of highly-reliable large systems.Sztrik and Kim (2003) has been appliedthe Markov-modulated finite-source queueing models in evaluation of computer and communication systems. Chen (2003) offered a new way for examining the fuzzy system reliability established on vague sets.Kumar andKumar and Aggarwal(1993) peformed Petri net modeling and reliability evaluation of distributed processing systems. Aliev and Kara (2004) studied fuzzy system reliability using time dependent fuzzy sets.Kumar et al. (2009) developed a mathematical model for a serial process in butter-oil processing plant and computed the fuzzy availability of the system. Garg and Sharma (2011) discussed the notion of fuzzy set theory to characterize the failure and repair data and evaluated the performance of the system using several reliability measures. Kumar and Kumar (2011) analyzed the fuzzy availability of a biscuit manufacturing plant.The intuitionistic fuzzy numbers in place of conventional reliability for reliability evaluation has been used by Kumar and Yadav (2012).Confidence Interval Based Fuzzy Lambda-Tau methodology for performance evaluation of complex systems has been proposed by Garg and Rani (2013).Aggarwal et al. (2014) studied the availability and performance of a butter oil production system by developing a mathematical model using fuzzy reliability theory. Aggarwal et al. (2016) articulated a mathematical model and obtained the results of fuzzy availability for the serial processes in feeding system of sugar plant. But most of the approaches used in the literature is time consuming. Also, the computer networks does not obey the rule of binary state. So in the present study, we make an effort to study the computer network as a whole system under fuzzy environment by using an advance numerical method Runge–Kutta method of order four. The needful data has been collected from the IT personals of a private university situated at Jaipur, India.

System Description:

A computer network is a system in which multiple computers are connected to each other to share information and resources. Computer network is designed by a combination of various subsystems. The main subsystems of a computer network isnetwork cables, distributors, routers, internal network cards and external network cards. The network cables and distributorscan be worked in degraded stage. The subsystems has been connected in series configuration with previous units and complete failure of the units resulted the complete failure of the whole system. The systematic flow diagram of the computer network and state transition diagram have been shown in figure-1& 2.

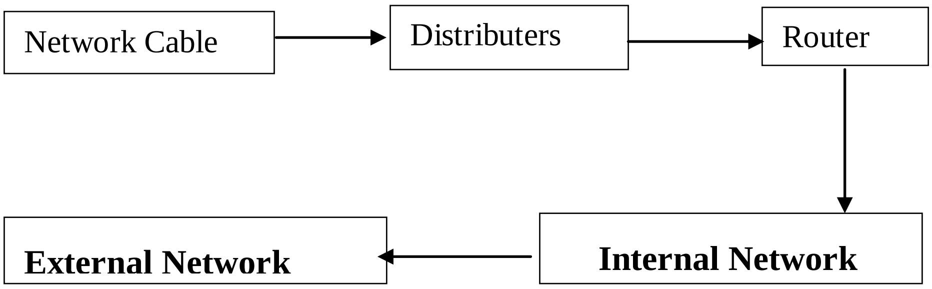

Figure-1: Flow Chart of Computer Network

Subsystem – A (Network Cables): The network cables plays a key role in system configuration. These are used to connect computers.
Subsystem- B (Distributors): It is a device to connect a computer to another one via a serial port but if we want to connect a number of computers to produce a network, thana central body is used to connect the computers. This central body is known as distributer.

Subsystem – C (Router): A router is a sort of device which acts as the central point among computers and other devices that are a part of the network. It is equipped with holes called ports. Computers and other devices are connected to a router using network cables.

Subsystem – D (InternalNetwork Card):Network card is a necessary component of a computer without which a computer cannot be connected over a network. Motherboard has a slot for internal network card where it is to be inserted. Internal network cards are of two types in which the first type uses Peripheral Component Interconnectconnection, while the second type uses Industry Standard Architecture.
Subsystem – E (External Network Card): External network cards can be divided into two categories one is wireless and other is USB based.

Material and Methods:

Fuzzy Set: Cai (1996) defined the fuzzy sets as a mathematical tool to investigate the real world systems fuzziness. Let $x \in X$ be an element of a conventional set then fuzzy set has been defined as a ordered pair of the element and the corresponding membership function over the interval [0, 1]. Mathematically $A = \{x, \mu_A(x)\}$ over [0, 1].

Profust Reliability: Cai (1996) defined the profust reliability as

$$R(t_0, t_0 + t) = P\{T_{SF}\, doesn't\, occur\, during\, the\, interval\, (t_0, t_0 + T)\}$$

$$= 1 - \sum_{i=1}^{n}\sum_{j=1}^{n} \mu_{T_{SF}}(m_{ij}) P\{m_{ij}\ occurs\ during\ (t_0, t_0 + T)\}$$

Where m_{ij} is confined to be the transition from state S_i to state S_j without passing via any intermediate state.

Fuzzy Availability:

Kumar and Kumar (2011) stated a fuzzy probabilistic semi- Markov model {(Sn, Tn), n € N} consisting of 'n' states together with transition time. Let U = {S1, S2,…,Sn} denote the universe of discourse. On this universe, we define a fuzzy success state S, S=$\{(S_i, \mu_S(S_i)); i = 1, 2, \ldots n\}$ and a fuzzy failure state F, $F = \{(S_i, \mu_F(S_i)); i = 1, 2, \ldots n\}$, where $\mu_S(S_i)$ *and* $\mu_F(S_i)$ are trapezoidal fuzzy numbers, respectively. The fuzzy availability of the system is defined as:

$A(t) = \sum_{i=1}^{k} \mu_S(S_i) P_i(t)$, where k denotes the operative states.

Markov Process:

If the state of the system is probability based, then the model is a Markov probability model. The fundamental assumption in Markov process is that, the probability P_{ij}, depends entirely on states S_i and S_j, and is independent of all previous states except the last one state S_i.

Notations:

α_1 & β_1: Failure and repair rates of subsystem A

α_2 & β_2: Failure and repair rates of subsystem B

α_3 & β_3: Failure and repair rates of subsystem C

α_5 & β_5: Failure and repair rates of subsystem D

α_4 & β_4: Failure and repair rates of subsystem E

$P_i(t)$: Probability that the system remains in state i at time t.

C: Coverage factor which varies from 0 to 1.

○ : Operative state of the system

◇ : Partially failed state of the system

□ : Failed State of the system

ENC: External Network Cards

INC: Internal Network Cards.

Assumptions:

- Two or more units cannot failssimultaneously.
- All random variables are statistically independent.
- Units after repair become as good as new.
- Failure and repair rates of original and partially failed units are equal.
- All random variables related to failure and repair follows exponential distribution.

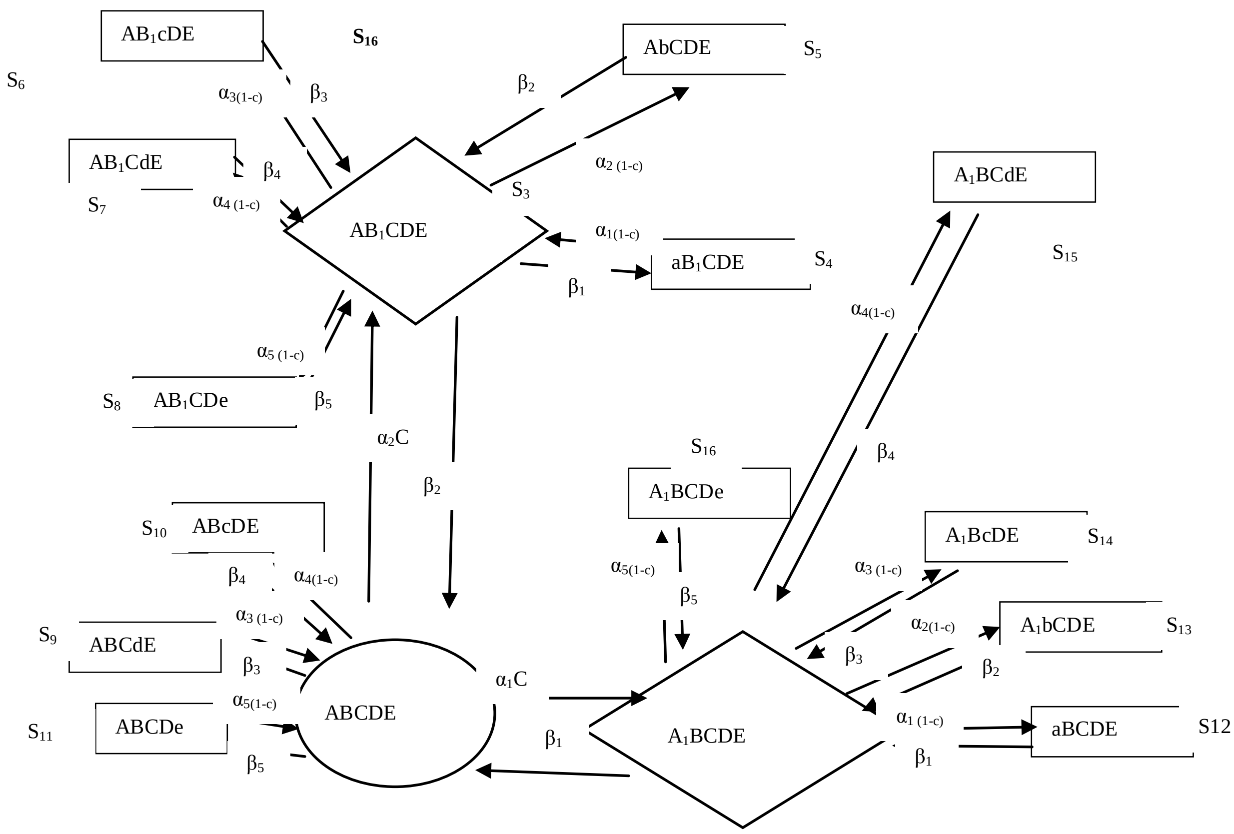

Fig. 2: State Transition Diagram

Formulation of Mathematical Model:

A mathematical model for a computer network has been formulated using Markov birth-death process. The followingChapman-Kolmogorov equations have been derived:

$$P_1(t+\Delta t)=[1-(\alpha_1 C+\alpha_2 C+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]\Delta t P_1(t)+\beta_1\Delta t P_2(t)+\beta_2\Delta t P_3(t)$$
$$+\beta_3\Delta t P_9(t)+\Delta t\beta_4 P_{10}(t)+\Delta t\beta_5 P_{11}(t)$$

$$P_1(t+\Delta t)-P_1(t)+[(\alpha_1 C+\alpha_2 C+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]\Delta t P_1(t)=\beta_1\Delta t P_2(t)+\beta_2\Delta t P_3(t)$$
$$+\beta_3\Delta t P_9(t)+\Delta t\beta_4 P_{10}(t)+\Delta t\beta_5 P_{11}(t) \qquad (*)$$

Dividing equation (*) both sides by Δt, we get

$$\frac{P_1(t+\Delta t)-P_1(t)}{\Delta t}+[(\alpha_1 C+\alpha_2 C+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]P_1(t)=\beta_1 P_2(t)+\beta_2 P_3(t)$$
$$+\beta_3 P_9(t)+\beta_4 P_{10}(t)+\beta_5 P_{11}(t) \qquad (**)$$

Taking limit $\Delta t\to 0$ on equation (**), we obtained

$$\frac{dP_1(t)}{dt}+[(\alpha_1 C+\alpha_2 C+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]P_1(t)=\beta_1 P_2(t)+\beta_2 P_3(t)$$
$$+\beta_3 P_9(t)+\beta_4 P_{10}(t)+\beta_5 P_{11}(t) \qquad (1)$$

$$\frac{dP_2(t)}{dt}+[(\beta_1+\alpha_1(1-C)+\alpha_2(1-C)+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]P_2(t)=\beta_1 P_{12}(t)+\beta_2 P_{13}(t)$$
$$+\beta_3 P_{14}(t)+\beta_4 P_{15}(t)+\beta_5 P_{16}(t)+\alpha_1 C P_1(t) \qquad (2)$$

$$\frac{dP_3(t)}{dt}+[(\beta_2+\alpha_1(1-C)+\alpha_2(1-C)+\alpha_3(1-C)+\alpha_4(1-C)+\alpha_5(1-C))]P_3(t)=\beta_1 P_4(t)+\beta_2 P_5(t)$$
$$+\beta_3 P_6(t)+\beta_4 P_7(t)+\beta_5 P_8(t)+\alpha_2 C P_1(t) \qquad (3)$$

$$\frac{dP_4(t)}{dt}+\beta_1 P_4(t)=\alpha_1(1-C)P_3(t) \quad (4)$$

$$\frac{dP_5(t)}{dt}+\beta_2 P_5(t)=\alpha_2(1-C)P_3(t) \quad (5)$$

$$\frac{dP_6(t)}{dt}+\beta_3 P_6(t)=\alpha_3(1-C)P_3(t) \quad (6)$$

$$\frac{dP_7(t)}{dt}+\beta_4 P_7(t)=\alpha_4(1-C)P_3(t) \quad (7)$$

$$\frac{dP_8(t)}{dt}+\beta_5 P_8(t)=\alpha_5(1-C)P_3(t) \quad (8)$$

$$\frac{dP_9(t)}{dt}+\beta_3 P_9(t)=\alpha_3(1-C)P_1(t) \quad (9)$$

$$\frac{dP_{10}(t)}{dt}+\beta_4 P_{10}(t)=\alpha_4(1-C)P_1(t) \quad (10)$$

$$\frac{dP_{11}(t)}{dt}+\beta_5 P_{11}(t)=\alpha_5(1-C)P_1(t) \quad (11)$$

$$\frac{dP_{12}(t)}{dt}+\beta_1 P_{12}(t)=\alpha_1(1-C)P_2(t) \quad (12)$$

$$\frac{dP_{13}(t)}{dt}+\beta_2 P_{13}(t)=\alpha_2(1-C)P_2(t) \quad (13)$$

$$\frac{dP_{14}(t)}{dt}+\beta_3 P_{14}(t)=\alpha_3(1-C)P_2(t) \quad (14)$$

$$\frac{dP_{15}(t)}{dt}+\beta_4 P_{15}(t)=\alpha_4(1-C)P_2(t) \quad (15)$$

$$\frac{dP_{16}(t)}{dt}+\beta_5 P_{16}(t)=\alpha_5(1-C)P_2(t) \quad (16)$$

with initial conditions:

$$P_i(0)=\begin{cases}1, & if\ \ i=1\\ 0, & if\ \ i\neq 1\end{cases} \quad (17)$$

The numerical method Runge-Kutta method of 4th order has been used to solve the system of linear differential equations (1) to (16) along with initial condition delivered by equation (17). The numerical result has been achieved for above defined set of assumptions. The system's fuzzy availability has been computed for a duration of 360 days. To highlight the importance of the study various choices of failure rate, repair rate and coverage factor have been taken. The equation of fuzzy availability is composed as follows:

$$Fuzzy\ Availability=P_0(t)+\frac{4}{5}\ P_1(t)\ +\frac{4}{5}\ P_2(t) \quad (18)$$

Performance Analysis

In this section, a numerical results have been obtained for the fuzzy availability of a computer network using equation (18) for a stationary set of values of the various parameters. The analysis has been done with respect to various values of repair rate, failure rate and coverage factor.

Effect of coverage factor (c) on the fuzzy availability of the computer network

For a specified set of failure and repair rates stationary values the numerical results of fuzzy availability has been depicted for various values of coverage factor , i.e., for c= 0, 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1 with respect to time as shown in table- 1. The specified values are defined as follows: $\alpha_1 = 0.0025$, $\alpha_2 = 0.0002$, $\alpha_3 = 0.0021$, $\alpha_4 = 0.0001$, $\alpha_5 = 0.004$ and $\beta_1 = 0.5$, $\beta_2 = 0.71$, $\beta_3 = 0.4$, $\beta_4 = 0.55$, $\beta_5 = 0.65$. The time duration has been taken up to 300 hours with a constant variation of 30 hours. From table-1, it is identified that the fuzzy availability decreased with respect to time. The coverage factor plays a key role in the fuzzy availability of the system if the fault has been detected successfully with high value of coverage factor then system is highly available for use. There is approximately 1 % variation in the value of fuzzy availability for c=0 to c=1. Therefore, we conclude that for c=1 system is highly available whereas for c=0 system is less available.

Table 1: Effect of coverage factor (C) on the fuzzy availability of computer network w.r.t.time

Time	C=0	C=0.1	C=0.2	C=0.3	C=0.4	C=0.5	C=0.6	C=0.7	C=0.8	C=0.9	C=1
60	0.9886	0.9896	0.99078	0.99176	0.99276	0.99376	0.99486	0.99586	0.99686	0.99796	0.99904
120	0.9886	0.9896	0.99078	0.99168	0.99276	0.99376	0.99486	0.99586	0.99686	0.99796	0.99904
180	0.9886	0.9896	0.99058	0.99168	0.99268	0.99368	0.99478	0.99576	0.99686	0.99796	0.99904
240	0.9886	0.9896	0.99058	0.99168	0.99268	0.99368	0.99478	0.99576	0.99686	0.99796	0.99904
300	0.9886	0.9896	0.99058	0.99168	0.99268	0.99368	0.99478	0.99576	0.99686	0.99796	0.99904

The effect of failure and repair rates of network cables on the fuzzy availability of the computer network has been analyzed for different values of failure and repair rates of network cables. The failure rate (α_1) and repair rate (β_1) lies in the intervals $[0.0025, 0.2]$ and $[0.5, 1.4]$ respectively. From table-2, it is identified that availability decreases as failure rate increase and increases as repair rate increases. For c=1, there is no effect of variation in the repair and failure rates on the system's availability.

Table 2: Effect of failure rate (α_1) and repair rate (β_1) of network cable on the fuzzy availability of computer network w.r.t. time

Coverage Factor	Time (days)	Failurerate of Network Cable $\alpha_1 = 0.0025$			Repair rates of Network Cable $\beta_1 = 0.5$		
			$\alpha_1 = 0.02$	$\alpha_1 = 0.2$		$\beta_1 = 0.98$	$\beta_1 = 1.4$
C=1	60	0.99904	0.99234	0.943	0.99904	0.99944	0.99968
	120	0.99894	0.99234	0.94274	0.99894	0.99944	0.99968
	180	0.99894	0.99234	0.94264	0.99894	0.99944	0.9995
	240	0.99894	0.99208	0.94264	0.99894	0.99934	0.9995
	300	0.99894	0.99208	0.94264	0.99894	0.99934	0.9995
C=0.8	60	0.99686	0.99128	0.93132	0.99686	0.99734	0.99738
	120	0.99686	0.9912	0.93132	0.99686	0.99724	0.99738
	180	0.99686	0.9911	0.93122	0.99686	0.99716	0.99728
	240	0.99686	0.991	0.93122	0.99686	0.99716	0.99728
	300	0.99686	0.991	0.93114	0.99686	0.99716	0.99728
C=0.5	60	0.99376	0.98996	0.9302	0.99376	0.994	0.994
	120	0.99376	0.98988	0.9302	0.99376	0.99392	0.9939
	180	0.99368	0.98988	0.9302	0.99368	0.99392	0.9939
	240	0.99368	0.98988	0.9302	0.99368	0.99384	0.9939
	300	0.99368	0.98978	0.92994	0.99368	0.99374	0.9939
C=0	60	0.9886	0.9885	0.9885	0.9886	0.9886	0.9886
	120	0.9886	0.9885	0.9885	0.9886	0.9886	0.9886
	180	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886
	240	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886
	300	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886

The effect of failure and repair rates of distributers on the fuzzy availability of the computer network has been analyzed for different values of failure and repair rates of network cables. The failure rate (α_2) and repair rate (β_2) lies in the intervals $[0.0002, 0.5]$ and $[0.71, 1.9]$ respectively. From table-3, it is identified that availability decreases as failure rate increase and increases as repair rate increases. For c=0.5, 0.8 &1, there is steep variation in system's availability w.r.t failure and repair rates.

Table 3: Effect of failure rate (α_2) and repair rate (β_2) of distributers on the fuzzy availability of computer network w.r.t. time

Coverage Factor	Time (days)	Failure rate of Distributers $\alpha_2 = 0.0002$	$\alpha_2 = 0.03$	$\alpha_2 = 0.5$	Repair rates of Distributers $\beta_2 = 0.71$	$\beta_1 = 1.2$	$\beta_1 = 1.9$
C=1	60	0.99904	0.99098	0.91702	0.99904	0.99906	0.99898
	120	0.99894	0.99098	0.91692	0.99894	0.99906	0.99898
	180	0.99894	0.99098	0.91692	0.99894	0.99906	0.99898
	240	0.99894	0.99088	0.91692	0.99894	0.99896	0.99898
	300	0.99894	0.99088	0.91692	0.99894	0.99888	0.99898
C=0.8	60	0.99686	0.99004	0.8803	0.99686	0.9969	0.99688
	120	0.99686	0.99004	0.8803	0.99686	0.9968	0.99688
	180	0.99686	0.98996	0.8803	0.99686	0.9968	0.99688
	240	0.99686	0.98986	0.8803	0.99686	0.9967	0.99688
	300	0.99686	0.98986	0.8803	0.99686	0.9967	0.99688
C=0.5	60	0.99376	0.98912	0.86256	0.99376	0.99378	0.9937
	120	0.99376	0.98912	0.86246	0.99376	0.99378	0.9937
	180	0.99368	0.98912	0.86246	0.99368	0.99378	0.9937
	240	0.99368	0.98902	0.86246	0.99368	0.99378	0.9937
	300	0.99368	0.98902	0.86246	0.99368	0.99378	0.9937
C=0	60	0.9886	0.9885	0.9885	0.9886	0.9886	0.9886
	120	0.9886	0.9885	0.9885	0.9886	0.9886	0.9886
	180	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886
	240	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886
	300	0.9886	0.9884	0.9884	0.9886	0.9886	0.9886

The effect of failure and repair rates of router on the fuzzy availability of the computer network has been analyzed for different values of failure and repair rates of network cables. The failure rate (α_3) and repair rate (β_3) lies in the intervals $[0.0021, 0.9]$ and $[0.4, 1.6]$ respectively. From table-4, it is identified that availability decreases as failure rate increase and increases as repair rate increases. For c=0.5, 0.8 & 1, there is steep variation in system's availability w.r.t failure and repair rates.

Table 4: Effect of failure rate (α_3) and repair rate (β_3) of router on the fuzzy availability of computer network w.r.t. time

Coverage Factor	Time (days)	Failure rates of Router $\alpha_3 = 0.0021$ $\alpha_3 = 0.3$ $\alpha_3 = 0.9$			Repair rates of Router $\beta_3 = 0.4$ $\beta_3 = 0.9$ $\beta_3 = 1.6$		
C=1	60	0.99904	0.99904	0.99904	0.99904	0.99904	0.99904
	120	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	180	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	240	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	300	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
C=0.8	60	0.99686	0.86786	0.68844	0.99686	0.99746	0.99756
	120	0.99686	0.86786	0.68844	0.99686	0.99746	0.99756
	180	0.99686	0.86786	0.68834	0.99686	0.99736	0.99746
	240	0.99686	0.86786	0.68834	0.99686	0.99736	0.99746
	300	0.99686	0.86786	0.68834	0.99686	0.99736	0.99746
C=0.5	60	0.99376	0.72522	0.46976	0.99376	0.99528	0.99568
	120	0.99376	0.72522	0.46964	0.99376	0.99518	0.99568
	180	0.99368	0.72522	0.46964	0.99368	0.99518	0.99558
	240	0.99368	0.72522	0.46964	0.99368	0.99518	0.99558
	300	0.99368	0.72522	0.46964	0.99368	0.99518	0.99558
C=0	60	0.9886	0.5694	0.3071	0.9886	0.9914	0.9924
	120	0.9886	0.5694	0.3071	0.9886	0.9914	0.9924
	180	0.9886	0.5694	0.3071	0.9886	0.9914	0.9924
	240	0.9886	0.5694	0.307	0.9886	0.9914	0.9924
	300	0.9886	0.5694	0.307	0.9886	0.9914	0.9924

The effect of failure and repair rates of External Network Cards (ENC) on the fuzzy availability of the computer network has been analyzed for different values of failure and repair rates of network cables. The failure rate (α_4) and repair rate (β_4) lies in the intervals $[0.0001, 0.83]$ and $[0.55, 1.3]$ respectively. From table-5, it is identified that availability decreases as failure rate increase and increases as repair rate increases. For c=0, 0.5, 0.8 there is very steep variation in system's availability w.r.t failure and repair rates.

Table 5: Effect of External Network Cards (ENC) failure rate (α_4) and repair rate (β_4) on the fuzzy availability of computer network w.r.t. time

Coverage Factor	Time (days)	Failure rates of ENC $\alpha_4 = 0.0001$ $\alpha_4 = 0.5$ $\alpha_4 = 0.83$			Repair rates of ENC $\beta_4 = 0.55$ $\beta_4 = 0.9$ $\beta_4 = 1.3$		
C=1	60	0.99904	0.99904	0.99904	0.99904	0.99904	0.99904
	120	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	180	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	240	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	300	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
C=0.8	60	0.99686	0.84386	0.76616	0.99686	0.99686	0.99686
	120	0.99686	0.84378	0.76616	0.99686	0.99686	0.99686
	180	0.99686	0.8437	0.76616	0.99686	0.99686	0.99686
	240	0.99686	0.8437	0.76616	0.99686	0.99686	0.99686
	300	0.99686	0.8437	0.76616	0.99686	0.99686	0.99686
C=0.5	60	0.99376	0.68444	0.5678	0.99376	0.99378	0.99378

	120	0.99376	0.68444	0.5678	0.99376	0.99378	0.99378
	180	0.99368	0.68434	0.5678	0.99368	0.99368	0.99368
	240	0.99368	0.68434	0.5678	0.99368	0.99368	0.99368
	300	0.99368	0.68434	0.5678	0.99368	0.99368	0.99368
C=0	60	0.9886	0.5207	0.3968	0.9886	0.9886	0.9887
	120	0.9886	0.5207	0.3968	0.9886	0.9886	0.9887
	180	0.9886	0.5206	0.3968	0.9886	0.9886	0.9886
	240	0.9886	0.5206	0.3968	0.9886	0.9886	0.9886
	300	0.9886	0.5206	0.3968	0.9886	0.9886	0.9886

The effect of failure and repair rates of Internal Network Cards (INC) on the fuzzy availability of the computer network has been analyzed for different values of failure and repair rates of network cables. The failure rate (α_5) and repair rate (β_5) lies in the intervals $[0.0001, 0.83]$ and $[0.55, 1.3]$ respectively. From table-6, it is identified that availability decreases as failure rate increase and increases as repair rate increases. For c=0, 0.5, 0.8 there is very steep variation in system's availability w.r.t failure and repair rates.

Table 6: Effect of Internal Network Cards (INC) failure rate (α_5) and repair rate (β_5) on the fuzzy availability of computer network w.r.t. time

Coverage Factor	Time (days)	Failure rate of Network Cable $\alpha_5 = 0.004$	$\alpha_5 = 0.4$	$\alpha_5 = 0.91$	Repair rates of Network Cable $\beta_5 = 0.65$	$\beta_5 = 0.92$	$\beta_5 = 1.5$
C=1	60	0.99904	0.99904	0.99904	0.99904	0.99904	0.99904
	120	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	180	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	240	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
	300	0.99894	0.99894	0.99894	0.99894	0.99894	0.99894
C=0.8	60	0.99686	0.88876	0.77994	0.99686	0.99716	0.99756
	120	0.99686	0.88876	0.77994	0.99686	0.99716	0.99746
	180	0.99686	0.88876	0.77994	0.99686	0.99706	0.99746
	240	0.99686	0.88876	0.77994	0.99686	0.99706	0.99746
	300	0.99686	0.88876	0.77994	0.99686	0.99706	0.99746
C=0.5	60	0.99376	0.7627	0.58708	0.99376	0.99458	0.99538
	120	0.99376	0.7627	0.58698	0.99376	0.99458	0.99538
	180	0.99368	0.76262	0.58698	0.99368	0.99458	0.99538
	240	0.99368	0.76262	0.58698	0.99368	0.99458	0.99538
	300	0.99368	0.76262	0.58698	0.99368	0.99458	0.99538
C=0	60	0.9886	0.617	0.4157	0.9886	0.9903	0.9919
	120	0.9886	0.6169	0.4157	0.9886	0.9903	0.9919
	180	0.9886	0.6169	0.4157	0.9886	0.9903	0.9919
	240	0.9886	0.6169	0.4156	0.9886	0.9902	0.9919
	300	0.9886	0.6169	0.4156	0.9886	0.9902	0.9919

Conclusion

The availability analysis of computer network carried out above helps in increasing the successful operation of any network or industry based on it. For above analysis, we analyze that coverage factor along with increased failure rate of subsystems plays key role in the failure of a system. A comparative study shows that router, internal network cards (INC) and external network cards

(INC) have a prominent effect on the system than that of the other units. The network cables and distributers have the capability to work in the degraded situation but router, internal network cards (INC) and external network cards (INC) failed directly. So, we conclude that by improving the process of fault coverage, providing standby units to router, internal network cards (INC) and external network cards (INC) and adopting proper maintenance policies the fuzzy availability will be improved.

References

1. Aggarwal, A. K., Kumar, S., & Singh, V. (2016). Mathematical modeling and fuzzy availability analysis for serial processes in the crystallization system of a sugar plant. *Journal of Industrial Engineering International*, 1-12.
2. Aggarwal, A. K., Singh, V., & Kumar, S. (2014). Availability analysis and performance optimization of a butter oil production system: a case study. *International Journal of System Assurance Engineering and Management*, *8*(1), 538-554.
3. Aliev, I. M., & Kara, Z. (2004). Fuzzy system reliability analysis using time dependent fuzzy set. *Control and Cybernetics*, *33*(4), 653-662.
4. Biswas A, Sarkar J (2000) Availability of a system maintained through several imperfect repair before a replacement or a perfect repair. Stat Reliab Lett 50:105–114
5. Ball, M.O. "Complexity of network reliability computations", *Networks*, vol. 10, pp. 153-165, 1980.
6. Cai, K. Y. (1996). Introduction to Fuzzy Reliability. Kluwer Academic Publishers. *Norwell, MA, USA*.
7. Cheng CH, Mon DL (1993) Fuzzy system reliability analysis by interval of confidence. Fuzzy Sets Syst 56(1):29–35
8. Chen, S. M. (1994). Fuzzy system reliability analysis using fuzzy number arithmetic operations. *Fuzzy sets and systems*, *64*(1), 31-38.
9. Chen, S. M. (2003). Analyzing fuzzy system reliability using vague set theory. *International Journal of Applied Science and Engineering*, *1*(1), 82-88.
10. Dayal B, Singh J (1992) Reliability analysis of a system in a fluctuating environment. Microelectron Reliab 32:601–603
11. Dhillon BS, Singh C (1981) Engineering reliability-new techniquesand applications. Wiley, New York
12. Fratta, L. Montanari, U. G.. "A Boolean algebra method for computing the terminal reliability in a communication network", *IEEE Trans. Circuit Theory*, vol. CT-20, pp. 203-211, May 1973.
13. Ghafoor, A. Goel, A.L. Chan, J.K., Tsorng-Ming Chen, Sheikh, S., "Reliability analysis of a fault-tolerant multi-bus multiprocessor system", *Parallel and Distributed Processing 1991. Proceedings of the Third IEEE Symposium on*, pp. 436-443, 1991.
14. Garg H, Sharma SP (2011) Multi-objective optimization of crystallization unit in a fertilizer plant using particle swarm optimization.Int J Appl Sci Eng 9(4):261–276
15. Garg, H., & Rani, M. (2013). An approach for reliability analysis of industrial systems using PSO and IFS technique. *ISA transactions*, *52*(6), 701-710.
16. Knezevic, J., &Odoom, E. R. (2001). Reliability modelling of repairable systems using Petri nets and fuzzy Lambda–Tau methodology. *Reliability Engineering & System Safety*, *73*(1), 1-17.
17. Kumar, K., & Kumar, P. (2011). Fuzzy availability modeling and analysis of biscuit manufacturing plant: a case study. *International Journal of System Assurance Engineering and Management*, *2*(3), 193-204.
18. Kumar, M., & Yadav, S. P. (2012). The weakest t-norm based intuitionistic fuzzy fault-tree analysis to evaluate system reliability. *ISA transactions*, *51*(4), 531-538.
19. Kumar, K., Singh, J., & Kumar, P. (2009). Fuzzy reliability and fuzzy availability of the serial process in butter-oil processing plant. *Journal of Mathematics and Statistics*, *5*(1), 65-71.
20. Kumar P., Aggarwal K.K.: Petri net modeling and reliability evaluation of distributed processing systems. Reliab. Eng. System Safety **41**(2), 167–176 (1993)
21. Kumar D, Singh J (1989) Availability of a washing system in the Paper Industry. Microelectron Reliab 29:775–778

22. Kumar, D., Singh, J., & Pandey, P. C. (1989). Availability of a washing system in the paper industry. *Microelectronics Reliability*, *29*(5), 775-778.
23. Lin,M. S., Chen. D. J., The computational complexity of reliability problem on distributed systems. *Information Processing Letters*. 64(3): 143–147, 1997.
24. Loman, J., Wendai Wang, "On reliability modeling and analysis of highly-reliable large systems", *Reliability and Maintainability Symposium 2002. Proceedings. Annual*, pp. 456-459, 2002, ISSN 0149-144X.
25. Selvam,S., Moinuddin, Kamal, Ahmed,U. "Reliability Evaluation of Distributed Computing Networks using 2-mode Failure Analysis", *IETE Technical Review*, vol. 18, pp. 45, 2001, ISSN 0256-4602.
26. Singer, D. (1990). A fuzzy set approach to fault tree and reliability analysis. *Fuzzy sets and systems*, *34*(2), 145-155.
27. Singh J, Mahajan P (1999) Reliability of utensils manufacturing plant—a case study. Oper Res 36(3):260–269
28. Utkin, L. V., &Gurov, S. V. (1996). A general formal approach for fuzzy reliability analysis in the possibility context. *Fuzzy sets and systems*, *83*(2), 203-213.
29. Zadeh, L. A. (1965). Fuzzy sets. *Information and control*, *8*(3), 338-353.