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PEFORMANCE ANALYSIS OF A BASE TRANSCEIVER SYSTEM WITH CONSIDERATION OF REGULAR AS WELL AS EXPERT REPAIR TEAMS

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Abstract

In this study a stochastic model for a Base Transceiver System (BTS) is proposed considering two types of repair teams - a regular repair team and expert repair team to handle various types of major/minor hardware and software faults, hardware-software interactions faults, common cause failures and manual network restoration on traffic congestion. The regular repair team is, generally, available on site whereas expert repair team is available only on call.The occurrence of a minor fault leads to partial failure whereas a major fault and common-cause failure leads to complete failure of the system. Whenever a major/minor fault is detected, the regular repair team available on site inspects the system to judge whether there is a hardware/software fault or hardware-software interactions faults and accordingly repair the system. However the regular repair team may not be able to repair some complex faults. In case the team is not able to repair the system successfully, the expert repair team is called for the purpose that instantaneously resolves the problem. Network traffic congestion can be removed automatically or in case not, regular repair team first inspects that how much traffic congestion is there, then accordingly hardware or software expansion of the system is done. Using Markov processes and regenerative point technique various measures of system performance are obtained. On the basis of these measures the performance analysis of the system is carried out. Various conclusions about reliability and performance of the system are made on the basis of the graphical studies.

Keywords: Base Transceiver System (BTS), hardware based software fault, software based hardware fault, common cause failure, Mean time to system failure, expected uptime, expected degradation time, expected congestion time, hardware expansion, software expansion, Profit, Markov process and regenerative point technique.

INTRODUCTION

Mobile Phones are the most perfect way to stay connected and this importance of mobile phones has led mobile operators/companies to focus more and more on improving performance of mobile communication systems and that too without much increase in cost to face market competition. A base transceiver station (BTS) is the most important networking component of the system from which all signals are sent and received and its reliability and performance plays a crucial and significant role.

Several researchers including Bothwell et al (1996), Purohit and Tokekar (2008) and Ahsan et al (2010) discussed performability of different mobile communication systems.

Hammer and Michael (1999) investigated traffic congestion patterns. Ohsneme et al (2012) evaluated performance of mobile network interconnections. Sugawara (2013) provided solution to congestion problems of mobile communication services during major natural disasters. Kumar and Kapoor (2013) carried out performance evaluation of a BTS considering various operational modes and catastrophic failures. Kumar and Kapoor (2014) analyse the performance of a Base Transceiver system considering software based hardware faults and common cause failures. Moreover in past, some researchers Tuteja et al. (1991), Rizwan (2007), Sindhu and Gupta (2002) have also analysed other systems considering different types of repairman. However none of the researcher has carried out the performance analysis of a BTS considering two types of repair teams-Regular and Expert along with various other hardware/software/hardware-software interactions faults and hardware/software expansion on network traffic congestion.

Keeping this practical situation in view a stochastic model for a Base Transceiver System (BTS) is considered with two types of repair teams - a regular repair team and expert repair team to handle various types of major/minor hardware and software faults, hardware-software interactions faults, common cause failures and manual network restoration on traffic congestion. The regular repair team is, generally, available on site whereas expert repair team is available only on call.The occurrence of a minor fault leads to partial failure whereas a major fault and common-cause failure leads to complete failure of the system. Whenever a major/minor fault is detected, the regular repair team available on site inspects the system to judge whether there is a hardware/software fault or hardware-software interactions faults and accordingly repair the system. However the regular repair team may not be able to repair some complex faults. In case the team is not able to repair the system successfully, the expert repair team is called for the purpose that instantaneously resolves the problem. Network traffic congestion can be removed automatically or in case not, regular repair team first inspects that how much traffic congestion is there, then accordingly hardware or software expansion of the system is done.Using Markov processes and regenerative point technique various measures of system performance are obtained. On the basis of these measures the performance analysis of the system is carried out. Various conclusions about reliability and performance of the system are made on the basis of the graphical studies.

Other Assumptions

1. A minor or major fault may be in a pure hardware or pure software or hardware based software components.
2. In the system network traffic congestion takes place at any time and can be removed automatically or manually.
3. Rates of occurrence of fault/failure, network traffic congestion, automatic/ manual restoration on traffic congestion are constant whereas repair/ replacement and inspection time distributions are arbitrary.
4. Regular repair team may not be able to repair some complex faults whereas expert repair team able to repair perfectly all kinds of the faults.
5. Only the expert repair team carries out repairs on common cause failures and hardware expansion of the system.
6. Both the teams take negligible time to reach the system.
7. The system is as good as new after each repair.
8. Switching is perfect and instantaneous.
9. All random variables are mutually independent.
10. Faults are self announcing by alarm.

Acronyms

MTSF	Mean Time to System Failure
H/W , S/W	Hardware , Software
HBS/W	Hardware based Software
SBH/W	Software based Hardware

States of the System

O	Operative state
O_c	Congestion state
O_i / F_i / O_{c_i}	Degradation state/Failed state/Congestion state under inspection
O_{h_r} / O_{s_r} / O_{hs_r}	Degradation state due to hardware/software/hardware based software fault under repair
$O_{sh_{rp}}(t)$ / $F_{sh_{rp}}(t)$	Degradation state/failed state due to minor/major software based hardware fault under replacement
O_{c_h} / O_{c_s}	Congestion state under hardware/software expansion
F_{h_r} / F_{s_r} / F_{hs_r}	Failed state due to hardware/software/hardware based software fault under repair
$O_{h_{re}}$ / $F_{h_{re}}$	Degradation/Failed state due to hardware fault under repair by expert repair team
$O_{s_{re}}$ / $F_{s_{re}}$	Degradation/Failed state due to software fault under repair by expert repair team
$O_{hs_{re}}$ / $F_{hs_{re}}$	Degradation/Failed state due to hardware based software fault under repair by expert repair team
$O_{sh_{rpe}}$ / $F_{sh_{rpe}}$	Degradation/Failed state due to software based hardware fault under replacement by expert repair team
$F_{cf_{re}}$	Failed state due to common cause failure under repair by expert repair team
$O_{c_{hre}}$ / $O_{c_{sre}}$	Congestion state under hardware/software expansion by expert repair team

Notations

$\lambda_1(t)/\lambda_2(t)$	Rate of occurrence of major/minor faults
$\lambda_3(t)/\lambda_4(t)$	Rate of occurrence of major/minor hardware based software faults
$\lambda_5(t)/\lambda_6(t)$	Rate of occurrence of major/minor software based hardware faults
η	Network traffic congestion rate
δ_1	Automatic network restoration rate
δ_2	Manual network restoration rate
a_1 / a_2	Probability that the major/minor hardware fault occurs in the system
b_1 / b_2	Probability that the major/minor software fault occurs in the system
c_1 / c_2	Probability that the major/minor hardware based software fault occurs in the system
d_1	Probability that the common cause failure occurs in the system
p_1 / q_1	Probability that the system restored automatically/manually from traffic congestion
p_2 / q_2	Probability that hardware/software expansion is carried out
$q_{ij}(t)/Q_{ij}(t)$	Probability of transitions from state 'i' to state 'j'
$g_{h_1}(t)/g_{h_2}(t)$	P.d.f. of repair time of major/minor hardware fault

$g_{s_1}(t)/g_{s_2}(t)$	P.d.f. of repair time of major/minor software fault
$g_{h_3}(t)/g_{h_4}(t)$	P.d.f. of repair time of major/minor hardware based software fault
$g_{c_f}(t)/G_{c_f}(t)$	P.d.f./C.d.f of repair time of common cause failure
$i_1(t)/i_2(t)$	P.d.f. of inspection time of major/minor fault
$I_1(t)/I_2(t)$	C.d.f. of inspection time of major/minor fault
$i_3(t)/I_3(t)$	P.d.f/C.d.f of inspection time of traffic congestion
$u_{h_1}(t)/U_{h_1}(t)$	P.d.f/C.d.f. of the hardware expansion time of the system
$u_{s_1}(t)/U_{s_1}(t)$	P.d.f/C.d.f. of the software expansion time of the system
$G_{h_1}(t)/G_{h_2}(t)$	C.d.f. of repair time of major/minor hardware fault
$G_{s_1}(t)/G_{s_2}(t)$	C.d.f. of repair time of major/minor software fault
$G_{h_3}(t)/G_{h_4}(t)$	C.d.f. of repair time of major/minor hardware based software fault
$h_{h_3}(t)/h_{h_4}(t)$	P.d.f. of replacement time of major/minor software based hardware fault
$H_{h_3}(t)/H_{h_4}(t)$	C.d.f. of replacement time of major/minor software based hardware fault
p_3/q_3	Probability that regular repair team is able/unable to repair the system, $q_3=1-p_3$
$g_{he_1}(t)/G_{he_1}(t)$	P.d.f./C.d.f. of repair time of major hardware fault by expert repair team
$g_{he_2}(t)/G_{he_2}(t)$	P.d.f./C.d.f. of repair time of minor hardware fault by expert repair team
$g_{se_1}(t)/G_{se_1}(t)$	P.d.f./C.d.f. of repair time of major software fault by expert repair team
$g_{se_2}(t)/G_{se_2}(t)$	P.d.f./C.d.f. of repair time of minor software fault by expert repair team
$g_{he_3}(t)/G_{he_3}(t)$	P.d.f./C.d.f. of repair time of major hardware based software fault by expert repair team
$g_{he_4}(t)/G_{he_4}(t)$	P.d.f./C.d.f. of repair time of minor hardware based software fault by expert repair team
$h_{he_3}(t)/H_{he_3}(t)$	P.d.f./C.d.f. of repair time of major software based hardware fault by expert repair team
$h_{he_4}(t)/H_{he_4}(t)$	P.d.f./C.d.f. of repair time of minor software based hardware fault by expert repair team
$g_{c_{fe}}(t)/G_{c_{fe}}(t)$	P.d.f./C.d.f of repair time of common cause failure by expert repair team
$u_{he_1}(t)/U_{he_1}(t)$	P.d.f./C.d.f. of the hardware expansion time of the system by expert repair team
$u_{se_1}(t)/U_{se_1}(t)$	P.d.f./C.d.f. of the software expansion time of the system by expert repair team

The Model

The various states of transition of the system are shown in transition diagram given in **fig. 1.** The epochs of entry in to state 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 are regenerative point, i.e. all the states are regenerative states.

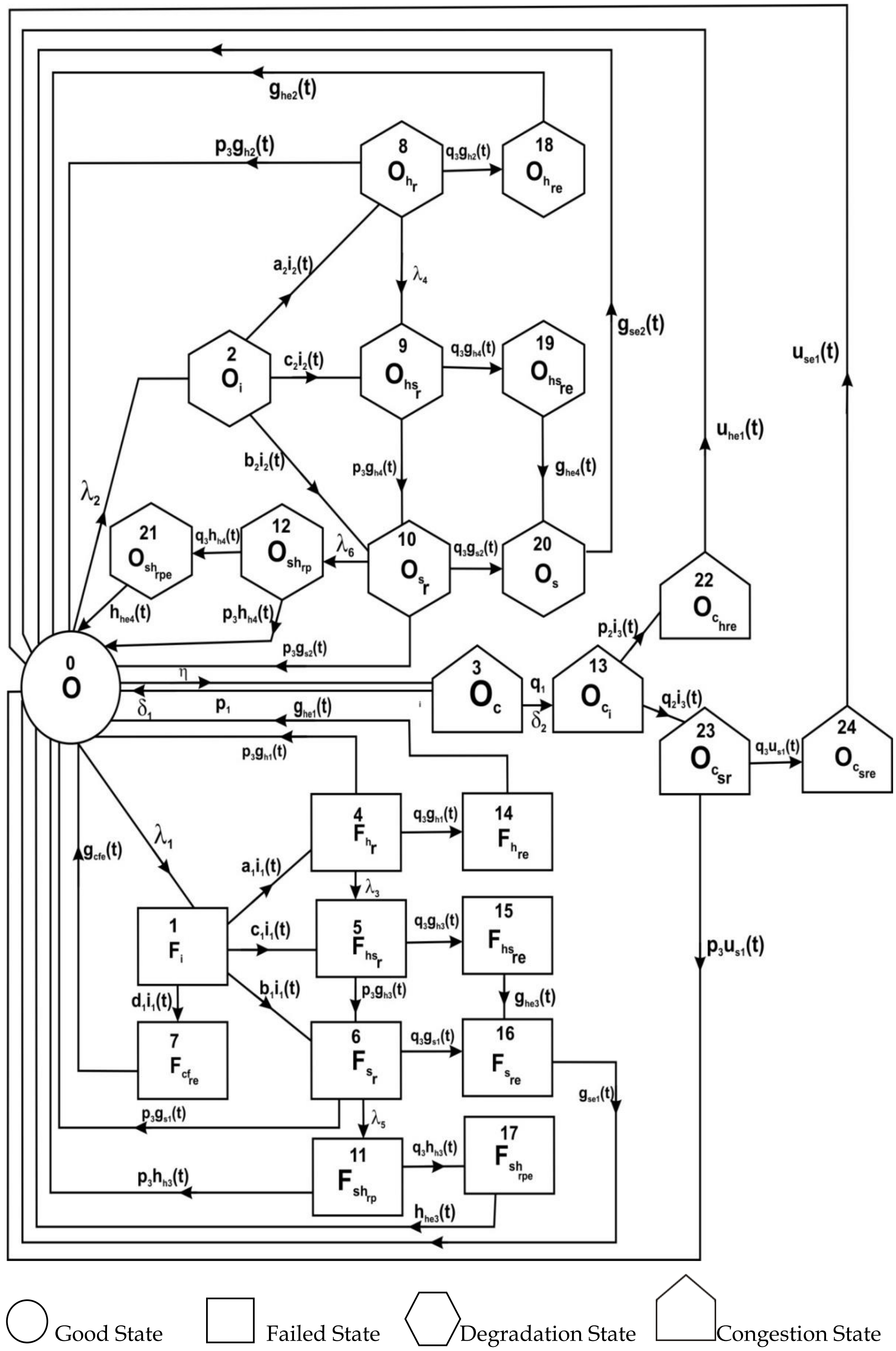

Fig.1 State Transition Diagram

Transition Probabilities and Mean Sojourn Times

The non-zero elements $p_{ij} = \lim_{s\to 0} q_{ij}^*(s)$ are given as under:

$$p_{01} = \frac{\lambda_1}{\lambda_1+\lambda_2+\eta} \qquad p_{02} = \frac{\lambda_2}{\lambda_1+\lambda_2+\eta} \qquad p_{03} = \frac{\eta}{\lambda_1+\lambda_2+\eta}$$

$$p_{14} = a_1 i_1^*(0) \qquad p_{15} = c_1 i_1^*(0) \qquad p_{16} = b_1 i_1^*(0)$$

$$p_{17} = d_1 i_1^*(0) \qquad p_{28} = a_2 i_2^*(0) \qquad p_{29} = c_2 i_2^*(0)$$

$$p_{2,10} = b_2 i_2^*(0) \qquad p_{30} = p_1 \qquad p_{3,13} = q_1$$

$$p_{40} = p_3 g_{h_1}^*(\lambda_3) \qquad p_{45} = 1 - g_{h_1}^*(\lambda_3) \qquad p_{4,14} = q_3 g_{h_1}^*(\lambda_3)$$

$$p_{56} = p_3 g_{h_3}^*(0) \qquad p_{5,15} = q_3 g_{h_3}^*(0) \qquad p_{60} = p_3 g_{s_1}^*(\lambda_5)$$

$$p_{6,11} = 1 - g_{s_1}^*(\lambda_5) \qquad p_{6,16} = q_3 g_{s_1}^*(\lambda_5) \qquad p_{70} = g_{c_{fe}}^*(0)$$

$$p_{80} = p_3 g_{h_2}^*(\lambda_4) \qquad p_{89} = 1 - g_{h_2}^*(\lambda_4) \qquad p_{8,18} = q_3 g_{h_2}^*(\lambda_4)$$

$$p_{9,10} = p_3 g_{h_4}^*(0) \qquad p_{9,19} = q_3 g_{h_4}^*(0) \qquad p_{10,0} = p_3 g_{s_2}^*(\lambda_6)$$

$$p_{10,12} = 1 - g_{s_2}^*(\lambda_6) \qquad p_{10,20} = q_3 g_{s_2}^*(\lambda_6) \qquad p_{11,0} = p_3 h_{h_3}^*(0)$$

$$p_{11,17} = q_3 h_{h_3}^*(0) \qquad p_{12,0} = p_3 h_{h_4}^*(0) \qquad p_{12,21} = q_3 h_{h_4}^*(0)$$

$$p_{13,22} = p_2 i_3^*(0) \qquad p_{13,23} = q_2 i_3^*(0) \qquad p_{14,0} = g_{he_1}^*(0)$$

$$p_{15,16} = g_{he_3}^*(0) \qquad p_{16,0} = g_{se_1}^*(0) \qquad p_{17,0} = h_{he_3}^*(0)$$

$$p_{18,0} = g_{he_2}^*(0) \qquad p_{19,20} = g_{he_4}^*(0) \qquad p_{20,0} = g_{se_2}^*(0)$$

$$p_{21,0} = h_{he_4}^*(0) \qquad p_{22,0} = u_{he_1}^*(0) \qquad p_{23,0} = p_3 u_{s_1}^*(0)$$

$$p_{23,24} = q_3 u_{s_1}^*(0) \qquad p_{24,0} = u_{se_1}^*(0)$$

By these transition probabilities, it can be verified that

$$p_{01} + p_{02} + p_{03} = p_{14} + p_{15} + p_{16} + p_{17} = p_{28} + p_{29} + p_{2,10} = p_{30} + p_{3,13} = 1$$
$$p_{40} + p_{45} + p_{4,14} = p_{56} + p_{5,15} = p_{60} + p_{6,11} + p_{6,16} = 1$$
$$p_{80} + p_{89} + p_{8,18} = p_{9,10} + p_{9,19} = p_{10,0} + p_{10,12} + p_{10,20} = 1$$
$$p_{11,0} + p_{11,17} = p_{12,0} + p_{12,21} = p_{13,22} + p_{13,23} = p_{23,0} + p_{23,24} = 1$$
$$p_{70} = p_{14,0} = p_{15,16} = p_{16,0} = p_{17,0} = p_{18,0} = p_{19,20} = 1$$
$$p_{20,0} = p_{21,0} = p_{22,0} = p_{24,0} = 1$$

The mean sojourn time (μ_i) in the regenerative state i is defined as the time of stay in that state before transition to any other state. If T denotes the sojourn time in regenerative state i, then

$$\mu_i = \int_0^\infty P(T_i > t)\,dt$$

gives

$$\mu_0 = \frac{1}{\lambda_1+\lambda_2+\eta} \qquad \mu_1 = -i_1^{*'}(0) \qquad \mu_2 = -i_2^{*'}(0)$$

$$\mu_3 = \frac{p_1}{\delta_1} + \frac{q_1}{\delta_2} \qquad \mu_4 = \frac{1}{\lambda_3}(1 - g_{h_1}^*(\lambda_3)) \qquad \mu_5 = -g_{h_3}^{*'}(0)$$

$$\mu_6 = \frac{1}{\lambda_5}(1 - g_{s_1}^*(\lambda_5)) \qquad \mu_7 = -g_{c_{fe}}^{*'}(0) \qquad \mu_8 = \frac{1}{\lambda_4}(1 - g_{h_2}^*(\lambda_4))$$

$$\mu_9 = -g_{h_4}^{*'}(0) \qquad \mu_{10} = \frac{1}{\lambda_6}(1 - g_{s_2}^*(\lambda_6)) \qquad \mu_{11} = -h_{h_3}^{*'}(0)$$

$\mu_{12} = -h^{*'}_{h_4}(0)$ $\mu_{13} = -i^{*'}_3(0)$ $\mu_{14} = -g^{*'}_{he_1}(0)$

$\mu_{15} = -g^{*'}_{he_3}(0)$ $\mu_{16} = -g^{*'}_{se_1}(0)$ $\mu_{17} = -h^{*'}_{he_3}(0)$

$\mu_{18} = -g^{*'}_{he_2}(0)$ $\mu_{19} = -g^{*'}_{he_4}(0)$ $\mu_{20} = -g^{*'}_{se_2}(0)$

$\mu_{21} = -h^{*'}_{he_4}(0)$ $\mu_{22} = -u^{*'}_{he_1}(0)$ $\mu_{23} = -u^{*'}_{s_1}(0)$

$\mu_{24} = -u^{*'}_{se_1}(0)$

Thus,

$m_{01} + m_{02} + m_{03} = \mu_0$ $m_{14} + m_{15} + m_{16} + m_{17} = \mu_1$

$m_{28} + m_{29} + m_{2,10} = \mu_2$ $m_{30} + m_{3,13} = \mu_3$

$m_{40} + m_{45} + m_{4,14} = \mu_4$ $m_{56} + m_{5,15} = \mu_5$

$m_{60} + m_{6,11} + m_{6,16} = \mu_6$ $m_{70} = \mu_7$

$m_{80} + m_{89} + m_{8,18} = \mu_8$ $m_{9,10} + m_{9,19} = \mu_9$

$m_{10,0} + m_{10,12} + m_{10,20} = \mu_{10}$ $m_{11,0} + m_{11,17} = \mu_{11}$

$m_{12,0} + m_{12,21} = \mu_{12}$ $m_{13,22} + m_{13,23} = \mu_{13}$

$m_{14,0} = \mu_{14}$ $m_{15,16} = \mu_{15}$

$m_{16,0} = \mu_{16}$ $m_{17,0} = \mu_{17}$

$m_{18,0} = \mu_{18}$ $m_{19,20} = \mu_{19}$

$m_{20,0} = \mu_{20}$ $m_{21,0} = \mu_{21}$

$m_{22,0} = \mu_{22}$ $m_{23,0} + m_{23,24} = \mu_{23}$

$m_{24,0} = \mu_{24}$

Other Measures of System Performance

Using probabilistic arguments for regenerative processes, various recursive relations are obtained and are solved to derive following important measures of the system performance in steady state:

Mean Time to System Failure (T_0) **=N/D**

Expected Uptime of the system (UT_0) **= N_1/D_1**

Expected Degradation Time of the System (DT_0) **= N_2/D_1**

Expected Congestion Time of the System (CT_0) **= N_3/D_1**

where

$N = \mu_0 + p_{02}\mu_2 + p_{03}\mu_3 + p_{02}p_{28}\mu_8 + p_{02}(p_{28}p_{89} + p_{29})\mu_9 + p_{02}(p_{28}p_{89}p_{9,10}$
$+ p_{29}p_{9,10} + p_{2,10})\mu_{10} + p_{02}(p_{28}p_{89}p_{9,10} + p_{29}p_{9,10} + p_{2,10})p_{10,12}\mu_{12}$
$+ p_{03}p_{3,13}\mu_{13} + p_{02}p_{28}p_{8,18}\mu_{18} + p_{02}(p_{28}p_{89} + p_{29})p_{9,19}\mu_{19} + p_{02}[(p_{28}p_{89}$
$+ p_{29})(p_{9,10}p_{10,20} + p_{9,19}p_{19,20}) + p_{2,10}p_{10,20}]\mu_{20} + p_{02}(p_{28}p_{89}p_{9,10}$
$+ p_{29}p_{9,10} + p_{2,10})p_{10,12}p_{12,21}\mu_{21} + p_{03}p_{3,13}p_{13,22}\mu_{22} + p_{03}p_{3,13}p_{13,23}\mu_{23}$
$+ p_{03}p_{3,13}p_{13,23}p_{23,24}\mu_{24}$

$D = p_{01}.$

$N_1 = \mu_0$,

$N_2 = p_{02}\mu_2 + p_{02}p_{28}\mu_8 + p_{02}(p_{28}p_{89} + p_{29})\mu_9 + p_{02}(p_{28}p_{89}p_{9,10}$
$+ p_{29}p_{9,10} + p_{2,10})\mu_{10} + p_{02}(p_{28}p_{89}p_{9,10} + p_{29}p_{9,10} + p_{2,10})p_{10,12}\mu_{12}$
$+ p_{02}p_{28}p_{8,18}\mu_{18} + p_{02}(p_{28}p_{89} + p_{89})p_{9,19}\mu_{19} + p_{02}[(p_{28}p_{89}$
$+ p_{29})(p_{9,10}p_{10,20} + p_{9,19}p_{19,20}) + p_{2,10}p_{10,20}]\mu_{20} + p_{02}(p_{28}p_{89}p_{9,10}$
$+ p_{29}p_{9,10} + p_{2,10})p_{10,12}p_{12,21}\mu_{21}$

$N_3 = p_{03}\mu_3 + p_{03}p_{3,13}\mu_{13} + p_{03}p_{3,13}p_{13,22}\mu_{22}$
$+ p_{03}p_{3,13}p_{13,23}\mu_{23} + p_{03}p_{3,13}p_{13,23}p_{23,24}\mu_{24}$

$D_1 = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{03}\mu_3 + p_{01}p_{14}\mu_4 + p_{01}(p_{14}p_{45} + p_{15})\mu_5$

$+ p_{01} (p_{14} p_{45} p_{56} + p_{15} p_{56} + p_{16}) \mu_6 + p_{01} p_{17} \mu_7 + p_{02} p_{28} \mu_8 + p_{02} (p_{28} p_{89}$
$+ p_{29}) \mu_9 + p_{02} (p_{28} p_{89} p_{9,10} + p_{29} p_{9,10} + p_{2,10}) \mu_{10} + p_{01} (p_{14} p_{45} p_{56}$
$+ p_{15} p_{56} + p_{16}) p_{6,11} \mu_{11} + p_{02} (p_{28} p_{89} p_{9,10} + p_{29} p_{9,10} + p_{2,10}) p_{10,12} \mu_{12}$
$+ p_{03} p_{3,13} \mu_{13} + p_{01} p_{14} p_{4,14} \mu_{14} + p_{01} (p_{14} p_{45} + p_{15}) p_{5,15} \mu_{15}$
$+ p_{01} [(p_{14} p_{45} + p_{15}) (p_{5,15} p_{15,16} + p_{56} p_{6,16}) + p_{16} p_{6,16}] \mu_{16} + p_{01}(p_{14} p_{45} p_{56}$
$+ p_{15} p_{56} + p_{16}) p_{6,11} p_{11,17} \mu_{17} + p_{02} p_{28} p_{8,18} \mu_{18}$
$+ p_{02} (p_{28} p_{89} + p_{29}) p_{9,19} \mu_{19} + p_{02} [(p_{28} p_{89} + p_{29}) (p_{9,10} p_{10,20} + p_{9,19} p_{19,20})$
$+ p_{2,10} p_{10,20}] \mu_{20} + p_{02} (p_{28} p_{89} p_{9,10} + p_{29} p_{9,10} + p_{2,10}) p_{10,12} p_{12,21} \mu_{21}$
$+ p_{03} p_{3,13} p_{13,22} \mu_{22} + p_{03} p_{3,13} p_{13,23} \mu_{23} + p_{03} p_{3,13} p_{13,23} p_{23,24} \mu_{24}.$

Particular Case

For graphical analysis, following particular case is considered:

$g_{h_1}(t) = \beta_{h_1} e^{-\beta_{h_1} t};$ $g_{h_2}(t) = \beta_{h_2} e^{-\beta_{h_2} t};$ $g_{s_1}(t) = \beta_{s_1} e^{-\beta_{s_1} t};$

$g_{s_2}(t) = \beta_{s_2} e^{-\beta_{s_2} t};$ $g_{h_3}(t) = \beta_{h_3} e^{-\beta_{h_3} t};$ $g_{h_4}(t) = \beta_{h_4} e^{-\beta_{h_4} t};$

$h_{h_3}(t) = \gamma_{h_3} e^{-\gamma_{h_3} t};$ $h_{h_4}(t) = \gamma_{h_4} e^{-\gamma_{h_4} t};$ $u_{s_1}(t) = \xi_{s_1} e^{-\xi_{s_1} t};$

$g_{he_1}(t) = \beta_{he_1} e^{-\beta_{he_1} t};$ $g_{he_2}(t) = \beta_{he_2} e^{-\beta_{he_2} t};$ $g_{se_1}(t) = \beta_{se_1} e^{-\beta_{se_1} t};$

$g_{se_2}(t) = \beta_{se_2} e^{-\beta_{se_2} t};$ $g_{he_3}(t) = \beta_{he_3} e^{-\beta_{he_3} t};$ $g_{he_4}(t) = \beta_{he_4} e^{-\beta_{he_4} t};$

$h_{he_3}(t) = \gamma_{he_3} e^{-\gamma_{he_3} t};$ $h_{he_4}(t) = \gamma_{he_4} e^{-\gamma_{he_4} t};$ $g_{c_{fe}}(t) = \beta_{c_{fe}} e^{-\beta_{c_{fe}} t};$

$i_1(t) = \alpha_1 e^{-\alpha_1 t};$ $i_2(t) = \alpha_2 e^{-\alpha_2 t};$ $i_3(t) = \alpha_3 e^{-\alpha_3 t};$

$u_{he_1}(t) = \xi_{he_1} e^{-\xi_{he_1} t};$ $u_{se_1}(t) = \xi_{se_1} e^{-\xi_{se_1} t}$

Graphical Interpretation

Various graphs for measures of system performance viz. MTSF, expected uptime, expected degradation time, expected congestion time are plotted for different values of rates of faults $(\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6)$, probabilities of hardware/ software/ hardware based software faults/ common cause failures(a_1,a_2,b_1,b_2,c_1,c_2,d_1), inspection rates $(\alpha_1, \alpha_2, \alpha_3)$, probabilities of automatic/manual network restoration (p_1,q_1), probabilities of hardware/ software expansion (p_2,q_2), probabilites that regular repair team is able/ unable to repair the fault (p_3,q_3), hardware/ software/ hardware based software/ common cause failure repair rates by regular and expert repair team (β_{h_1}, β_{h_2}, β_{s_1}, β_{s_2}, β_{h_3}, β_{h_4}, β_{he_1}, β_{he_2}, β_{se_1}, β_{se_2}, β_{he_3}, β_{he_4}, $\beta_{c_{fe}}$), software based hardware replacement rates $(\gamma_{h_3}, \gamma_{h_4}, \gamma_{he_3}, \gamma_{he_4})$, by regular and expert repair team, network traffic congestion, automatic and manual network restoration rates $(\eta, \delta_1, \delta_2)$, rates of hardware/ software expansion by regular and expert repair team $(\xi_{h_1}, \xi_{s_1}, \xi_{he_1}, \xi_{se_1})$.

The curves in **fig. 2** shows the graph between MTSF(T_0) and rate of minor software based hardware faults (λ_6) for different values of probability that regular repair team is able to repair the system (p_3). The graph reveals that MTSF decreases with increase in values of the rate of minor software based hardware faults and it has higher values for higher values of the probability that regular repair team is able to repair the system.

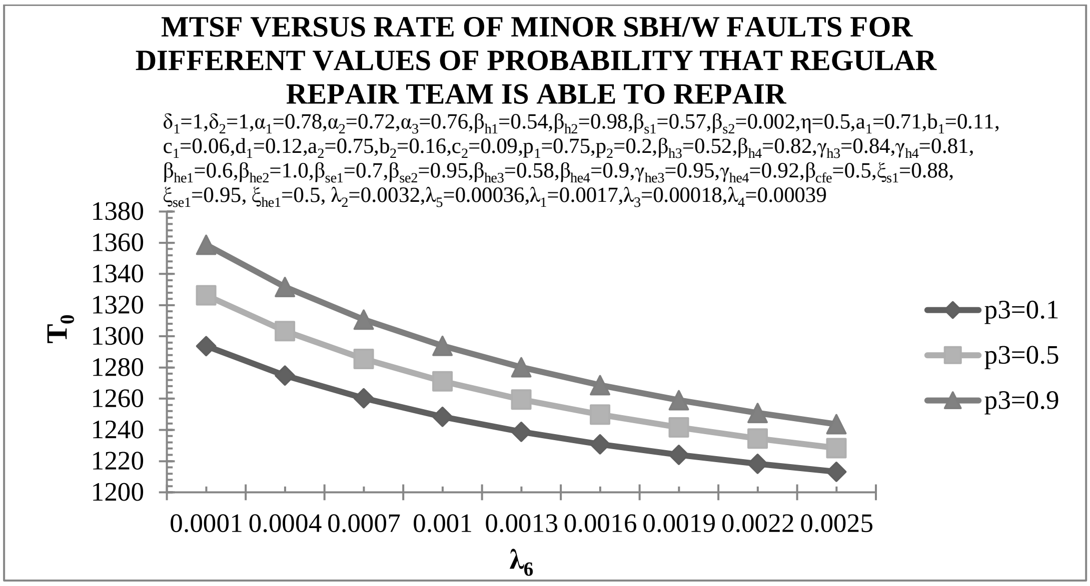

Fig. 2

Fig.3 presents the graph between MTSF (T_0) and rate of major faults (λ_1) for different values of probability of minor hardware fault (a_2). It is concluded from the graph that MTSF decreases with increase in the values of the rate of major faults and it has lower values for higher values of the probability of minor hardware faults.

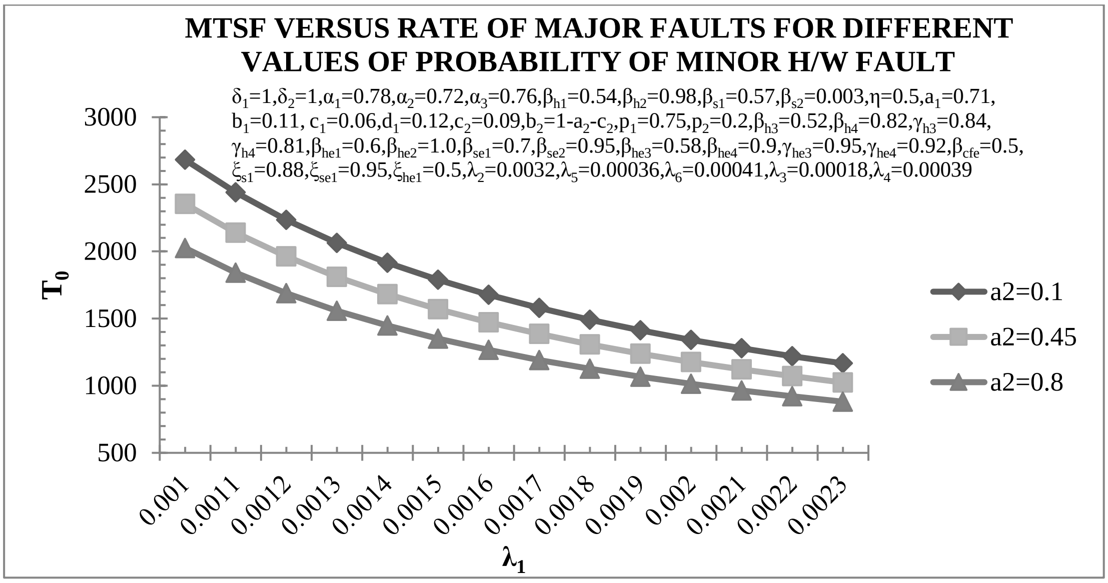

Fig. 3

Fig. 4 gives the graph between expected uptime of the system (UT_0) and rate of major software based hardware faults (λ_5) for different values of probability that regular repair team is able to repair the system (p_3). The graph conclude that expected uptime decreases with increase in the values of rate of major software based hardware faults and has higher values for higher values of probability that regular repair team is able to repair.

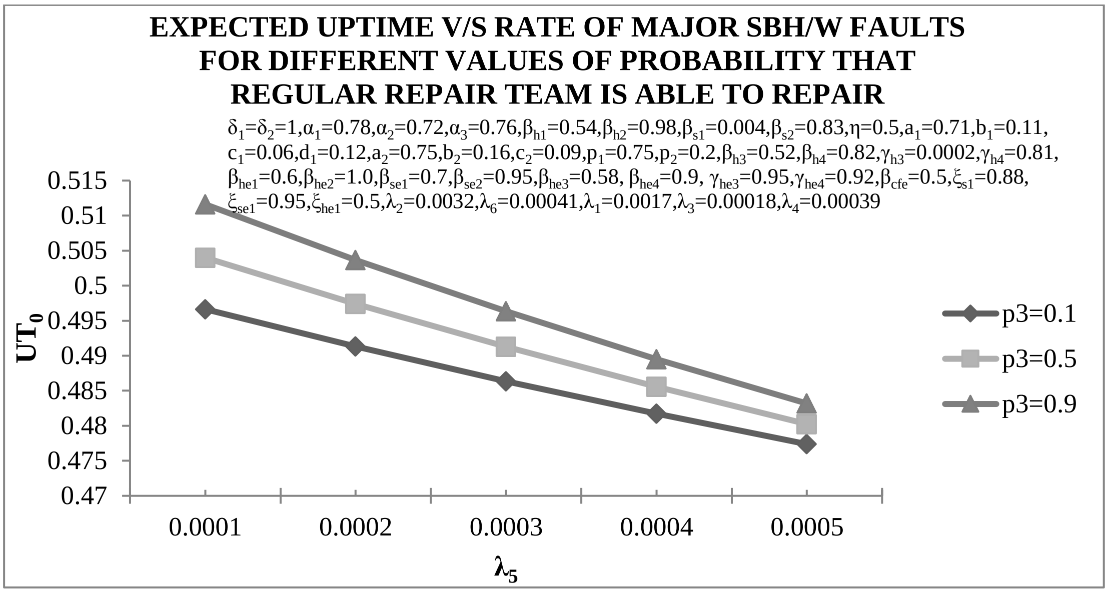

Fig.4

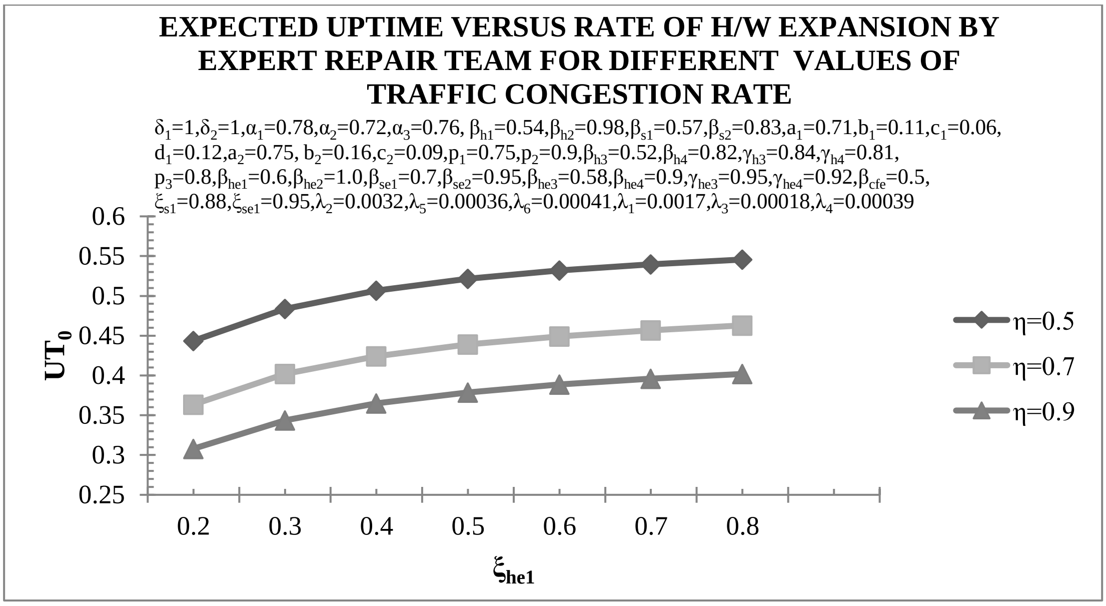

Fig. 5

Fig. 5 shows the graph between expected uptime of the system (UT_0) and rate of hardware expansion by the expert repair team (ξ_{he_1}) for different values of network traffic congestion rate (η). The curves indicate that the expected uptime of the system increases with increase in the values of rate of hardware expansion by the expert repair team and has smaller values for higher values of the network traffic congestion rate.

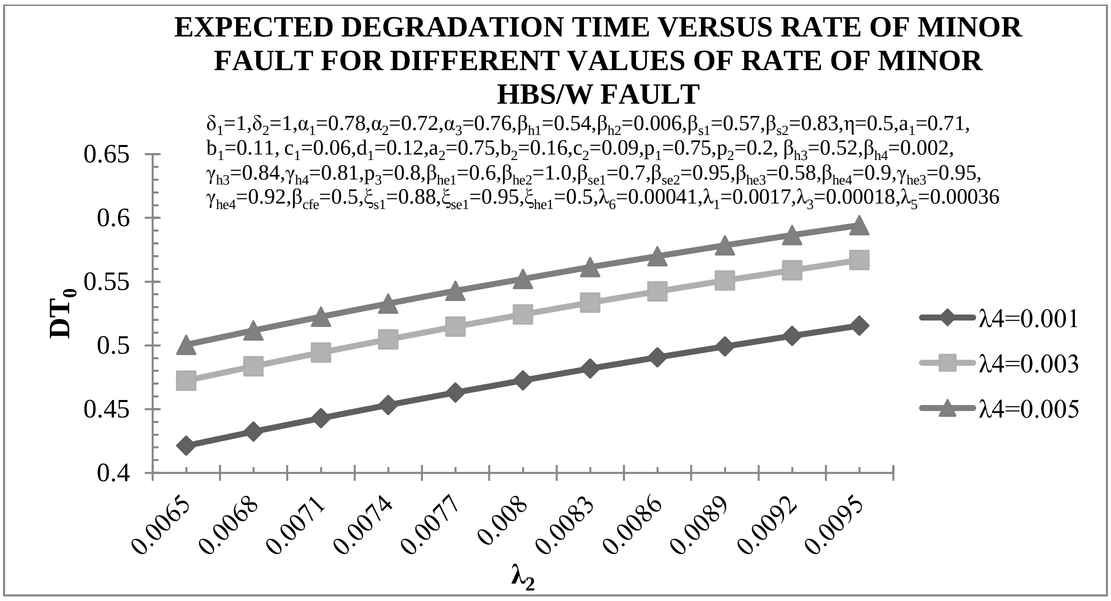

Fig.6

Fig. 6 presents the graph between expected degradation time of the system (DT_0) and rate of minor faults (λ_2) for different values of rate of minor hardware based software faults (λ_4). The graph depicts that expected degradation time increases with increase in the values of rate of minor faults and has higher values for higher values of the rate of minor hardware based software faults.

Fig. 7 gives the graph between expected congestion time (CT_0) of the system and rate of hardware expansion by expert repair team (ξ_{he_1}) for different values of probability of hardware expansion (p_2). The curves in the graph reveal that expected congestion time decreases with increase in the values of rate of hardware expansions by the expert repair team and has higher values for higher values of probability of hardware expansion.

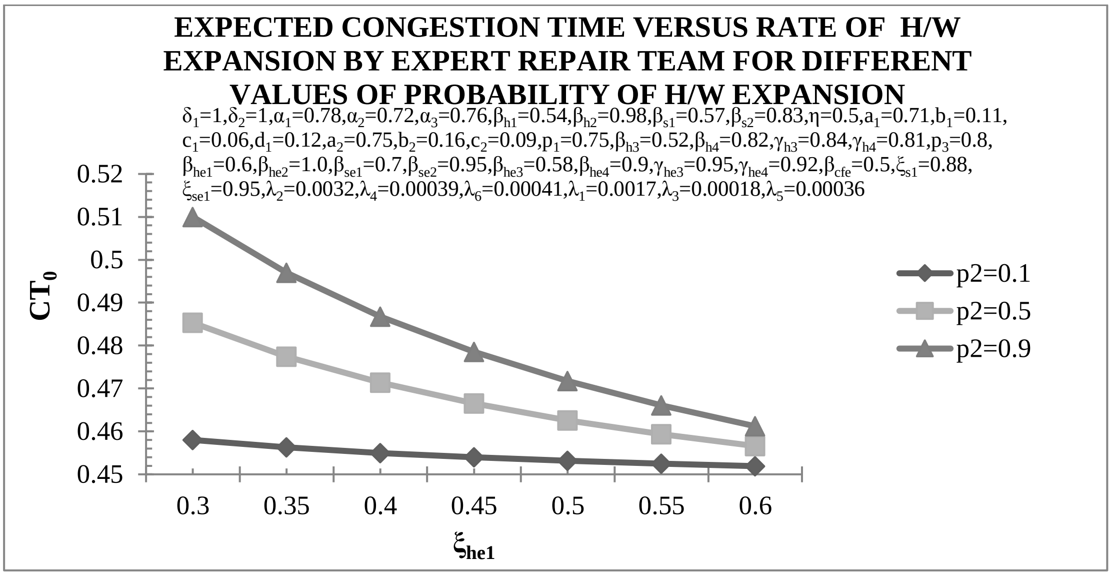

Fig. 7

CONCLUSION

From the graphical analysis it may be concluded that the mean time to system failure (MTSF) and expected uptime of the BTS increases with the increase in the values of the probability that regular repair team is able to repair the fault. Further it is observed that the MTSF and expected uptime decreases with the increase in the values of rate of occurrence of major/minor faults and major/minor hardware-software interaction faults. It is also observed that MTSF decreases with increase in the values of probability of minor hardware faults. Expected uptime decreases with increase in the values of network traffic congestion rate and increases with increase in the values of rate of hardware expansion by expert repair team.

On the other hand, the expected degradation time of the BTS increases with the increase in the rates of occurrence of major/minor and major/minor hardware-software interactions fault. Expected congestion time increases with the increase in values of probability of hardware expansion. Further it is observed that it decreases with increase in the values of rate of hardware expansion by expert repair team.

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