SERVICE QUALITY AND RELIABILITY ASSESSMENT OF MOBILE COMMUNICATION INFRASTRUCTURE

A THESIS

submitted by

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under the guidance of

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DECLARATION

I hereby declare that the thesis entitled “**SERVICE QUALITY AND RELIABILITY ASSESSMENT OF MOBILE COMMUNICATION INFRASTRUCTURE**” submitted by me to the Cochin University of Science and Technology, Cochin in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy have not been submitted and will not be submitted to any other University or Institute for the award of any degree, diploma, associateship, fellowship or other similar title of recognition.

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THESIS CERTIFICATE

This is to certify that the thesis entitled "**SERVICE QUALITY AND RELIABILITY ASSESSMENT OF MOBILE COMMUNICATION INFRASTRUCTURE**" submitted by Sunilkumar K to the Cochin University of Science and Technology, Cochin in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by him under my supervision. The contents of this thesis have not been submitted and will not be submitted to any other University or Institute for the award of any degree.

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ABSTRACT

Keywords: *Availability, reliability, maintainability, mobile communication network, simulation, service quality, competing risk models*

Abstract: The service quality of any sector has two major aspects namely technical and functional. Technical quality can be attained by maintaining technical specification as decided by the organization. Functional quality refers to the manner which service is delivered to customer which can be assessed by the customer feed backs. A field survey was conducted based on the management tool SERVQUAL, by designing 28 constructs under 7 dimensions of service quality. Stratified sampling techniques were used to get 336 valid responses and the gap scores of expectations and perceptions are analyzed using statistical techniques to identify the weakest dimension. To assess the technical aspects of availability six months live outage data of base transceiver were collected. The statistical and exploratory techniques were used to model the network performance. The failure patterns have been modeled in competing risk models and probability distribution of service outage and restorations were parameterized. Since the availability of network is a function of the reliability and maintainability of the network elements, any service provider who wishes to keep up their service level agreements on availability should be aware of the variability of these elements and its effects on interactions. The availability variations were studied by designing a discrete time event simulation model with probabilistic input parameters. The probabilistic distribution parameters arrived from live data analysis was used to design experiments to define the availability domain of the network under consideration. The availability domain can be used as a reference for planning and implementing maintenance activities. A new metric is proposed which incorporates a consistency index along with key service parameters that can be used to compare the performance of different service providers. The developed tool can be used for reliability analysis of mobile communication systems and assumes greater significance in the wake of mobile portability facility. It is also possible to have a relative measure of the effectiveness of different service providers

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NOMANCLATURE

A	Availability
BH	Busy Hour
BSC	Base Station Controller
BTS	Base Transceivers
CI	Consistency Index
DR	Call Drop Rate
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HLR	Home Location Register
VLR	Visiting Location Register
DB	Data Base
MLE	Maximum Likelihood Estimate
MS	Mobile System
MSC	Mobile Switching Centre
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
P	Probability
R	Reliability
RACH	Random Access Channel
RF	Radio Frequency
S	Survivor Fraction

SB	SDCCH Call Blocking Index
SDCCH	Standalone Dedicated Control Channel
SERVQUAL	Service Quality
SI	Service Index
SLA	Service Level Agreements
SR	Call Setup Success Rate Index
t	Time
TB	TCH call blocking index
TCH	Traffic Channel
TRAI	Telecom Regulatory Authority of India
α	Scale Parameter (Weibull distribution)
β	Shape Parameter (Weibull distribution)
ε	Mean (Lognormal Distribution)
λ	Failure Rate
μ	Repair Rate
σ	Standard Deviation (Lognormal distribution)

Chapter 1

Introduction

The telecommunication industry is one of the fastest growing industries in the world. According to the Telecommunication Regulatory Authority of India the total subscribers crossed 510 million and the revenue generated by this sector crossed Rupees 1.5 Trillion in the year 2009. The use of mobile is not limited to verbal communication but is being used for messaging, data transfer, banking, commercial bookings, travel assistance, financial transactions, entertainment etc. The technological advance in this area is miraculous. In the past human operators were engaged at switching stations but now it is almost unhanded. Communication revolution has been achieved by taking it to rural villages and remote areas. People cannot think of a life without this facility now. However, the dependability of mobile communication sector needs to be addressed properly.

The dependability is the culmination of various aspects of service as discussed below

Reliability

Whenever the system or its component fails, the service is interrupted. We really wish to have a system which does not fail in service but that's only a dream. So a system which does not fail frequently is reliable

Maintainability

The system or part failure is unavoidable. When it fails the service gets interrupted. As long as the system is under repair or replacement the service cannot be provided. We wish the system to be easily repairable or maintainable that is restored in service in very short time. This accounts to the maintainability of system.

Availability

Even though the reliability and maintainability is a reality we expect the service to be available when ever we need it. For any customer the most important aspect will be the service availability at his or her demand

Survivability

The failure to service is unavoidable. But to what extend the people are affected is always important. The ability of the system to provide emergency or necessary service in wake of failure is survivability. In vast networks, some portions of network may fail but the service will be provided in some other sections. Reliability issues of these types of systems, which do not fails completely and provide service partially is considered as multi state reliability problem.

Data Confidentiality

Whenever a data is transferred or communicated, one of the most important aspect of communication is the data is accessed by the authorized person only. Unauthorized access makes the communication channel unreliable.

Data Integrity

Nobody other than the communicating authorized person should be able to edit or modify the data.

General public, without going to the technical aspects of service, will always expect a high quality service and react if it is not provided at the instant of their demand. The service provider is obliged to honor the expectations and perceptions of the customer

On a commercial point of view the availability is an important key parameter to the service provider. Since huge investments on the infrastructural facilities are already made, even a one percent change in availability will lead to a revenue loss of Rupees150 Billion (TRAI, 2009).

The first two parameters mentioned above together constitute the availability of a system. Since the failure and repair time are random variables, the complete variability of these variables and their combined effect on availability are always the focus of interest.

The study is mainly focused on the first four aspects of dependability of mobile communication network. Modeling and analysis of the system is based on the field failure data. An attempt is also made the extract the customer expectation and perception on the various aspects of service and pin point the weakness. Sensitivity analysis based on the various parameters are also carried out by modeling the system

Chapter 2

Literature Survey

2.1 Introduction

Reliability engineering has emerged as a key aspect of study in any engineering or technology application due to the high cost involved in uncertainty on availability of the equipment. Reliability is a popular concept that has been celebrated for years as a commendable attribute of a person or an artifact. The word reliability was first coined by Samuel T. Coleridge, and from its modest beginning in 1816, reliability grew into an omnipresent attribute with qualitative and quantitative connotations that pervades every aspect of our present day technologically intensive world. The unreliability of vacuum tubes during the Second World War was the first identified problem of reliability. The development of mass production techniques and statistical methods of analysis catalyzed the development of the branch reliability. (Saleh et al 2006).

The paper (Zio 2009) brings out the new challenges in reliability engineering and various new areas that have been identified relevant to this topic for detailed study. Human reliability, and associated safety and risk factors, maintenance strategy formulation based on reliability, dynamic reliability issues in a dynamic environment and application of new theories in uncertainty are highlighted in his paper. One of the major areas of new challenge described by him is the multi state system reliability. Distribution systems of water, gas and oil, networked systems of power supply, land and mobile communication etc can not be evaluated based on the 2 state systems such as functioning or not functioning. The system can be specified with 50% functioning or 75% functioning etc which require a different approach of reliability study. The general issues in multi state system and multi state components have been addressed by Ramirez-Marquez, J. E., & Coit, D (2005) by evaluating and implementing composite importance measures. The issues of incorporating security in designs are elaborated by Brian Snow (2005) along with the reliability and quality

Saraswat and Yadava (2008) presented the survey of publication in reliability, availability, maintainability and supportability (RAMS) engineering in the various areas during 1988 to 2005. The paper highlights the relevant publications and explain the aspects such as , identification of parameters in RAMS engineering, different methodologies adopted for the analysis of RAM , design and support issues and various simulation and modeling studies in RAMS. He concludes that the majority of the work in this area excludes at least one aspect of RAMS and concentrates on specific industries such as defense and aerospace. The need, use and exploration of information technology and allied service sectors, are stressed by him. He points outs that RAMS philosophy should include how RAMS should organize and how it should be integrated in the manufacturing industry or service industry. Standardized procedures for documentation and routine examination of RAMS are to be formulated.

The parameters availability and reliability are the good evaluation of a system performance. It is useful to obtain the value of the availability importance measure for each component. Javad Barabady et al (2007) presented the concept of availability importance measure for a component or sub system. It shall be used to priorities the component or subsystem on reliability design. In order to calculate the criticality of each component or subsystem from the availability point of view the concept of availability importance measure is introduced. He also demonstrates the application of such importance measures for achieving optimal resource allocation to arrive at the best possible availability. The research study indicates that the availability importance measures could be applied in developing a strategy for availability improvement.

A concept of Total Reliability Management (TRM) is proposed by Christian N. Madu (1999) in comparison to Total Quality Management (TQM) concept. According to him quality performance of a firm is often assessed by the reliability of the firm's equipment or machinery, but, reliability has not received the same attention as quality yet. He emphasized on the need of a link between reliability, company's bottom line and corporate survival. Gouri Shankar and Vandana Sahani (2003) integrated the strategies for preventive maintenance with the reliability of the system and presented the maintenance float problem as a model to describe catastrophic and/or wear-out failures. It is applicable in systems with a large number of independent and identical units.

Away from the defense and aerospace, nuclear plants have been a major concentration by the reliability engineers. Studies of availability of networks in many services are also carried out based on reliability theories. Chathurvedi and B S Misra (2002) proposed a hybrid method to evaluate the reliability of complex computer network based on the evaluation of terminal reliability. The reliability aspects of mobile phones were carried out by Daya Perera (1995). The fast changing technology and increased market demand have brought good and bad in reliability of MS.

Bobbio et al (2010) brought out the issue of availability of services of Supervision, Control and Data Acquisition (SCADA) system which in turn depends upon availability of interconnecting network supporting services. The paper concentrates on the actual failure scenario, occurred in Rome in January 2004 which involved the outage of critical SCADA communication links inter connecting a power grid and Telco network.

2.2 Telecommunication Systems

As pointed out by Zio (2009), reliability issues in communication system is to be analyzed as a multi state problem. Bennett and S. E. Makris (1999) bring out the statistics of major telecommunication service outages occurred in United States during July 1992 to June 1999. The results of his analysis indicate procedural errors as the main causes of outages. Insufficient supervision, insufficient training and lack of documentations are listed as sub causes of procedural errors. According to Andrew P Snow (2001) rapid technical evolution, market pressure and complexity have contributed large outage in data and voice networks in USA. The increase of customers and need of faster and cheaper carriers has lead to the unreliability of service. In a complementary literature the generations of technologies in mobile communication is explained by Naveen Chandran (2001). The three level physical hardware systems in second and third generations in mobile communication are all similar but for the capacity, technology and bandwidth. Li Zhen, Zhou Wenan, Song Junde and Hou Chunping (2002) studied the vision and framework of fourth generation and proposed adaptable technologies. This also points out the reliability threats in future technology.

The use of mobile communication in business and commerce transactions and development of business models has further necessitated the reliable transactions. Upkar Varshney (2000, 2008) proposes a business model as well as a frame work for mobile commerce to accommodate the new developments. Steven Chamberland (2005) used Tabu search algorithms to identify the optimum position of BTS and reduce cost and other linking issues. Simulated annealing and a new ant colony system algorithm are used by Graham (2008) to illustrate the combined approach of traditional binary constrained approach and the signal to noise based cost function approach for frequency assignment.

Reliability of communication has been on scanner for years. In fact, there are regulatory systems controlled by state which evaluates the reliability of service. Due to the complexities and volume of services, such regulatory measure or metric designed to assess the service quality takes care of limited aspects of service only.

2.2.1 Metrics and key parameters

The reliability metric could be used for two purposes. The first purpose is to monitor the performance of the system through time. Whenever the value of the reliability metric falls below a predetermined threshold or floor value, it is an indication that the system requires an inspection. The second purpose of the metric is to provide a guideline for the continuous improvement of an information system. The customer utility of system components incorporated in the metric can be used as a guide in making improvement decisions. Fatemeh Mariam Zahedi (1997) suggested a metric for the reliability of information system.

In United States the Federal Communication Commission (FCC) has put forward some metrics for analyzing the network performance. It is mandatory to report major telecommunication outages to the commission based on the metric defined by the product of number of potential customers affected and duration of outages. But the live data of outages need not be made public. FCC has made it mandatory to report the outages of following nature distinctly

- General outages causing local switch isolations (at least 30,000 users and 30 minutes)
- Outages caused by Fire (1000 lines, 30 minutes duration)
- Special Outages (any size and duration national security / emergency preparedness (NS/EP)

- E911 outages (tandems, any size, 30 minutes duration; E911 facility, 30,000 users, 30 minutes duration)

However, the Automated Reporting Management Information System (ARMIS) will record the local switch outage of 2 minutes or more. Andrew P Snow (2003, 2004, and 2005) compares the outage information of over 18000 switches and evaluates the masking of outage information. He also compared the outage impact metrics such as line lost hours (Product of number of potential customers affected and time in hours) and the outage index created by Standards Committee T1 accredited by American National Standards Institute (ANSI). The outage index is calculated with outage-triple approach, allowing an outage episode to be characterized as a single impact metric by incorporating service, duration and magnitude weights, as given in equation 5.1.

$$I(O) = \sum_{J=1}^{N} W_S W_D W_M \tag{1.1}$$

where $J=1,\ldots, N$ are the services impacted by the outage, W_S = Service Weight, W_D = Duration Weight, and W_M = Magnitude Weight.

There exists very significant communications loss due to total local switch failures below the FCC-reportable threshold and if the ANSI accredited Standards Committee T1 outage index is used, the significance of the communication loss below the threshold is not recognized, and the loss above the threshold is overstated.

Andrew P Snow and Shweta Agarwal (2004) also evaluate the extent of information masking regarding the outage information if the FCC reporting threshold is followed. They substantiate that the present threshold of reporting is inferior and a modified threshold of reporting is essential

In India the Telecom Authority of India (TRAI) publishes performance reports of operators in every quarter detailing the average performance for the period. This also gives the details of providers who could not meet the bench mark TRAI (2009, 2010).

It is in the form of a consolidated three months data report, provided by each service providers. It is comparative statements which do not give much insight to the reliability aspects. The actual live data of failure is not made available to public. The following quality of service is bench marked by the TRAI.

i) Call drop rate < 2%

ii) Call setup success rate >95%

iii) Accumulated outage of Base Transceiver BTS <2%

iv) Traffic Channels (TCH) call blocking <2%

v) Standalone Dedicated Control Channel (SDCCH)call blocking <2%

The TRAI proposed a new metric, Percentage Accumulated down Time (not available for service) of BTS, which is a modified version of average availability of BTS discarding all outages of less than one hour duration.

The reliability and availability of infrastructure for communication is a concern among the organizations which lease / utilize the communication links. Eric Bouillet, Debasis Mitra, and K. G. Ramakrishnan (2002) propose a structure for quality of service centered service level agreements in the wake of reliability issues. The probability of meeting the service level agreements is also a subject of research. Network performance evaluation measure called topology life time is being assessed by Zari Dzalilov, I. Ouveysi, and A. Rubinov (2003). Some modifications to this approach were also suggested.

Survivability is another term specifically used in network system. It refers the ability of the system to provide service in lesser volumes in the wake of outages. Some portion of the network will continue to provide service and some portion will be cut off. The concept of multi level system providing service between 0 and 1 can be explained as survivability. Localized and immediate neighbor network survivability in large scale regional failure scenario, cellular survivability and network performance after a BTS failure were studied by Bijan Bassiri and Sharam Shah Heydari (2009), Jack Freund(2005) and Neetesh Purohit and Sanjiv Tokekar (2007).

2.3 Customer Satisfaction

The service quality measurements of a service sector necessarily need sufficient knowledge of the sector and its complexities. Meeting the technical specification of any product will be considered as quality by the manufacturers but how it perceived by the customer decides the market. The concept of service quality is not universally understood and is often used as an umbrella term to cover a range of impressions gathered by customers when dealing with vendors. (Fogarty 2000). A comparison of the expectation and perception of any service sector gives the satisfaction gap. Identification of the number of constructs and dimension closely associated with service sector was taken up by Parasuraman et al. (1988). It describes the development of 22 item instruments called service quality instruments or SERVQUAL, for assessing the expectation and perception of service quality in service sector and retailing organizations. The paper explains the conceptual background of formulation constructs and gives evidence of reliability and validity based on the application of four deferent type data. However, other researchers have developed and recommended a number of measurement approaches including SERVPERF – service performance (Cronin and Taylor, 1994), and direct investigation approach (DIA). Fogarty, G., Catts, R., & Forlin, C (2000) presented a validation study, employing four different datasets, of a shortened 15-item version of the SERVPERF scale to be called SERVPERF-M. Exploratory and confirmatory factor analytic techniques were used to explore the dimensionality of the scale. Parasuraman et al (1991, 1993) modified and improved his own tools and suggests the areas of application. Hoffman and Bateson, (2001) illustrated that among the tools developed for service quality analysis the SERVQUAL developed by Parasuraman et al. (1988), is the most useful and widely adopted tool by the researchers

Rakshit Negi (2009) in his research used the SERQUAL tool to assess the service quality of mobile communication sector at Adisababa. The number of dimension is increased to 7 the analysis was made with 226 samples. In this present work this tool and constructs have been used after further improvement and adding relevant instruments for mobile communication sector and collecting data from a larger domain.

Cronbach's alpha is the most commonly used measure of reliability (i.e., internal consistency). It was originally derived by Kuder & Richardson (1937) for dichotomously scored data (0 or 1) and later generalized by Lee J Cronbach (1951) to account for any scoring method Cronbach Alpha is fairly easy to compute, but its application requires conceptual understanding such as true score, observed score, measurement error, variance, covariance matrix, consistency, and dimensionality. Cronbach coefficient Alpha is a measure of squared correlation between observed scores and true scores. Reliability is measured in terms of the ratio of true score variance to observed score variance.

Cronbach's basic equation for alpha is

$$\alpha = \frac{n}{n-1}\left\{1 - \frac{\sum V_i}{V_{test}}\right\} \quad (1.2)$$

where

n = number of questions,

V_i = variance of scores on each question

V_{test} = total variance of overall scores on the entire test

One could compute Cronbach Coefficient Alpha, Kuder Richardson (KR) Formula, or Spilt-half Reliability Coefficient to examine internal consistency within a single test. Cronbach Alpha is recommended over the other two as Cronbach Alpha can be used for both binary-type and large-scale data, KR can be applied to dichotomously scored data only. Alpha value of 0.7 or above is considered acceptable and indicates the consistency of the questionnaire. For higher the variances, it can be concluded that the respondents were able to differentiate properly and the constructs are consistent.

2.4 Survivability of Mobile Communication.

The wired line communication systems were experiencing frequent outages and the study of the dependability was always on the focus. When the mobile communication was introduced, it was believed that, it will be more reliable as there are very less physical cables. But due many factors such as physical network, channel availability and software related problems mobile communication suffered outages. Many researchers compared the performance of mobile communication with wired system with same quality of service parameters. However the need of separate parameters for the evaluation of mobile communication was put forwarded by many others. One of such parameter namely survivability is the ability of the network to cater service in the wake of outage in certain sections.

A general framework for telecommunication survivability network performance based on the results ANSI technical subcommittee A1T1 activities was brought out by Ali Zolfaghari (1994).He lists the features of outage as unnservability, duration and weight. He quantifies the network outages as a function of these three features. The outages are classified as catastrophic, major and minor based on the above features.

He describes two models on general survivability performance and claims wide applicability in planning survivable networks.

A communication network is susceptible to volatility in traffic and failures of communication links and other system components. A network can be protected against such contingencies by over-dimensioning the network and providing physically diverse routes. Ouveysi, I. and Y.K. Tham (1994) have considered the construction of a protection network that can carry overload traffic due to any two link failures or congestions. Medhi and D Tipper (1997) classified the failures as physical-type failures and software-type failures. The identified sub sets of failures include failures due to typical events resulting in a failure such as accidental cable cuts, hardware malfunctions, software errors, natural disasters (e.g. hurricane, earthquake), human error (e.g., incorrect maintenance), and malicious attack. He also provides review of literatures in this area. Medhi and D Tipper (2000) extended their work on survivability specifically on multi layered networks and suggested a frame work for analysis. One of the infrastructural insufficiencies associated with the unreliability of telecommunication identified as electric power failures.

Chatanyam K , G. Weckman, and P. Campbell (2006) presented the analysis of telecommunication failures due to power outages in United States for an eight years span. The triggered cause and root cause of such power failures are identified and analyzed.

Yun Liu and Kishore S Trivedi (1998) also proposed a general survivability quantification framework which is applicable to a wide range of system architectures, applications, failure/recovery behaviors, and desired metrics. In this framework, deterministic survivability measures can be modeled as a network flow graph and quantified by the use of the max-flow min-cut theorem and the corresponding labeling algorithm. They also brought out the different definitions of survivability in literature. They define survivability as a measure of the fraction of the available resource after the occurrence of failures. Suppose resource N is affected by failures. Expected survivability E[N] is the fraction of the available resource over all failure scenarios. r-percentile survivability Nr is the probability that N is no greater than r% of the total resource. Zero survivability N0 is the probability that no resource is available. These definitions are more relevant in telecommunication service. The 5-step procedure proposed by them can be used for different desired metrics to obtain a comprehensive understanding of system survivability behavior under abnormal environments.

A series of work on this area is carried out by Upkar Varshney and Andrew P Snow.

Upkar Varshney , Andrew P Snow and Alisha D Maloy (1999) illustrated that reliability, availability and survivability are intertwined. Design techniques that improve reliability and availability will enhance survivability. Without wireless survivability empirical data, it is difficult to derive current survivability levels, or the effectiveness of some of the specific design strategies. They also investigate issues related to end-to-end service availability for mobile users in cellular and PCS networks. The reliability of an individual component is dependent upon the degree or amount of redundancy within the component. Certain components of an end-to-end connection have higher reliability, because of varying levels of redundancy. Some designs with relevant redundancies are also explained by them.

Wireless and mobile networks are more prone to failure and loss of access than their wired counterparts (Upkar Varshney, et al 1999). Attention must be paid towards designing survivable wireless and mobile networks. In general a wireless or mobile network consists of switches, base station, databases, mobile devices and wireless links. **A** failure could involve one or more of these components. The impact of failure can be measured in terms of number of users affected and the duration of outage caused by a certain failure. However without wireless survivability empirical data, it is difficult to derive current survivability levels, or the effectiveness of some of the specific design strategies used.

Andrew P Snow (2000) illustrated the outage prone areas of mobile network and challenges in the mobile communication in the future. He considered each and every element in the network separately and explains the possible failure causes. According to him, wireless and mobile networks are more prone to failure and loss of access than their wired counterparts. A failure can involve one or more of a wireless or mobile network's components—switches, base stations, databases, mobile devices, and wireless links. He suggests that in addition to directing some attention to designing survivable wireless and mobile networks, developers must also keep in mind that increasingly pervasive and demanding services will further escalate the importance of reliability and survivability requirements. Apart from explaining the probable component failures, he evaluates the outage index proposed by FCC. Regarding the enhancement of survivability he suggests use of architectural changes such as usage of sonnet rings, usages of multi function multi mode devices and network overlays. He also stress the need on concentration on end to end reliability approach in heterogeneous network

According to Eason, B. Noble, and Andrew P Snow (2001) networks are more prone to failure due to three reasons namely (1) Rapid deployments of new products and services into network infrastructures. (2) Software up gradations to widespread indigenous pieces of equipment in large-scale network infrastructures. (3) Deficient network management tools to operate and maintain increasingly complex systems. In such environments, errors due to inadequate installation or operator instructions, lack of necessary skills, training, or tools to help manage complexity, design errors not identified by adequate pre-release testing and deployment errors that defeat fault-tolerant designs leads to unavailability of network.

Upkar Varshney et al (2001) present a scalable approach to model and simulate the reliability and survivability of infrastructural oriented wireless networks. They introduced wireless infrastructure building block approach and scaling of these infrastructural elements to investigate reliability and survivability attributes. They recommend that even a small change in MTTF will improve the reliability and survivability attributes. The survivability can be improved by adding fault tolerant features in the network. Issues due to user mobility, poor RF strength and increased call blocking probability are also evaluated.

Upkar Varshney and Alisha D Malloy (2001) explained the complexities due to the unavailability of failure details to public. Simulation techniques are used to identify the effects of sonnet, ring topologies in dependability. They have addressed the dependability issues of wireless networks by proposing as integrated approach for dependability based on design changes and the use of fault tolerant wireless architecture. Their findings include the evaluation that fault tolerant architectures are less useful when the reliability levels of individual components and links are low. However the reference values of reliability were not from any live outage data as it was not available to public

The dependability issues are more relevant in heterogeneous or multi carrier multi operator inter connected networks. Alisha D Malloy el al (2002) attempts to optimize the dependability attributes of wireless networks by proposing design changes including fault tolerance by introducing block level redundancy. They have computed the network dependability by varying the block level redundancy. The optimal or near optimal size of network is computed by them.

Chamsripinyo and D Tipper (2002) proposed a novel network design model that incorporates the user mobility factor for fault tolerant wireless access networks. They present a two phase design approach to solve the problem. The redundancy and fault tolerance are arranged with small additional costs and capacity. The problem formulation is based on the integer programming model to minimize the total network inter connect cost, satisfying the user demand of survivability

David Tipper (2002) discussed the effects of failures and survivability issues in PCS networks with emphasis on the unique difficulties presented by user mobility and the wireless channel environment. A simulation model to study a variety of failure scenarios on a PCS network is described, and the results show that user mobility significantly worsens network performance after failures, as disconnected users move among adjacent cells and attempt to reconnect to the network. Regarding the architecture he suggests that instead of root-branch leaf topology, with the MSC at the root, alternate routes must exist between the network components with appropriate traffic restoration methods, or intelligent spare components provisions for the network to be survivable. A multilayer survivability framework is presented to facilitate survivable wireless network design. This framework includes metrics for quantifying network survivability, possible survivability strategies, and restoration techniques for each layer

Valery Koval (2002) has carried out the study of index of reliability – probability of the radio access of cellular networks to stationary base networks. He defines guaranteed period of engineering operation of equipment of radio access

Iradj Ouveysi Andrew Wirth and Annie Yeh (2003) addressed the problem of dimensioning of a telecommunication network subject to some survivability constraints and alternative routing schemes. Their objective is to design a minimum-cost network to satisfy traffic flow requirements for all services in the case of any single link failure. They model the failure scenario with linear programming model. Their model is designed with an assumption that the costs associated with all links are equal.

Upkar Varshney and Alisha D Maloy (2003) compares the improvements in wireless dependability achieved by multi-level fault-tolerance by introducing redundancy at component, link, block and interconnection levels and demonstrates the selective redundancy could be achieve the desired level of fault tolerance. The study also incorporates macro level mobility to system level. Dependability has been analyzed in inter carrier and interconnected wireless networks.

Andrew P Snow, Restogi and Weckman (2005) modify the work by Upkar Varshney et al (2001) by using the neural network to arrive the key parameters of network service. The advantages include fast simulation and easy assessment

Shyam Menon and Ali Amiri (2005) present an optimal approach to solving important problems observed in the design of partially survivable cellular telecommunications networks. By selectively fixing decision variables, the problem is reduced to a significantly smaller binary knapsack problem which is then solved to optimality via the dynamic programming approach. The optimal approach presented in this paper solves even the large problems almost instantaneously, renders the use of other heuristic approaches unnecessary. The fact that the implementation of the optimal approach involves minimal disruption to the existing setup provides a convenience which combined with the recurring cost benefits that result provide a significant benefit that, over time, could result in a significant economic benefit.

Guosheng Zhao, Huiqiang Wang, Jian Wang (2006) proposed a novel quantitative analysis method for network survivability based on grey relational analysis. Starting with the normalization of decision matrix with interval number, the proposed method firstly applied grey relational analysis to assess the best affiliate degree and survival probability of every key service. Then, it analyzes the changes of every key service's survivability based on network entropy difference. Finally, it takes care of the synthetical analysis for the whole network survivability

Sangjoon Park (2006) proposed a survivability strategy called the forced handover scheme to improve the maintenance of essential service of the mobile network system. With the survivability scheme, the mobile network can use an overlap base station of the cellular network architecture after a base station system failure. The performance of the proposed scheme is analyzed using the Markov model and computer simulation is used for the scheme analysis. The proposed scheme shows that service of the mobile network can be provided under the BS system failure. Forced hand over scheme can be used to provide continuous mobile services because the survivability concept means the service is sustained during a system fault.

Exact computation of network reliability is feasible in small network only and for this reason researchers adopted simulation techniques. Network reduction techniques are mainly used with exact approaches such as factoring to compute network reliability. Abdullah Konak (2007) explains the effect of using network reduction before estimating network reliability using simulation. The sources of variance are also explained with comparison values of theoretical and empirical results.

Survivability index (SI) has been proposed by Neetesh Purohit et al (2007, 2009) for proper quantification of quality of service. SI has a weighted sum form which takes into account following features of a cellular network (i) blocking probability, (ii) dropping probability, (iii) voice quality, in terms of carrier to co-channel interference ratio (C/P) and (iv) Availability. Its analysis has also been done for GSM network by considering two different failure scenarios.

Supporting quality of service in wireless networks is an interesting area of research. Many significant advances have been made in supporting QoS in single wireless networks. But the support for QoS across multiple heterogeneous wireless networks will be required in future wireless networks (Punith Ahluwalia and Upkar Varshney 2007). In connections spanning multiple wireless networks, end-to-end QoS will depend on several factors such as mobility patterns, connection patterns, and the QoS policies in each of the networks. They present architecture for multiple heterogeneous wireless networks, several QoS schemes, a simulation model and several interesting results. Their results show that end-to-end QoS depends on several factors, including system utilization, mobility levels, and the individual QoS schemes implemented in individual networks.

Dharmaraja, Vaneetha Jindal and Upkar Varshney (2008) constructed an analytical model to determine reliability and survivability attributes of third generation and beyond Universal Mobile Telecommunication Systems networks. Hierarchical architecture of this network is modeled using stochastic models such as Markov chains, semi-Markov process, reliability block diagrams and Markov reward models to obtain these attributes. It is illustrated that incorporating fault tolerance increases the network reliability and survivability. The results are also useful for reliable topological design of Universal Mobile Telecommunication Systems networks.

Ghassan Semaan (2008) discussed different issues related to network availability. First, the paper presents some of the elements that impact the availability of a solution. Then the paper discusses how network designers can calculate the exact availability of their solution. Factors such as budget constraints, limited time, or skills and experience of the staff at hand decide the network design and availability obtained. As a result, most organizations end up with solutions that have a sub-optimal level of availability. These solutions will have either too much availability or worse, too little. Finally it provides means to determine the optimal level of availability. Using these elements, network designers may be able to evaluate which of the options at hand provide that adequate level of availability

When a BTS stops all functioning, it is designated as BTS failure which is primarily considered in developing models and further analysis by Neetesh Purohit and Sanjiv Tokekar (2008). Markov models have been developed for accessing the performance, availability and survivability of GSM with a scheme developed for minimizing the impact of failure. Its merits over ordinary GSM network are established in terms of performability and various attributes of survivability.

Key sectors of our society are becoming increasingly dependent upon highly distributed network systems, whose survivability is an unsolved science problem. Wang Xue-Guang (2009) surveys and discusses research results in recent years, including definition and development of survivability system, survivability analysis and architecture. At the end of the paper he points out the key problems of survivability research from view of theory and technology.

It is clear that study of survivability of telecommunication is a continuous process using different approaches. As suggested above the actual data of failure is very important for analysis but due to unavailability live data such analysis is seldom carried out. Simulations are mainly based on the empirical relations and logically assigned values.

2.5 Capacity and Channel Allocation Issues

Apart from the network failures, the capacity related issues are also significant in telecommunication networks. Since the channel allocation and time sharing are controlled by the software and algorithms many refer this issue as software reliability. Researchers introduce many new algorithms for reducing call drops and better channel allocation schemes for the improvement of reliability.

Handover is a process by which the control of one MS is transferred from one BTS to another. The transfer may be inter BSC/MSC or intra BSC/MSC. An unsuccessful handover results in call drop. Whenever the free channel is not available for use, the incoming call will be blocked. Hand over calls, generally given preference over new attempts, drops if the resources are not available. Frequency hopping helps to maintain same quality of voice to all calls by varying the frequency. Some calls will be clearer at particular frequencies and some other will be very poor in certain frequencies. Reliability issues due to call admission control, call drop, call blocking, hand off, frequency hopping etc are addressed separately by researches.

A widely accepted set of parameters describing the network performance with respect to handover consists of the elements (Miltiades E. 1994) such as handover rate, handover blocking probability, call blocking probability, duration of interruption of user traffic - in band signaling. When the signal strength or signal to interference ratio of a call falls below the required threshold the call drops. In practice it is not just the threshold but the time duration with low strength than threshold, forces the call to drop. Narayan B. Mandayam (1996) analyses the minimum time duration after which the call drops. They formulate the outage condition as a level crossing problem and extend asymptotic results from the theory of level crossing to derive analytical results for probability of outage.

Call admission control is one of the key elements in ensuring the quality of service in mobile wireless networks supporting multimedia applications. The traditional trunk reservation policy and its numerous variants give preferential treatment to the handoff calls over new arrivals by reserving a number of radio channels exclusively for handoffs. Such schemes, however, can lead to potentially poor radio channel utilization, due to the static nature. Si Wu et al (1998,2002) takes into account the effects of limited capacity and time dependence on the call dropping probability and, instead of implementing the control by adjusting the admission threshold, propose a scheme by computing the acceptance ratio, which spreads the new calls uniformly over the control period and leads to more effective and stable control. Jianping Jiang (2000) proposed a new approach that combines dynamic channel allocation and call admission control for bandwidth management. He confirmed that the proposed approach is capable of keeping the call dropping rate below a pre specified value while improving bandwidth utilization by 20% to 30%. Anand S et al (2000) conducted a call blocking probability analysis in cellular system under dynamic channel allocation. Reducing the call drop probability due to slow hand off problems is addressed by Deepa Ramakrishna (1999). Graziosi et al (2001) also analyses the hand over triggered dropping probability.

Srihari Nelakuditi (1999) proposes a scheme to reduce call blocking probability. According to him call admission control schemes in wireless cellular networks attempt to reduce call dropping probability possibly at the expense of increased call blocking probability. His proposal of using channel reassignments in a controlled manner minimizes call dropping while maintaining high spectrum utilization. He proposes to use guard channels to control the number of reassignments. The number of guard channels is dynamically determined using reassignment frequency as feedback. A method to calculate outage probability in non frequency hopping and frequency hopping schemes in GSM- GPRS is suggested by Shaoji Ni (2000).

A measurement based pre assignment technique was designed by Xiaoyuan Luo (2000) to prevent hand off failure due to lack of resources in cellular networks. Unlike the guard channel based schemes, it allows hand off channel to utilize a pre reserved channel pool before competing for the shared channels with new calls. The scheme proposed by Shigeki Shiokawa (2002) estimates the call dropping probability of the cell when a new call is generated and accepts the call only if the probability is less than a threshold value decided in advance. Yuguang Fang (2005) uses mixed Erlang distribution for the time variables of call holding and claims more flexibility in computing performance parameters as a probability

When a call is in progress the total time that a user engages in communication is referred as Actual Call Connection Time (ACCT). This time has significance as it decides the probability of sharing of resources in a network. Yuguang Fang (2002) characterized the ACCT and related performance metrics for wireless mobile networks under a newly proposed general channel allocation scheme. This scheme generalizes the non prioritized scheme, the reserved channel scheme, the queuing priority scheme and the sub rating scheme in such a way as to reduce the blocking probability of the handoff calls while keeping the ACCT as long as possible.

A successful handover is necessary while the MS is moving across the boundary of cells. The basic concepts of mobility are explained by Jun-zhao sun (2002).A scheme of channel allocation, prioritized based on the speed of the movement of MS is proposed by Felipe A. Cruz-Pirez (2003). This mobility-aware handoff prioritization strategy for cellular systems with 'heterogeneous platform types reduces the forced termination probability of fast moving user calls without exceeding the permissible levels of dropping probability for slow moving users. The cell residence time, time during which a MS resides in a service area of a cell, is relevant in calculation of probability of successful connection. The period between when a call arrives at the MS and when the MS move out the cell is called the excess life of the cell residence time for that MS. This excess life has significance as its distribution can decide whether the call will be handed over or dropped. Hui-Nien Hung (2006) developed the excess-life random number generation procedures for cell residence times with gamma, Pareto, Lognormal, and Weibull distributions.

Bong-Ju Lee (2003) proposed a new call admission control scheme considering the call dropping probability of ongoing calls in low earth orbit satellite networks. A neural-network-based multicast routing algorithm is proposed for constructing a reliable multicast tree that connects the participants of a multicast group by Vijay Kumar P B and Venkataram P (2003)

The grade of service at the call level is represented by handoff call dropping probability, while the quality of service at the packet level is represented by transmission accuracy and delay. Lei Wang's (2003) new call admission control scheme ensures satisfaction of both quality of service and grade of service, and achieves maximal resource utilization. In the paper by Zari Dzalilov Z., Ouveysi I. and Rubinov Awe (2003) proposed a methodology for dynamic reconfiguration of telecommunication networks and implements to achieve network recovery in the case of any failure in the network.

The commercial aspect of maintaining higher reliability was also studied by researchers. The network provider and network user may have various service level agreements regarding the network service. Breach in some of the agreements will be panelized. Mathematical modeling of network failure recovery with dynamic reconfiguration is presented by Zari Dzalilova and Iradj Ouveysi (2009) in part 1 and part 2. Mathematical linear programming methods are used to optimize the reconfiguration in both penalization and non penalization scenario. The customers can select their level of service by opting gold, silver and bronze schemes which will vary in priority in service as well as charges applicable. All these customers cannot claim equal reliable services.

2.6. Simulation Approaches.

A study of the system using simulation techniques is the only feasible resort in many occasions. System complexities can be readily incorporated in a study by designing a simulated model. Real systems cannot be spared for research experimentations due to the obvious reasons. A portion or a sub system of a network is simulated in various studies. The basic and essential things to be incorporated in a simulation process are explained by Law AM & David Kelton W (2003) and Blanks J (1999). The simulation model facilitates the reliability modeling by design engineers and reliability analysts early in the design process. (Landers, T. L., Taha, H. A., & King, C. L 1991) The models can also be applied to preliminary feasibility and design tradeoff studies. Kenneth E. Murphy and Charles M. Carter (2001) provide practical thump rules for reliability simulations. Questions such as how long and how many replications etc for reliability simulations are answered by them. The rules of thumb provide a structured methodology that determines a solution space as a function of simulation length and number of trials such that the value of the reliability, availability and maintainability parameters in question can be considered good enough.

According to Wang, H., & Pham, H. (1997) Monte Carlo technique combined with Bayes method is a powerful tool to solve network problems. In his survey, the typical existing Monte Carlo reliability, availability and MTTF simulation procedures, variance reduction methods, and random variant generation algorithms are analyzed and summarized. The advantages, drawbacks, accuracy and computer time of Monte Carlo simulation in evaluating reliability, availability and MTTF of a complex network are also discussed.

He´lio Fiori de Castro and Katia Lucchesi Cavalca (2003) uses genetic algorithm for availability optimization in an engineering system assembled in a series configuration which has the redundancy of units and teams of maintenance as optimization parameters. The objective was to reach the maximum value of availability, considering installation and maintenance costs, weight, volume and available maintenance teams as constraints. A simple Monte-Carlo Simulation is proposed by Yeh, W. C. (2004) in the article for estimating the system reliability of a stochastic multi-state network without needing to know all of the minimal path sets/cut sets (MPs/MCs) in advance. The estimates of the simulation approach are compared to the existing best-known Monte-Carlo simulation approach and exact solution. The analysis claims that the proposed method out performs the existing best-known MCS in both solution quality and computational effort perspectives

Monte Carlo sampling methodology for computing network reliability, previously proposed by Rocco is extended by Rocco, S, Claudio, M., & Zio, Enrico (2005) by developing cellular automata for the solution of the all-terminal and *k*-terminal connection problems and the maximum un splittable flow problem. It can be considered as a particular, simplified case of the maximum flow distribution problem.

Discrete time event simulation to ascertain the fault tolerance of mobile communication network is carried out by Upkar Varhney and Alisha D Malloy (2001, 2006). This model considers the mobile communication network as repeated units of block which consists of certain number of switches and interconnecting links. The redundancy requirement at each level for satisfactory performance is evaluated with simulation. The detailed performance results indicate that fault tolerance at component, link, block, and interconnection levels can significantly improve the overall dependability performance. To achieve highest dependability, fault tolerance at link, component or block level is not sufficient and must be combined with the interconnection level fault-tolerance

Zio, et al (2006) combined Monte Carlo simulation and cellular automata for computing the availability of a complex network system and the importance measures of its elements.

A repairable system is one which, after failing to perform one or more of its functions satisfactorily, can be restored to optimal performance without replacing the entire system. The links and switches are repairable to large extend. Yi-Hui Liang (2008) proposes a new method for predicting the reliability of repairable systems. A predictive model constructed by integrating neural networks and genetic algorithms. Poul E. Heegaard and Kishor S. Trivedi (2009) demonstrates alternative modeling approaches to quantify network survivability, including stochastic reward nets and continuous time Markov chain models, and cross-validates with a process-oriented simulation model. It is clear from literature that simulation is the best option for network performance study. Based on the issue analyzed the sub systems of a large network is modeled and simulated by many researches.

2.7 Data Analysis and Probability Distribution.

The times to fail and time to repair of components are random in nature. Many times it is modeled using probability distribution. The complexities involved in defining such process are the various unknown factors affecting the failure and repair process. The assumption of invariant failure or repair time helps to analyze such problems easily. Such assumptions are supported by literature. The time to failure shall be effectively modeled with exponential distribution if the hazard rate is constant. (Barolini 2004, Sreenath 1998). The time to repair will vary depending upon the factors locating the fault, reach to the spot and testing etc. The long tile property of log normal distribution is well suited to incorporate such factors and many researches represent time to repair in lognormal distribution (Barolini 2004, Sreenath 1998). Literature analyzing the outage data of mobile communication is very limited. On the other hand, theoretical modeling of time to failure and repair, broadly applicable to all areas are discussed in text books. General guidelines to arrive at a distribution and significance each models are described in Martin J Crowder (2001), Richard A Johnson and C B Gupta (2008), and Benjamin Epstein and Ishay Weissman (2008).

Kenneth E. Murphy (2002) in his paper explained the selection of model and implementation for simulation. He discusses about the widespread applicability and mathematical tractability of the exponential distribution and demonstrates the risks of the exponential assumption when used to represent redundant subsystems when used within simulations. This paper provides insight into the good aspects of using the exponential distribution but more importantly, into the ubiquitous misuse of the most commonly implemented reliability distribution.

Stephene E. Chick (2001) presented a self-consistent evaluation of the uncertainty about the mean value of the simulation output, when there is uncertainty in both the parameters and functional form of input distributions (structural uncertainty), and uncertainty due to the stochastic nature of simulation output (stochastic uncertainty), as is common in simulation practice. He cautions authors who have identified problematic issues with techniques used in simulation practice for selecting probability distributions and their parameters for input to stochastic simulations. He proposes an algorithm for randomly sampling input distributions and parameters before each simulation replication, using a Bayesian posterior distribution. He provides examples to illustrate the issues in selecting distributions for discrete time event simulation.

Yonghuan Cao (2002) provided a general closed-form formula for the steady-state availability of a system with multiple outage types of arbitrary distributions. He points out that popular all-exponential model that assume that all times to outages and recoveries are exponentially distributed can under-estimate or over-estimate system availability if used for a system with generally distributed times to outages, of which limited information is known. He distinguishes distributions for the planned and unplanned outages for evaluation steady state availability.

The selection of distribution with modification of conventional models is also suggested in literature. Joshua lam (2007) in his paper, Log Shifted Gamma (LSG) approximation is proposed to calculate the sum of correlated lognormal random variables. The LSG approximation provides an accurate evaluation of the outage probabilities with correlated lognormal interferers in most cases with a wide range of dB spreads, number of interferers M, correlation coefficients r among interference components, and noise power N.

From the literature it is clear that mobile communication reliability has been studied by number of researchers especially in transport and other layers. Simulation of small switches and adjoining network were carried out for analyzing admission control, call drops etc. However analysis of real outage data was not yet carried out to model the network failure pattern. Also simulation with parameters arrived from real data has not been used in any study. Hence the present study attempts to rectify the above limitations and simulate the real time network with real network capacity and complexities. Service quality studies were conducted based on the perception and expectation by customers to arrive at the weakest dimension of service, which provided the necessary justification of the relevance of the work.

2.8 Objective of the Research

The focus of the work is to analyze the outage as obtained from the field data and there by develop a model for reliability analysis of the mobile communication network. The major objectives of the study include;

1) To analyze the customer expectation and perceptions on mobile telecom service using management tools and to identify the weak dimensions of service
2) To study the impact of network maintainability on the availability of the mobile communication network
3) To analyze the industrial policy issues in tune with network availability and to study the impact of BTS outage in relation with the accepted standards
4) To develop a mathematical model for risk analysis and to predict the availability domain for a given network
5) To study the sensitivity of mobile communication network

2.9 Conclusion

An elaborative research survey was conducted to gain knowledge about the existing studies and literature in the field of mobile communication reliability. A number of researches focused on a small domain with emphasis on software and related algorithm associated with mobile communication. In this contest the present work assumes significance as the analysis is mainly focused on network infrastructural dependability analysis.

Chapter 3

Service Quality Analysis

3.1 Introduction

It is intended to identify service quality gaps as experienced by the subscribers of the mobile services of state owned BSNL in the geographical area of Ernakulam district. It also indicates the strengths and weakness of service based on the various dimensions. The service quality gaps have been arrived by obtaining the difference between expected and perceived service, as experienced by the users and by examining the overall perceived service quality of mobile subscribers

3.2 Identification of Service Dimension and Preparation of Instruments

Hoffman and Bateson, (2001) suggests that among the tools of measuring service quality of organization SERVQUAL developed by Parasuraman et al. (1988) seems to be useful and widely adopted by researchers. The Instruments in SERVQUAL analysis is modified for application in mobile communication service sector. The instruments are under seven dimensions such as Tangibles, Reliability, Responsibility, Assurance, Empathy, Network and Convenience. 28 modified instruments (questionnaires) under the seven dimensions were prepared and used for survey. The questions were presented in both English as well as Malayalam (local language) for better understanding. A preliminary survey was conducted to ascertain the acceptability of questionnaire and corrections were made accordingly. Since the service sector varies in mode of service and significance of service, a weighted average value of each dimensions were also collected in the preliminary survey.

Modifications of the number of instruments based on the field of application especially the network aspect, and collection of data from a larger domain are the uniqueness of this study. Further, this technique is not been used to assess the telecommunication service sector in Indian cities so far.

Ernakulam is a thickly populated district of Kerala and has around half a million subscribers for state owned BSNL mobile service. The recommended sample size for such a survey is

$$S_n = N/(1 + Ne^2) \tag{3.1}$$

where N is the approximate population and e is the probability of error.

The BSNL mobile subscribers in Ernakulam are around 500000 in numbers and with a probability of error 5% (confidence level 95%) the number of samples shall be 399. The stratified sampling technique was used and 362 samples were collected, out of which 336 were valid. That amounts to a probability of error 5.5% that is at 94.5% confidence level

Table 3.1 Five point Likert scale

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
1	2	3	4	5

3.3 Field Survey

The responses are marked with five point Likert scales as given in Table 3.1 for both expectation and perception. Samples were collected under a stratified sampling method by dividing the sampling area of Ernakulam district into five different strata, namely Kalamassery, Aluva, Vypin, Thripunithura and Ernakulam city. The survey was held personally after explaining the significance and specialties of questionnaires to the respondents. The expectations of the customer are based on their level of requirement and imaginations and perceptions are the evaluation of what they really receive. Each instrument was to be evaluated based on expectation and perceptions and mark their option in the five point Likert scale. The questionnaire is provided in Table 3.2

Table 3.2 Questionnaires

Dimension	Q.No	Instruments
Tangibles	1	Service provider will have up-to-date equipment
	2	The physical facilities at service provider will be visually appealing
	3	Employees will be well dressed and appear neat
	4	The appearance of the physical facilities will be in line with the type of services provided
Reliability	5	When the service provider promises to do something by a certain time , it will do so
	6	When a customer has a problem, service provider will show a sincere interest in solving it
	7	Service provider will be dependable
	8	Service provider will provide its services at the time it promises to do so
	9	Service provider will keep its records accurately
Responsiveness	10	Service provider will tell customers exactly when services be performed
	11	Employees will give prompt service to customers
	12	Employees will always be willing to help customers
	13	Employees will never be too busy to respond to customers' request promptly
Assurance	14	The behavior of employees will instill confidence in customers
	15	Customers will feel assured that service requests are duly followed up
	16	Employees providing services will be courteous
	17	Employees will have the knowledge to answer customers' questions
Empathy	18	Service provider will be expected to give individual attention to customers
	19	It will not be unrealistic to expect employees (giving services) understand specific need of their customers
	20	It will not be unrealistic to expect service provider to have customers' best interests at heart
	21	Service provider will have operating hours convenient to all its customers

Network Aspects	22	Service provider's network will have excellent voice quality
	23	Service provider will have wider network coverage
.	24	Service provider's network will support no call drops
	25	Service provider's network will be available at all instances
Convenience	26	Service provider will have sufficient offices in different geographic areas
	27	Service provider will have toll-free numbers, websites etc. for clarification of problems, knowing account status etc. by customers
	28	It will be easy to get scratch cards from or pay bill to the service provider

Apart from these instruments, personal data pertaining to gender, age, geographical strata, financial income group, education level and the years of mobile usage experience were also collected along with the instruments. The respondents were asked to rate the overall performance of the service provider

The statistical divisions of respondents are 61% male and 39% female. Regarding mobile usage 37% has used the mobile for 1 to 3 years, 19%, 24% and 20% has used mobile for less than one year, three to five years and more than five years respectively. Regarding the overall service quality, about half of respondents were happy with the service stating good (43%) and very good (5%). But 32% rates as average, 16% below average, and 4% rate poor. Significance of these responses indicates that there is section of customers dissatisfied with the service and unless the service is improved, they may utilize the number portability options and move to other service providers (Refer Fig 3.1 to 3.4)

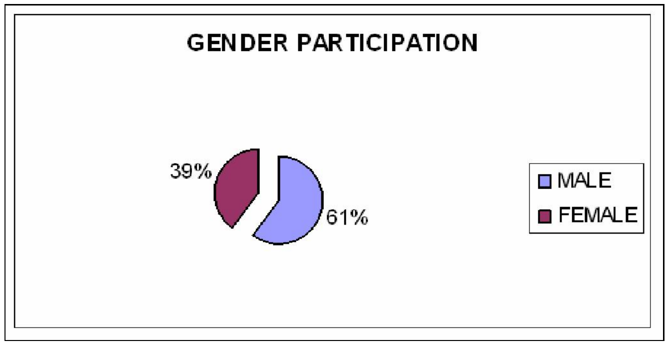

Fig 3.1 Gender participation

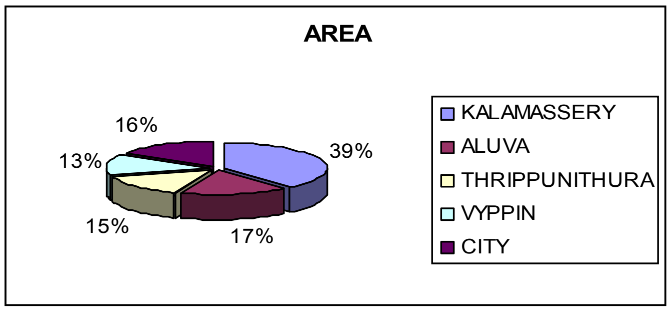

Fig 3.2 Strata

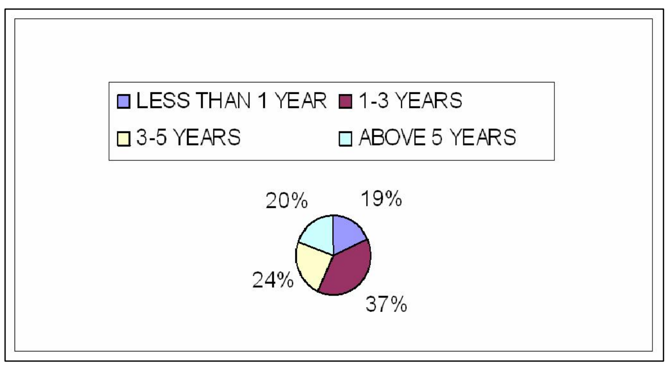

Fig 3.3 Usage experience

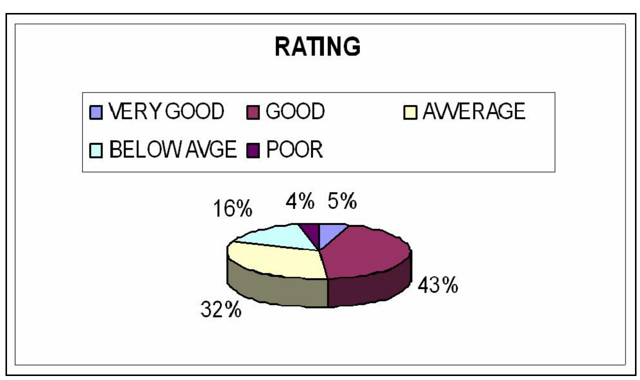

Fig 3.4 Overall rating

3.4 Response Validation

The reliability or internal consistency of the scale is validated by calculating the Cronbach Alfa values. It was originally derived by Kuder & Richardson (1937) for dichotomously scored data (0 or 1) and later generalized by Cronbach (1951) to account for any scoring method. Cronbach coefficient Alpha is a measure of squared correlation between observed scores and true scores. In other words, reliability is measured in terms of the ratio of true score variance to observed score variance. It is calculated based on the variance of score for each questions and total variance. Cronbach Alpha value more than 0.7 is acceptable and indicates the internal consistency of instruments. The overall Alpha value was calculated as 0.8793. Table 3.3 presents the various Alpha values

Table 3.3 CRONBACH Alpha values

Q.NO	*Dimension*	*Dimension ALPHA*	*ALPHA If Item deleted*
	TANGIBLES (T)	*0.513223*	
1			*0.878821*
2			*0.877460*
3			*0.879296*
4			*0.876811*
	RELIABILITY (R)	*0.649344*	
5			*0.872961*
6			*0.872917*
7			*0.879809*
8			*0.872790*
9			*0.876556*
	RESPONSIVENESS(S)	*0.736480*	
10			*0.873695*

11			*0.870839*
12			*0.872030*
13			*0.871636*
	ASSURANCE (A)	*0.668211*	
14			*0.873236*
15			*0.873843*
16			*0.875169*
17			*0.875834*
	EMPATHY (E)	*0.682069*	
18			*0.873077*
19			*0.875151*
20			*0.875540*
21			*0.872781*
	NETWORK (N)	*0.682186*	
22			*0.876600*
23			*0.877901*
24			*0.877575*
25			*0.878418*
	CONVENIENCE (C)	*0.577273*	
26			*0.876425*
27			*0.876862*
28			*0.877469*
	OVER ALL		***0.879372***

3.5 Data Analysis and Results

Pilot surveys with 36 respondents were conducted to obtain weightage of different dimensions, as each dimension evaluates different aspects of service quality. The network dimension needed a special attention as the instruments should be non technical and answerable by the respondents. The instrument added regarding the availability of network had largest gap score indicating the significance of this dimension in service quality analysis of mobile communication. The question regarding the availability of service at the instance of demand recorded a largest gap score (-1.98) indicating the most significant aspect of service. The average customer expectation is given in Fig 3.5. Customer expects maximum quality in network aspects and convenience dimensions and they do not care much about the empathy aspects.

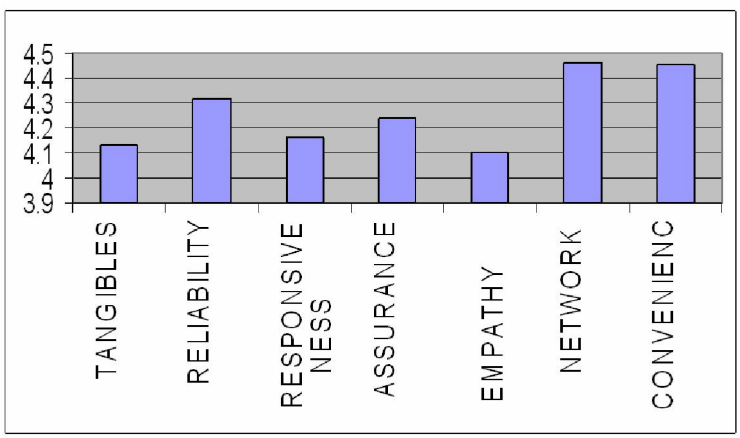

Fig 3.5 Average customer expectations

Customer dissatisfaction is highest for the network related service as indicated in the Fig 3.6. The tangibles, empathy and convenience dimensions do not contribute much on dissatisfactions. As suggested by Parasuraman et al. (1994) the gap analysis is accurate in identifying service short falls in an operation.

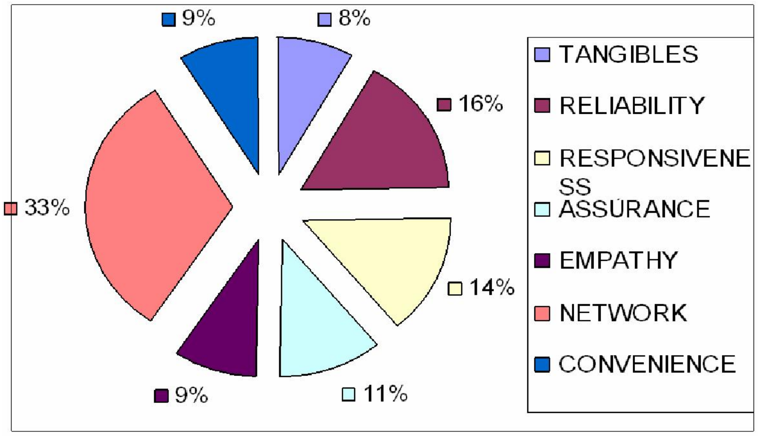

Fig 3.6 Customer dissatisfaction reasons

Addressing these identified shortfalls is the foundation for planning strategies to ensure customer experiences that are consistent with their expectations and thus increasing the probability of satisfaction. It is evident that in general, customers' perceptions of BSNL mobile service quality did not meet their expectations (perception minus expectation gap scores being negative). While the larger mean gaps score were reported for the dimensions of network aspect (-1.695) and responsiveness (-1.3), the smaller mean gap scores were obtained with tangibles (0.892) and convenience (0.95). The gap score and its significances are given Table 5.4

Table 3.4 Gap scores

Dimension	Q No:	E	P	P-E	Σ(P-E)/N
TANGIBLES	1	4.36012	3.39881	-0.96131	
	2	3.95238	3.13095	-0.82143	
	3	4.11310	3.22619	-0.88690	
	4	4.10714	3.20536	-0.90179	
				-3.57143	-0.89286
	5	4.22321	2.80952	-1.41369	

RELIABILITY	6	4.35417	2.89881	-1.45536	
	7	4.20833	3.09226	-1.11607	
	8	4.28274	2.94048	-1.34226	
	9	4.34524	3.24405	-1.10119	
				-6.42857	-1.28571
RESPONSIVENESS	10	4.13393	2.95536	-1.17857	
	11	4.16071	2.83333	-1.32738	
	12	4.27381	2.90476	-1.36905	
	13	4.07440	2.74107	-1.33333	
				-5.20833	-1.30208
ASSURANCE	14	4.21726	2.97024	-1.24702	
	15	4.16071	2.97619	-1.18452	
	16	4.21131	3.05952	-1.15179	
	17	4.37202	3.16071	-1.21131	
				-4.79464	-1.19866
EMPATHY	18	4.11607	2.92857	-1.18750	
	19	4.01786	2.97619	-1.04167	
	20	4.00298	2.94345	-1.05952	
	21	4.25595	3.08036	-1.17560	
				-4.46429	-1.11607
NETWORK	22	4.41667	2.98512	-1.43155	
	23	4.53274	2.91964	-1.61310	
	24	4.42560	2.67262	-1.75298	
	25	4.47321	2.49107	-1.98214	
				-6.77976	-1.69494
CONVENIENCE	26	4.37798	3.19940	-1.17857	
	27	4.52083	3.64881	-0.87202	
	28	4.45536	3.65476	-0.80060	
				-2.85119	-0.95040

Table.3.5 SERVQUAL Scores

DIMENSIONS	WEIGHTAGE	GAP SCORE	SERV SCORE
TANGIBLES	0.12	-0.89286	-0.10714
RELIABILITY	0.16	-1.28571	-0.20571
RESPONSIVENESS	0.14	-1.30208	-0.18229
ASSURANCE	0.12	-1.19866	-0.14384
EMPATHY	0.1	-1.11607	-0.11161
NETWORK	0.24	-1.69494	-0.40679
CONVENIENCE	0.12	-0.9504	-0.11405

The SERVQUAL analysis refines the significance of dimensions based on the weighted gap score since the importance of each service dimensions are different for different services. Mobile communication is a service in which personal intervention is least now days. The appearance of infrastructural facility and behavior of service providers do not affect much. This idea is clear from the data received in the preliminary survey and the weightage for each dimension is different. The network aspect recorded a weight age of 24% where as the empathy recorded just 10%. The weighted gap score are given in the table 3.5

The correlations presented in Table 3.6 between the dimensions indicate the independence of dimensions except for empathy, responsiveness and assurance. Since these three dimensions are slightly influencing each other, the correlation is acceptable. The customer expectation is highest in the network and convenience dimensions and least in empathy and tangibles which makes sense, considering the nature of the service sector. The technical quality status of network found to be worth analyzing, as the customer dissatisfaction is highest in this dimension.

Table 3.6 Correlation coefficients

	Tangibles	Reliability	Responsiveness	Assurance	Empathy	Network	Convenience
Tangibles	1						
Reliability	-0.101118	1					
Responsiveness	0.195559	-0.133206	1				
Assurance	0.289615	-0.133777	0.702207206	1			
Empathy	0.262724	-0.054261	0.540629189	0.5113561	1		
Network	0.160508	-0.050205	0.286027484	0.1615213	0.34592	1	
Convenience	0.000654	0.09641	0.499085996	0.3117876	0.37276	0.26599	1

3.6 Conclusion

In spite of considerable dissatisfaction in network related service, half of the customers are happy with the service. Dimensions significant in personal service are not influenced much in the overall ratings. It is clear that network performance is not satisfactory as the voice quality (-1.43), network coverage (-1.61), call drop (-1.75) and instantaneous availability (-1.98) recorded the maximum gap score. The expectations of the customers are very high in these dimensions and unless they are met properly, there is a chance of losing customers. In the wake of mobile number portability facility and the competing market environment, ‘network’ dimension is crucial in maintaining the market shares. The availability of the service needs further study and evaluation, based on actual service data to ascertain the reasons for the unreliability

Chapter 4

Mathematical Modeling of Service Outages

4.1 Introduction

The end to end availability of mobile communication network is a function of the availability of all the intermediate elements. The physical network elements of 2G and 3G communication system are similar with three tier switching systems. Since there are number of different switches such as MSC, BSC and BTS which are connected in series the availability of each switch is important. Availability of interconnecting cables or micro wave links also affects the availability of network. Since the whole network is not affected by outage of some elements, this is considered as multi state reliability problem by the researchers. Apart from the physical failure of these elements, the insufficient capacities of these elements also affect the customer. A connected call may drop due to hand over problems or RF fading. That is, there are three distinct categories of failure which could affect a customer when one is trying to connect a call.

1) Network outages
2) Lack of the carrier capacity at the time of connectivity
3) Issues causing the retain ability of connected call, which also depends upon resources

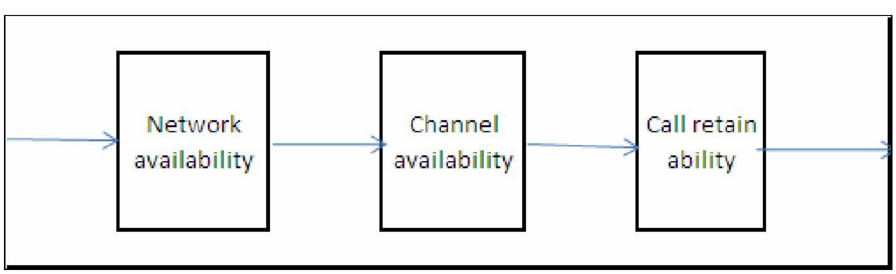

Figure 4.1

The end to end availability depends on the availability of all these stages. For heterogeneous network the connectivity issues at point of interconnectivity also causes unavailability. The instantaneous availability shall be defined as probability of the availability at the instance of demand. The availability of service will be function of availability of network, availability of channel and availability of retainable resources as given in equation 4.1

$$P_{(\text{service availability})} = P_{(\text{network availability})} \times P_{(\text{channel availability})} \times P_{(\text{retain ability})} \qquad (4.1)$$

In GSM network there are a series of electronic switches and links which are prone to failure / breakage. The probability of failure and MTTF of these components contribute to outages. The probability of availability of network depends upon the probability of availability of switches such as MSC, BSC, BTS and cable links

$$P_{(\text{network availability})} = P_{(\text{switch availability})} \times P_{(\text{cable availability})} \qquad (4.2)$$

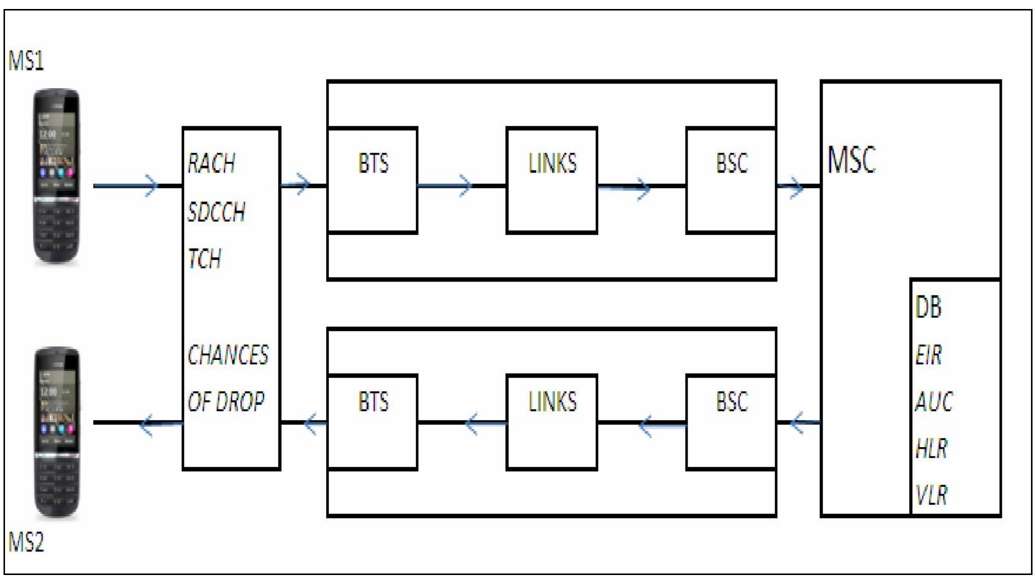

Figure 4.2

The channel availability also depends upon availability of free channels in SDCCH and TCH

$$P \text{ channel availability} = (P_{\text{SDCCH availability}}) * (P_{\text{TCH availability}}) \qquad (4.3)$$

That is, the availability of service will depend upon the product of probability of availability of various components in the net work

$$\text{Availability} = \prod P_r \tag{4.4}$$

where 'r' is the number of deferent elements connected in series

A careful examination and analysis of the cause of outage reveals that there are number of causes by which the network fails. Analyzing the outage data using statistical techniques will help identification of a trend or pattern in the failure, which shall be used to predict or arrange preventive maintenance or replacement. Topological and climate influences on outage can also be identified using failure data analysis.

The service outage due to the BTS failure is studied by analyzing the live data. The actual outage data of one of the GSM service provider in Kerala state was collected for six months. The observed network consists of 2360 BTS (discarding the new erection/commissioning and test sites during the period of study) providing service to nearly 3.5 million subscribers. The data collected include the identification number of the failed BTS, time of outage, time of restoration of service and nature and cause of outage. The time at which the observation commenced is taken as starting time. History of outage prior to this instant is not considered. All switches and cables were considered as fresh as new. A separate data giving the capacity related performance is also collected. Data pertaining to outages more than thirty minutes are analyzed. Statistical summary analysis of various causes of service outages are carried out. Exploratory analysis using competing risk models are also carried out to arrive at the outage patterns.

The scope of the work includes

a) Examine the deferent causes of outage and group them to evaluate the severity

b) Analyze the capacity related unavailability issues from the data and point out the short comings

c) Analyze the outage data so as to arrive at a mathematical model and parameterize.

d) To propos a metric, to represent the capacity related performance of the network

4.2 Statistical Summary Analysis

4.2.1 Network failures

There have been a number of causes for network outage and they are classified and included in five different causes such as equipment failures, link failures power failures planned outages and other causes. The equipment failure refers to all type of hardware failures at BTS level. The link failure is the actual outage of link as well as the upstream failures so that incoming link to BTS is broken. Outage due to power failure is recorded only if all the sources of power at BTS level fail together. Planned outages include actual maintenance, reinstallation and up gradation time. The other causes include human causes, environmental causes and random causes.

Table 4.1 Outage comparison

Nature of outage	Percentage by time	Percentage by frequency
Power failure	36	41
Planned	13	12
Other	23	19
Link failure	21	23
Equipment fail	06	05

Table 4.2 Power outage components

Power outage causes	Percentage by time	Percentage by frequency
Power plant BTS	10	8
ELCB trip	8	9
Generator fail	25	26
Lightning	0.4	1
Auto mode fail	15	20
Power fail SSA	1	1
No generator	32	27
Other	9	8

It is evident that the service outage due to actual hardware failure in the switch level is just 6 percent. That is the usual reliability analysis of the hardware failure will take care of only 5% of service outages. Due to the up gradation of hardware as well as software, expansion of network and maintenance the planned outages are also high.

Being the major cause of outage, the power failure is further analyzed. As per the recommended 'industrial best practice' there should be a three tier system for power supply, with municipal power supply as main source, diesel generator as stand by power source and sufficient powered back up battery as the third source. But the operators heavily depend upon municipal supply and the service is interrupted whenever that fails. No generators, generators under repair, no fuel are the some of the recorded reasons for power failure. The statistical details of failure and causes are given in Table 4.1and 4.2.

4.2.2 Unavailability due to lack of capacity

Each network switch is designed with a fixed number of physical channels for communication. A ten times higher numbers of customers are expected to be served by this switch. Since the probability of usage is less, every one gets connected as and when they attempt. This concept fails in many occasions due to mobility and usage pattern of subscribers.

The call attempt will not be registered when the RACH request is discarded by the system. If the SDCCH is not available SDCCH blocking will be recorded. If TCH is not available TCH blocking will be recorded. If the carrier is not available due to mobility or RF fading call drop results. Each operator automatically records the blocking percentages in its BH of the day. The call drop details are recorded on daily basis. The TRAI reports give three months high values without indicating the number of occasions the bench mark was exceeded. Further the blockage data of instances other than BH is not recorded. The numbers of incidents of various call blockages in three months are presented from the daily data of service provider. This is done in comparison with TRAI report which gives only three months average value. Further the blockages are compared with a lenient lower value rather than bench mark. TCH block >15%, SDCCH block > 5%, Call set up success rate > 80% and call drop >4% are given in the Figures 4.3, 4.4 and 4.5

The number of cells experience call blocking is very high compared with the bench mark. It is the data in busy hour of the day. Maximum blockage is experienced in busy hour but it does mean that the blockage was below bench mark during other hours of the day. The call setup success rate is also below 80% in a large number of occasions in busy hour. Similar failure might have experienced in other hours also. A connected call drops during a conversation will certainly annoy the customer.

The cells experienced call drops more than four present (The bench mark is 2%) in three months indicates considerable number of call drops

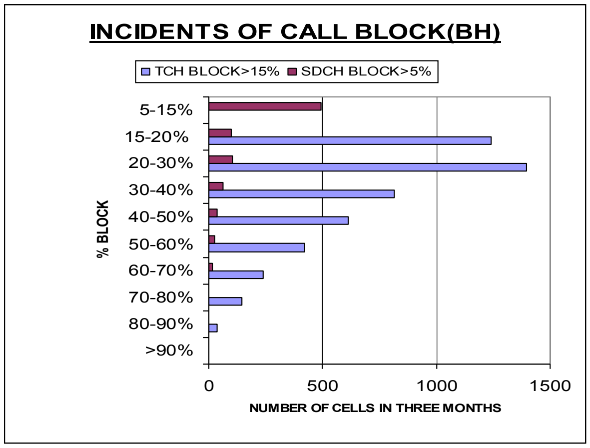

Figure.4.3 SDCH and TCH Call blocking incidents

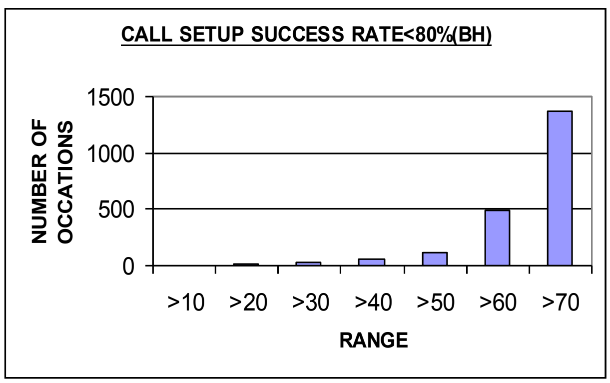

Figure.4.4 Call set up success rate

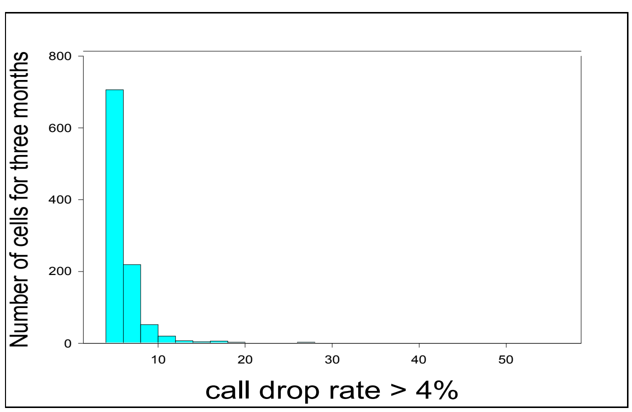

Figure 4.5 Call drop rates more than 4%

During the observation period, it was noted that almost all BTS (2264 out of 2360) experienced at least one outage of half an hour more duration. The details of number of BTS experienced more than one failure are given in Figure.4.6

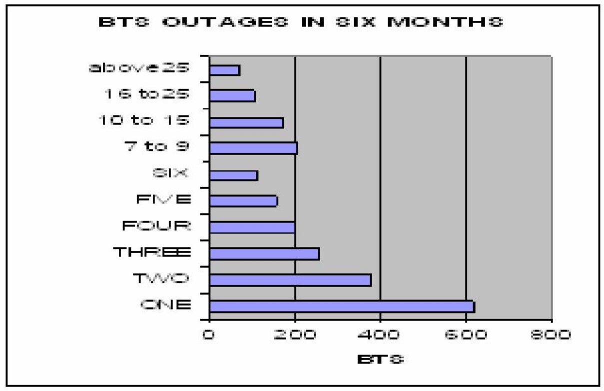

Figure 4.6. BTS Outage frequency

4.3. **Modeling of Time to Failure**

The classical competing risks models are applicable to the failure or survival data which has a continuous variable, say, time T, and are being observed for the failures due to a discrete numbers of causes C. The cause variable Cj (j = 1,….,p) can have p number of values. Till failure occurs the causes are only risks and become causes after failure. That is, the risks are competing to be causes.

The identifiable probabilistic aspect of the model is the joint distribution of C and T. However cause specific sub distribution functions shall be derived from the failure data

$$F(j,t) = P(C = j, T \leq t) \tag{4.5}$$

The cause specific sub survivor function is

$$\overline{F}(j,t) = P(C = j, T > t) \tag{4.6}$$

Further the marginal survivor function and marginal density of T shall be calculated

$$\overline{F}(t) = \sum_{j=1}^{p} \overline{F}(j,t) \tag{4.7}$$

$$f(t) = \sum_{j-1}^{p} f(j,t) \tag{4.8}$$

At the starting at time t=0, the beginning of observation period, it is assumed that all equipments and links are as good as new. It is observed that some BTS did not fail within the period of observation. The number of surviving BTS at the end of observation is the right censored data. Again when we analyze the failure due a particular cause, the failures due to other causes is also censored data. Analysis has been done incorporating all these censored data. During the observation period 2264 numbers of first failures were recorded out of the 2360 BTS. The details of observed first failures and the censored data are given in Table 4.3

The simple assumption of constant hazard rate was found to be violated based on the collected data, and hence an assumption of a model with varying hazard rate is considered.

Table 4.3, First failures and censored failures of BTS

Service interruption due to failure of	Share in first failure	Right censored	Censored failures 2nd	3rd	4th failure
Equipment	70	2290	152	75	16
Link	259	2101	440	198	25
Power	274	2086	474	191	21
Others	1661	699	343	40	1
All causes	2264	96	NA	NA	NA

Two parameter Weibull distributions, very commonly used in reliability analysis, incorporate the decreasing or increasing trend. The Weibull distribution is characterized by the following relations

$$F(t) = 1 - e^{-(\alpha t)^{\beta}} \tag{4.9}$$

$$f(t) = \alpha\beta\ (\alpha\beta\ )^{\beta - 1} e^{-\alpha\beta^{\beta}} \tag{4.10}$$

$$\text{MTTF} = \frac{1}{\alpha}\ \Gamma\left[1 + \frac{1}{\beta}\right] \tag{4.11}$$

If the value of shape parameter, β, is more than one, it indicates an increasing hazard rate where as if it is less than one it indicates the hazard rate is decreasing. Α is the scale parameter of the distribution and Γ represents gamma function. The Weibull parameters are calculated both parametrically and non-parametrically. For the non parametric estimation the Kaplan Meier estimator, survival fraction of the failure data is calculated. Considering the four major causes of outages (excluding planned outages-being less random in nature), a cause specific competing risk model is derived. The cause specific and over all Kaplan Meier product limit estimator are obtained using the following relationships.

$$Sj(t) = \prod_{i=ti<t} (1 - \frac{d_{ji}}{n_{ji}}) \tag{4.12}$$

where n_{ji} denotes the number of subjects at risk at time t_{ji} and d_{ji} denotes the number of failures due to cause j at time t_{ji}. The overall survivor fraction can be obtained from

$$S(t) = \Pi_{j=1}^{p} S_j(t) \tag{4.13}$$

A plot of log(-log(S(t))) against the log time of the data , in comparison with Weibull plot provide a straight line with a slop equal to the shape parameter and the Y intercept equal to the product of β and log α. The mean time to fail can be obtained from (4.11). These values were further validated with probability (reliability) plots in Weibull and the maximum likely hood estimate (MLE) values. The Kaplan Meier estimator and Weibull plots for different causes of outage are given are given in Figures 4.7 to 4.14. A plot of cumulative hazard function is given in Figure 4.15 for comparison.

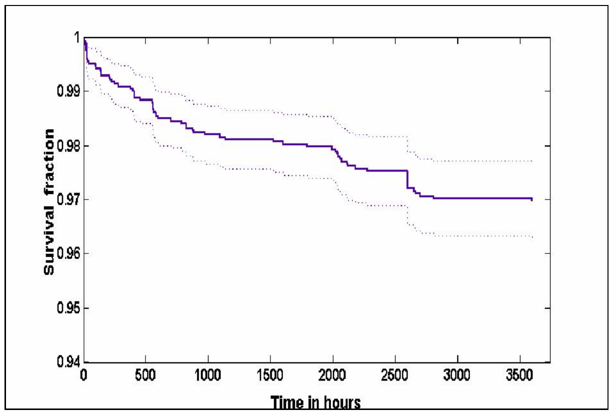

Figure 4.7. KM Estimator Equipment failure

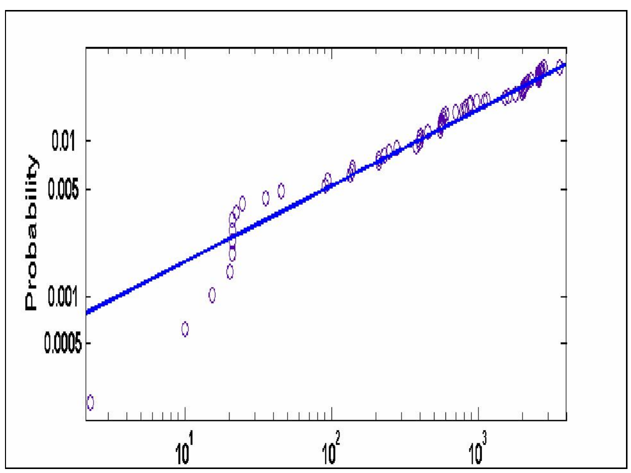

Figure 4.8. Weibull Probability plot equipment failure

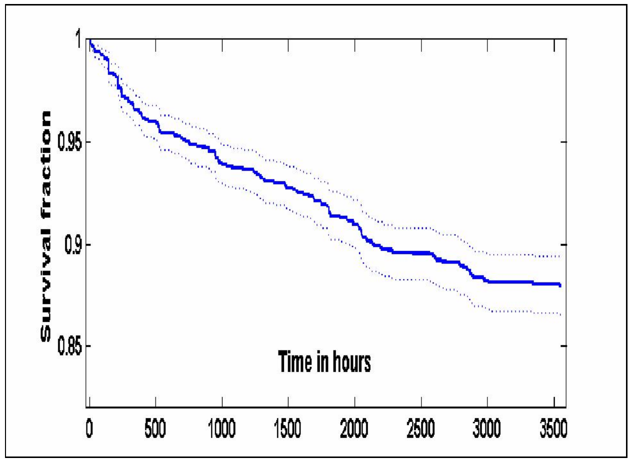

Figure 4.9. Kaplan Meier Estimator link failure

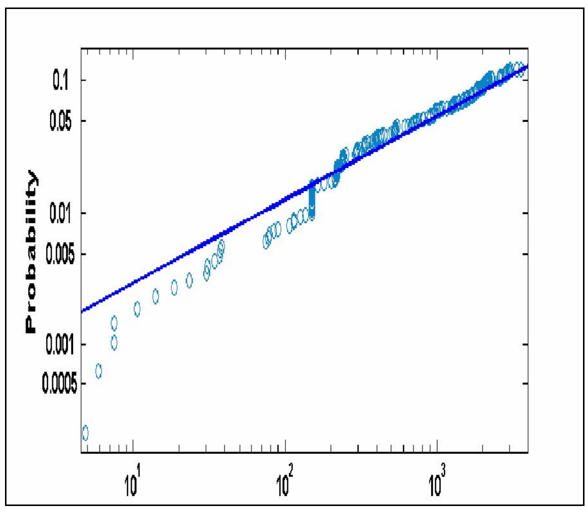

Figure 4.10 Weibull Probability plot link failure

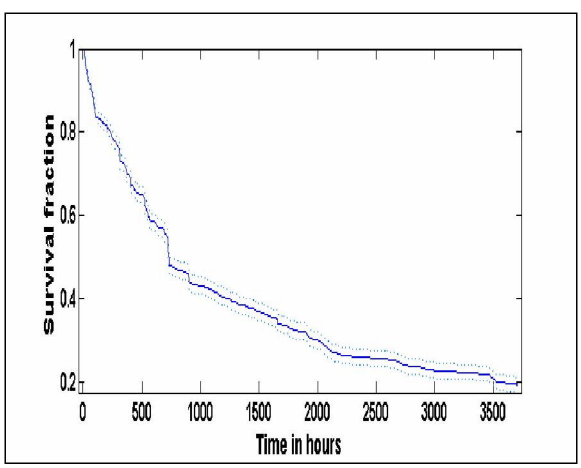

Figure 4.11. Kaplan Meier Estimator failure due to other causes

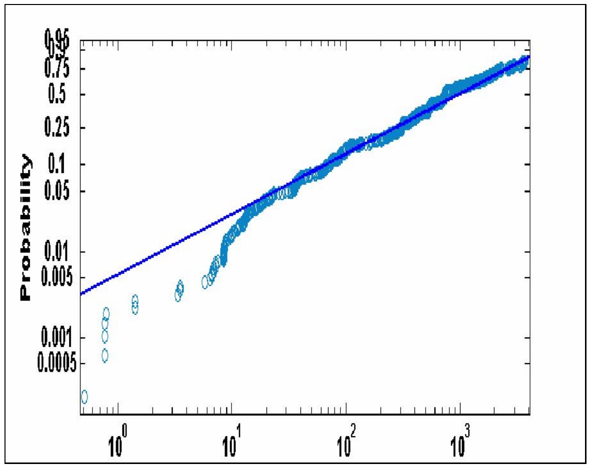

Figure 4.12 Weibull Probability plot failure due to other causes

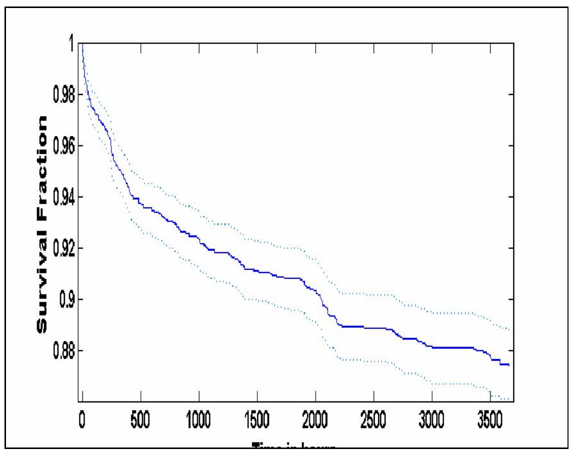

Figure 4.13. Kaplan Meier Estimator power failure

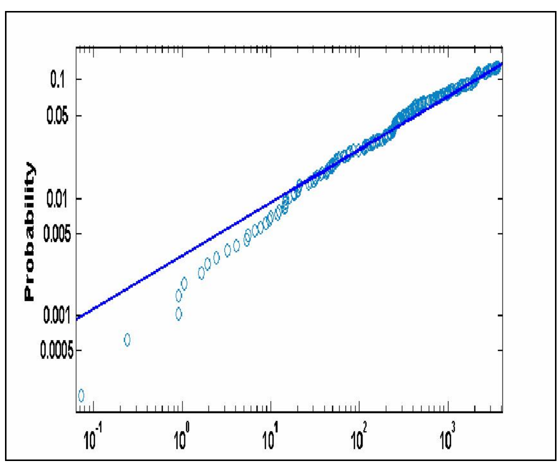

Figure 4.14. Weibull Probability plot power failure

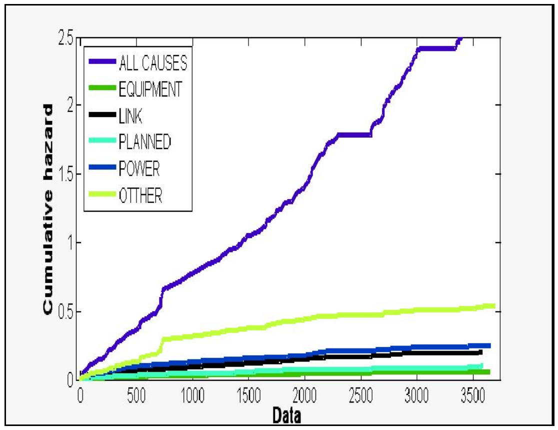

Figure 4.15 Comparison of cumulative hazards

Table 4.4, Weibull fit

Service Fail in BTS Due to	WEIBULL FIT		
	α	β	MTTF (HRS)
EQUIPMENT	4489980	0.49	9336890
LINK	88543	0.64	123353
POWER	294646	0.46	712046
OTHER	1606	0.70	2031
ALL CAUSES	1301	0.95	1330

The parameters of Weibull distributions are obtained with a 95% confidence level and these values are given in Table.4.4

For comparison, a more generous homogeneous poison process model is also obtained as per equation 4.14 and the parameters are given in Table 4.5.

$$\bar{F}(t)=\sum_{j=1}^{p}\pi_j e^{-\alpha_j t_{jj}} \quad (4.14)$$

The marginal survivor function defined by the above relation represents the exponential mixture model of competing risks with π_j mixture fractions for j^{th} group and α_j the corresponding exponential parameter. Considering a time independent hazard function the proportional hazards are also calculated.

The failure time distribution of the observed data can be modeled by the following relation

$$F(t) = \pi_E(1-e^{-(\alpha_E t)\beta_E)} + \pi_L(1-e^{-(\alpha_L t)\beta_L))} + \pi_P(1-e^{-(\alpha_P t)\beta_P))} + \pi_O(1-e^{-(\alpha_O t)\beta_O))} \quad (4.15)$$

Here $\pi_E + \pi_L + \pi_P + \pi_O = 1$

where the subscripts represents failure causes such as E – Equipment failure; L – link failure; P- power failure O- other reasons. The corresponding values of α and β are given in Table 4.4

Table. 4.5. Parameters of homogeneous poison process model

Service Fail In BTS due to	Share in First failures	πi	MTTF (HRS)	Proportional hazards
EQUIPMENT	70	0.03	116652	0.01
LINK	259	0.11	26560.5	0.05
POWER	274	0.12	24558.7	0.05
OTHER	1661	0.73	1652.77	0.80
ALL CAUSES	2264	--	1320	--

4.4 Parametric Modeling of Repair Time

The time to return to service after a failure may include, time to reset, time to identify the fault, and time to repair. Since the data do not provide information distinctly, the total time to restore service is considered as time to repair. This is the time during which the service could not be provided. The MTTR or mean time to restore service in this data has significance as it indicates the ability of organization to restore their service. MTTR values are very much useful in deciding maintenance strategy.

For the analysis of repair time, parametric best fit techniques based on the Chi square ranking is carried out. Among the possible distribution Lognormal distribution had the least Chi square score. However the level of confidence is not sufficient to make a hypothesis of goodness of fit, Lognormal is found to be the best fit for the available live data based on the statistical techniques. The lognormal plots and the estimated parameter values along with standard deviations are given in Fig 4.16 and 4.18. The probability- probability plot of log normal distribution (Fig 4.17 and Fig. 4.19) is almost linear which indicates the visual acceptability of the distribution.

The lognormal distribution is characterized by the equation

$$F(t) = \frac{1}{2\pi} \int_{-\infty}^{\frac{\ln(\varepsilon t)}{\sigma}} e^{-\frac{x^2}{2}} dx \qquad (4.15)$$

Available literature, points out that the repair times are distributed in lognormal effectively due to its long tile property. The parameters ε, σ and MTTR calculated from data are given in Table 4.6.

Table 4.6 MTTR distribution parameters

Service restoration after	LOGNORMAL FIT		
	ε	σ	MTTR (hours)
Equipment failure	1.24	1.13	6.58
Link failure	1.08	1.1	5.37
Failure due to all causes	-1.24	1.52	0.92
Power failure	0.95	1.2	5.25

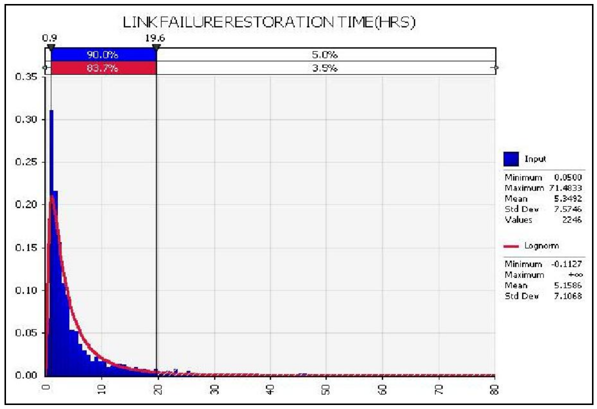

Figure.4.16. .Distribution of time to restoration link failure

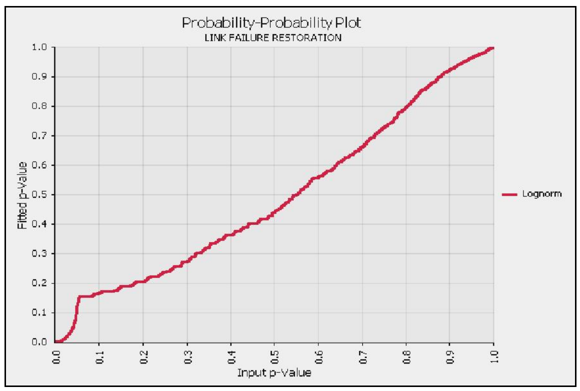

Figure.4.17. Probability-probability plot link fail

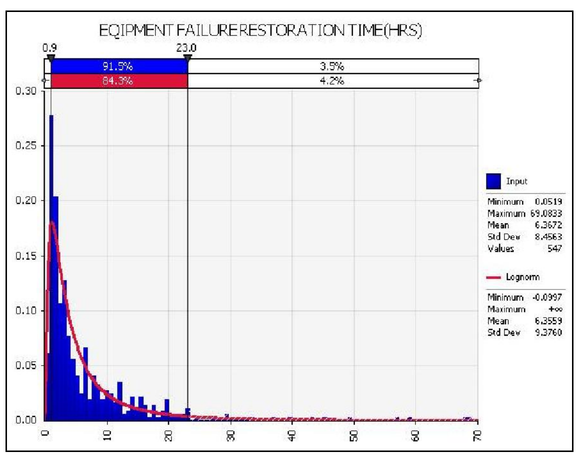

Figure.4.18, .Distribution of time to restoration equipment failure

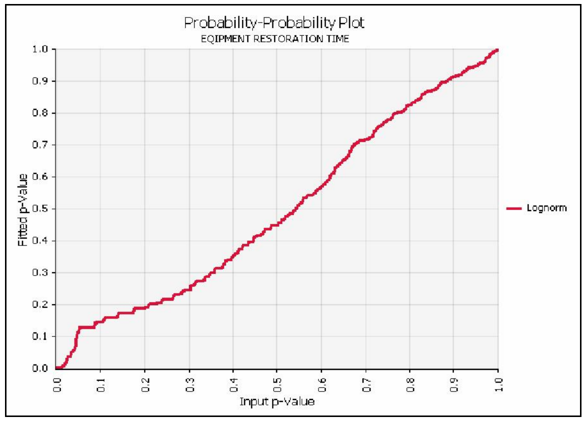

Figure.4.19. Probability -probability plot equipment fail

4.5 A New Metric Highlighting Capacity Related Key Parameters

The call attempt will not be registered when the Random Access Channel (RACH) request is discarded by the switch. If the Standalone Dedicated Control Channel (SDCCH) is not available, SDCCH blocking will be recorded. If Traffic Channel (TCH) is not available, TCH blocking will be recorded. If the carrier is not available due to mobility or RF fading call drop results. Each operator automatically records the blocking percentages in its Busy Hour (BH) of the day. The call drop details are recorded on daily basis. The TRAI reports give three months high values without indicating the number of occasions the bench mark was exceeded. The blockage data of instances other than BH is not published. Unlike the physical availability the changes are dynamic and availability also changes dynamically. This dynamic data for every hour is collected for three months and the incidents of significant change in key parameter are analyzed. This is done in comparison with TRAI report which gives only three months average value. There have been considerable instances of blockages outside busy hour.

The proposed metric indicates all the modes of unavailability of a network so that the customer can be aware of the quality of service provided to them. Service level agreement based on such metric will be more useful to customers. If the average network availability of the service providers' own network on each day is made available it will give insight to network stability and maintenance strength of the service provider. Regarding the capacity issues at cell level, a service index is proposed. The call setup success rate of the originating call as per TRAI benchmark is above 95% at busy hours. An index (call setup success rate index SR) is assigned with zero value for 90% or below success rates, and a value of 1 for 100%. The values in between are linearly assigned. Similarly SDCCH call blocking Index (SB) is assigned a value of zero for 5% and above blocking and 1 for no blocking. TCH call blocking index (TB) is assigned zero value for 5% and above blocking and 1 for no blocking. The call blocking rates published pertains to the busy hour, but there is a fair chance of deviation from bench mark in other instances also. In order to consider this, one more index called consistency index CI is defined. The call blocking rates at each hour can be measured and the number of times it exceeds the bench mark is noted. Out of maximum 23, if it exceeds 8 or more times (one third of the time in a day) the index is zero. If it is nil the indexes will be 1. The call Drop Rate (DR) index is assigned a value of 0 for 5% and above drop rate per day and 1 for no drop. The service index (SI) is defined for each day for each cell giving 20% weight age for each index an is expressed as

$$S_I = \frac{S_R + S_B + T_B + D_R + C_I}{5} \tag{4.16}$$

The value of SI will be between zero and one and it will be an indicator of major capacity related issues that exists in the cell. The average network availability along with the SI value will be an indication of network strength.

4.6 Conclusions

Confining to the domain of the data collected significant conclusions was drawn. There have been significant improvements in telecom technology but the availability is mainly affected by lack of infrastructural backings. Following industrial best practices on power supply can improve the availability scenario considerably in mobile communication sector.

The service outages in mobile communication due to various reasons can be modeled in Weibull probability distribution. The competing risk model gives a better representation of outage distributions. The parameter values are significant input to the network managers for plan, and attain the service level agreements. The maintenance strategy and resources allocations can be decided based on the repair time distribution parameters.

Analyzing the capacity related outage data, it can be confirmed that such outages are significant while calculating service availability. The data pertaining to the BH is only an indicative parameter does not provide actual availability values. The new metrics proposed for network service qualities incorporating various capacity related issues so as to enable the evaluation of service by customers can be justified in this contest.

Chapter five

Simulation and Modeling

5.1 Introduction

The service provider and the network management necessarily need a tool to assess their ability to provide availability as per their SLA or targets. The reliability and the maintainability are the two variables which constitute the availability. The adverse effects due to the change of one variable can be compensated with the improvement of the other variable. The live network cannot be used for sensitivity analysis. Analytical modeling and empirical relations help to develop basic idea of functioning, but the randomness of the events and probabilistic nature of input parameters with significant standard deviation or variance cannot be effectively incorporated in analytical models. Upkar Varshney and Malloy (2001, 2006) have proposed and used a set of switches under a controlling switch as a block for simulation purpose and analyzed the network fault tolerance with standard input parameters. A model with a series such blocks to suite the present large networks with its functional hierarchical arrangements are implemented here.

5.2 Network Architecture

A schematic diagram of the network architecture is shown in Figure 5.1. This GSM (Chandran 2001) network has the end user MS as the basic unit at subscribers end. This instrument communicates to the lowest element in the network, BTS through radio frequency communication signals.

A number of such BTS are controlled by BSC through wire line or micro wave links. The BSCs are controlled by MSC through wire lines. This MSC is linked with the DB registries, such as HLR (registry keeps the data of subscribers registered in that area), VLR – (registry keeps the data of visiting subscribers of that area) and an

Authentication Center. A set of one MSC, DB, few BSC and few BTS along with its links shall be considered as one basic unit which is repeated for larger network. The connectivity to Public switched Telecommunication Network (PSTN) and other networks are through a GMSC (gate way) which also has same features of MSC.

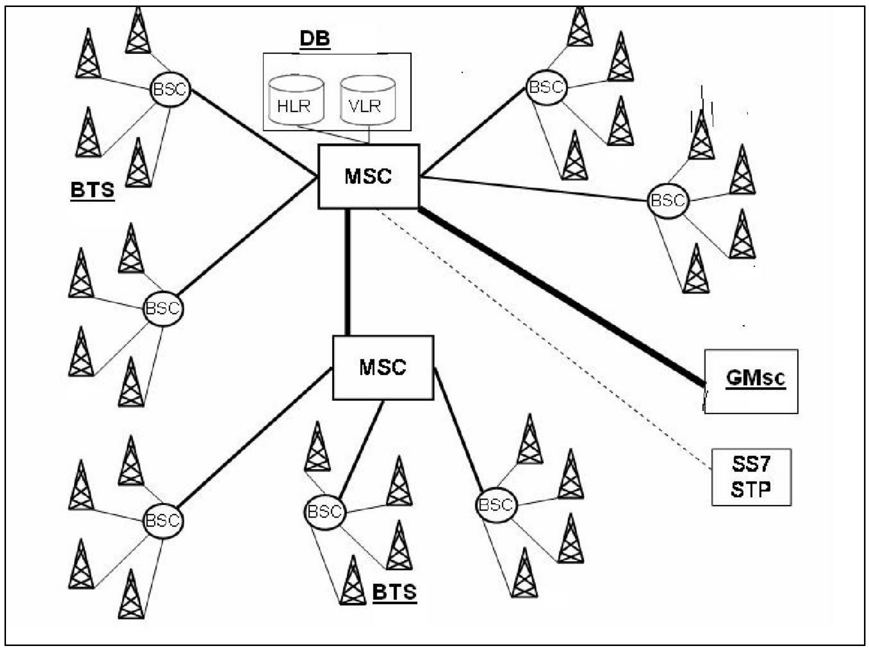

Figure 5.1 Network topology

The failure of DB, MSC and BSC and their links affects all the subscribers in their servicing area. The incoming communication from outside areas to this area also affected by this outage. In urban areas, outage of one BTS may not affect the service severely as the surrounding BTS can meet demands to some extend. One of the service providers in one of the state of India has subscriber strength of more than three million. (TRAI, 2009) Infrastructure of such a network with features given in Table 5.1 is considered for simulation. The performance of a network with eight such blocks is simulated in this work totaling the subscriber capacity to more than three millions.

Table 5.1 Network elements in one block

Components in one block	NOS	Potential Subscriber Strength (per element)
MSC	1	400000
DATA BASE	1	400000
MSC BSC LINKS	5	80000
BSC	5	80000
BSC BTS LINKS	40	2000
BTS	40	2000

5.3 Dependability parameters

The dependability aspects of the network shall be studied based on the reliability and maintainability of the network elements.

5.3.1 Reliability

Reliability is the characteristic of an item expressed by the probability that the item will perform the required function under given condition for a stated time of interval (Barolini, 2004, Sreenath, 1998)

For an item with constant failure rate, the reliability can be defined by Probability of no failure in time t

$$Pr(X=0, t) = e^{-\lambda t} = R(t) \tag{5.1}$$

The mean time to fail the item is exponentially distributed (Barolini, 2004) with a mean value of $(1/\lambda)$ which is denoted by *MTTF*.

5.3.2 Maintainability

When a failure occurs the system shall be restored to service in some time. This time is for corrective maintenance includes time for identifying, locating and reach. Maintainability can be defined as ability of an item to be retained in or restored to a specific state. The expected value (mean) of the repair time is denoted by *MTTR* (mean time to repair). For an invariant repair rate "μ" the *MTTR* is equal to ($1/\mu$). The time to repair is well distributed with lognormal distribution (Barolini, 2004)

5.3.3 Availability

The major dependability measure is the availability. It shall be defined by the ability of item to perform its required function under given conditions at a stated instant of time. When an item is repaired or restored it is considered as "as good as new". (Barolini, 2004, Sreenath, 1998). The average availability *A(t)* shall be computed based on λ and μ as follows

$$A(t) = \mu/(\mu + \lambda) + \lambda/(\lambda+\mu).e^{-(\lambda - \mu)t} \qquad (5.2)$$

For t tending to infinity the second term vanishes and the average availability will be

$$A=\mu /(\mu + \lambda) \qquad (5.3)$$

The availability of network shall be defined by the percentage of time the network was available for use. The total availability of a series of components shall be the product of availability of each component

5.3.4 Survivability

Survivability is a metric used by many researchers to denote the performances of networks. The ability of the network to continue to provide acceptable service during and wake of failure is defined as survivability. It shall be described by the number of subscribers affected during an outage. (Snow 2000, 2004)

$$Survivability =1-((\Sigma \text{ line lost hours})/ (\text{total line hours}) \qquad (5.4)$$

5.3.5 Accumulated BTS down time

One of the Quality of Service metric used by TRAI is the Accumulated BTS down time (not available for service) TRAI (2009)

Percentage Accumulated BTS down time in a month =

(Total outage time of all BTS in hoursX100)/ (24X no of days in the month X no of BTS in network licensed area) - (5.5)

While calculating the outages, outages of less than one hour durations are discarded. TRAI bench mark on this metric is <2%

5.3.6 ELLH

To evaluate the severity of outage one of the measures used is the Effective line lost hours. It is calculated as the product of time of outage and potential number of subscribers. However TRAI do not publish or indicate its values.

5.3.7 Worst affected BTS due to downtime

It is the unavailability in a month and TRAI bench mark is <2%.

5.4 Analytical Modeling

In the absence of sufficient redundancy, the outage of switch or cable link will directly affect the network causing service loss to customers. For analyzing the network performance, one of the major parameter to be considered is the probability of outage of elements. The probable number of outages in a specified time can be obtained using mathematical techniques. This can be used to compare and validate the results of simulation. By modeling the failure arrival rate in Poisson process with an invariable λ through out the period of study, the relation for probability of failure of any one element can be expressed as

$$P(t) = 1 - e^{-\lambda t} \qquad For\ 0<t<\infty \qquad (5.6)$$

At time $t = 0$, $P(0)$ will be zero and at time $t=\infty$, $P(\infty)$ will be one. For invariable failure rate, α is the inverse of *MTTF*. That is, the probability of occurrence of failure of one BTS for time t can be expressed as

$$P_{bts}(t) = 1 - e^{-t/MTTF_{bts}} \tag{5.7}$$

If there are N numbers of BTS in the system, the probability of failure of r number of BTS can be calculated with combinatorial probability

$$P_{nbts} = {}^{N}C_{r} \,.\, (P_{bts})^{r} \,.\, (1-P_{bts})^{N-r} \tag{5.8}$$

The probability of all possible combination of BTS from $r = 1$ to N can be obtained by summing up all such probabilities

$$P_{allbts} = \sum_{r=1}^{N} {}^{N}C_{r} \,.\, (P_{bts})^{r} \,.\, (1-P_{bts})^{N-r} \tag{5.9}$$

The probable number of failure can be expressed as

$$N_1 = P_{allbts} \times \textit{Total time duration} \tag{5.10}$$

For example, with an MTTF of 365 days and 1600 BTS spread over 40 BSCs, the expected number of items that fail for 8760 hours (one year) is equal to 1612. The expected number of failures on rough estimation is the number of item divided by MTTF which is equal to 1600. The values of failure numbers of BTS determined using rough estimation, analytical modeling and simulation modeling are compared and found to be within the acceptable range.

5.5 Simulation Parameters

The study of the network includes the assessment of present weakness of the system and the response with improved of variables. It is not feasible to use the live network for any sensitivity studies and hence a simulation model is designed to study the dependability aspects of mobile communication network. Apart from being a model for any sort of management studies at any time, the simulation model will provide answers to the following issues.

1) The two major variables directly affect the dependability of any equipment is the reliability and maintainability. One can compensate, to certain level, the adverse state of reliability or maintainability by improving the other parameter. How does the dependability and quality of service vary with the parameters reliability and maintainability can be assessed by simulation study.

2) Considering the economic interest, the management question of choosing the right choice, whether arrange fast maintenance facility or use high reliable components at different levels, can be answered.

3) The network of the service provider will always under go expansion and modification. The number of customers at any BTS is decided by the number of physical channel arranged and the probability of usage. But, as the customer strength increases in a BTS area the chance of getting connected decreases. The call set up probability decreases and call drop probability increases. The service provider will arrange one more BTS in the same area as the customer population increases. Since the changes in BSC levels are seldom done, the reliability of network will be adversely affected by this expansion. Study of dependability with the change in network size can be carried out with simulation.

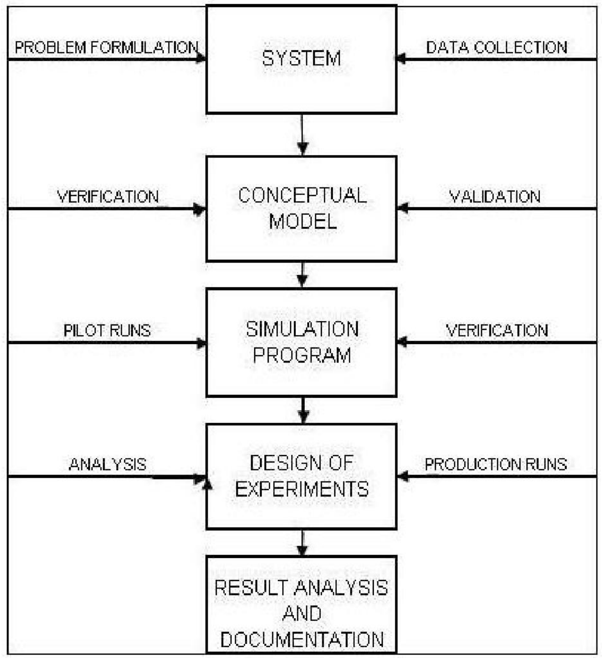

Figure 5.2 Steps in simulation study

Discrete time event simulation is adopted for modeling the network. The model development, verification and validation was carried out as per the procedures explained Law & David Kelton (2003). The various steps followed in this process are listed in the Figure 5.2

To model the network infrastructure, each entity with its characteristics are modeled and connected to each other according to the system architecture based on GSM. The architecture consists of eight blocks of network, each consisting of one MSC which is connected to 5 BSC and each BSC connected to 40 BTS, is considered for simulation. The basic operation process reveals that when a BTS is failed all the customers in that area will not be able to connect. (In thickly populated areas, the neighboring BTS has the ability to take up partial load with higher chance of call blocking). This will also happen if the cable connecting BTS and BSC fail. Similarly when BSC / MSC or incoming cable fails all the customers in that area will be cut of from network. The customer will not be able to get the service till the repair time is over.

The following assumptions are made for the simulation.

1) It is assumed that each block has the same architecture.
2) The switches and cables will be either working (on) or not working (off) state. No partial working state is considered.
3) The MTTF of all similar switches and cables are same. All of them follow same probability distribution.
4) The MTTR of all similar switches and cables are same. All of them follow same probability distribution
5) The mean values of the variables are considered invariant during the whole simulation period.
6) All items are considered as good as new after repair or replacement and do not exhibit any memory.
7) All the failures are considered as independent of each other and not influenced by any other failure.
8) The actual topology of network may have varying cable lengths and varying switch capacity. Here switches with same topology with same capacity are considered.
9) With reference to available literature the inter arrival time is Poisson process. So the probability distribution of failure time for both switches and cable links are distributed in exponential distribution
10) Due to the long tile property the repair time is well distributed in lognormal distribution.

Eight such blocks are considered for this network serving nearly 3 million subscribers. Each MSC is connected to the DB, and 5 BSC. Each BSC is connected to 40 BTS. The interconnecting links are also modeled. Simulation software was prepared in MATLAB 7.4™ and verified. Pilot runs were done to verify the output and found agreeable with distribution mean and variance. Microsoft excel was used for tabulation and analysis. The input output elements of simulation are indicated in Figure 5.3

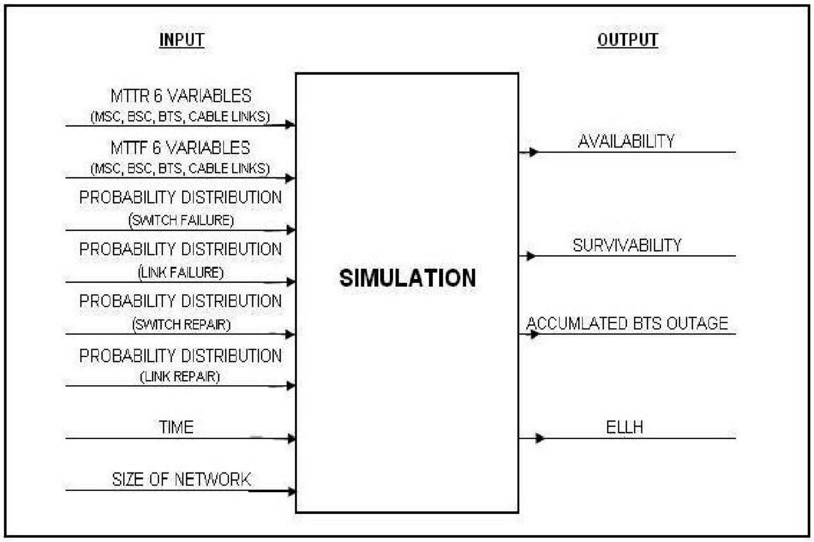

Figure 5.3 Simulation block

5.6. Algorithm and Procedure

- The time to fail of each component is generated instantaneously by random numbers generated on exponential distribution.

Table 5.2 Nominal values

Components	***MTTF* NOMINAL (in days)**	***MTTR* NOMINAL (in hours)**
MSC	2737.5	0.15
DATA BASE	1095	0.15
MSC BSC LINKS	1460	4
BSC	1460	1.5
BSC BTS LINKS	1095	4
BTS	730	1.5

- The time to repair of each component is generated in lognormal distribution with standard deviation unity..
- The *MTTF* and *MTTR* data given in Table 5.2 was taken from published data (Upkar Varshney and Malloy, 2006).
- The simulation program checks the status of each component from MSC to last BTS in a block sequentially in every one hour based on the time to fail generated at each instant.
- The reliability of the component is calculated by mathematical relations.
- If the component has failed, the mean time to repair is generated in lognormal distribution.
- The component is considered to be under repair during the period of time to repair
- The status of this component is not checked until the repair time is over.
- All the sub components in the lower stream of that component are also affected due to the outage.
- A link checked for status, if found failed will affect all the switches in its downstream. The number of potential customers affected due to the outage of each switch or link is given in Table 5.1
- The simulation is run for one year duration with status checking of all components in every one hour.
- A warm up period of two months (nearly 20%) is incorporated before recording the output values.
- Repeated simulations are carried out with the same data input to observe the replication changes.

- Mathematical relations mentioned in Section 5.3 are used to calculate the output parameters.
- Data received is analyzed using Excel™ and the various metric parameters are generated as above.
- For validation the numbers of components failed are done with comparison of expected values. The results are listed in the Table 5.3
- The output values of both distributions are validated with chi square tests with 95% confidence level

The mobile service providers expand their network as a whole that is extending the network to new areas or increasing the servicing cells in their service area. The requirement of later expansion is mainly done to improve the grade of service. As the number of customers increases in a particular area, the call blocking probability increases. As this value becomes unacceptable for the service provider, new cells are created so that probability of call blocking decreases. The limitation to this expansion is the reusability of channel frequencies. But quite often the effect on availability is not considered.

This situation is also studied by simulation, by increasing the number of BTS under one BSC from 10 to 50 in five steps the change in availability is evaluated. The reduction in availability is considerable. The result is shown in Figure 5.4

Table5.3. No of BTS Failed during the entire test period

MTTF (days)	Approximation	Analytical modeling	Simulation Result
365	1600	1612	1672
730	800	806	868
1095	533	526	579
1460	400	386	410
1825	320	320	336

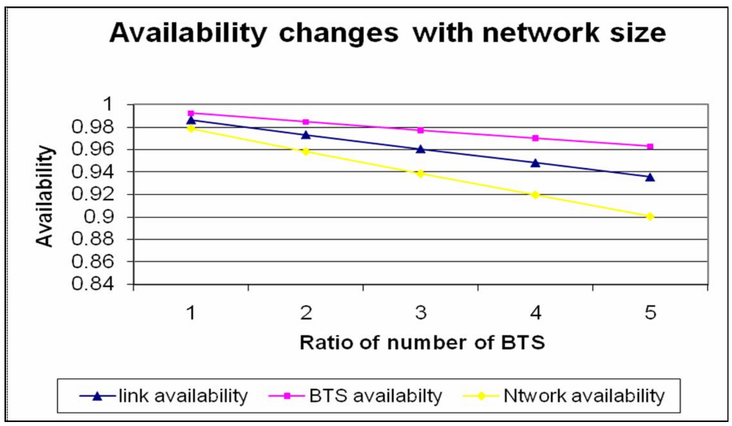

Figure 5.4 Availability changes

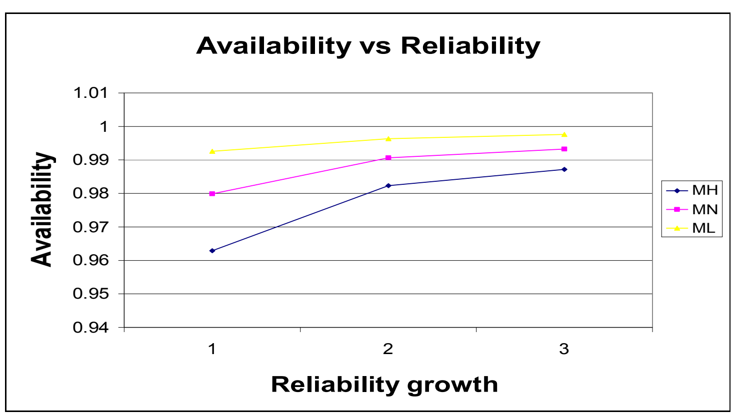

Figure 5.5 Availability

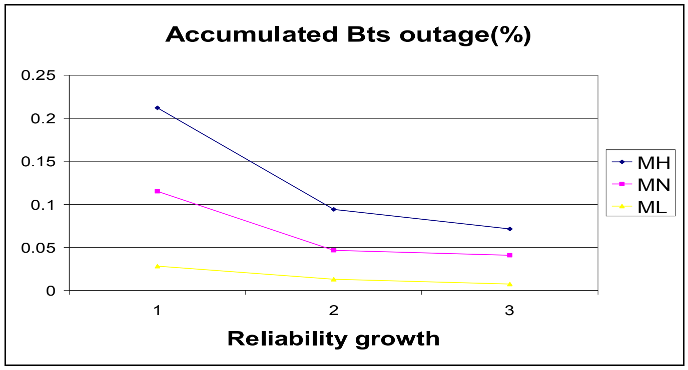

Figure 5.6. Percentage Accumulated BTS outage

5.7 Design of experiments

For investigating the response of the system for various inputs such as higher and lower reliability as well as higher and lower maintainability, three distinct values of MTTF and MTTR are selected. The simulation was run these options of higher reliability, nominal reliability, degraded reliability along with higher value for maintainability, nominal value for maintainability and lowest value for maintainability in all combinations. The network performance is observed as poor at lower reliability and higher *MTTR* value and best for high reliability and low *MTTR* value justifying the simulation procedures. The values of MTTF and MTTR used for simulation are given in Table 5.4 and 5.5

Table 5.4 MTTF in days

COMPONENT	LOW	NOMINAL	HIGH
MSC	1825	2737.5	3650
DB	730	1095	1460
MSC-BSC Link	1095	1460	1825
BSC	1095	1460	1825
BSC-BTS Link	365	1095	1825
BTS	365	730	1095

Table 5.5   MTTR in hours

COMPONENT	HIGH	NOMINAL	LOW
MSC	0.075	0.15	1
DB	0.075	0.15	1
MSC-BSC Link	1	4	8
BSC	1	1.5	2
BSC-BTS Link	1	4	8
BTS	1	1.5	2

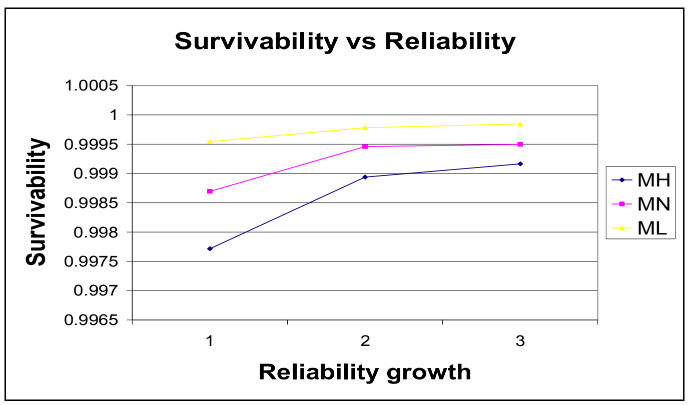

Figure5.7 Survivability

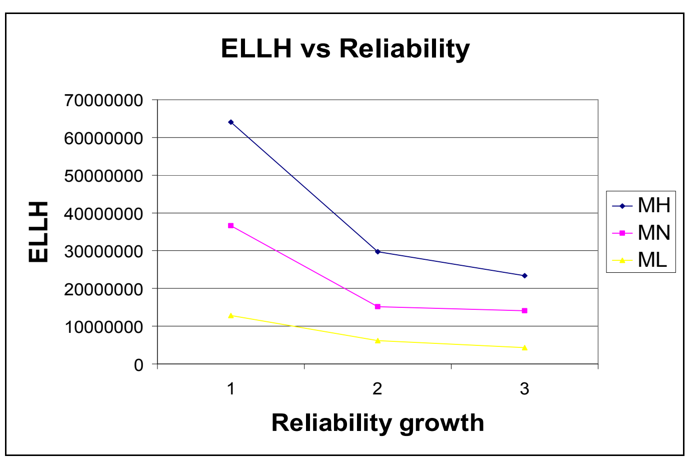

Figure 5.8 ELLH

5.8 Results and discussion

The output points out that simulation technique can be used for the study of mobile communication networks effectively. The changes in reliability and maintainability affect the availability and survivability of the system. The results of simulation are given in Figures 5.5 to 5.8.

When the maintainability is long that is a degraded scenario the change in availability is very much predominant with reliability. On the other hand if the maintenance is done very fast (low *MTTR*) the reliability (*MTTF*) changes are not much affected to network. Faster maintenance is the better strategy than using higher reliable components for achieving the higher quality of service and network reliability.

Similar observations shall be made on survivability and ELLH also. Even though the numbers of outages are increasing at higher rates for degrading reliability values the effective maintenance can bring down the effective line lost hours considerably.

The affinity to outages or unavailability increases with the size of network. As the network size increases, it is more prone to outages. Increasing the number of BTS will help increase physical channels but reduce network reliability.

However, this study takes care of MTTF of switches and Cable links only. From the analysis of outage data in section 4, it is clear that the hardware failures at switch level contribute only 6% of outages. If the general service outage of network is considered there are other predominant reasons for outage which is not included here. This model can be extended with incorporating other causes of outage so that the actual outage scenario can be obtained.

Chapter six

Availability Domain

6.1 Introduction.

The assumption that the inter arrival time of failure is a Poisson process is based on literatures. A constant hazard model has relatively simple empirical relations for calculations and implementations. As pointed out in section 4, the actual data suggests a decreasing hazard rate trend. Further the repair time values have a considerable variance. So the actual network has different input distributions. Using the distributions and parameters derived from the exploratory data analysis, a more accurate model is provided which is used for sensitivity analysis. The probabilistic distribution and the parameters of time to failure of service and time to restore service is represented by the best fit values of the live network with all its complexities and randomness.

The cable links uses fault tolerant mechanisms such as ring topology etc for redundancy in higher levels of network. The cables connecting MSC and BSC are protected with redundant interconnectivities and better topologies so that the failures are rare events. But it is not feasible to include redundancies at the BTS level and outages are experienced frequently. The outage data collected gives the time during which the service was interrupted due to BTS unavailability. Even though the data pertaining to the failure at BSC and MSC levels were not available separately, the pattern of their service failures, which eventually affects the end element BTS, are reflected in the available data. While determining the availability, only the outage of BTS is considered, as outages of any other element, leading to service loss to the customer will reflect as BTS outage. The higher level switches such as BSC and MSC are comparatively very reliable and they are protected with sufficient precautions.

The results in Section 4 clearly indicate that there are more relevant causes of service outage other than BTS switch failure. The equipment failures observed at BTS level amount to just 6% of total service outages. In the simulation model created the cable links failure and switch failures are taken as input. The various cause of failure is not separately considered. To suit the model the outage data is analyzed again with grouping the outage causes logically. All causes outage end up with failure of BTS are taken together. It includes power failure at BTS site, equipment failure and similar cases of the other causes. All causes of outage which breaks the incoming cable link to a BTS is taken as link failure. This includes all the upstream failures which eventually disconnect the BTS from the rest. Both the time to failure of BTS and link as well as time restoration of service after BTS and link failures together define service pattern of the network.

6.2 Exploratory Analysis

Keeping the relevant variables as link failure and BTS outages, the exploratory analysis of data was carried out. As done in section 4 the probability distribution of time to fail of link and BTS as well as the probability distribution of time to repair of both link and BTS were obtained.

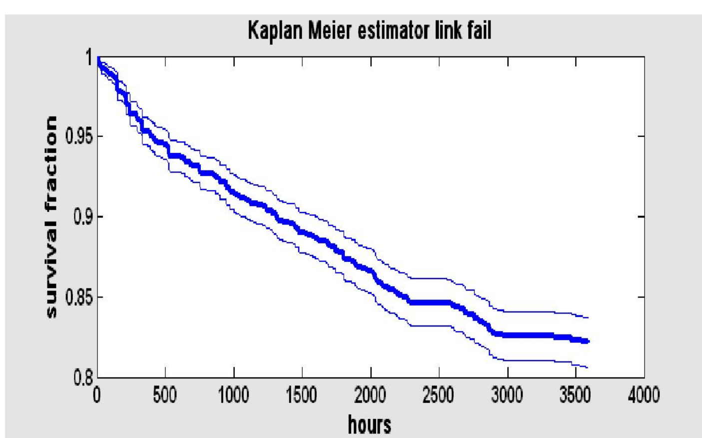

Figure 6.1 KM estimator for link failure

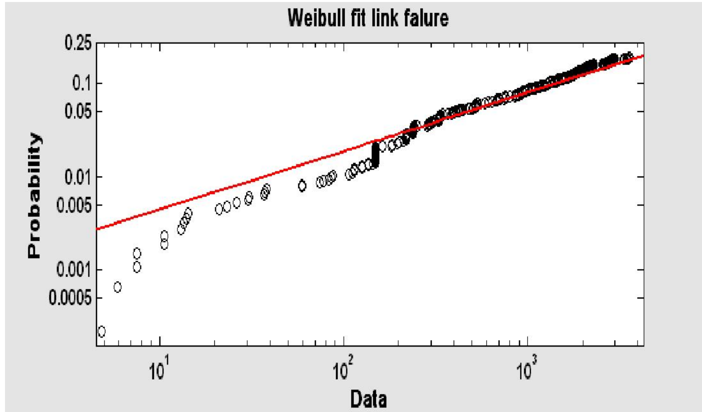

Figure 6.2 Probability plot link failure

The Figures 6.1 to 6.4 give the KM estimator and the probability plot of the link failure and BTS failure. The parameters of Weibull distributions are obtained with a 95% confidence level and these values are given in Table. 6.1

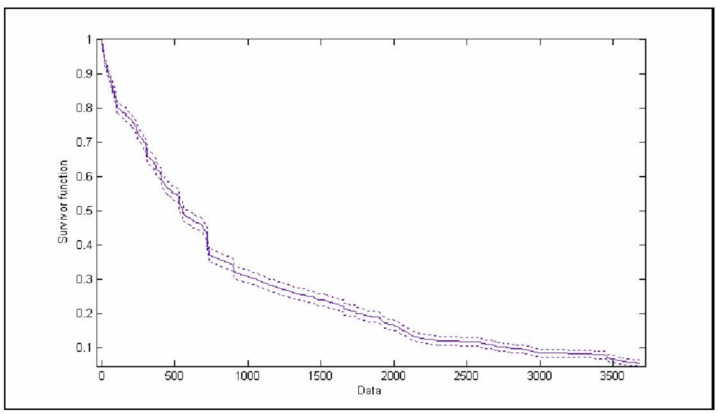

Figure 6.3 KM estimator for BTS failure

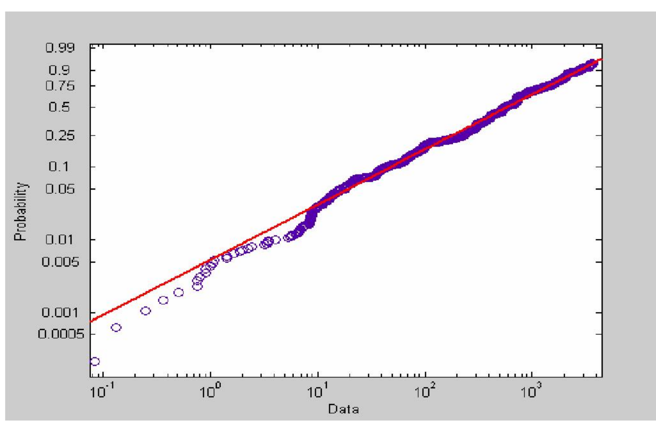

Figure 6.4 Probability plot BTS failure

$$F(t) = \pi_B (1 - e^{-(\alpha_E t)^{\beta_E}}) + \pi_L (1 - e^{-(\alpha_L t)^{\beta_L}}))$$

(6.1) where the subscripts represent failure causes such as B – BTS failure; L – link failure. The corresponding values of α and β are given in Table 6.1

The time to restore service after failure in both link and BTS failure is also analyzed. The probability distribution plots are given in Figures 6.5 and 6.6. The parameters are given in Table 6.1. As explained in section 4.4 the chi square ratings of the distribution is not hypothesis the goodness of fit it the best distribution that can be fitted to repair time data.

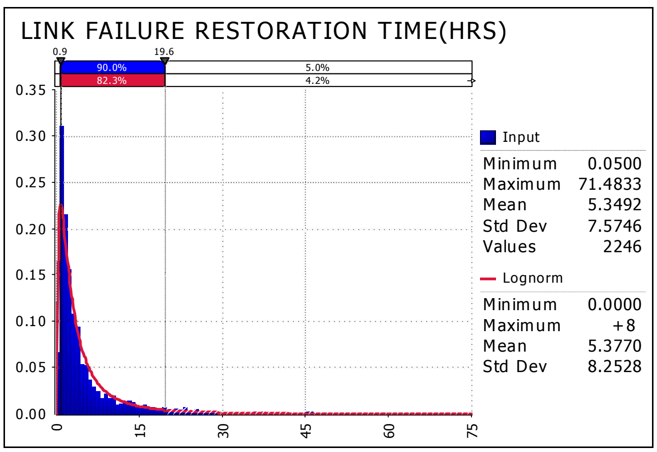

Figure 6.5 Distribution of service restoration time after link failure

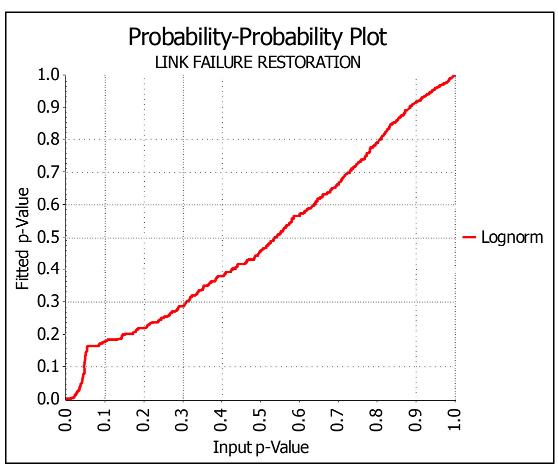

Figure 6.6 Probability- probability plot of service restoration after link failure

Table 6.1 Parameters of failure and repair distribution

Time to Service Failure	WEIBULL PARAMETERS		
	α	β	MTTF (Hours)
LINK FAIL	9045	0.86	9790
BTS FAIL	933	0.76	1094
Time to Restore service	LOGNORMAL PARAMETERS		
	ε	σ	MTTR (Hours)
LINK FAIL	1.08	1.1	5.37
BTS FAIL	-1.44	1.49	0.71

6.3 Experimentation

The distribution and the parameters of time to failure and the time restore service are the characteristic of the whole network arrived based on the service outage details for six months. The maintenance policy, equipment quality, climatic and other disturbances the topology and strength and weakness of organization etc together decide this pattern. The probability of outage, probability of repair and probability of availability are defined by this distribution. However the mean values do not remain same for different period of time. Variations in the above factors will improve or worse the availability situation. Keeping up the randomness associated with the distribution and varying the reliability and maintainability parameters will provide the various possible availability scenarios. Experimentation is designed for estimating the probable variations of availability based on the outcomes of parameterization.

Keeping the distribution and variances fixed, very low to very high mean time to failure values can be accommodated. This variation makes sense, as the mean values do not remain same for different period of service. Simulation is carried out with five different values of reliability from very low to very high and five different values of maintainability again from very low to very high, with all possible combinations. The input distributions of Weibull and lognormal are generated for each of the above mean values to obtain the resulting availability of network.

The model developed in the previous section is utilized for the simulation. The number of BTS in the network is taken as 2400 which is very close to the network of which the outage data was analyzed. Instead of the published data used in the previous section the parameters obtained in the section 4 is taken as base values. With the various combinations of reliability and maintainability twenty five number of simulation combination was obtained. Multiple runs with of the same combination (replication) were also carried out and data was collected after the stabilization of simulation. The variation in availability due to change of network size is also studied. The availability domain of the service derived by all possible variation of MTTF and MTTR of both link and BTS outages is given in Fig.6.7 The results of simulation is validated with the probable number of failures and the availability calculations from empirical relations. A plot of availability obtained from both mathematical calculations and simulations for MTTR values of BTS is given in Fig 6.8.

The key parameters are calculated from the output data of simulation study as per the TRAI recommendations. The Availability variation in worst affected BTS, the accumulated BTS outages in low reliability low maintainability to high reliability and high maintainability scenarios etc are provided in figures 6.9 to 6.11

Table 6.2 Simulation input values MTTF

LINK FAIL			
	α	β	MTTF (DAYS)
VERY LOW	11.57	0.86	12.5
LOW	23.15	0.86	25
MEDIUM	46.30	0.86	50
HIGH	370.37	0.86	400
VERYHIGH	1481.48	0.86	1600
BTS			
	α	β	MTTF (DAYS)
VERY LOW	1.17	0.76	1.375
LOW	3.50	0.76	4.125
MEDIUM	9.34	0.76	11
HIGH	37.35	0.76	44
VERYHIGH	74.70	0.76	88

Table 6.2 Simulation input values MTTR

LINK FAIL				
	ε	σ	SD	MTTF (DAYS)
VERYHIGH	4.45	0.10	8.2	86.4
HIGH	4.16	0.13	8.2	64.8
MEDIUM	3.45	0.25	8.2	32.4
LOW	1.08	1.10	8.2	5.4
VERY LOW	-1.52	1.91	8.2	1.35
BTS				
	μ	σ	SD	MTTF (DAYS)
VERYHIGH	2.13	0.23	2	8.64
HIGH	1.69	0.34	2	5.76
MEDIUM	0.86	0.63	2	2.88
LOW	-1.41	1.47	2	0.72
VERY LOW	-4.13	2.20	2	0.18

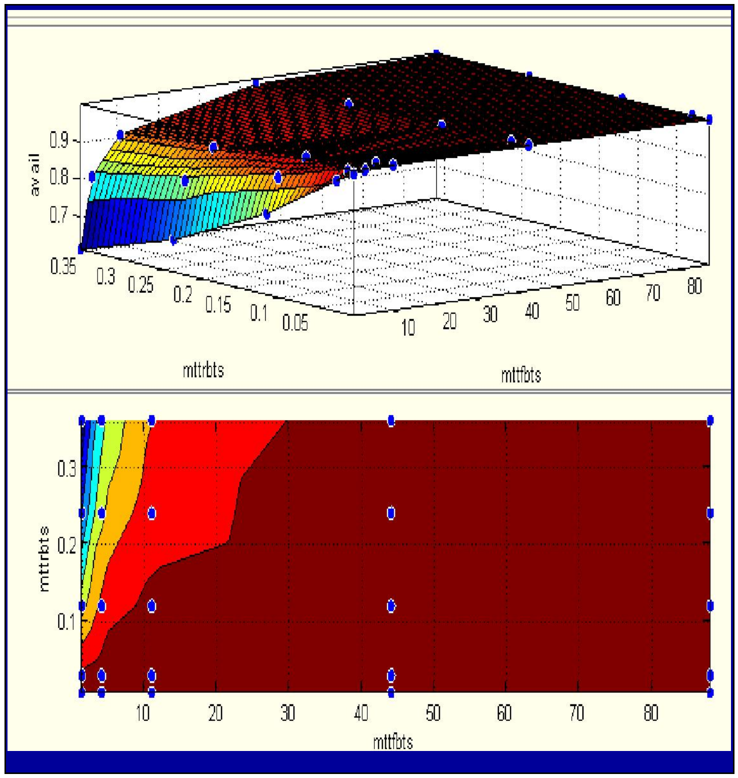

Figure 6.7 Availability domain

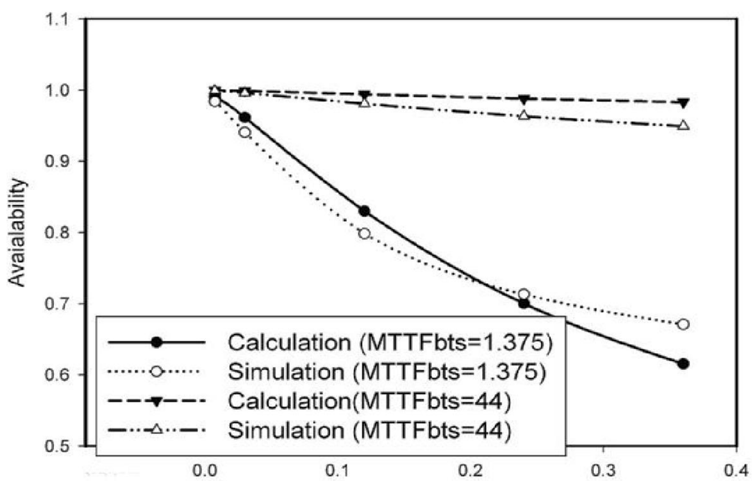

Figure 6.8 Results comparison of Simulation and Calculation

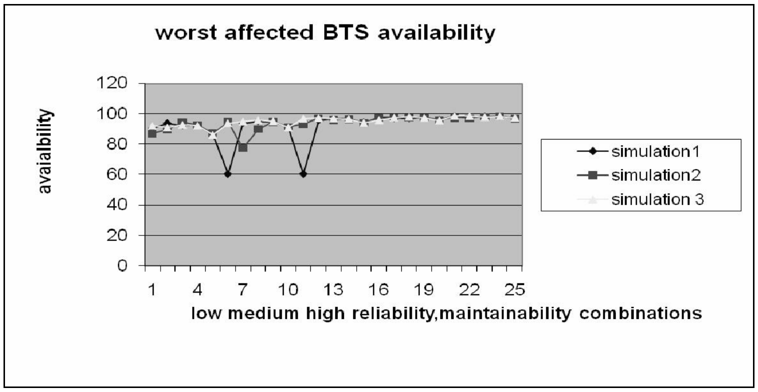

Figure 6.9 Worst affected BTS availability

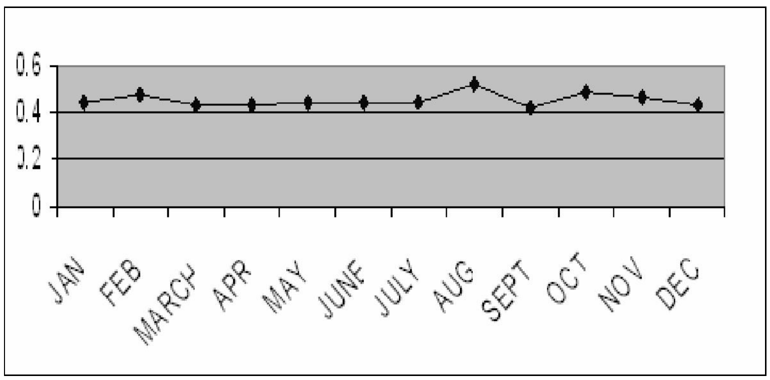

Figure 6.10 Percentage accumulated BTS outage
(Simulation -Medium reliability and Medium restoration time)

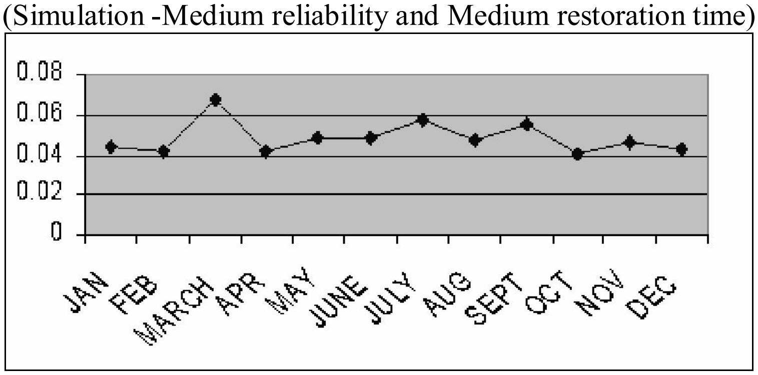

Figure 6.11 Percentage accumulated BTS outage
(Simulation –very high reliability and very low restoration time)

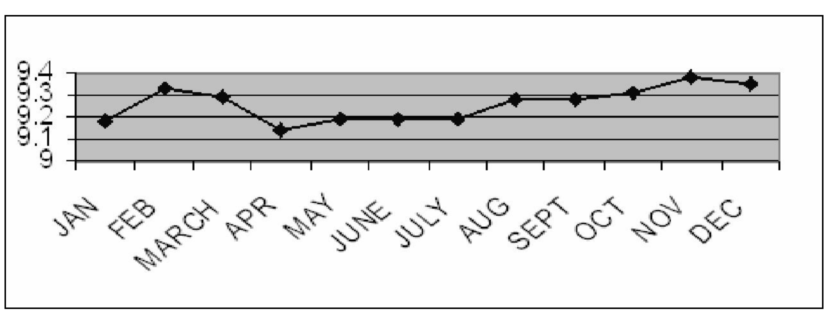

Figure 6.12 Percentage accumulated BTS outage
(Simulation –very low reliability and very high restoration time)

6.4 Results and Conclusions

The availability domain provides the probable variations of availability with the present complexities of the network and it can be used as a management tool for aiming and attaining specific availability for the network. The unavailability of the network will lead to revenue loss. The simulation model shall be used for the study of network with the existing and new parameters. The difference in calculated and simulated values of availability is very less indicating the validity of model.

From the simulated results it is clear that attaining 99.99% availability is very difficult to achieve in the present network. The maintainability have to be improved to considerable extend to attain it. The five nine availability is almost a dream with the present arrangements.

The mean time to failure of the BTS was obtained as 1094 hours and the mean time to repair as 0.71 hours, where as the mean time to failure of link failure was 9790 and mean time to repair 5.37hours. It indicates on an average the cables faults are repaired in five and half hours which is to be improved very much.

Chapter 7

Conclusions and Research findings

A new methodology for evaluating the mobile communication reliability and availability was developed. The focus was on the analysis of the communication network infrastructure based on the service outages as reported by a major service provider catering more than 3.5 million customers. Based on the service outages a deterministic model was developed which marks the availability domain of a given network.

The major findings of the research are listed below.

1) The maintainability of the network is found to be a more significant variable than reliability in availability domain.
2) The time to failure of mobile communication network is not constant. It is well distributed with Weibull distribution with β value less than one. The time to repair was best fitted with lognormal distribution
3) Only the highest reliability and fastest maintainability provides four nine availability in the network. This cannot be attained with the present parameters of network.
4) The industrial policy of attaining five nine availability is a remote possibility with the existing network, as the corresponding parameters are tending to theoretical values.
5) Service quality of mobile communication service assessed using the SERVQUAL tool reveals that the network dimension was the least reliable.
6) Competing risk, mathematical model of time to failure (MTTF) and time to restore service (MTTR) of the live failure data have been derived using exploratory analysis.

7) The power failure is the major source of network outage which can be reduced by following the ‘industrial best practices’
8) The percentage of accumulated BTS outage seldom remains below TRAI recommended values
9) The mean time to failure of the BTS was obtained as 1094 hours and the mean time to repair as 0.71 hours, where as the mean time to failure of link failure was 9790 and mean time to repair 5.37hours.
10) The availability of the network is adversely affected with the increase of size of network.
11) Availability domain for the equivalent size of the existing mobile network in one of the state of India was predicted along with other key parameters.
12) The availability domain plot can be used by the network managers to aim at a specific availability
13) The developed simulation model for mobile communication network can be used for outage and sensitivity study of mobile communication network and can be regarded as a powerful managerial tool in decision making.

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Publications Related to Research.

International Journal Publications

1. K Sunilkumar, PS Sreejith and N H Jayadas **,** Competing Risk Models for the service availability of Mobile communication Network International Journal of Industrial Engineering Practices Vol. 3 No 2, July Dec 2011 International science Press (ISSN - 0974-7745)
2. K Sunilkumar, PS Sreejith and N H Jayadas Ref. No.: RESS-D-11-00374 Availability Domain of Mobile Communication Network using Simulation Reliability Engineering & System Safety Elsevier (communicated)
3. K Sunilkumar, P S Sreejith , N H Jayadas Analysis of Reliability availability and maintainability of mobile communication network using simulation The Technology world Volume V issue 1 quarterly journal March-April 2010 ISSN 2180-1614
4. K Sunilkumar, P S Sreejith , N H Jayadas Availability of Mobile Communication Service DOI: SE032011008, CiiT international journal of software engineering ,Print: ISSN 0974 – 9748 & Online: ISSN 0974 – 9632 , March 2011

International Conference Publication

1. K Sunilkumar, PS Sreejith, N H Jayadas- Analysis of Quality of Service (QoS) and Dependability (RAMS) of telecommunication network using simulation techniques. International conference of simulation and modeling NIT Calicut Dec 2009
2. K Sunilkumar, PS Sreejith, N H Jayadas Analysis of end to end Availability of mobile communication service. International Conference on Information and Communication Technology (ICICT-2010) TSM Madurai Dec 2010
3. K Sunilkumar, PS Sreejith N H Jayadas Service Reliability Analysis using Competing Risk Models , IEEE Catalog Number: CFP11WNM-CDRISBN: 978-1-4244-6251-3 WICOM 2011, Wuhan China