



**Addis Ababa University**

**Addis Ababa Institute of Technology**

**School of Electrical and Computer Engineering**

**Root Cause Analysis of Base Station Outage using Bayesian Network for**

**Addis Ababa**

By

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in

Partial Fulfillment of the Requirements for the Degree of Master of Science in

Telecom Network Engineering

February 2020

Addis Ababa, Ethiopia

**Addis Ababa University**

**Addis Ababa Institute of Technology**

**School of Electrical and Computer Engineering**

**Telecommunication Engineering Graduate Program**

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February 2020  
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## DECLARATION

I, the undersigned, declare that the thesis comprises my own work in compliance with internationally accepted practices; I have fully acknowledged and referred all materials used in this work.

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Signature

## Abstract

For telecom operators, base station is one of the most important mobile network component from which messages are sent and received directly to/from users. The base station consists of different hardware and software components. Any of these components could experience various types of faults (critical, major and minor) that may cause partial or full failure of the base station until correction is made. Base station outage results in its users' service interruption or quality degradation that in turn brings to the operator churn of users/services and loss of revenue. Therefore, outage is needed to be monitor and its cause should be identified timely for timely maintenance actions.

To reduce maintenance time and cost, different advanced outage root cause analysis methods have been studied and applied. However, there are limited studies in the context of Ethiopia. The objective of this thesis is to present root cause analysis of base station outage for Addis Ababa using Bayesian network empowered by trouble ticket, log file, and history alarm.

Results show that application of root causes analysis can be achieved to identify, categorize and define appropriate supportive action for base station outage. By analyzing, the base station outage based on collected history alarm, log file and trouble ticket data can compute probability distribution and provide a priority checking. For instance, the result from historical data collected for year shows that the performance of Bayesian network with an accuracy of 94%.

**Keywords:** *root cause analysis, trouble ticket, history alarm, log file, Bayesian network.*

## Acknowledgements

First and for most I would like to thank the almighty God for being my strength and guidance to accomplish this thesis.

I would like to thank my thesis advisor Dr. Beneyam Berehanu Haile for the continuous support of my thesis work, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of writing this thesis.

I would also like to thank my friends Tegene Tesfaye, Mesfine Geremew and Megersa Lelissa for supporting and giving data. I am thankful to ethio telecom for giving me full scholarship.

Finally, I must express my very profound gratitude to my parents (father, mother, sisters and brothers) and to my wife (Aski), sons (Saron, Nabihot and Miheret) for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of writing this thesis. This accomplishment would not have been possible without them.

# Table of Content

Abstract.....	i
Acknowledgements .....	ii
List of Figures .....	v
List of Tables .....	vi
List of Acronyms .....	vii
CHAPTER 1. Introduction.....	1
1.1 Background and Motivation.....	1
1.2 Problem Statement .....	3
1.3 Objectives.....	8
1.3.1 General Objective .....	8
1.3.2 Specific Objectives.....	8
1.4 Methodology .....	8
1.5 Related Work .....	9
1.6 Scope and Limitation .....	10
1.7 Contribution of the Thesis.....	11
1.8 Outline of Thesis.....	11
CHAPTER 2. Mobile Network Outage.....	12
2.1 Mobile Network Services .....	12
2.2 GSM and UMTS Network Architecture.....	12
2.3 Base Station Outage .....	14
2.4 Root Cause for Base Station Outage and its Analysis.....	15

2.5	Base Station Outage Monitoring .....	16
CHAPTER 3. Root Cause Analysis Technique .....		20
3.1	Overview .....	20
3.2	Bayesian Network .....	22
CHAPTER 4. Base Station Outage for Addis Ababa .....		26
4.1	Root Cause and causes of Base Station Outage .....	26
4.2	Root Cause Analysis of Base Station Outage in Addis Ababa .....	27
CHAPTER 5. Modelling and Assumption .....		31
5.1	Bayesian Network Model.....	31
5.2	Construction of Bayesian Network.....	31
5.3	Mathematical Explanation of Bayesian Network.....	32
CHAPTER 6. Results and Discussions.....		37
6.1	Result.....	37
6.2	Discussion.....	45
CHAPTER 7. Conclusion and Future Works.....		48
7.1	Conclusion.....	48
7.2	Future Works .....	49
Reference .....		50
Appendix A.....		54
Appendix B .....		57
Appendix C.....		58

## List of Figures

Figure 1. 1 Flow chart of maintenance method [9].....	4
Figure 1. 2 Graphical representation of 2G six month NAR.....	6
Figure 1. 3 Graphical representation of 3G six month NAR.....	7
Figure 1. 4 Methodology of root cause analysis .....	9
Figure 2. 1 Simplified GSM network architecture diagram [19] .....	13
Figure 2. 2 UMTS network architecture overview [20] .....	14
Figure 3. 1 A simple Bayesian network .....	24
Figure 3. 2 Diverging connections .....	25
Figure 3. 3 Converging connections .....	25
Figure 3. 4 Serial connections .....	25
Figure 5. 1 Directed graph .....	34
Figure 5. 2 Bayesian network .....	34
Figure 5. 3 BN for the TX system .....	34
Figure 6. 1 Bayesian network relationship between events in different components .....	37
Figure 6. 2 IP root cause .....	40
Figure 6. 3 Weekdays root cause.....	41
Figure 6. 4 Weekend root cause .....	41
Figure 6. 5 Percentage of RC failure vs RNC .....	42
Figure 6. 6 A single BS the first phase five-month data .....	45
Figure 6. 7 A single BS the second phase five-month data .....	46
Figure A. 1 Existing BS element model.....	57
Figure A. 2 System model using MATLAB.....	58

## List of Tables

Table 1. 1 Number of outage mobile network elements .....	6
Table 1. 2 Operational performance of mobile sites in terms of availability .....	7
Table 2. 1 Examples of BTS external alarm .....	19
Table 3. 1 Fault detection and diagnosis methods [3].....	21
Table 3. 2 Algorithm [3].....	22
Table 4. 1 Sample data for base station alarm created .....	30
Table 5. 1 Examples of events.....	32
Table 5. 2 CPT for the node TX .....	35
Table 5. 3 CPT for the node BTS.....	35
Table 6. 1 Input parameters .....	38
Table 6. 2 Sample data input format .....	39
Table 6. 3 Prior probability for the input data .....	40
Table 6. 4 Labelling of root cause.....	43
Table 6. 5 Results after training.....	44
Table 6. 6 Other root cause of the first five-month data.....	45
Table 6. 7 Other root cause of the second five-month data.....	46
Table 6. 8 Higher frequent down times with root cause .....	47
Table A. 1 Cause of IP failure .....	54
Table A. 2 Cause of transmission failure .....	54
Table A. 3 Cause of power failure .....	55
Table A. 4 Cause of RAN failure.....	56

## List of Acronyms

2G	Second generation
3G	Third Generation
BN	Bayesian network
BS	Base station
BSC	Base station controller
BTS	Base transceiver station
CPD	Conditional probability distribution
DAG	Directed acyclic graph
DG	Diesel generator
FC	Fiber cut
GSM	Global system for mobile communication
NE	Network element
NMS	Network management system
NN	Neural network
NNOC	National network operation center
PWR	Power
RC	Root cause
RCA	Root cause analysis
RNC	Radio network controller
TS	Troubleshoot
TT	Trouble ticket
UMTS	Universal mobile telecommunication system

# CHAPTER 1. Introduction

---

In this chapter, the background and motivation of the presented research is described. The root cause analysis of base station outage in telecom industry is outlined. Current research gap and the challenges are detailed followed by objectives and methodology. Furthermore, related work, thesis scope and limitation are discussed.

---

## 1.1 Background and Motivation

Mobile operators encounter failures in their network equipment due to several reasons including power, transmission equipment and link failures [1]. Mobile base station (BS) is one of the important mobile network equipment, which is subject to failure. When BS failure occurs, operator's maintenance team need to quickly identify root causes (RC) of the outage and perform corrective action so that customer complain and revenue loss are avoided [2].

RC is the reason why a failure occurs and its analysis primarily is a reactive method of problem solving. This means that the analysis is done after an event has occurred. By gaining expertise in root cause analysis (RCA), it becomes a pro-active method. Thus, RCA is able to forecast the possibility of an event even before it could occur. Methods and technologies for analyses and process these data are required. For that different advanced RCA algorithms and tools have been proposed, investigated and implemented. Some of the techniques to detect fault and diagnose the RCs are principal component analysis, clustering, neural network, ask five why's, Bayesian network(BN), causal tree, decision table and others [3][4].

BS faults can be classified into two groups: malfunction and outage. BS malfunction is said to occur when it is partially working while BS outages occur when it is entirely knocked out. Malfunctioned BSs are normally characterized by performance degradation

in various performance parameters; for example, increase in noise level and in delay. An outage is commonly clear such that network users might notice complete service outage. Impacts of outage on services being offered can be quantified in terms of monetary values [5][6].

BS outage in ethio telecom network are reported to the national operation center (NOC) in the form of alarms. An alarm is a message emitted by a network device when a problem or an abnormal phenomenon is encountered. In the maintenance and operation activity, fault management system collect alarms. Thus, trouble tickets (TT) are dispatch to operator's maintenance team. TT contains information about support interventions made by technical support staff. A maintenance team cleared the alarms to fix BS outages.

A network management system (NMS) is an application or set of applications that lets network engineers to manage a network [7]. NMS used to monitor both software and hardware components in a network. It usually records data from a network's remote points to carry out central reporting to a system administrator. Network engineers use NMS to handle a variety of operations such as monitoring and analyzing performance, detecting devices, and enable notifications. NMS identifies, configures, monitors, updates and troubleshoots (TS) network devices.

NMS processes trouble calls from customers and analyzes them to determine probable outage locations [8]. The system also acts as the central repository for outage and outage restoration information and can generate outage and outage restoration notifications. NMS also keeps a history of all events that were known to affect a customer. NMS receives and processes events from network elements in the network. It can be viewed as the main console for network operations in detecting faults. The ability to detect problems quickly in any network is critical. Network operations personnel can rely on a graphical network map to display the operational states of critical network elements.



The mobile network systems in ethio telecom generate various alarm signals, which are difficult to realize accurate sources of faults in the network. BS outages have an impact in a quality of service provided to customers and increase operational cost for the service provider. From the history of alarms, maintenance team understand the alarm messages (i.e., the meaning of the alarms, impact on services and customers, and its solution). In order to maintain service quality to customers, maintenance team should follow basic TS methods such as analyzing alarm information, indicator status, traffic statistics, and meter test result.

In case of ethio telecom, there is a tremendous amount of work to reduce BS outage. It is difficult to identify the cause of BS outage and to analysis RC for the outage. One of the limitations of the maintenance system used today for ethio telecom is that they do not take into consideration systematic approach to identify the actual RC of the problem and diagnose the fault, which is essential to address the problem of the RCs. The primary issue is the lack of a systematic approach for such case to be followed. It is also essential to have a methodology to analyze BS outage and meantime to recovery.

## 1.2 Problem Statement

Fault (including BS outage) maintenance method applied by ethio telecom is a corrective maintenance approach, which helps only to correct services after the network is degraded or down. The applied methodology is summarized ethio telecom adopted the methodology proposed in Figure 1.1.

However, there is a gap during trouble shooting. The team, query event logs or suggestion box are used as a reference to handle the fault but does not match with the real problem. For example, the system suggestion box suggest the following reasons for a particular fault occur in the BS.

1. Certain other alarms occur at the opposite station.
2. The receive unit of the local station is faulty.
3. The transmit power of the opposite station is low.

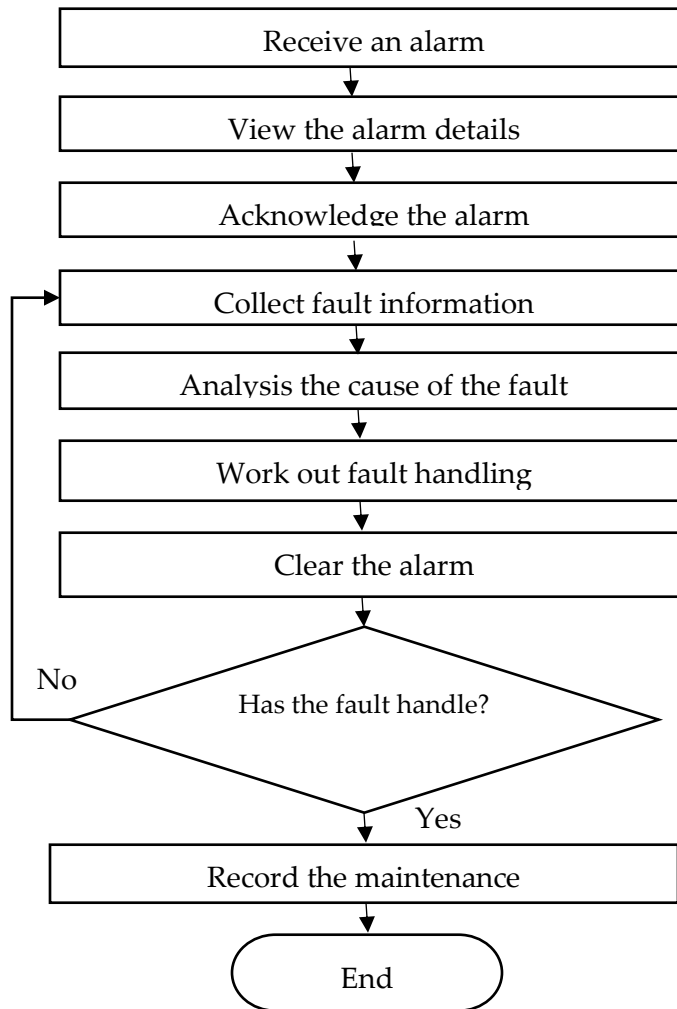


Figure 1. 1 Flow chart of maintenance method [9]

For this, the possible reason does not tell the exact solution for that particular fault. Moreover, on the history alarm, the RC cannot be identified easily rather NOC create a TT and assign to field technicians with no detail information. Thus, ping-pong happen between different sections.

Since ineffective team formation, field technicians cannot easily diagnose the alarm, team members from different sections are travel to the faulty site for maintenance. Most of the time, it is difficult to decide which team could solve the problem. Additionally, personal interests of employees have an influence on the maintenance team to engage full responsibilities for the task. However, by knowing the probable cause of faults/outage, maintenance team can respond immediately to make mobile sites reliable and available.

Mostly causes of outages are identified manually which is based on knowledge and experience of members of the maintenance team. As a result, the process can also take long time. There is also no standardized approach for RCA. All this happened irrespective of availability of huge amount of outage data that can be exploited using advanced RCA methods.

Lack of advanced RCA method, is longer outage maintenance time means longer downtime, which decreases the working time of a system [10]. Availability (a measure of the percentage of time the equipment is in an operable state) of a system cannot be constant, but it can increase or decrease based on the reliability and/or the maintainability performance. For example, if a telecommunication network's availability is increasing, it is because either the occurrence of outages is rare (high reliability) or there is an efficient maintenance process.

Table 1.1 shows sample report of outage number of mobile network elements for early few days on date 12/26/2018. For instance, Bahirdar has 12, 5 and 2 down sites for less than one day, in between one and three days, ( $3 < \text{Days} < =1$ ) and for greater than, or equal to three days respectively, which is a total of 19 down sites for an average of 151.88hr was unavailable.

Table 1. 1 Number of outage mobile network elements

Region	<1 Day		3 < Days <=1		> = 3Days		Total	
	Number of down sites	Average duration (Days)	Number of down sites	Average duration (Days)	Number of down sites	Average duration (Days)	Number of down sites	Average duration (Days)
Dessie	0	0	3	1.63	0	0	3	1.63
Bahirdar	12	0.45	5	1.41	2	150.02	19	151.88
Nekemt	0	0	0	0	0	0	0	0
Mekele	4	0.18	1	2.61	1	36.93	6	39.72
Dire Dawa	8	0.25	4	2.31	5	10.76	17	13.32
SOMALLI	6	0.53	6	2.38	5	59.93	17	62.84
ASSOSA	0	0	0	0	1	102.81	1	102.81
Jimma	1	0.14	2	1.3	0	0	3	1.44
Wolaita	13	0.4	2	1.61	1	136.54	16	138.55
Old Airport(Addis Ababa)	4	0.71	1	2.86	1	13.37	6	16.94
TOTAL	48	2.66	24	16.11	16	375.36	88	394.13

Source: network unavailability report for ethio telecom.

Network availability is determined by the frequency of failures and the speed of maintenance. Figure 1.2 and Figure 1.3 shows, 2G six months and 3G six-month network availability report (NAR) respectively. Ethio telecom determine network availability the target value is 99.5%. However, there is a gap from the actual value and the target value for both figures.

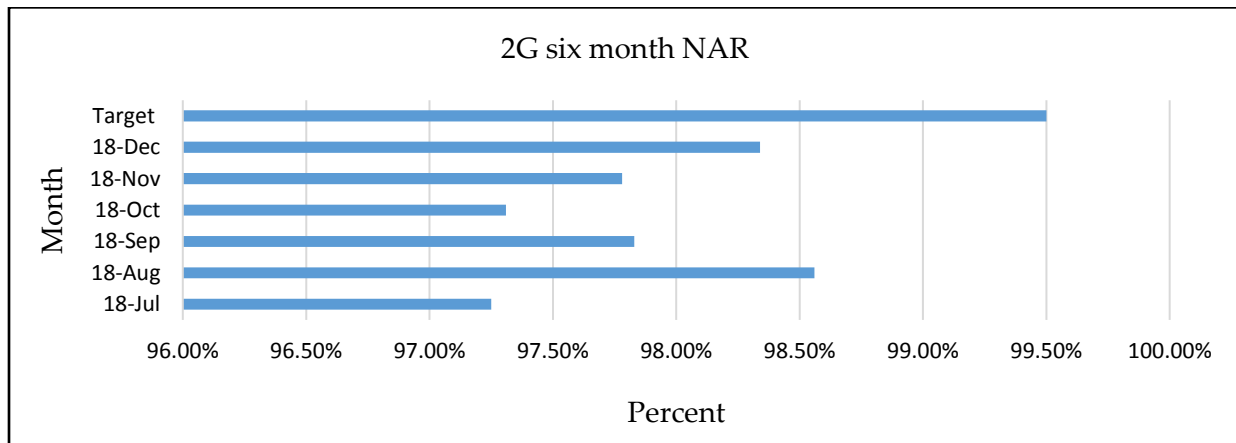


Figure 1. 2 Graphical representation of 2G six month NAR

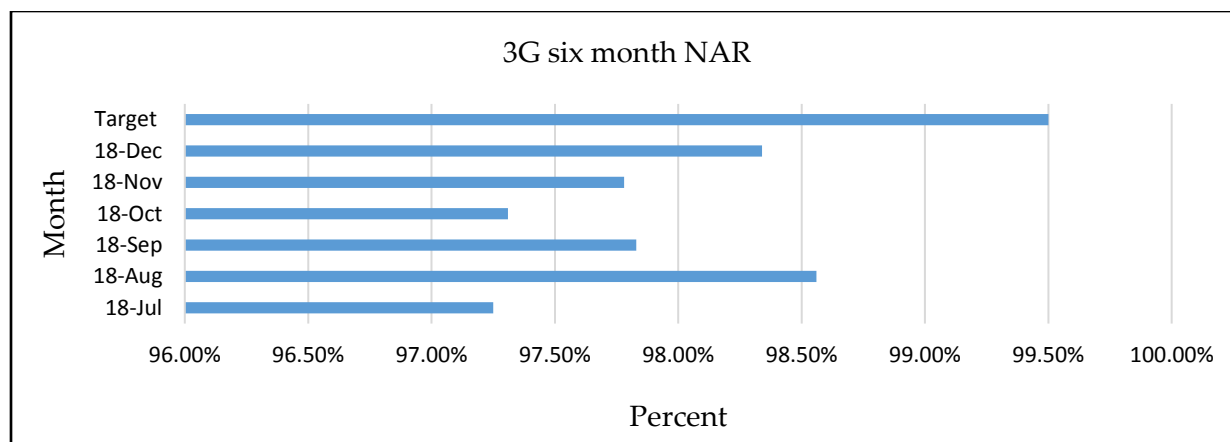


Figure 1. 3 Graphical representation of 3G six month NAR

Operational performance of mobile sites for Addis Ababa and its region in terms of availability depicts in Table 1.2. The design target of network availability of mobile network sites (base stations) is 99.999% [11]. However, there is performance gap from the design target due to an efficient maintenance process. Thus, it is necessary to analysis RC of mobile site fault occurrence, in order to mitigate the faults. This implies there is a need of network availability improvement of mobile sites. Accordingly, it is essential to analysis BS outage.

Table 1. 2 Operational performance of mobile sites in terms of availability

Technology/Region/Vendor	Network availability (%)
GSM-Addis Ababa(Huawei)	99.004
3G-Addis Ababa (Huawei)	98.774
LTE-Addis Ababa(Huawei)	99.84
GSM-Region-Huawei	89.01
3G-Region-Huawei	90.14
2G & 3G-Region-ZTE	93.42
Average	95.03

Source: network performance report, 2017 ethiotelecom

## 1.3 Objectives

### 1.3.1 General Objective

The general objective of this thesis is to present RCA of BS outage using BN empowered by TT, log file and history alarm data and its impact on maintenance approach.

### 1.3.2 Specific Objectives

The specific objectives of this thesis are:

- i. Data collection and processing in perspective of BS outage and its causes.
- ii. To study and calibrate Bayesian network for RCA.
- iii. To investigate and analyze RCs of BS outage.
- iv. To produce results in terms of probability of the RCs

## 1.4 Methodology

The methodology in this thesis starts by identifying problems of BS outage based on statistical analysis of data collected from a historical alarm, TT and a related log file. Followed by reviewing of related literature, then filtering and pre-processing the data based on their type and analyzing the data using an appropriate model for the RC. Finally label and learn the relation between elements and evaluate the analysis data. Figure 1.4 shows the modelling approaches of the RCA. TT, history of alarms and system log files are an input.

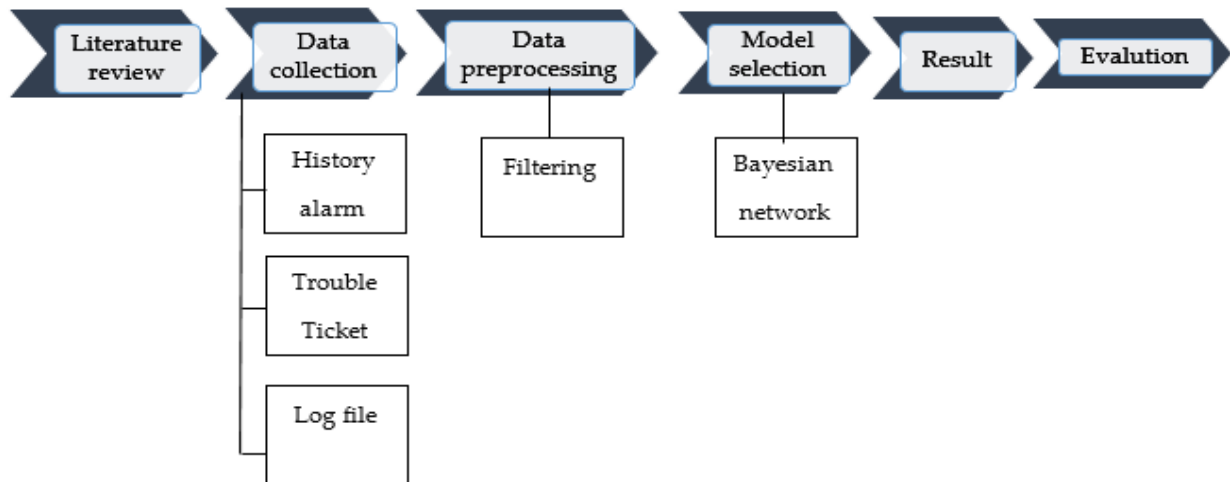


Figure 1. 4 Methodology of root cause analysis

## 1.5 Related Work

The author states the application of BN for diagnosing faulty components by constructing the BN structure based on input data. Probability reasoning is a method to deal with uncertain information, and BN is a tool. In this paper, a general procedure for constructing a BN structure proposed to learn the BN from data. Historical data and expert knowledge are employed to specify the conditional probabilities. A probability distribution, which is computed through the BN with given evidence, and ranking of faulty. This can provide the system operators a priority checking. The limitation of the paper only use historical data and expert knowledge as an input. However, the accuracy of the learned BN is largely affected by the ‘richness’ of the data and the prior knowledge of the network ordering [12].

The author of the paper presents an automated diagnosis in TS for universal mobile telecommunications system (UMTS) networks using a BN approach. TS comprises fault detection (FD); cause diagnosis and solution deployment, namely fixing the problem. The diagnosis of the cause of faults is the most complex and time-consuming one. A cause could be a hardware failure (like a broken base-band card in a node B) or a bad parameter

value (i.e., transmission (TX) power (PWR), antenna tilt, or a control parameter such as a radio resource management (RRM) parameter). Two components of the diagnosis system have been distinguished, i.e., the model and the inference method. The diagnosis model represents the knowledge on how the identification of fault causes is carried out. The elements of the model are causes and symptoms. The inference method is the algorithm that identifies the cause of the problems based on the value of the symptoms. The chosen BN structure is a so-called Naïve Bayes Model (NBM). The NBM consists of a parent node, whose states are the possible fault causes, and children nodes, which represent the symptoms and may have any discrete number of states. The author states specifying prior probabilities of the causes can be easily defined by diagnosis experts, taking into account their experience on the frequency of occurrence of each fault type [13] [14][15].

The author states based on a naive Bayesian classifier can identify the fault cause in mobile network system. The goal of the paper is trouble shooting of the radio access network (RAN), which consists of detecting faults, identifying the cause and solving the problems. Using a list of faults, symptoms and a relation between fault and symptom and apply BN. The method is based on a naive Bayesian classifier, which calculates the probabilities of all the possible causes using the Bayes' rule and address the problem of the root cause. The naive Bayesian classifier can be studied using the theory of BNs, which allows efficient representation of a joint probability distribution over a set of random variables [16].

## 1.6 Scope and Limitation

The scope of this thesis is to detect fault occurrence and study RC of BS outage by analyzing the TT, log file, and fault history data. In addition, to produce probability of the RCs for selected BSs of Addis Ababa.

One of the limitations of this thesis work is that it does not take into consideration (covered) all elements of mobile network.

## 1.7 Contribution of the Thesis

The main contribution of this thesis work is RC identification to improve the quality of mobile network services for telecom operators. Ethio telecom become cost effective while reducing delay during proper maintenance team assignment, which minimize redundant fault investigation by different section. This encourages ethio telecom to implement BN based RCA during fault identification.

## 1.8 Outline of Thesis

The remaining parts of the thesis document is organized as follows: chapter 2: In this chapter introduces the mobile network services and architecture. The concept of mobile base station outage, root cause and its analysis are discussed. Then, mobile base station outage monitoring and maintenance are described. Chapter 3: This chapter describes the modelling technique of Bayesian network. Chapter 4: This chapter presents the root cause of mobile base station outage and its analysis in case of Addis Ababa are described. Chapter 5: In this chapter, how Bayesian network model construction and mathematical explanation are described. Chapter 6: In this chapter describes the Bayesian network relationship between events and discusses the results of root cause analysis for mobile base station outage. Finally Chapter 7: This chapter presents conclusion and addresses future thesis direction.

## CHAPTER 2. Mobile Network Outage

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This chapter introduces the mobile network services and architecture. The concept of mobile base station outage, root cause and its analysis are discussed. Then, mobile base station outage monitoring and maintenance are described.

---

### 2.1 Mobile Network Services

Currently, mobile network services are part of everyone's life. The services are playing a major role in communicating with others from one place to another place. Mobile services are not only for making call, but they are being used in communicating in others way such as through messaging via text and multimedia and connect to the internet. Therefore, the demand for the mobile services continuously grows. Several services such as international roaming, mobile money transfer, internet facilities and teleconferencing facilities giving customers a range of choices from only just make and receive call when the innovation of mobile communication services being held. The goals of most of the operators are to maintain their existing customers and retain new customers without losing any of them [17].

### 2.2 GSM and UMTS Network Architecture

The GSM and the UMTS network architecture provided a simple architecture to provide the services needed for a 2G and 3G cellular system respectively. The GSM network architecture provide the services needed for a 2G cellular system [18][19]. The overall GSM network architecture elements like the base transceiver station (BTS), base station controller (BSC), mobile switching center (MSC), authentication center (AUC), home location register (HLR), visitor location register (VLR) and the like are brought together to form the overall system. In order that the GSM system operates together as a complete

system, the overall network architecture brings together a series of data network identities, each with several elements.

The GSM network architecture is defined in the GSM specifications and it can be grouped into four main areas. These are network and switching subsystem (NSS), base-station subsystem (BSS), mobile station (MS), operation and support subsystem (OSS). The different elements of the GSM network operate together, and the user is not aware of the different entities within the system. Figure 2.1 is a basic diagram of the overall system architecture for 2G GSM with these four major elements.

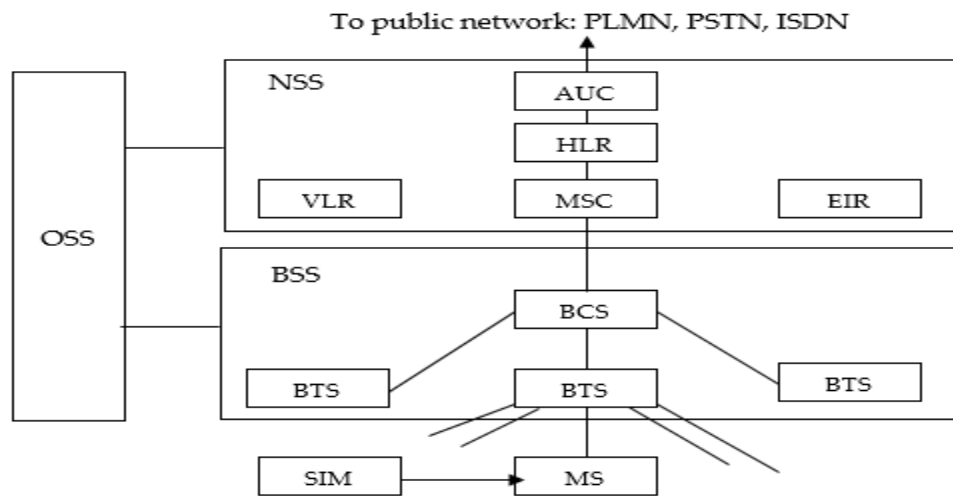


Figure 2. 1 Simplified GSM network architecture diagram [19]

The UMTS network architecture can be divided into three main elements [20]: user equipment (UE), radio network subsystem (RNS) and core network (CN). Figure 2.2 depicts UMTS network architecture overview.

**User Equipment:** The name given to the mobile, or cellphone.

**Radio Network Subsystem:** Also known as the UMTS Radio Access Network, UTRAN, is the equivalent of the previous BSS in GSM. It provides and manages the air interface.

**Core Network:** Provides all the central processing and management for the system. It is the equivalent of the GSM NSS. The core network is then the overall entity that interfaces

to external networks including the public phone network and other cellular telecommunications networks.

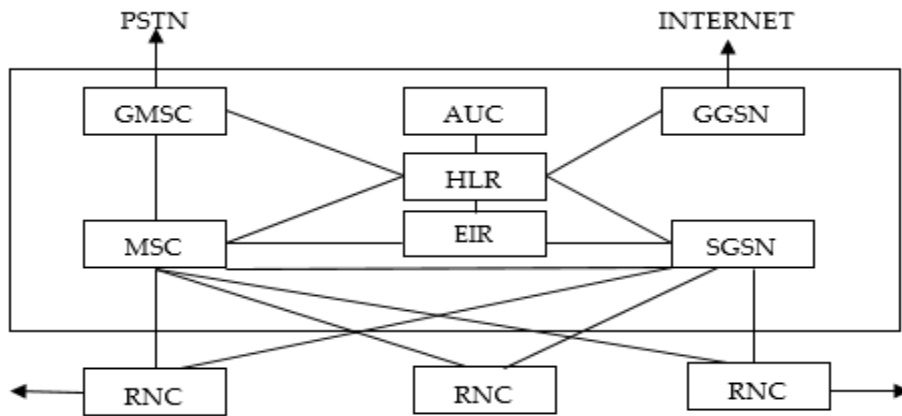


Figure 2. 2 UMTS network architecture overview [20]

### 2.3 Base Station Outage

When there is a mobile network outage, the mobile network operator’s customer base will be unable to use the data, voice and any means of communication functions through mobile. This means no texting, calls, and internet browsing or social media. There is also an impact in a quality of service provided to customers and increase operational cost for the service provider.

Mobile network outages occur due to various reasons. The main reasons for the outage is due to BS faults. A BS is a system in a mobile communication network that houses radio receivers and is used for wireless communication between users and network providers that is under the control of BSC or radio network controller (RNC) and then the exchange [20]. BTS is the element connected to GSM antennas. BTS is installed in a small building next to the tower in the site and it is connected through cables to the antenna in the top. BTS manage all the antennas/cells of the same site. Node B is similar to BTS in UMTS network. NodeB are equipment installed in the site connected to antennas sending and receiving 3G signal. Same than BTS a Node B manage all UMTS cells in the site.

BS processes and handles local radio communications with cellular phones and facilitates communication between the networks. Service outage in mobile networks are caused by different reasons. To realize the reason why the BS outage occur needs RCA. Interconnection of BS element model depicts on Appendix B.

## 2.4 Root Cause for Base Station Outage and its Analysis

The power consumption of wireless communication networks has become a major economic and environmental issues, providing dedicated power supply for cell sites is one of the major issues for mobile communication system. In wireless communication network such as mobile communication BS, smooth network function is necessary. The reasons behind outages can range from bad weather to human errors and network changes. Weather can have a particularly bad effect on mobile signal, as the heat, cold, rain and stormy conditions can disrupt telecom masts. Human error can also be attributed to mobile network outages [21].

If an engineer has incorrectly rerouted traffic or encountered further issues while attempting to fix an existing problem, then often the network can be taken offline until it is properly repaired. In all circumstances, the operator will attempt to mitigate the number of users affected [22]. Attempts to upgrade or change network infrastructure can also be blamed for downtime. Changes to the network requires mobiles to reconnect and if the network is particularly busy, this can take time. Making changes to the network technology can also cause delays and introduce new problems, which have an impact on the quality of mobile service. Also, the Generator fuel being unnoticed by the site personnel or any means of power, transmission, IP and RAN failure which stops completely working procedure of the system.

To protect the mobile BS and its proper uninterrupted operation, monitoring the conditions of BS and analysis the causes of the problem are needed. The core of the

solution is monitoring state of BS similarly the maintenance team is alerted of any unexpected situation and can attend to it immediately to avoid total outage of communication system[21].

RCA is a class of problem solving methods aimed at identifying the RCs of problems or incidents. The practice of RCA is that problems are best solved by attempting to correct or eliminate RCs, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at RCs, it is hoped that the likelihood of problem recurrence will be minimized. However, it is recognized that complete prevention of recurrence by a single intervention is not always possible. Thus, RCA is often considered an iterative process, and is frequently viewed as a tool of continuous improvement. General principles of root cause analysis [23] are:

1. Identify the RC of a problem in order to create effective corrective actions that will prevent that problem from ever re-occurring.
2. A RCA must be performed systematically as an investigation, with the conclusions and the RC backed up by documented evidence.
3. There is always one true RC for any given problem; the difficult part is having the stamina to reach it.
4. The analysis must establish a sequence of events or timeline to understand the relationships between contributory factors, the RC and the defined problem.

## 2.5 Base Station Outage Monitoring

Alarms are used to monitor the site for maintenance team. In case of fault happen, the alarm panel automatically generate the alarm for corresponding fault at site. Maintenance team is responsible for fault management. These teams' are checking a daily basis in order to identify the cause of the problem. During the procedure, several applications and databases have to be queried to analyze performance indicators, cell

configurations and alarms. Finding the RC of a problem is essential for effective fault management. [24] The most difficult task in finding the RC of the fault is to localize the fault into a right place in the system. When single fault happens, it sometimes creates a several alarms. Alarm correlation may be used for network fault isolation.

The NMSs provide thousands of alarms, which are triggered by certain events. They may indicate a fault or not. For example, if the traffic increases an alarm may be triggered, which would not indicate a fault. On the other hand, a fault in a piece of equipment may affect another piece of equipment, making its alarms trigger. Due to these reasons, it is very difficult to identify the cause of problems based only on alarms. TS in a cellular network consists of fault detection, fault diagnosis, and fault recovery [25].

The first step in TS is the detection that is the identification of the problems. A problem is a situation that has an influence in the service. Every operator uses a different method to identify the problem. Once the problems are isolated, a diagnosis of the cause of the problems should be done. A cause or fault is the defective behaviour of some logical or physical component that can provoke failures and generate a problem, for example hardware fault. A symptom is a performance indicator whose value can be a manifestation of a fault, for example the number of handovers due to interference. Finally, a failure is an anomalous value of a symptom, which can be caused by a fault, for example excessive number of interference handovers. Therefore, a problem is a type of failure that has an influence in the service. Finally, some actions should be carried out in order to solve the problems.

Alarm monitoring plays a critical role of site maintenance. Hence, it is known as one of the key factors that the operation and maintenance center needs. Uninformed site failures results lots of blame and loss of money. Fault type is critical, major, minor and warning

- **Critical alarm:** Affects service quality. If a critical alarm is generated, immediate actions are necessary even when the fault occurs during non-working hours.
- **Major alarm:** Affects service quality and requires immediate action.
- **Minor alarm:** Generally does not affect service quality, but requires handling or observation in a reasonable amount of time to avoid more faults that are serious.
- **Warning alarm:** Indicates a potential error that may affect service quality. It requires different actions depending on errors.

Each BS site generates alarms, which is critical for daily maintenance operations. Alarms categorize [26][27]: BSS equipment failure alarms (responsible for BSS engineers), Transmission failure alarms (responsible for transmission engineers)), Power failure alarms (responsible for power engineers).

When BS create alarms and send to its controller. They are collected by operation and maintenance servers. The alarm system receives alarm indications such as from the sources in the radio network: BS equipment alarms, BS software alarms, external alarms from the BS site, alarms from Abis interface equipment, transmission equipment alarms. The main contribution of this theis is to develop a statistical alarm analysis of historical alarms to assist the operators in better understanding network failures. Some of the alarms are listed below [9] [28].

**Radio link failure/transmission faults:** Some of the alarms are transmission device board or E1 is faulty, E1 connection quality is bad, the ground system is faulty, A-bis interface fault (interface between the BTS and the BSC), A- interface fault (the link between BSC and the MSC), transcoder faulty, and fiber cut.

**IP transmission faults:** If an IP transmission fault occurs, messages and service data cannot be transmitted between communication devices, and a peer device cannot be pinged. Related alarms for IP transmission faults: Ethernet link fault, IP address conflict,

IP path fault, stream control transmission protocol fault, cell unavailable, user plane path fault, eNodeB control plane transmission interruption, aeronautical telecommunication network offline, cell site gateway failure, service function chain module problem, IP interface and management problem.

**Power faults:** There are various alarm reported on power. Some of the alarms are AC, generator, solar, rectifier and battery failure.

**RAN transmission faults:** There are several alarm reported on RAN transmission. Some of the alarms are base band unit, radio frequency unit, and optical interconnections.

Some examples of BTS external alarm depicts on Table 2.1. Some cell outage cases are detected by operation and maintenance through Performance counters and/or alarms, others may not be detected for hours or even days. It is often through relatively long-term performance analyses and/or subscriber complaints that these outages are detected. The goal of cell outage management is to minimize the network performance degradation when a cell is in outage through quick detection and compensation measures.

*Table 2. 1 Examples of BTS external alarm*

Alarms	Root cause
Site on battery	All the rectifiers in the power plant failed
DG fails to start/stop	When the PIU/AMF panel fails to start/stop
DG running without load	DG runs without load
Low fuel level	When the fuel as an example reaches 40% of the tank capacity
High room temperature	When the temperature reaches 45°
AC fails	When AC gets fails
Rectifier fails	When any one rectifier fails
Low battery voltage	When the power plant voltages reaches 47V
Fire and smoke as site	When there is fire or smoke at the site

Source: <https://www.scribd.com/document/46061276/BTS-External-Alarm-Definition-KK>



## CHAPTER 3. Root Cause Analysis Technique

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This chapter describes the modelling technique of Bayesian network.

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### 3.1 Overview

Mobile network customers have different requirements and needs. To attract and retain this customers operation of the network is good status at all times with proper operation and maintenance of the network itself. [29] The growing complexity of cellular networks makes the task of supervising the network and identifying the cause of performance degradation more challenging for the network operators. Operators deploy monitoring systems in order to provide an accurate status of the network to identify any issues. The analysis is often time consuming and inefficient. Operators would like to analysis the RC, in order to detect, and fix the problem.

A RC is a fundamental reason for the occurrence of a problem. Problems arise from their RCs such as antenna alignment problem, fiber cut, power failure and configuration problem. Therefore, the way to solve a problem is to resolve its RCs. However, some RCs are not easy to find. Cause analysis tools are helpful for conducting a RC analysis for a problem or situation. It identifies many possible causes of a problem. Thus, use RCA to look deeper into problems and find out why they are happening. By means of the RCA technique for finding RCs, the problem solved. RCA is frequently used to detect the RC of serious problems.

RCA is a logical thinking process to collect evidence to support or deny actual causes of a problem. RCA helps to identify what, how, and why an event or failure happened. In general, RCA means finding the specific source(s) that created the problem so that the effective action can be taken to prevent recurrence of the situation. Some of the techniques

to detect fault and diagnosis the root causes method are principal component analysis, clustering, neural network, and BN.

Table 3.1 depicts fault detection and diagnosis methods. A lot of data-driven fault detection and diagnosis methods have been proposed [3]. Comparing the methods based on the four comparative criteria:- the consideration of uncertainties, the possibility of using both data and expert knowledge, the possibility for the user to know the existing causal relationships between the different parameters (semantic) and the resources needed to implement the method (time needed for modelling tasks, amount of memory consumed, necessary computing time,...).

Table 3. 1 Fault detection and diagnosis methods [3]

Method	Consideration of uncertainty	Expert knowledge and data	Semantic	Resource needed
Principal component analysis	-	-	+	--
Clustering	-	-	-	-
Neural network	-	+	-	--
BN	+	+	+	---

Where “-” = No or negative

“+”=Yes or positive

Among the studied methods, the BN formalism is the framework that explicitly incorporates uncertainties and allow exploiting both data and expert knowledge. The semantic of the BN makes it possible to understand the causal mechanism linking a symptom to its RC. BN nonetheless requires more resources compared to the other methods. Bayesian theory has been chosen to set up causal framework.

Table 3. 2 Algorithm [3]

Method	Robust	Transparent	Mixed data	Large data	Probabilistic	Adaptive
DT	Yes	Yes	No	Yes	Yes	Yes
BN	Yes	Yes	Yes	Yes	Yes	Yes
SVM	Yes	No	No	Yes	Yes	Yes
K-NN	Yes	Yes	Yes	No	Yes	Yes

Based on the algorithms decision tree (DT), BN, support vector machine (SVM) and K-NN are some of the methods. Comparing to robust, transparent, mixed and large data, probabilistic and adaptive criteria BN is selected as indicated in Table 3.2. BNs, also called belief probabilistic networks, have been proposed by many authors as the modelling technique for the development of diagnosis systems. In this thesis, also BN model is selected to analysis the RCs. This is because BNs have been used mostly to analyze data on previous fault situations.

### 3.2 Bayesian Network

BNs are a type of Probabilistic graphical model that can be used to build models from data and/or expert opinion. They can be used for a wide range of tasks including prediction, anomaly detection, diagnostics, automated insight, reasoning, time series prediction and decision making under uncertainty. They are also commonly referred to as Bayes nets, Belief networks and sometimes-causal networks [30]. BNs are probabilistic because they are built from probability distributions and also use the laws of probability for prediction and anomaly detection, for reasoning and diagnostics, decision making under uncertainty and time series prediction.

BNs can be depicted graphically which is made up of nodes and directed links between them [31]. The BN is defined by a graphical structure and a probabilistic representation. The graphical structure consists of a Directed acyclic graph (DAG) denoted as  $G = (V, E)$ , where  $V$  is the set of vertices (i.e., nodes) and  $E$  is the set of edges.

The BN is also defined by the probabilistic representation. It is determined by the parameters, which are the conditional probability tables (CPT) that expose the probability distribution of each random variable. The joint probability distribution of a given BN is computed using the following expression:

$$P(V) = \prod_{i=1}^n P(V_i | \text{parents}(V_i)),$$

Where  $V$  is the joint probability distribution.  $\text{Parents } V_i$  is the set of the parents of the variable  $V_i$  in the graph  $G$  and  $n$  is the number of nodes in the corresponding BN.

The computation of conditional probability is ensured by the Bayes theorem. For two-variables  $V_1$  and  $V_2$  such that  $P(V_1) \neq 0$ , the conditional probability of  $V_2$  given  $V_1$  is:

$$P(V_2 | V_1) = \frac{P(V_1 | V_2)P(V_2)}{P(V_1)}.$$

BN is a probabilistic graphical model that represents a set of variables and their probabilistic independencies [32]. For example, a BN could represent the probabilistic relationships between diseases and symptoms. Given symptoms, the network can be used to compute the probabilities of the presence of various diseases. Formally, BNs are DAGs whose nodes represent variables, and whose missing edges encode conditional independencies between the variables. Nodes can represent any kind of variable, be it a measured parameter, a latent variable or a hypothesis.

A simple BN in Figure 3.1 consists of only three nodes and two links. It represents the conditional probability distribution (CPD), Prior probability and joint probability distribution.

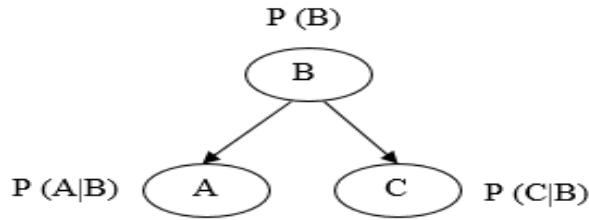


Figure 3. 1 A simple Bayesian network

CPD: is specified at each node that has parents. Example A and C has parents. CPDs of variables A and C, are  $P(A | B)$  and  $P(C | B)$  respectively.

$$P(A | B) = \frac{P(B | A) * P(A)}{P(B)}$$

Prior probability: is specified at node that has no parents (the root node). Example B has no parents the prior probability of B is  $P(B)$ .

The edges in the BN represent the joint probability distribution of the connected variables. For example, the joint probability distribution for the edge (B, A) is  $P(A, B)$  which represents the probability of joint event A and B.

$$P(A, B) = P(A | B) * P(B)$$

The following features make BNs, in many cases, a suitable technique [32]:

Knowledge representation: it is easy to maintain consistency and completeness in probabilistic knowledge bases.

Conditional independence: can be calculated by an expert using graphical models.

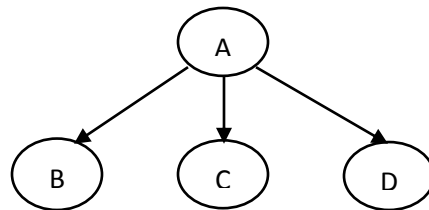
Flexibility: BNs allow using the same model to evaluate, predict, diagnose, and optimize decisions.

Moreover, BNs are:

- Graphical models, capable of displaying relationships clearly and intuitively.
- Capable of representing cause-effect relationships.
- Can handle uncertainty through the established theory of probability.
- Mathematical support: allows the analysis of the model in view of the knowledge of its performance and precision before an implementation is carried out.
- Robustness: approximate answers can be obtained, even when the existing information are incomplete whenever new information become available.
- It is simple and effective.

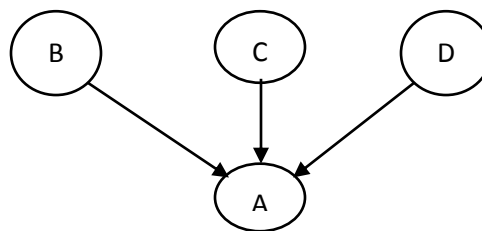
Types of BN connections are diverging, converging and serial connection [33].

Diverging connection: Information can flow between the children of A, unless A is known.



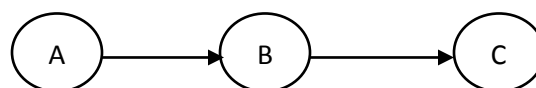
*Figure 3. 2 Diverging connections*

Converging connection: Information cannot flow between the parents of A, unless A is known.



*Figure 3. 3 Converging connections*

Serial connection: Information can flow from A through B to C, unless B is known.



*Figure 3. 4 Serial connections*

## CHAPTER 4. Base Station Outage for Addis Ababa

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This chapter presents the root cause of mobile base station outage and its analysis in case of Addis Ababa are described.

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### 4.1 Root Cause and causes of Base Station Outage

For ethio telecom, there is a challenge in identifying the RC of BS outages. For instance, failure of transmission is the cause of BS outage. Indoor unit, outdoor unit, antenna, patch cord, are some of the RC of transmission failure. Detail descriptions are listed below and in Appendix A.

**Transmission problem:** The cause of transmission problem is due to microwave and optical.

Microwave: The BS uses microwave radio communication. It is composed of several antennas mounted on a tower and a building with electronics in it at the base. The cell phone and BS communicate back and forth by radio, and the radio waves use microwave. Some of the RCs for microwave transmission failures are radio transmission node, link loss of frame, gigabit interface, indoor unit and outdoor unit.

Optical: The installation of optical fiber specifically to provide BTS connectivity in mobile networks has an impact on the quality of services experienced by the customer. The optical fiber cables can provide tremendous data transmission capabilities. Fibers can be broken or have transmission losses, patch cord, fiber cut are some of the RCs for optical fiber failure.

**IP problem:** In the field of mobile communication networks, services apart from voice (such as e-mail, Internet access, and music downloading) are expanding. As a result, “all-IP networks” which can also provide voice communication services on a network based

on IPs are being established. Some of the RC for the IP failure is aeronautical telecommunication network, cell site get way, internet protocol interface.

**Power problem:** BS site needs power supply from alternating current, generator and solar power supply. The power consumption of wireless access networks have become a major economic and environmental issue. The following listed are the RC of BS failure due to power, diesel generator, rectifier, battery and solar.

**RAN problem:** Failure of the RAN equipment, route unavailability and other causes are the impacts of BTS failure due to RAN problem. RCs such as failure of base band unit, remote radio unit, and configuration are the causes of RAN problem.

To identify the causes of BS outage, RCA is necessary. By analyzing and comparing all possible causes and then excluding impossible factors, can determine the specific fault causes. To effective, diagnose the RCs, first find causes of the fault.

The RCA for the transmission, IP, power and RAN reasons of BS outage has process [34]. These are define the problem, understanding the problem, immediate action, corrective action, and confirm the solution.

## 4.2 Root Cause Analysis of Base Station Outage in Addis Ababa

RCA is a process designed for use in investigating and categorizing the RCs of events with safety, health, environmental, quality, reliability and production impacts [35]. The term “event” is used to identify occurrences that produce or have the potential to produce these types of consequences. Simply stated, RCA is a tool designed to help identify not only what and how an event occurred, but also why it happened [36]. Only when investigators are able to determine why an event or failure occurred would they be able to specify workable corrective measures that prevent future events of the type observed. Understanding why an event occurred is the key to developing effective

recommendations. Generally, RCA is a technique that helps technicians answer the question of why the problem occurred in the first place and seeks to identify the origin of a problem. It uses a specific set of steps, with tools such as the BN, to find the primary cause of the problem, so that can determine what happened, why it happened and figure out what to do to prevent its recurrence.

The deployment of Addis Ababa BTS scattered all over the vicinity of residence, work and schools. A BTS is a permanent location in a mobile cellular network used for radio communications with mobile units. The major work of a BTS is to allow a good process of information transmission and reception between mobile stations. The BS consists of transmitter and receiver antennas. These antennas, which are mostly directional antennas for mobile telecommunications, are positioned strategically on a tower in order to render services to certain geographical area. The location of a BTS is of crucial importance; the positioning of the BTS as well as the strategic inclination of the communication antennas can influence the quality of service rendered to the customers. Due to this reason, some BSs are located on a hilly terrain free from blockage of any structures in order to enhance quality connectivity and coverage.

When there is an outage of the mobile network, ethiotelecom customer base will be unable to use the data and communication function of their phones. This means no texting, calls, and internet browsing or social media. Clearly, this can cause a host of issues for those who need to use their mobiles. The reasons behind outages is transmission, power, IP, RAN, bad weather and human errors. Weather can have a particularly bad effect on mobile signal, as the heat, cold, rain and stormy conditions can disrupt telecom masts and kill hopes of getting a signal. Some cell outage, cases are detected by operation and maintenance system through performance counters and/or alarms, others may not be detected for hours or even days [37]. In any case, disruption in signal often requires engineers to fix the issue.

Fault management support a number of management services. Some examples of the fault management is inform the operator and of the current NE condition; Provide timely and accurate data regarding any abnormal change; Provide procedures, which allow system recovery either automatically or on operator demand after a fault detection [38].

The NNOC team are informed of a NE failure by means of functions provided by the alarm surveillance component: the alarm reporting functions. Some of the requirements for BS, RCA is achieved by means of alarm surveillance, fault localization, fault correction. The information provided by alarm reporting should be sufficient to localize the fault. However, if necessary, the team may also use the testing capabilities to obtain further details for fault diagnosis.

Depending on the type of the detected fault and its impact on the ethiotelecom services, the fault correction service provides manual actions to configure the network element to minimize the loss of the ethiotelecom services. When the faulty unit(s) is repaired, the fault correction again provides manual actions to restore the previously faulty unit(s) to its normal operation. To complete the fault management process, ethiotelecom is able to perform a final test to confirm the behaviour of the repaired system.

Maintenance team aware the alarms. Each alarm has a severity level that defines the importance of the alarm. The severity level helps to determine investigate raised alarms. When deciding which alarms to investigate first, maintenance team need to take into account both the severity and status. For example, an alarm with low severity can be more important than an alarm with high severity if the low severity alarm is unacknowledged and Unclear and the high alarm has been acknowledged or cleared. (An acknowledged alarm typically indicates that someone is aware of the alarm's existence and its cause is under investigation. A cleared alarm means that the abnormal condition

that caused the alarm is no longer apparent). BS outage is critical alarms. Table 4.1 shows sample data for BS alarm.

*Table 4. 1 Sample data for base station alarm created*

Severity	Alarm ID	Name	Occurred on	Cleared on	Acknowledge on	Acknowledge by
critical	301	NE discon	10/1/2018 11:00	10/1/2018 11:10	10/1/2018 11:10	<System operator>

The parameters of Table 4.1 as well as some basic definitions describe as follows:-

**Severity:** Type of the alarm that indicates minor, major and critical alarms.

**Alarm:** A message reported when a fault is detected.

**Alarm ID** indicates the ID of an alarm (uniquely identifies an alarm).

**Acknowledge** indicates that the user or system operator has known the alarm information. If the alarm is acknowledged by the user, Acknowledged By the user who acknowledges. If the alarm is unacknowledged, Acknowledged By <system operator >.

**Occurrence date and time:** Indicates the alarm generated date and time.

**Cleared date and time:** Indicates the alarm has been cleared.

**History alarm:** Faults that occur on the equipment in a past period of time or the log records all the alarms and events reported by the NE.

**Trouble ticket:** Contains information about support interventions made by technical support staff. Have a unique reference number.

**Log file:** A file records by maintenance technicians about the cause of the NE after the maintenance task is completed.

**System suggestion box:** To view technicians the possible cause of the failure.

## CHAPTER 5. Modelling and Assumption

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In this chapter, how Bayesian network model construction and mathematical explanation are described.

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### 5.1 Bayesian Network Model

BN are graphical models, which means that they contain a part that can be depicted as a graph. The reasons for choice are multiple. Above all, to demonstrate and apply the ideas, and on which to evaluate the resulting algorithms and to use probability theory. Finally, deriving cause-effect relationships from data [39].

### 5.2 Construction of Bayesian Network

The steps to construct a BN on this thesis are:

1. The random variable should be defined. There are forty variables such as indoor unit, outdoor unit, antenna, radio transmission node, link loss of frame, gigabit interface, Ethernet, fiber cut, patch cord etc.
2. The relation between variables will be defined. This relation leads to the BN structure.

The conditional probabilities for each random variable should be computed. These conditional probabilities values will be stored in their corresponding tables. System model of BN structure using MATLAB depicts on Appendix C.

Since BNs are graph and used for modeling whole relationships between variables can be used as a robust model. In addition, BNs can also show non-linear and causal relationships using the CPT. These networks can be used for different types of inference, such as diagnostic, predictive, and so on.

Table 5.1 shows critical alarms for different causes. The table does not specify all possible alarm type. Alarm type is different for different type of cause but the alarm name may or may not be similar. Alarm name such as NE disconnected on the alarm-monitoring terminal displayed when the causes such as power, transmission, IP and RAN failure occurs. The same alarm name, the same alarm severity for different type of cause different alarm type will perform. Thus by observing the alarm name difficult to differentiate the cause.

Table 5. 1 Examples of events

Type of cause	Alarm Severity	Alarm type	Alarm Name
Power	Critical	Communication alarm	Site Abis control link broken
	Critical	Processing error alarm	NE disconnected
Transmission	Critical	HARD_BAD	NE disconnected
	Critical	MW-LOF	NE disconnected
	Critical	ETH-LOF	NE disconnected
	Critical	Communication alarm	NE disconnected
	Critical	Equipment alarm	NE disconnected
IP	Critical	IP device board power off	NE disconnected
	Critical	IP address conflict	NE disconnected
RAN	Critical	Local cell unusable	NE disconnected
	Critical	RF unit RX channel unbalanced	NE disconnected

### 5.3 Mathematical Explanation of Bayesian Network

Bayesian belief networks or BNs are probabilistic graphical models represented as DAGs. These are applied in many field where reasoning under uncertainty is required. The networks are composed of nodes, representing variables of interest (e.g. the occurrence

of an event or a component of a system), and links joining the nodes, representing causal relations among the variables. Nodes and links constitute the qualitative part of the network, i.e. its structure, while the quantitative part is represented by the probability associated with the variables. Each node has a finite number of exhaustive and mutually exclusive states that it can assume. Every node with direct predecessors (parent) is associated with a CPT that contains the probability of each state of the node for any possible combination of the states of the parents.

For the nodes with no parents (root nodes), the CPT specifies the probability of being in each of the states of the associated variable. When the states of some of the variables in a network are known, it is possible to calculate the updated probability, given the new evidence, of the remaining unknown variables. Evaluating this probability, known as posterior probability, is the main task in a BN [40].

A graph is defined as a set  $V$  of vertices or nodes together with a set  $E$  of edges or links connecting some vertices in pairs. A variable is associated to any vertex and the links represent a certain relation that correlates two variables. When an edge has a single arrowhead, it is directed. When all edges in a graph are directed, then the graph itself is directed. Figure 5.1 shows an example of a directed graph with  $V = \{IDU, FC, MW, OPT, TX, BTS\}$  and  $E = \{(IDU, MW), (FC, OPT), (MW, TX), (OPT, TX), (TX, BTS)\}$ .

A path in a graph is a sequence of edges such that each of them starts with the vertex ending in the previous edge, e.g.  $\{(IDU, MW), (MW, TX), (OPT, TX)\}$  in Figure 5.1, where the notation  $(IDU, MW)$  represents the edge connecting the vertex IDU to vertex MW.

Two vertices in a graph are connected if there exists a path between them. Although self-loop cycles are not admitted in a graph, i.e. an edge cannot connect the same vertex (e.g.  $(IDU, IDU)$ ), a directed graph may have directed cycles, that is a path starting and ending

with the same vertex. A graph is called acyclic if it contains no such directed cycles. When a graph is both directed and acyclic, then it is called a DAG.

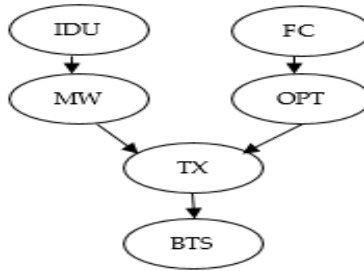


Figure 5.1 Directed graph

Example of BN with five variables as in Figure 5.2. The joint distribution is given by:

$$P(\text{IDU}, \text{ODU}, \text{MW}, \text{TX}, \text{BTS}) = P(\text{IDU}), P(\text{ODU}), P(\text{MW}|\text{IDU}, \text{ODU}), P(\text{TX}|\text{MW}), P(\text{BTS}|\text{TX}).$$

The prior probability has to be specified for IDU, ODU that are the only nodes without parents. For all other variables, a CPT has to be provided.

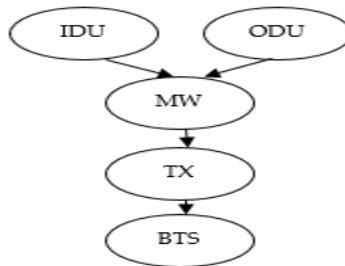


Figure 5.2 Bayesian network

Exemplary: Transmission System

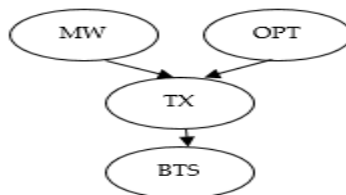


Figure 5.3 BN for the TX system

Let us take Figure 5.3 the exemplary of BN for the transmission system. The transmission caused by a MW or by an OPT. There is a certain probability the transmission will fail in MW and OPT cases. When the transmission fail, BTS is fail. The variables of a BN that can model this system are MW, OPT, TX and BTS and they will be binary with the states true (t) and false (f).

To specify the joint distribution the prior probability for the variables without parents, MW and OPT, are needed. To compute the probability for the given exemplary let us assume:

$$P(MW = t) = 0.001, P(MW = f) = 0.999$$

$$P(OPT = t) = 0.1, P(OPT = f) = 0.9$$

Moreover, the CPTs for the variables TX and BTS are shown in Table 5.2 and Table 5.3.

Table 5. 2 CPT for the node TX

Parent nodes		TX	
MW	OPT	T	F
T	T	0.9	0.1
	F	0.8	0.2
F	T	0.8	0.2
	F	0.01	0.99

Table 5. 3 CPT for the node BTS

Parent node	BTS	
TX	T	F
T	0.9	0.1
F	0.01	0.999

The probability of BTS can be calculated using the formula

$$P(BTS) = \sum_{TX} \sum_{MW} \sum_{OPT} P(BTS, TX, MW, OPT),$$

Since from Figure 5.3 the cause of BTS outage is due to transmission failure and its RC is MW and OPT.

Writing explicitly the sums for the variable OPT, MW and TX, becomes

$$\begin{aligned}
 &P(BTS, TX = t, MW = t, OPT = t) + P(BTS, TX = t, MW = t, OPT = f) \\
 &+ P(BTS, TX = t, MW = f, OPT = t) + P(BTS, TX = t, MW = f, OPT = f) \\
 &+ P(BTS, TX = f, MW = t, OPT = t) + P(BTS, TX = f, MW = t, OPT = f) \\
 &+ P(BTS, TX = f, MW = f, OPT = t) + P(BTS, TX = f, MW = f, OPT = f).
 \end{aligned}$$

Each of these can be obtained in terms of the conditional probabilities and the prior probabilities, therefore the probability of BTS becomes:

$$\begin{aligned}
 P(BTS) &= P(BTS|TX = t) P(TX = t|MW = t \wedge OPT = t) P(MW = t) P(OPT = t) \\
 &+ P(BTS|TX = t) P(TX = t|MW = t \wedge OPT = f) P(MW = t) P(OPT = f) \\
 &+ P(BTS|TX = t) P(TX = t|MW = f \wedge OPT = t) P(MW = f) P(OPT = t) \\
 &+ P(BTS|TX = t) P(TX = t|MW = f \wedge OPT = f) P(MW = f) P(OPT = f) \\
 &+ P(BTS|TX = f) P(TX = f|MW = t \wedge OPT = t) P(MW = t) P(OPT = t) \\
 &+ P(BTS|TX = f) P(TX = f|MW = t \wedge OPT = f) P(MW = t) P(OPT = f) \\
 &+ P(BTS|TX = f) P(TX = f|MW = f \wedge OPT = t) P(MW = f) P(OPT = t) \\
 &+ P(BTS|TX = f) P(TX = f|MW = f \wedge OPT = f) P(MW = f) P(OPT = f)
 \end{aligned}$$

For the state true of BTS, from the CPTs, it follows that:

$$\begin{aligned}
 P(BTS = t) &= 0.9 \times 0.9 \times 0.001 \times 0.1 + 0.9 \times 0.8 \times 0.001 \times 0.9 + 0.9 \times 0.8 \times 0.999 \times 0.1 + 0.9 \times \\
 &0.01 \times 0.999 \times 0.9 + 0.001 \times 0.1 \times 0.001 \times 0.1 + 0.001 \times 0.2 \times 0.001 \times 0.9 + 0.001 \times 0.2 \times 0.999 \times 0.1 \\
 &+ 0.001 \times 0.99 \times 0.999 \times 0.9 = 0.0816
 \end{aligned}$$

When evidence is introduced on some variables in the network, the posterior probability can be calculated employing Bayes' rule in general, for any joint distribution P, the application of the Bayes' rule leads to the formula:

## CHAPTER 6. Results and Discussions

This chapter describes the Bayesian network relationship between events and discusses the results of root cause analysis for mobile base station outage.

### 6.1 Result

For the BN the cause and RCs are identified and the relationship between variables are modelled. This model using BN are shown in Figure 6.1

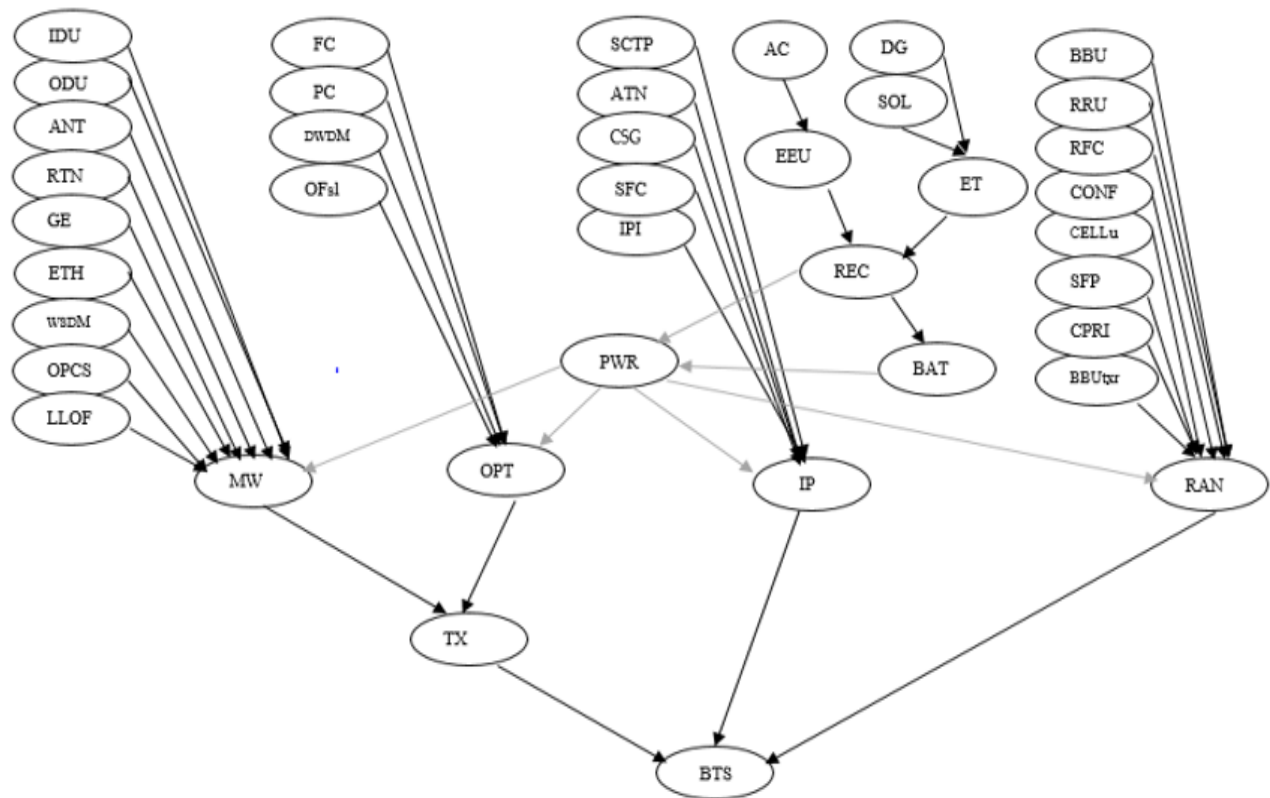


Figure 6. 1 Bayesian network relationship between events in different components

Where:

IDU-indoor unit; ODU-outdoor unit; ANT-antennas; RTN-radio transmission node; GE-gigabit Ethernet; ETH-Ethernet; WSDM-wave length space division multiplexing; OPCS-optical protect

for channel section; **LLOF**-link loss of frame; **FC**-fiber cut; **PC**-patch cord; **DWDM**-dense wavelength division multiplexing; **OFCsl**-optical fiber cut signal loss; **SCTP**-stream control transmission protocol; **ATN**-aeronautical telecommunication network; **CSG**-cell site gateway; **SFC**-service function chain; **IPI**-internet protocol interface; **MW**-microwave; **OPT**-optical; **IP**-internet protocol; **TX**-transmission; **RAN**: radio access network; **AC**-alternating current; **DG**-diesel generator; **SOL**-solar; **EEU**-Ethiopian electric utility; **ET**-ethio telecom; **REC**-rectifier; **BAT**-battery; **PWR**-power; **BBU**-base band unit; **BRU**-remote radio unit; **RFC**-request for comments; **CONF**-configuration; **CELLu**-cell user; **SFP**-small form factor pluggable; **CPRI**-common public radio interface; **BBUtxrx**-base band unit transmit and receive; **BTS**: base transceiver station.

A one-year data was collected for Addis Ababa mobile BS from the historical alarm, TT and log file. The data collected from June 2018 to May 2019. During data collection, the information for the RC for each fault occurrence cannot obtain easily. However to have full information the data collected from the three inputs are as follows:

Let the historical alarm data is H, TT data is T, log file data is L and let the number of the input parameters is N. Therefore N is H, T and L this means  $N = 3$

When the inputs of the volume of the data increase, the accuracy of the BS also increase. The input data are obtained from three options: historical alarm data, TT and system log file. To develop an exact information the three options should be the same occurrence date and the same occurrence time.

$$\text{Options: } 2^N = 2^3 = 8$$

*Table 6. 1 Input parameters*

Type of data	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
History alarm	N	N	N	N	Y	Y	Y	Y
Trouble ticket	N	N	Y	Y	N	N	Y	Y
Log file	N	Y	N	Y	N	Y	N	Y

Where N = no information from the data



Y = has information from the data

Having the information from Table 6.1, data is collected. The collected data is an information for the RC of the BS outage. Each cases is an option to acquire the reason why the BS is outage. Case 1 has no information the reason why the BS is outage. In this case, data collected from knowledge of expert thought by asking the probability of failure reason for the specific BS. The remaining cases have an information that can take a reason why the BS is out of service.

Having the above information, 12110 data was collected from June 2018 to May 2019 and the result is analyzed. The analysis result is based on data categorize into one-year for all BS, one-year for the specific month for all BS, and one-year for specific BS. The same analogy for RNC. In addition, one-year data is analyzed based on week (i.e. weekend and weekdays).

The proposed method was evaluated on the diagnosis (RCA) model, which is presented in Figure 6.1 or for detail shown in Appendix C. The results were run for the following statistical 12110 data from the historical alarm, TT and log file. Given for the BNs an input or evidence can calculate the conditional probability between the input nodes and the output nodes, and conduct a more accurate probability inference. The conditional probability will give valuable suggestions for the system failure diagnosis. Now given the evidence that the network outage happens, the conditional probability for each component, calculated using Bayes net tool, which is installed on MATLAB.

*Table 6. 2 Sample data input format*

Occurrence Date and Time	Device ID	RC	Specific RC
MM-DD-YY hh:mm:ss	BTS-x	PWR	AC

According to Table 6.2, sample data input format, an input of 12110 data for the BN model and provides an output of the probability of an event i.e. prior probability, shown in Table 6.3.

Table 6. 3 Prior probability for the input data

RC	ACPWR	ETHMW	FCOPT	ANTMW	OFsIOPT	SFCIP	RRURAN	IPPWR	ATNIP	RANPWR	RECPWR	BBURAN	SFPRAN
%	69.60	4.35	4.35	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17

Using Bayes theorem, Table 6.3 helps to find the CPD for all possible RC. For instance, consider the BS outage due to the cause of IP, Figure 6.2 the main RC for IP is SCTP, ATN, CSG, SFC, IPI and PWR.

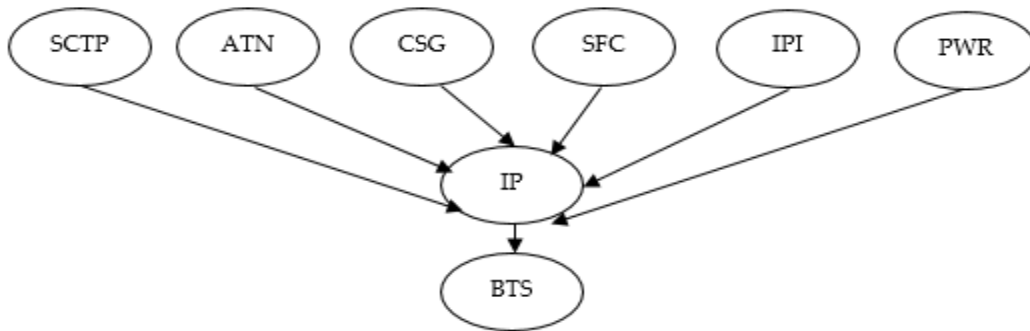


Figure 6. 2 IP root cause

Examples: Conditional probability of event PWR given event IP is:

$$P(PWR | IP) = \frac{P(PWR)P(IP | PWR)}{P(IP)}$$

Where:  $P(PWR)$  Prior probability

$$P(PWR) = P(ACPWR) + P(IPPWR) + P(RECPWR) = 73.94\%$$

$P(IP | PWR)$ : An event that has already occurred (likelihood) = 2.17%

$$P (IP) = P (ATNIP) + P (SFCIP) + P (IPPWR) = 2.17\% + 2.17\% + 2.17\% = 6.51\%$$

$$P (PWR | IP) = \frac{73.94\% * 2.17\%}{6.51\%} = 24.65\%$$

Results of RC, which is taken one-year data, in weekdays and weekend, is shown in Figure 6.3 and Figure 6.4 respectively.

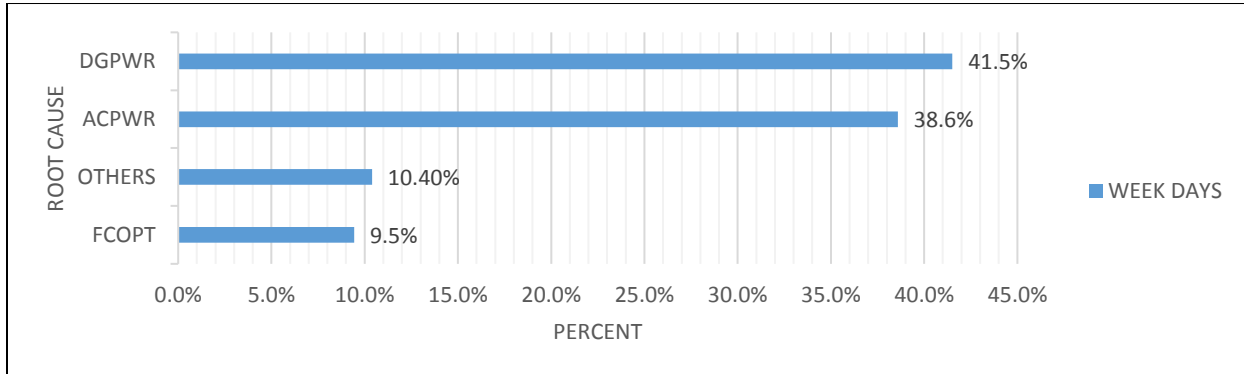


Figure 6.3 Weekdays root cause

In Figure 6.3, the main RC for the probability of BS outage is power (generator and AC failure). In addition, FC is also the RC of BS outage.

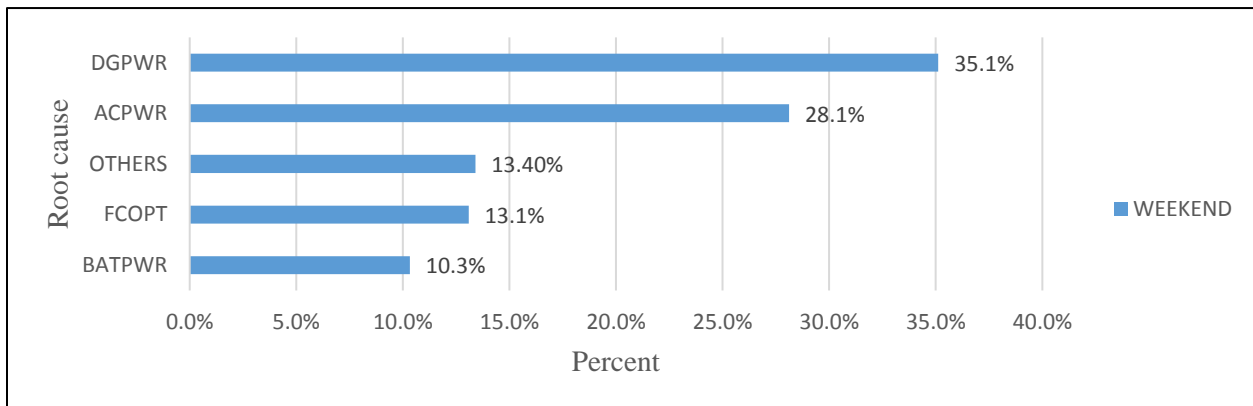


Figure 6.4 Weekend root cause

In Figure 6.4, the main RC for the probability of BS outage is power (generator, AC and battery failure). Moreover, FC is the RC of BS outage.

For both figures power and FC is the main issue for the probability of BS outage. Other RC comprise such as CSGIP, ATNIP, and RTNMW etc.

Comparing both figures in case of power, weekdays the BS more frequently down than weekend. Where as in case of FC, weekend the BS more frequently down than weekdays.

The BS is controlled by RNC. Totally, Addis Ababa has five RNC. Each RNC has a number of BS. Currently RNC 1, RNC 2, RNC 3, RNC 4 and RNC 5 has 133, 168,142, 132 and 167 BS respectively ( source: From ethiotelecom performance report).

Figure 6.5 shows total RNC, one-year data percentage of RC failure. For all RNC, power problem is the main issue. For instance, AC power problems are observed for RNC 1, 2 and 3. The remaining RNC 4 and 5, DG power is the highest problem observed.

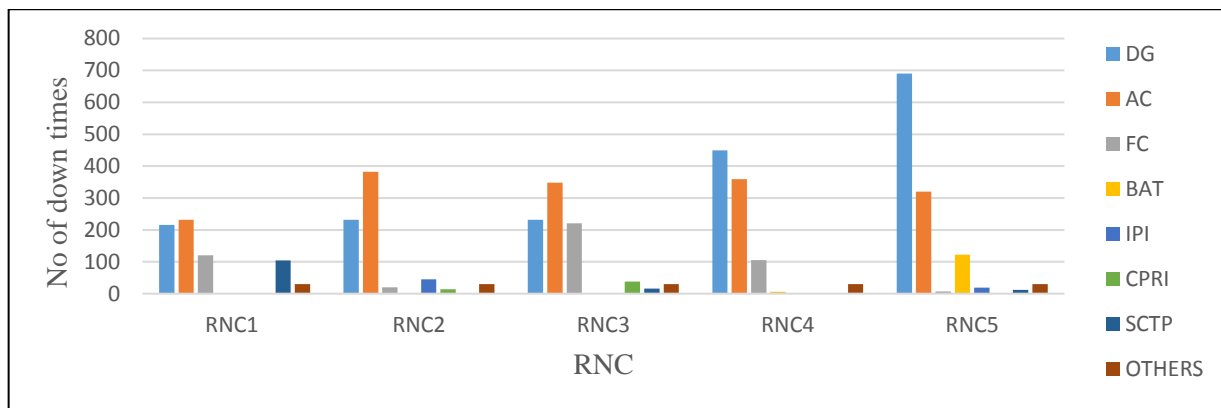


Figure 6. 5 Percentage of RC failure vs RNC

**Case Study:** Consider sample month August 2018:

The RC for sample month August 2018, all BS observed similar approach to the steps above by comparing weekdays and weekend. The analysis result mention as follows:

The main RC for the probability of BS outage on weekdays is power (generator and AC failure). FC is also the RC. Similarly weekend, the main RC for the probability of BS

outage is power (battery) also; transmission RTN and FC is the RC. Other RC for both cases is CSGIP, ATNIP etc.

Comparing weekdays and weekend in case of power, during weekdays the BS is down more frequently than weekend. Where as in case of FC, during weekend the BS is down more frequently than weekdays.

Similarly, total RNC, for August month one-year data were observed. For all RNC, power problem is the main issue. For instance, AC power problem observed for RNC 1, 2, 3 and 4. The remaining RNC 5, DG power is observed.

### Performance evaluation

BNT is an open-source MATLAB package for directed graphical models. BNT supports probability distributions, exact and approximate inference, parameter and structure learning, and static and dynamic models. Using naïve Bayes classifier, 30% holdout sample for testing and the remaining 70% for training. For the 12110 records 3633 for testing and 8477 for training.

Table 6. 4 Labelling of root cause

LABEL	IDU	ODU	ANT	RTN	LLOF	GE	ETH	WSDM	OPCS	FC	PC	DWDM	OFsl	SCTP	ATN	CSG	SFC	IPI	AC	DG	SOL	REC	BAT	BBU	RRU	RFC	CONF	CELLu	SFP	CPRI	BBUmx	RC	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	SFC
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	SFC
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	RRU
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	AC

As shown in the sample data in Table 6.4, the first row indicates the possibility of the RCs for the BS outage. The last column shows the occurrence of the exact RC among the listed RCs. For the first event, the RC is AC; the second event is also AC, proceeds the event

AC, AC, AC, AC, SFC, SFC, RRU and AC continued the event up to 12110 data. Accordingly mark one for the exact RC and zero for the other probability of RC. For example, the second row the RC is AC, under AC column mark one, the remaining column is zero. Another example, take row nine, the RC is SFC then mark one under the column of SFC, and the remaining RC is zero.

From the table the first column is the label that specifies the RC categories. For instance, AC category is label one, SFC category is label two, RRU label three etc. Thus, from the first column label one indicates AC, label two SFC and continued up to 12110 data. After preparing the data, can calculate the probability distribution of the RC using naïve Bayes classifier and can determine probability. The higher probability gives a priority checking.

In addition, train the data and sample results taken as depicts in Table 6.5. After training, the first column indicates the true label, and the second column is the predicted labels. Comparing the two column, the true and the predicted labels are the same except such as row ten the true labels is RRU and the predicted labels is AC.

The Bayes net classifier algorithm generalizes by estimating the test sample, and classification error. For the duration of testing, from the total 12110 collected data, the algorithm provides a loss of 0.0565 hence the accuracy is 0.9435.

*Table 6. 5 Results after training*

True labels	Predicted labels
'AC'	'AC'
'AC'	'AC'
'AC'	'AC'
'AC'	'AC'
'AC'	'AC'
'AC'	'AC'
'SFC'	'SFC'
'SFC'	'SFC'
'RRU'	'AC'
'AC'	'AC'

## 6.2 Discussion

Currently in ethiotelecom, identifying the RC is the main challenge. To resolve problems NNOC technician creates a TT that indicates the problem status, which is the fault description. BS outage occur due to various reasons such as RAN equipment, transmission, power and IP failures. The possible relations between elements are not explicitly well defined. In this thesis, the RCs of BS outage described using BN. The analysis result are discussed to specifically for a single BS data. Knowing the probability of RCs of the BS, technicians can inform the probable existence of root problems.

Exemplary for a single sample BS:

Case: 10-month data from June 2018 - Mar 2019 were collected. The data divided into two phases. Phase one the first 5-month data and phase two the second 5-month data.

### Phase one

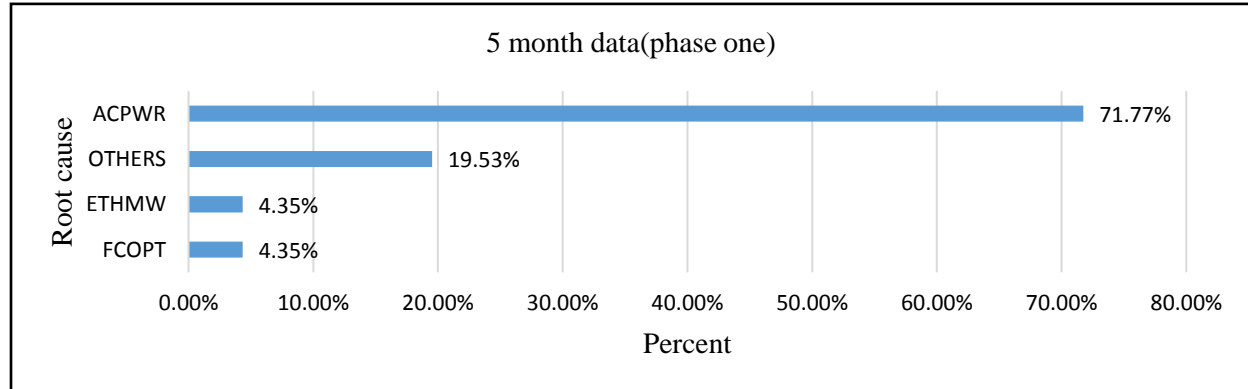


Figure 6. 6 A single BS the first phase five-month data

Table 6. 6 Other root cause of the first five-month data

ATNIP	OFsloOPT	SFCIP	RRURAN	IPIIP	ANTMW	PCOPT	RECPWR	BBURAN
2.17%	2.17%	2.17%	2.17%	2.17%	2.17%	2.17%	2.17%	2.17%

Figure 6.6 shows during the first phase of 5-month data 71.77%, 4.35%, and 4.35% was down due to AC power, MW transmission, and OPT transmission respectively. The remaining outage the RC is mentioned in Table 6.6. Generally, power case AC, transmission case microwave (ETHMW) and optical (FCOPT) is the major problem for the BS outage.

### Phase two

During the second phase of 5-month data as depicts in Figure 6.7, 72.12%, 3.28%, 3.28%, 6.56%, and 3.28% was down due to AC, REC power, ETHMW transmission, FCOPT transmission, and OFsl respectively. The other RC is mentioned in Table 6.7. In general, power case (AC and REC); transmission case microwave (ETHMW), optical case (FCOPT and OFslOPT) is the major problem for the BS outage.

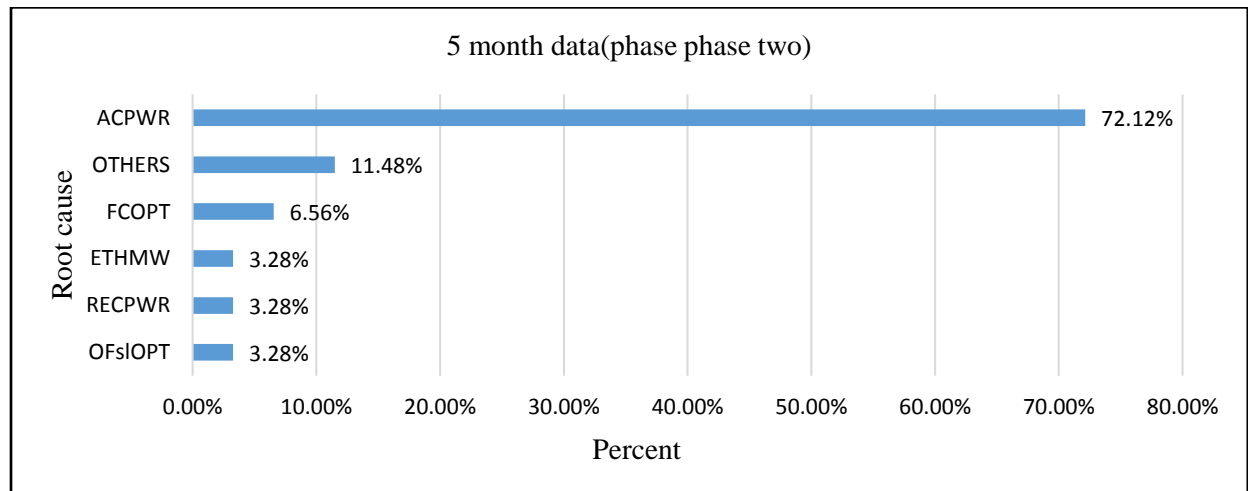


Figure 6.7 A single BS the second phase five-month data

Table 6.7 Other root cause of the second five-month data

ATNIP	SFCIP	RRURAN	IPIIP	RANPWR	PCOPT	BBURAN	SFPRAN
1.64%	1.64%	0.82%	1.64%	1.64%	1.64%	1.64%	0.82%

Generally, for both cases power (ACPWR), transmission (FCOPT, ETHMW) are higher probability as compared to the other RC. In addition, comparing weekdays and weekend

in case of power, in weekdays the BS down more frequently than weekend. Where as in case of transmission, in weekend the BS more frequently down than weekdays. Further information for both cases, higher frequent down time was 6hr, 9hr and 20hr.

*Table 6. 8 Higher frequent down times with root cause*

Higher frequent down times	Root cause	Phase 1	Phase 2	Comment
6hr	ACPWR	66.67%	61.50%	ACPWR is higher probability
	ATNPWR	8.30%	7.69%	
9hr	ACPWR	75%	71.40%	ACPWR is higher probability
20hr	ACPWR	86.0%	88.80%	ACPWR is higher probability

As indicated in Table 6.8 the major RCs for both cases (phase 1 and phase 2) is ACPWR and ATNPWR. Both RCs occur at 6hr. The probability of ACPWR is 66.67% and 61.50% similarly, the probability of ATNPWR is 8.30% and 7.69% for phase one and phase two respectively. Comparing both RC, ACPWR is higher probability and gives a priority checking.

Similarly, higher frequent down times at 9hr, the major problem is ACPWR 75% and 71.4% for phase one and phase two respectively. Correspondingly, at 20hr 86.0% and 88.80% is the RC for phase one and phase two respectively.

As a conclusion, for the given exemplary BS the higher probability for both cases (phase 1 and phase 2) is ACPWR and maintenance team can give a priority checking. Thus, for any BS maintenance team can analysis the RC to identify the reason of the BS outage and make a decision by giving priority checking for higher probability.

## CHAPTER 7. Conclusion and Future Works

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This chapter presents conclusion and addresses future thesis direction.

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### 7.1 Conclusion

For mobile operators, there is a challenge in identifying the RC of BS outages. The thesis reflected a BS outage of ethio telecom. Outages occurs when the active network elements are completely knocked out and do not work at all. It is difficult to realize accurate source of faults. Since there are various reasons for the outage, technicians cannot easily diagnose. The reason might be human error, failure of transmission, RAN equipment, power and IP. The company challenged to determine the exact cause of BS outage. Currently, if a fault alarm arises NOC technicians create TT to assign field technicians with no detail information. This effect increasing maintenance cost.

In order to fix the outages, RCA is require. There are fault detection and diagnose methods. Among the methods, BN is selected. BNs is probabilistic graphical model for the RCA, when given any evidence; it can calculate the conditional probability by analyzing collected historical data, log file and TT data. The conditional probability can be calculated using BN tool, which is installed on MATLAB.

Cause of BS outage analysis is performed to provide probability distribution for priority checking. For example, using one year collected data the probability of BS outage being power is found to be 41.5% and 38.6% due to AC and DG respectively on weekdays while in weekend 28.1% and 35.1%. In addition to this, FC is found to be the main problem of BS outage in both weekdays and weekend. Finally, the performance of BN shows an accuracy of 94% that help the maintenance team to respond immediately. As a result, quality of service of the company as well as cost reduction will be achieved.

## 7.2 Future Works

Here are some of the points as a future work that might be continuation of the thesis work:

- Other RCA techniques and tools that can be applied during cause of BS outage.
- Apply a solution for RCA to fixed access network technologies such as, MSAN, MDU and MSAG.

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## Appendix A

Table A. 1 Cause of IP failure

Cause	Root cause
BTS fail to receive the IP	Ethernet link fault
	IP address conflict
	IP path fault
	SCTP link fault
	Cell unavailable
	User plane path fault equipment
	eNodeB control plane transmission interruption

Table A. 2 Cause of transmission failure

Cause	Root cause
MW link failure	Antenna alignment problem
	MW link configuration error
	ODU problem
MW link Ethernet port down	BBU power down
	BBU failure
	Ethernet port (RJ45) or cable problem
	Ethernet port unplugged
MW link E1 Port down	E1/T1 service not accessed or down
	Interface on the DDF side is disconnected
	Cross-connect board is faulty.
MW link Mismatch Board	The board is not inserted
	The board is resetting
MW link loss of frames	The IF cable is loose or faulty.
	The IF port on the IF board is damaged.
	The power module of the ODU is faulty
MW link IF cable is open	The transmit unit of the opposite station is faulty
	The receive unit of the local site is faulty
	The IF board is faulty
MW link Hardware faulty	The board and the backplane are not connected properly.
	The system control, switching, and timing board is faulty.
	Board slot faulty
	Backplane problem
MW link Low receive power	The transmit power of the opposite station is very low.
	The local ODU is faulty.
	Signal attenuation on the radio link is high.

Table A. 3 Cause of power failure

Cause	Root cause
DG	ATS failure
	Refueling
	Generator starter battery problem
	breaker trip
	Fuel solenoid problem
	Fuel line air suck
	Engine control system problem
	Starter motor
	Relay problem
	Emergency stop button
	DG manual mode
	Sensors problem
	Engine temperature
REC	Back up battery problem
	Rectifier system problem
	Rectifier CSU problem
	DC breaker trip
	Rectifier module problem
Solar power	Solar regulator failure
	Solar array /panel/problem
	Solar battery problem
Power cable	AC power cable damaged
	DC Power cable damaged
AC	EEU substation failure
	EEU transformer damage
	EEU phase loss
	EEU fuse problem
	EEU under voltage
	EEU pole damage
	EEU main circuit breaker damage
	EEU: cable damage
	EEU: Power intermittent
	Mains phase over voltage
	Loos cable connection
BAT	All rectifier gets fail
	Damage battery
Fuse	Fuse burn

Table A. 4 Cause of RAN failure

Cause	Root cause
Route Unavailable	The faulty M3UA route cannot transfer data
	DSP is unreachable
M3UA Destination Entity Inaccessible	The route to the destination entity is inaccessible
	The configuration data at the two ends are inconsistent.
SCCP Subsystem Prohibited	The DSP of this SCCP subsystem is inaccessible.
	The peer SCCP data configuration is incorrect or abnormal
RAN equipment failure	UMPT board failure
	Ethernet cable fault

## Appendix B

### Interconnection of BS element model:

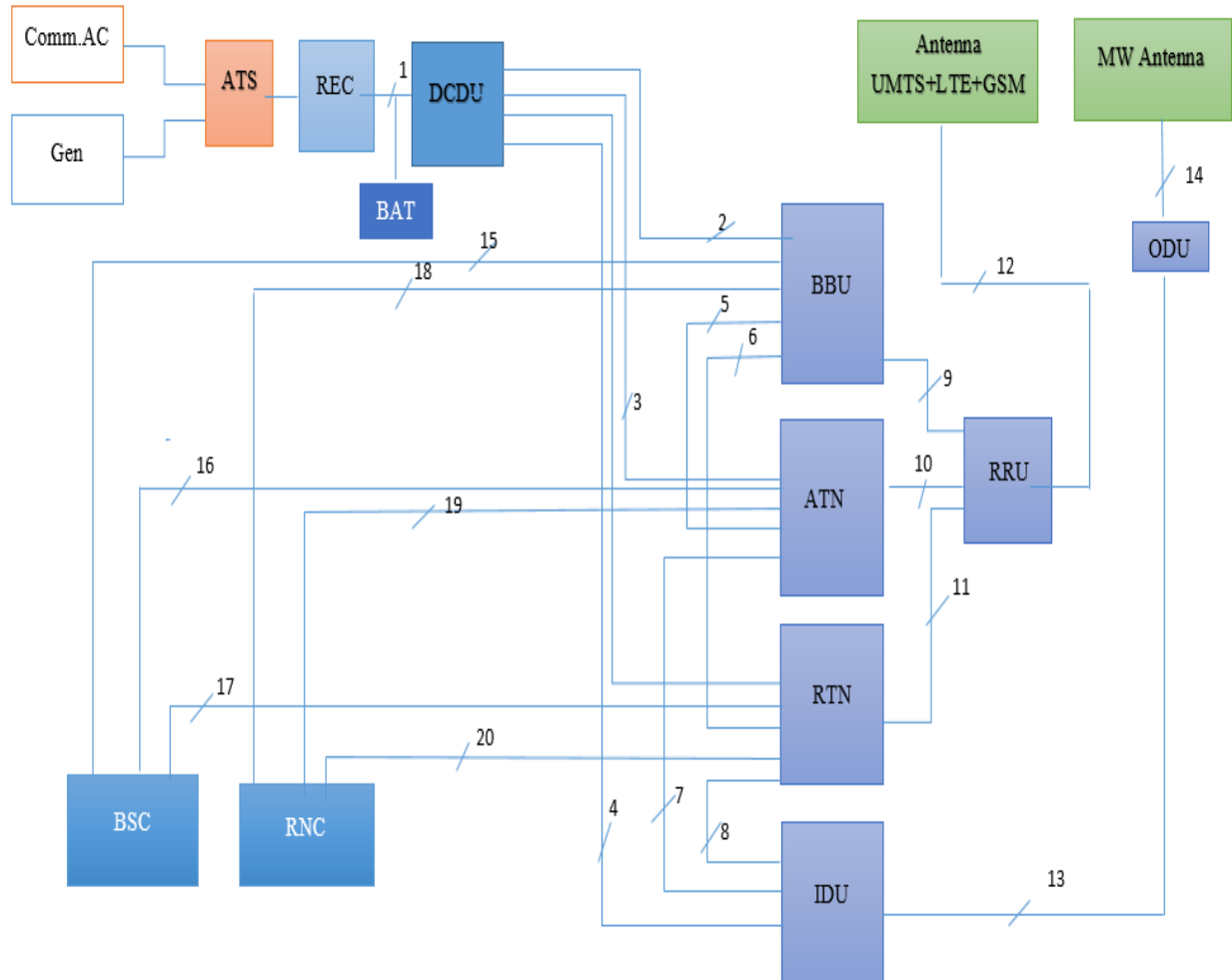


Figure A. 1 Existing BS element model

Key:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DC power cable	DC power cable	DC power cable	DC power cable	Network cable	Network cable	Network cable	Network cable	Fiber cable	Fiber cable	Fiber cable	RF jumper cable	IF cable	Wave guide	E1	E1	E1	FE	FE	FE

## Appendix C

### System Model:

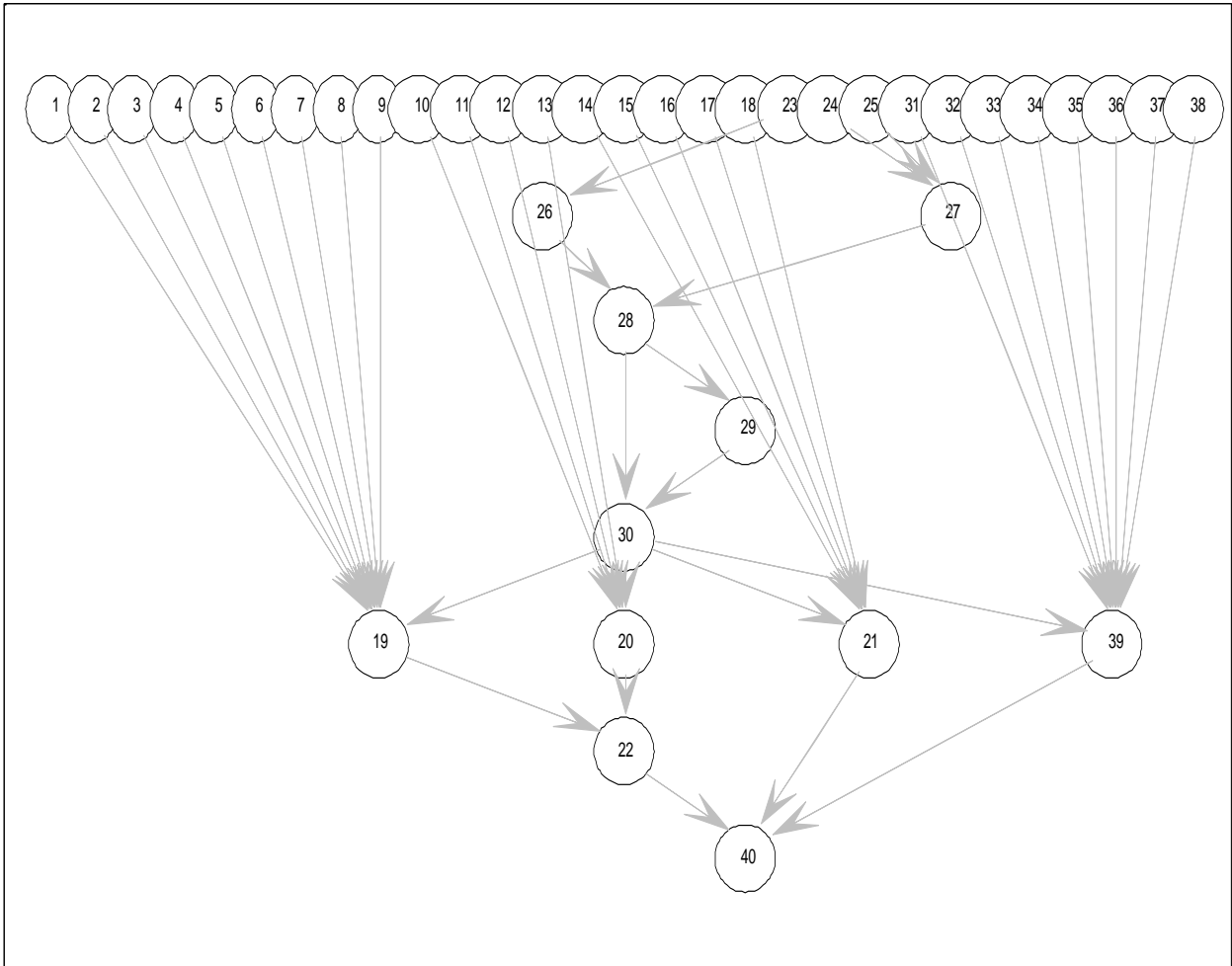


Figure A. 2 System model using MATLAB

Key:

IDU	ODU	ANT	RTN	GE	ETH	WSDM	OPCS	LLOF	FC	PC	DWDM	OFCsI	SCTP	ATN	CSG	SFC	IPI	MW	OPT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

IP	TX	AC	DG	SOL	EEU	ET	REC	BAT	PWR	BBU	RRU	RFC	CONF	CELLu	SFP	CPRI	BBUtxrx	RAN	BTS
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40