



**ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING  
TELECOMMUNICATION NETWORK ENGINEERING  
PROGRAM**

**Mobile Networks Accessibility and Retainability States Prediction  
Using Markov Chain**

**By**

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in Partial Fulfillment of the Requirements for the Degree of Master of Science in  
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**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
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## Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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## Abstract

*To deliver reliable services to customers mobile network operators monitor their network performance using different key performance indicators (KPIs). Network accessibility and retainability are two important KPIs that need to be assessed and monitored on daily basis by mobile operators. Monitoring KPIs is a time consuming and laborious task. Moreover, taking corrective action based on monitored KPIs is a reactive approach and contributes to network and service degradation until corrective action is taken.*

*Historical network performance data available with operators contains not only information about network status at the measurement instant but can be analyzed to provide information about possible trends and patterns about the network. So, a systematic way of monitoring and predicting the network performance status is required to guaranty the service quality.*

*In this thesis, a Markov chain (MC) model is used to predict, in a probabilistic sense, the accessibility and retainability states of a mobile network. Four months operator data is collected from 1,530 Universal Mobile Telecommunication System (UMTS) cells to formulate the MC model and investigate the prediction accuracy. Two scenarios are considered: first, two independent four-state MC models are used to separately model the accessibility and retainability state of a cell. Second, both accessibility and retainability states of the cell are jointly modeled using a single MC model with sixteen states.*

*The proposed predictive model for the first scenario achieves an accuracy of 96.09% when predicting accessibility and 96.87% when predicting retainability separately, while 94.61% prediction accuracy is obtained when predicting accessibility and retainability jointly as in the second scenario. The result indicates that it is possible to monitor and predict the performance of a network using the joint modeling approach instead of using separate models. In addition, the sixteen states help to see the probability of occurrence of both accessibility and retainability at the same time; for instance, we can see the occurrence of bad state at the same time in accessibility and retainability.*

*Key words: Accessibility, Retainability, KPI, UMTS, Markov chain*



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## Abbreviations

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
AMR	Adaptive Multi Rate
CDMA	Code Division Multiple Access
CDR	Call Drop Rate
CN	Core Network
CS	Circuit Switch
CSSR	Call Setup Success Rate
CTMC	Continuous Time Markov Chain
DTMC	Discrete Time Markov Chain
GGSN	Gateway GPRS Support Node
GMGW	Gateway Media Gateway
GMSC	Gateway MSC
GSM	Global System for Mobile
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IMT	International Mobile Telecommunication
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LTE	Long Term Evolution
MC	Markov Chain
ME	Mobile Equipment
MGW	Media Gateway
MSC	Mobile Switching Center
NMS	Network Management System
O&M	Operation and Maintenance



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PLMN	Public Land Mobile Network
PRS	Performance Report System
PS	Packet Switch
PSTN	Public Switch Telephone Network
QoE	Quality of Experience
QoS	Quality of Service
R99	Release 99
RAB	Radio Access Bearer
RAN	Radio Access Network
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RRC	Radio Resource Controller
RxLev	Received Signal Level
RxQual	Received Quality
SAE	System Architecture Evolution
SGSN	Serving GPRS Support Node
SMS	Short Message Service
SON	Self Organization Network
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
USIM	Universal Mobile Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband CDMA

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# 1. Introduction

## 1.1. Background

Nowadays the demand for mobile telecom services is increasing globally, and it is expected to increase in the coming years. The number of mobile subscribers reached 5.1 billion as of May 2020 [1]. To accommodate this increasing demand, new technologies, such as cell densification and diversity schemes, are being implemented. The new technologies, however, increase complexity of operation and maintenance (O&M) activities in mobile networks. To overcome this problem self-organizing network (SON) is introduced in Release 8 [2]. SON enables the networks to perform self-configuration, self-optimization, and self-healing processes [3].

In the Ethiopian telecom landscape, ethio telecom provides telecom services. The number of subscribers is increasing annually and reached more than 52 million subscribers as of September 2020. As a result, voice and data usage demand is increasing. To accommodate these large number of subscribers the company has deployed Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) in most areas of the country and Long-Term Evolution (LTE) network in the capital city Addis Ababa and major towns throughout the country. From the data obtained by the end of September 2020 more than 75% of the subscribers in ethio telecom are using third generation (3G) network and it is expected to serve most mobile subscribers in the coming few years too.

With the development of technology, networks become increasingly complex aiming to increase quality, efficiency, and availability of the network. As a result, the operation and maintenance activity become increasingly sophisticated [4]. Operators mostly perform maintenance activities to give reliable service to their customers. The maintenance activities could be corrective maintenance, preventive maintenance, or predictive (controlled) maintenance type. Of these three types of maintenance activities, predictive maintenance approach is recommended, as it tries to identify faults before occurring and take corrective actions; this in turn improve the service delivered to customers [5]. Hence, operators need to adopt predictive maintenance in addition to corrective and preventive type of maintenance activities. As an operator ethio telecom uses corrective maintenance activity, and preventive maintenance in few areas, so the company need to use predictive maintenance approach to deliver reliable service to its customers.

To give reliable service to customers, most telecom operators monitor their networks using centralized network management system (NMS). NMS provides different types of services to operators using different subsystems; for instance the alarm management subsystem generates different levels of alarms like critical alarm, major alarm, minor alarm and warning alarms based on the severity of the fault level, the network performance management subsystem generates different counter values which helps to calculate the network performance for the purpose of monitoring the quality of service (QoS) [6].

Though NMS provides necessary information through its different subsystems, managing the data obtained from the subsystem, monitoring the network performance, and taking remedial actions on time is a challenge for most operators. If operators are unable to take remedial action on time, it leads to customers dissatisfaction and will be one reason for losing customers. So, operators should fulfill the need of their customers. Customer's satisfaction depends on two main factors; namely, customers' expectation on QoS and on the actual QoS provided to customers by the operators. The QoS provided by operators could come from technical and non-technical aspects as shown in Figure 1-1 [7]. Network performance and terminal performance are the two parameters which are related to technical QoS. Whereas the service provided to customers at the sales point, for instance during new subscriber registration, SIM card replacement, as well as the availability of sales offices that is working hour of sales offices and the availability of these offices close to customers are some factors related to non-technical QoS.

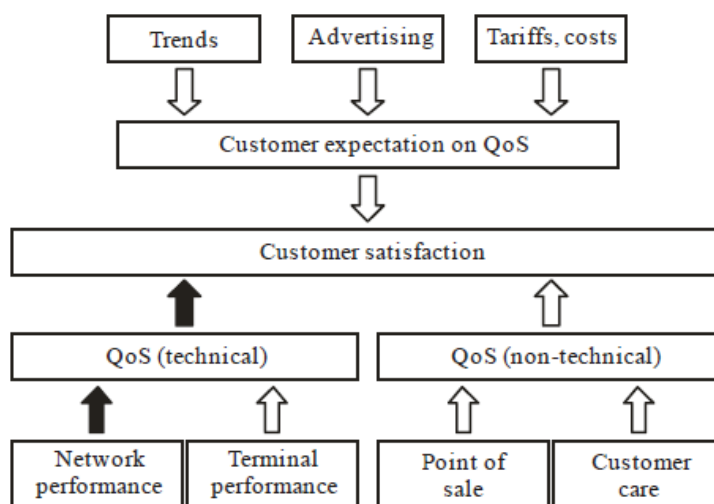


Figure 1-1. Relationship between user satisfaction, QoS and network performance [7].

A general model for QoS parameter related to network performance is expressed using four-layer model. Figure 1-2 shows the first three layers of the model used by International Telecommunication Union (ITU) [7]. The first layer is the “network availability”, which indicates whether the network is available or not during that specified interval of time. The second layer is “network accessibility”, that indicates whether a user can access the network or not. The third layer is a “service layer” that has three elements: namely, “service accessibility”, “service integrity” and “service retainability”. Service accessibility indicates the probability of obtaining the intended service when requested by a user. According to ITU definition service accessibility performance is defined as “The ability of a service to be obtained, within specified tolerances and other given conditions, when requested by the user” [8]. After the service is accessed, then the service integrity issue will come. Service integrity shows the QoS provided to users during the time when users get the service they requested. It indicates mostly the quality of message transmitted, like speech quality and bit error rate. Service retainability comes after service integrity. Service retainability indicates how well the network can complete the connection or it indicates the termination of the service either intentionally by the will of a user or unintentionally without the will of a user [7]. ITU defines service retainability performance as “The ability of a service, once obtained, to continue to be provided under given conditions for a requested duration” [8].

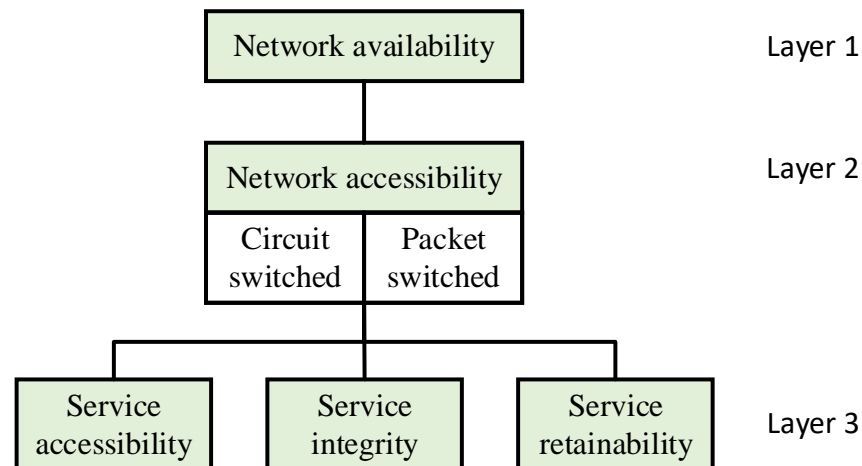


Figure 1-2. QoS aspects and the corresponding QoS parameters [7] .

Service accessibility performance and service retainability performance are two performance parameters used to measure the service provided by the network from accessibility and retainability point of views, respectively.

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Accessibility and retainability KPIs are two important KPI parameters operators need to monitor on daily and hourly bases because; the degradation of these two KPIs may create customer dissatisfaction, they are highly related to the income of the operator, and they utilize non-payable resource of the operator. For example, in the case of voice call, a user will pay for the duration of time only to the voice service he/she gets, and the signaling process to make a call is not payable. If we take for instance accessibility of voice call service, to make a call a user will occupy a signaling channel before getting voice service. If this request fails, then the user may try again and again until he/she gets the service or will stop to make a call. If a user tries to make a call again and again, this process at first place occupies a resource for non-payable signaling process, second this process may create user dissatisfaction. The same is true for retainability. If a call is dropped, then a user will redial again, this process occupies a resource as explained in accessibility. If a call drop happens again and again the user will not be satisfied. Operators get revenue and customers satisfaction as far as users are connected after call setup process. Hence to get more revenue, and customer satisfaction operators should monitor these two KPIs on daily and hourly bases.

To predict the performance of accessibility or retainability some research works are conducted using different machine learning algorithms like artificial neural network, regression models and decision tree. Every model has its own advantage and disadvantage based on some selection criteria like simplicity of the algorithm, prediction accuracy, computational speed, computational power, and memory usage.

Markov model is a powerful statistical tool that could be applied for component diagnostics, prognostics, and maintenance optimization in telecom industry [9]. Many researchers have used Markov model to optimize the network service and O&M activities because it is simple to apply, easy to understand, and needs only the current state to predict the next state. There are many processes in communication system that can be modeled and studied with the help of Markov model. Some application areas of Markov model includes call admission control [10], quality of experience (QoE) prediction [11], QoS prediction [12], efficient resource utilization [13], and mobility prediction [14].

## 1.2. Statement of the Problem

Though the telecom expansion project (TEP) undertaken in ethio telecom was big aiming to increase capacity, coverage, and quality of the network starting from 2013, there are still coverage and quality problems even in the capital city Addis Ababa.

When we see the accessibility and retainability performance of a given cell for some duration of time as shown in Figure 1-3, we observe variations of the performance in time. At times, the performance is below the set threshold values. Moreover, when we see the performance across different cells, we will get cells that perform as per the set key performance indicator (KPI) value, and on the other side we will get cells that perform below the set threshold KPI value. The variation could be due to many factors, of these, traffic volume variation is one, and overall healthiness of the network from user equipment (UE) to the core network (CN) level is another factor, for instance if some cells fail to operate, then the neighboring cells performance like call setup success rate KPI will be affected.

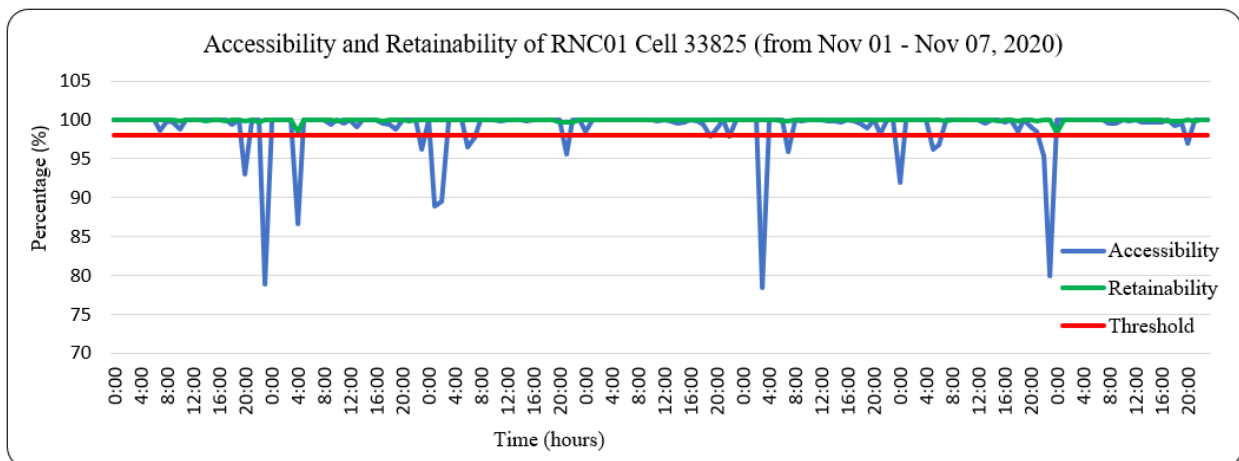


Figure 1-3. Accessibility and retainability of RNC01 cell 33825.

The network performance may degrade due to many factors. If a service provider is unable to predict this network degradation, then it may create customers dissatisfaction. So, operators should be able to monitor and predict the performance of their network to take remedial action and necessary optimization work timely before the degradation happens.

In the case of ethio telecom there are complaints from customers on voice and data service, some of the complaints from customers are like, unable to make call, unable to get Internet connection,

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and disconnection of voice or data service while transaction is taking place. To address these problems ethio telecom needs to assess the service quality the company provides to its customers. Generally, service providers need to have QoS prediction model that helps them to predict voice and data services quality they provide to their customers. So, they should be able to improve the service quality in advance before customers feel the service degradation, otherwise the degradation of the service will be one reason for customers to shift into another operator.

### 1.3. Literature Review

To evaluate the accessibility performance of a network clustering based method is proposed by Yan Wang and Zhensen Wu [15]. The aim of the research is to identify a comfortable zone where accessibility is high, and this enables to detect when accessibility begins to degrade. Five months packet switch (PS) data is taken from live network. First the cells are clustered into k number of clusters. Then using five different regression methods the best method for each cluster is selected based on error rate value. Then a value called separation is calculated using three parameters, these are cluster i, number of times the cell causes PS domain failed to establish the number of radio access bearer (RAB), and best number of cluster k. Then using a prediction function a comfortable zone is identified. The paper is limited to predict the performance of cells in cluster and performance per cell level is not considered, in addition RAB performance is used to predict the accessibility performance.

To predict radio resource controller (RRC) setup success rate of LTE system architecture evolution (SAE) network a discrete time Markov chain (DTMC) model is proposed by Hendrawan [16]. From the system hourly data of three cells is collected for a period of one month. Based on the value of RRC setup success rate cell's state in terms of RRC success rate accessibility performance is categorized into Good, Moderate, and Bad state, after identifying the state sequence, a transition probability matrix is used to predict future accessibility state of LTE network. Hendrawan [17] used a DTMC model to predict accessibility of LTE network. The author used call setup success rate (CSSR) KPI to predict the accessibility of a network. From the system hourly data of three cells is collected for a period of one month. Based on the KPI value, the cell's state is categorized into three states, High, Acceptable, and Low. Then using these states, a transition probability matrix is used to predict future accessibility state of LTE network. [16], [17] used three state Markov chain

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(MC) model, and the model is developed considering these three states as existing. The presence of Idle state, which could exist in some cells mostly during non-busy hour (after mid night), in addition to these three states is not considered. In a mobile network a cell could have a minimum of one state and a maximum of four states for one KPI value, but the author does not show how to handle these different situations.

To predict the performance of a radio access network (RAN) the work by Iyer et al. [18] use a bearer level RAN parameter. First, RAN parameters are classified into event based and nonevent or volume based metrics. Discrete event parameters which have binary outcome like failure and drop are grouped under event based parameter, and those parameters with continuous values such as bearer throughput are grouped under volume based metrics. For event based parameters a decision tree is used to predict the occurrence or non-occurrence of a call drop based on different coverage, uplink interference, and downlink interference parameters. For the case of volume metrics, regression model is used to diagnose the problem using throughput parameter at the radio link controller layer. Bearer level performance is used to predict the network performance like retainability, and parameters before the establishment of a bearer like call setup failure are not considered, in addition the system considers only problems due to access network without considering UE related problems.

Artificial neural network is used by Oluwafemi et al. [19] to predict the call drops in GSM network. Three months data is collected through drive test using test mobile system (TEMS) investigation software. Five QoS parameters are collected for the model, these are received signal level (RxLev), received quality (RxQual), frame error rate, bit error rate, and timing advance. Using these parameters, a drop call or no drop call is predicted as an output from artificial neural network. The model developed has an accuracy of 87.5% drop call prediction. Frame error rate and timing advance parameters are related to GSM network; thus, the system is applicable only to GSM network, in addition the system predicts the occurrence and non-occurrence of a call drop for a specific UE based on the five parameters.

Call drop rate (CDR), CSSR, network capacity, and bit error rate KPIs are used by Akanbasiam and Ngala [20] to evaluate second generation (2G) and 3G network performance of MTN in Ghana using four months data. The data are collected from the network using NMS. RxLev, RxQual, CSSR, CDR, and handover success rate KPIs are used by Olayinka et al. [21] to evaluate and

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compare the performance of 2G service provided by four network operators in Nigeria and using questioner users level of satisfaction is assessed, then the effect of quality of service on the customers satisfaction is examined using regression analysis method. CSSR and CDR KPIs are used by Abdulkareem et al. [22] to evaluate 2G network of MTN in Nigeria in different geographical areas. The data is collected from NMS for three months. In [20], [21], and [22] the aim is only to assess the performance of the network from accessibility, retainability and other parameters like handover.

In this work an MC model is proposed to predict accessibility or retainability of a network using four states (Idle, Good, Acceptable and Bad). The model is also used to predict accessibility and retainability using sixteen states. Generally, the model enables to predict the performance of n number of KPI parameters using  $4^n$  state MC. The  $4^n$  state MC model can predict all possible scenarios of n number of KPI parameters starting from a cell having only one state to a maximum of  $4^n$  states of a cell.

## 1.4. Objective

### 1.4.1. General Objective

The main objective of this thesis is state formation and prediction of cells accessibility and retainability state of Addis Ababa UMTS network using MC.

### 1.4.2. Specific Objective

To achieve the general objective, the following specific objectives are identified.

- To review related works from literature.
- To identify KPI parameters for accessibility and retainability prediction of UMTS network.
- To collect key accessibility and retainability data from NMS.
- To assess the existing network performance based on accessibility and retainability.
- To create cells state.
- To investigate the relationship between accessibility and retainability parameters.
- To predict the states of cells in terms of accessibility and retainability using selected parameters for close monitoring, optimization, and future expansion purpose.

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## 1.5. Scope and Limitation

The scope of this thesis is to develop an MC model that helps to predict cells accessibility and retainability of UMTS network and limited to cells accessibility and retainability states of Addis Ababa RNC01 UMTS network using selected counters.

## 1.6. Methodology

After identifying the problem and setting the objective, the following methodology is used to address the identified problem. The methodology used is presented using a workflow diagram shown in Figure 1-4 and the explanation will be as follows.

The research is conducted by modelling the accessibility and retainability service parameters of Addis Ababa UMTS network. In the literature review different related works are reviewed, then relevant data for the model are collected from ethio telecom NMS of mobile network per cell level and the data preprocessing is done before the data is used for the model. The processed data then split into training and test set. Then the training data set is converted into defined states, then these states and the transition from one state to another state is counted. Then the number of counted states will be transformed into transition matrix, then after converting each zero value to one in those rows whose row sum is zero, then the state transition matrix is changed into state transition probability matrix, then using MC model the next state is predicted, and the steady state of the system is also calculated. Finally, the model is validated based on the accuracy of the system to predict next state of the test set.

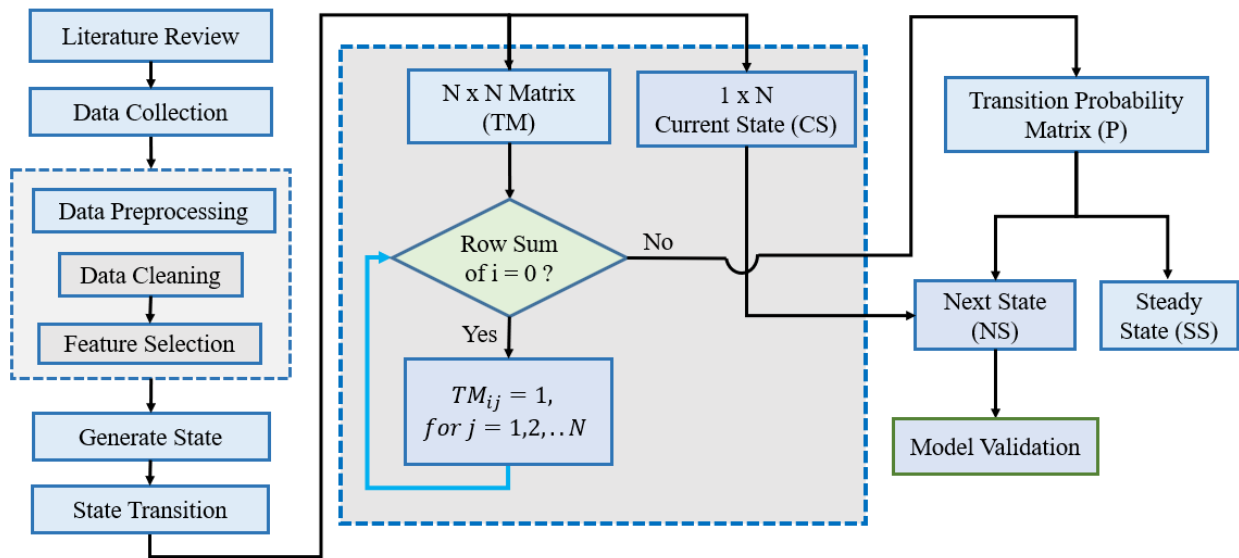


Figure 1-4. System model for state prediction.

## 1.7. Contribution

With the increase in number of cells monitoring and optimizing cells performance will become more complex, time taking and laborious. The result of this research enables operators to predict the performance of cells from accessibility and retainability point of view, and to know the steady state of cells in advance. Knowing the steady state helps operators to see historical data of cells performance in matrix form, and to easily identify cells that perform below the set threshold value. This helps operators to take remedial action on time. In addition to this the research could be used as a reference for further performance prediction, for instance in the prediction of radio network controller (RNC) and CN KPIs.

## 1.8. Thesis Outline

The rest of this thesis is organized as follows. Chapter Two describes the basics of UMTS technology. Chapter Three presents some important UMTS KPI's and associated counters. Chapter Four introduces some basic concepts of MC model and prediction using MC. Chapter Five presents results and discussion part. Finally, Chapter Six presents conclusion and future works.

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## 2. UMTS Overview

Knowing mobile cellular network system architecture is essential to understand mobile network performance. Hence in this chapter, basic technical background of UMTS network and its network architecture will be presented, then the basic services offered by this technology will be followed.

### 2.1. UMTS Background

The beginning of the first cellular mobile communication system was started in late 1970's. It was aimed for wireless voice communication system, and the system was deployed using analog transmission system, and this system is called first generation mobile system. Though first-generation mobile system paves the way for cellular communication system, it had many limitations, some of these are interoperability issue between operators and countries, cellular mobile equipment (ME) cost, and limitation of channel.

To overcome these problems, in early 1990's a 2G mobile system is developed with a new type of technology, here a digital transmission technology is introduced. The digital technology resolves major problems of the analogy system, some of these are like ME cost, and channel capacity. Because of these the technology is able to accommodate more mobile subscribers [23]. 2G mobile system is initially deployed for voice communication system but latter the technology enhances to provide additional services like short message service (SMS), and data services like Internet in addition to the growing demand of voice services. With the development of data service, 2G network is unable to support high speed data rate and multimedia connectivity demands to subscribers. Thus, a 3G cellular network is developed to overcome problems facing in 2G network, therefor the aim of 3G network mainly focuses on providing high speed data and multimedia connectivity to users. Based on the International Mobile Telecommunication (IMT) standards different technologies like code division multiple access (CDMA), UMTS and enhanced data for GSM evolution (EDGE) are developed.

UMTS is one of the 3G mobile cellular network technology mainly designed for multimedia communication with high quality of image, video, and access to information on public and private networks. The UMTS adopts wideband CDMA (WCDMA) as a technology for the air interface

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and it will be part of the IMT-2000 family of 3G standards and latter it was selected as the air interface for UMTS [23].

The first release of UMTS is called Release 99 (R99). In this system the CN contains two main subsystems namely, the circuit switched (CS) subsystem and the PS subsystem. The CS is used to provide voice related services and the PS is used to provide data related services. The radio part is also subdivided into two sub systems, these are, the base station subsystem (BSS) and radio network subsystem (RNS). In the RNS of 3G the air interface adopts WCDMA technology.

The second release of third generation partnership project (3GPP) is called Release 4. It is introduced to enhance the data service quality. The main difference between R99 and Release 4 from network architecture point of view is that, in this release, the mobile switching center (MSC) is subdivided into media gateway (MGW) and MSC server, and the gateway MSC (GMSC) is subdivided into gateway MGW (GMGW) and GMSC server. In this architecture the MSC server provides all connection control related services, and the MGW provides bearer connection related services [24].

To enhance the speed of data, different improvements are done mainly in the air interface part. In Release 5 of UMTS a high-speed downlink packet access (HSDPA) technology is introduced which uses different modulation schemes like quadrature phase shift key (QPSK) and 16 quadrature amplitude modulation (16QAM) techniques. Then to enhance the uplink speed a high-speed uplink packet access (HSUPA) technology is also introduced.

The combination of 2G and 3G networks improves the service quantity and quality of mobile network operators. The 2G network is mainly deployed for voice and coverage purpose, and the 3G network is deployed mainly for data service and capacity purpose.

## 2.2. UMTS System Architecture

The UMTS system architecture is evolved from the previous GSM structure with some modifications. The UMTS system is grouped into three subsystems based on their functionality. The first subsystem is the UE which helps to interface a user with that of the RAN, the second subsystem is UMTS terrestrial radio access network (UTRAN) which is responsible to handle all radio related functionality, and the third part of UMTS subsystem is the CN which is responsible

for switching and routing calls and data services as well as to connect the system with external networks for both voice and data services [25] as shown in Figure 2.1.

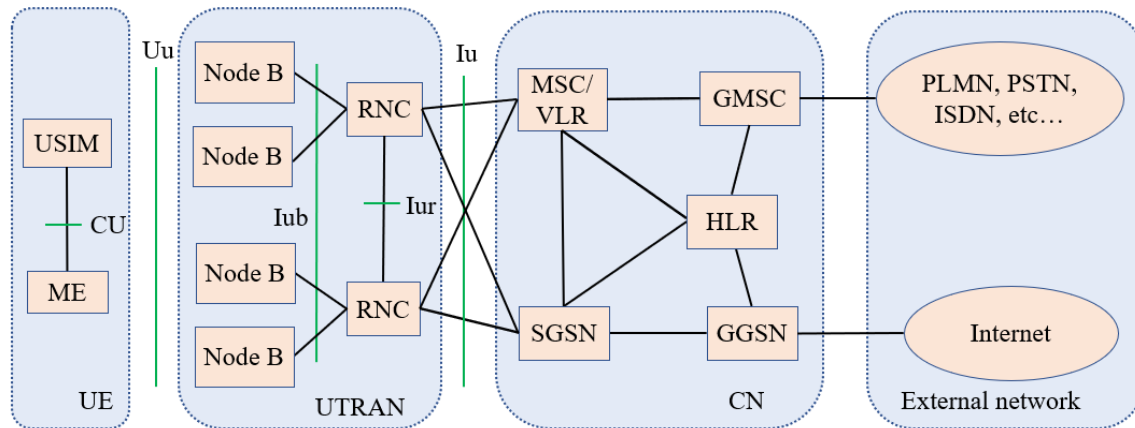


Figure 2-1. Network elements in a public land mobile network (PLMN) [25].

### 2.2.1. User Equipment

A UE consists of two main components, these are ME and the universal subscriber identity module (USIM), and these two units communicate using CU interface. A USIM contains subscriber specific information, and it also contains information like authentication and associated algorithms, and encryptions, whereas a ME in the case of mobile phones is a radio terminal which is used for radio communication over the Uu interface, and in the case of data terminals it is split into two, the first part is the mobile terminal (MT) which handles all the communication functions, and the terminal equipment is the point where the data streaming begins and ends [25].

### 2.2.2. Universal Terrestrial Radio Access Network

UTRAN is the second subsystem which is located in between UE and CN. The two most important elements of UTRAN are Node B and RNC.

- **Node B**

A base station for UMTS is called Node B. One of the functions of Node B is to communicate with UE through Uu air interface, thus Node B uses radio frequency transmitters and receivers to transmit and receive radio signal to and from UE. Node B also communicates with RNC using Iub interface. In addition to data transmission between UE and RNC, Node B is also responsible for the closed loop power control, for coding the physical channel, modulation or demodulation, error handling, radio resource management, etc. The number and location of

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these resources is determined by the number of users and the target coverage area intended to provide the service [23] [25].

- **Radio network controller**

A Radio network controller is a subsystem which is responsible to control the radio resources in its domain and manages all node B sites connected to it. Some of the functions of RNC are control or manage all radio resources, power control, channel allocation, admission control, handover management, and ciphering. Two RNC's communicate with each other mostly to perform soft handover using Iur interface [23] [26].

### 2.2.3. Core Network

A CN of UMTS is mainly sub divided into CS domain and PS domain. The CS domain consists of MSC, visitor location register (VLR) and GMSC, whereas the PS domain consists of serving GPRS support node (SGSN) and gateway GPRS support node (GGSN). These two subsystems ( CS and PS ) share resources like home location register (HLR), equipment identity register (EIR), and authentication center (AUC) [26].

- **Mobile switching center/Visitor location register**

The MSC and VLR are usually implemented as a single piece of hardware to minimize the communication between these two entities and thus mostly named as MSC/VLR subsystem. MSC is used mainly for switching CS transactions like voice call and it also handles signaling communications in its MSC serving area with RNC, HLR, etc. and VLR is used to hold the local copy of HLR's information of a mobile subscriber in its location area [27].

- **Gateway mobile switching center**

GMSC is used as a gateway or as a point of entry or exit to and from the local MSC to other circuit domain networks like PLMN and public switch telephone network (PSTN). The GMSC could stand separately in the case of big operators or could be integrated in one MSC in the case of small operators and in this case the MSC will perform both the functionalities of MSC and GMSC.

- **Serving GPRS support node**

SGSN is one of the two subsystems of PS domain, and the main function of SGSN is like that of MSC/VLR in the CS domain except that SGSN is used to provide PS services. Thus, SGSN

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acts as a router for data transfer. SGSN also keeps a local copy of users' information in its SGSN serving area like that of VLR, and it also performs all signaling communications in its SGSN serving area with all subsystems connected to it.

- **Gateway GPRS support node**

The function of GGSN is like that of GMSC and the only difference is that GMSC is used in the CS domain whereas GGSN is used in the PS domain to provide PS services or to connect the UMTS network with the external Internet.

- **Home location register**

HLR is a database which is used to store all users service profile permanently as far as the subscription of a user is not interrupted [26]. Since this system is a master database of users, it is the most important element or subsystem to the operators, hence mostly it is implemented with redundant HLR working in active standby mode, and most operators implement HLR using redundancy both in physical as well as in geographical ways. Some of the information's stored in the HLR are like services that are allowed by the subscriber, roaming areas allowed by the subscriber, value added services of the subscriber, and location area of the user for routing purpose. Generally, such type of information is created and stored in the HLR when a new subscriber is registered in the network.

#### 2.2.4. UMTS Network Interfaces

In a mobile network operators use different network equipment's that are manufactured by different vendors. Mostly the UE is supplied by different UE manufactures, the UTRAN could be from one or more vendors and the CN could be from another vendor. So, for these equipment's to operate or communicate as one system, a standard is required. A standard is defined by organizations like 3GPP to have an open interface between these subsystems, so that they will operate as one system. Some of these interfaces are listed here in below.

- **CU interface**

CU interface is an interface between USIM smartcard and ME.

- **Uu interface**

Uu interface is a WCDMA radio interface between UE and Node B of UTRAN. Since the media for this interface is air, this interface is mostly named as air interface.

- **Iub**  
Iub interface is an interface between Node B and RNC.
- **Iur**  
Iur interface is an interface between two RNC's and allows to have soft handover between these RNC's.
- **Iu**  
Iu interface is an interface between UTRAN and CN. Iu is further sub divided into Iu-CS and Iu-PS. Iu-CS is an interface between UTRAN and CS network, and Iu-PS is the interface between UTRAN and PS network.

### 2.3. UMTS Services

UMTS network is aimed to provide different types of voice and data services. Each service requires its own requirement in terms of speed and quality, but due to the restriction and limitation of the air interface, the QoS mechanism provided in the cellular network should be robust and able to provide reasonable QoS to subscribers [28]. The CN decides to proceed or terminate the execution of the transaction based on the UE's transaction request. Where a transaction is an exchange of information during voice or data service. Subsystems which are involved in the connection process will communicate each other to create a bearer. For instance, if a UE wants to make a call, then one transaction will be created between UE, UTRAN, and MSC. For every service request one transaction is initiated and this transaction will continue until it is terminated from UE or network side. Generally, a single UE could perform one or more transactions with a network at a time. Thus, if a transaction is to be executed, a network should allocate a RAB, and the allocated RAB resource will be released when the transaction is completed [24]. A network assigns a RAB based on the requested QoS. There are four UMTS QoS classes and they are also called traffic classes, these are conversational, streaming, interactive and background classes.

- **Conversational class**  
This class as the name indicates is used for applications related to real time conversations like voice traffic and real time data traffic such as video telephony, video gaming, etc. It is mainly characterized by that the transfer time shall be low. The maximum transfer delay is given by the human perception during audio and video conversation, thus the limit for acceptable traffic

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delay is very strict otherwise if the delay is above the required time the delay will result in unacceptable lack of quality or will be noticed by the end users.

- **Streaming class**

In this class the data are transferred in a steady and continuous stream, and the data are transport in one direction. The delay in this class is higher than the conversational class. Examples of this class are multimedia, real time video, real time audio, etc.

- **Interactive class**

In this class the end user either a machine or a human is online requesting data from remote equipment like server and waits for the information to arrive. Another application of this class is interactive traffic communication scheme which is characterized by the request response pattern of the end user, where a user expecting response for what he/she requests within a certain time. Examples of this class are web browsing and server access.

- **Background class**

In this class the end user, mostly a computer, send and receive data files in the background. In this class the destination is not expecting the data within a certain time and therefore it is time insensitive. SMS, background delivery of E-mail, downloading of data, and fax are examples of this class.

Table 2-1 summarizes the main distinguishing factors between these four classes [28].

Table 2-1. UMTS QoS classes

Traffic class	Fundamental characteristics
Conversational class	<ul style="list-style-type: none"> <li>- Preserve time relation (variation) between information entities of the stream.</li> <li>- Conversational pattern (stringent and low delay).</li> <li>- Example: voice</li> </ul>
Streaming class	<ul style="list-style-type: none"> <li>- Preserve time relation (variation) between information entities of the stream.</li> <li>- Example: streaming video</li> </ul>
Interactive class	<ul style="list-style-type: none"> <li>- Request response pattern.</li> <li>- Preserve payload content.</li> <li>- Example: web browsing</li> </ul>
Background class	<ul style="list-style-type: none"> <li>- The destination is not expecting the data within a certain time.</li> <li>- Preserve payload content.</li> <li>- Example: background download of emails</li> </ul>

## 2.4. UMTS Performance Monitoring Approaches

To provide the intended QoS to customers, operators use different approaches to monitor and evaluate their network performance. Most operators monitor and evaluate their network performance using different KPI's. Generally, KPI's are used to monitor the performance of a network when a user is in either of the three modes; these are, in idle mode, during the connection establishment phase, or after the connection is established or connected mode [29].

The network performance could be monitored using different approaches. One method of monitoring the network performance could be using different counter values extracted from NMS. The NMS collects all necessary counter values from different network elements, for instance during a given period the number of RAB normal release and number of RAB abnormal release values are counted from the system. Using these counter values, the network KPI values will be calculated, for example CDR is one KPI which is calculated using the above two counters shown in Equation 3.6 in the next chapter. Based on these KPI values the network performance will be evaluated based on the set target value. Another method of monitoring the network performance could be using drive test. In this approach different network parameters are measured using special software, so that the performance of a network will be evaluated at different locations and at



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different times. The other method could be to use probes. In this method different probes which have the capability of extracting different signaling messages will be used at different interfaces of the network, so that probes will count the necessary counter values, then the performance of the system will be evaluated after calculating the KPI values using appropriate formula [30]. In the next chapter counters extracted from the network using NMS for measuring the performance of a network during and after the connection establishment phase will be discussed in brief.

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### 3. UMTS Counters and Key Performance Indicators

In this chapter, an overview of mobile KPI parameters and counters which are related to accessibility and retainability of UMTS network will be presented.

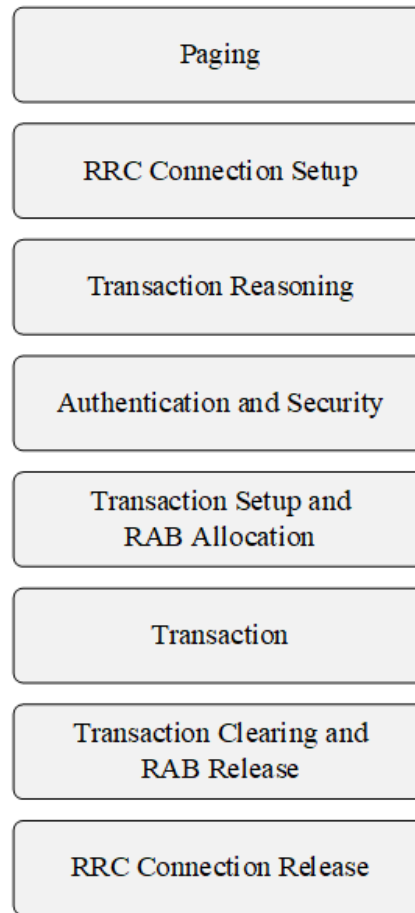
#### 3.1. UMTS Performance

In UMTS network, there are a lot of counters in every subsystem. The main purpose of these counters is for network operation, optimization, and maintenance activity. The counters in RNC subsystem mainly counts the transactions performed between RNC and Node B's connected to it. The counters in RNC also counts the transactions performed with other RNC if any, and the transactions performed with the CN. Using counters, the performance of a network will be monitored and evaluated as per the set KPI value during every transaction. For instance, making a call or connecting to a web are some of the transactions performed between UE and UTRAN.

##### 3.1.1. Elementary Procedure

During every service request whether it is mobile originating or mobile terminating a transaction is created. For instance, during a call setup process of mobile originating call the UE, UTRAN, and CN perform different transactions. To view and understand each transaction performed in mobile network a simple model and an elementary procedure is used. During a call setup procedure any mobile network perform some or all the eight steps or procedures shown in Figure 3-1 [24].

When a CN wants to communicate with the UE it uses “paging” procedure. In this procedure the CN through UTRAN sends a paging signal to all cells in the location area where the UE is registered. When the UE is within the network coverage area, then the UE responds to the paging message and the next procedure will be started, otherwise the communication fails [24].



*Figure 3-1. Basic model of UMTS network transactions [24].*

A procedure “RRC connection setup” is another procedure performed to establish a signaling connection between UTRAN and UE. When RRC connection setup procedure is completed successfully, then the next procedure will be “transaction reasoning”, here the UE through the UTRAN communicates with the CN about the kind of transaction required. Based on the type of transaction request the CN decides whether to proceed or terminate the transaction. If the CN decides to proceed the requested transaction, then the CN will perform all necessary authentication and security procedures, hence “authentication and security” procedure is a procedure next to transaction reasoning. If this procedure is completed successfully, then “transaction setup and RAB allocation” procedure will be followed. In this procedure different RABs will be assigned based on the type of service request by the UE. Upon receiving RAB assignment request from the CN, the RNC checks the availability of the requested resource, if there is enough resource then the RNC will provide the resource as per the request, or if there is limited resource then the RNC

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decides to provide the service with lesser QoS or to queue or interrupt the service. If the RNC allocates the required resource to the UE, then the UE sends radio bearer setup complete message to the RNC, and this is the procedure called “transaction” where the UE gets a bearer service from the network, or it is a procedure where a UE gets voice or data service from the network. If the RAB allocation procedure is completed successfully, then the next procedure will be “transaction clearing and RAB release” procedure. In this procedure either the UE or the CN requests a RAB release procedure, based on the request the network resources allocated for this specific transaction will be released. Then the final procedure will be “RRC connection release” procedure, this is a procedure to release all resources which are related to radio control connection between the UE and the UTRAN [24].

During all these elementary procedures, the request by the UE or the CN either completed successfully as intended, or the communication may be interrupted in the middle undesirably. The interruption of the communication could be seen broadly into two phases. First the interruption may happen before the required bearer connection is established or during an attempt to get access of service from the network, and second the interruption of the service may happen after the establishment of the bearer connection, that is during a time when voice or data communication is taking place.

### **3.1.2. Accessibility Performance**

As stated in the elementary procedure a communication between UE and the network may start and complete as intended successfully or may interrupt during the transaction. During each transaction, a counter will count each transaction at different points. Based on these counter values, the performance of a network is evaluated. Accessibility performance is a performance used to measure and assess the network performance during call setup procedure or before a bearer service is established. The communication may interrupt in the radio side (from UE up to UTRAN) or in the CN side. The Node B performance during the call setup procedure is measured in the RNC of UTRAN. To access the network, the main parameters for accessibility performance from RAN side are RRC connection procedure and RAB setup procedures [31].

### 3.1.2.1. RRC Setup Success Ratio

RRC setup procedure is initiated by a UE and this setup procedure is completed when the serving RNC receives an “RRC CONNECTION REQUEST” message from UE as shown in Figure 3-2. When the serving RNC receives this message then the counter in the RNC at point A1 of Figure 3-2 will increment by one. Based on the request the serving RNC may reject this message and send an “RRC CONNECTION REJECT” message to the UE, in this case the counter in the RNC at point A of Figure 3-3 will increment by one and the connection terminates. If the RNC accepts this request, then it sends “RRC CONNECTION SETUP” message to the UE, and the counter at point B of Figure 3-2 increases by one. When the UE receives RRC connection setup message from RNC, then it sends “RRC CONNECTION SETUP COMPLETE” message to the RNC. When the RNC receives this message then the counter at point C of Figure 3-2 increases by one.

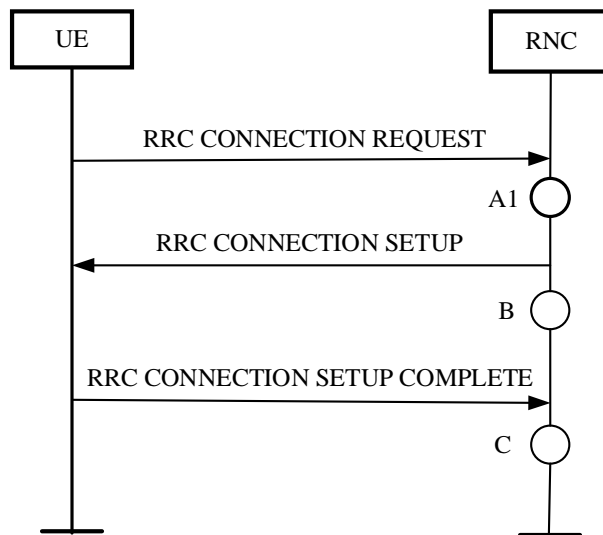


Figure 3-2. Successful RRC connection setup procedure [32].

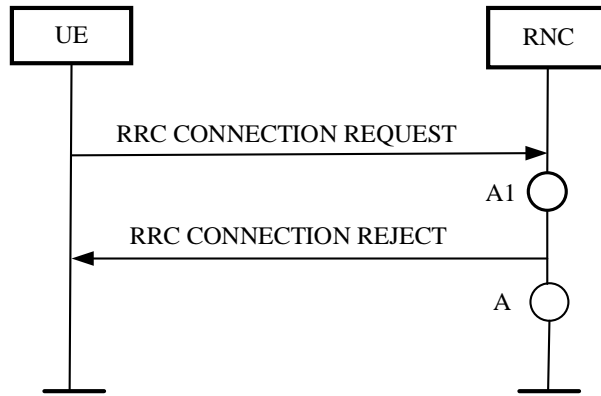


Figure 3-3. RRC connection reject procedure [32].

Different vendors use different counter names to count the occurrence of these events at point A1, B, C, and A of Figure 3-2 and Figure 3-3. Based on these counter values, RRC setup success rate will be calculated as shown in Equation (3.1) [32].

$$RRC\ setup\ Success\ Ratio = \frac{Number\ of\ RRC\ Setup\ Success}{Number\ of\ RRC\ Connection\ Attempts} * 100\% \quad (3.1)$$

The request for RRC connection by a UE has many reasons, to mention some, the request may be for conversational call, streaming call, background call, interactive call, emergency call or some other reasons. Based on the type of the service requested, the counters at these mentioned points (A1, B, C, and A) also varies. For instance, in Huawei UMTS network “RRC.SuccConnEstab.OrgConvCall” is a counter at point C for conversational call originated by UE, and “RRC.SuccConnEstab.OrgStrCall” is a counter at the same point C for streaming call [31].

### 3.1.2.2. RAB Setup Success Ratio

RAB setup procedure is initiated by the CN. The CN sends “RAB ASSIGNMENT REQUEST” to RNC. When RNC receives this message, it increments the counter at point A of Figure 3-4 by one. Then based on the request, RNC sends “RADIO BEARER SETUP” message to the UE. Then the UE may send “RADIO BEARER SETUP COMPLETE” message or “RADIO BEARER SETUP FAILURE” message to RNC. If RNC receives radio setup complete message from the UE, then the counter at point B in Figure 3-4 increments by one. If the message received by RNC is radio bearer setup failure, then the counter in Figure 3-5 at point B increments by one. Then according

to the message received from the UE, the RNC sends a “RAB ASSIGNMENT RESPONSE” message to the CN.

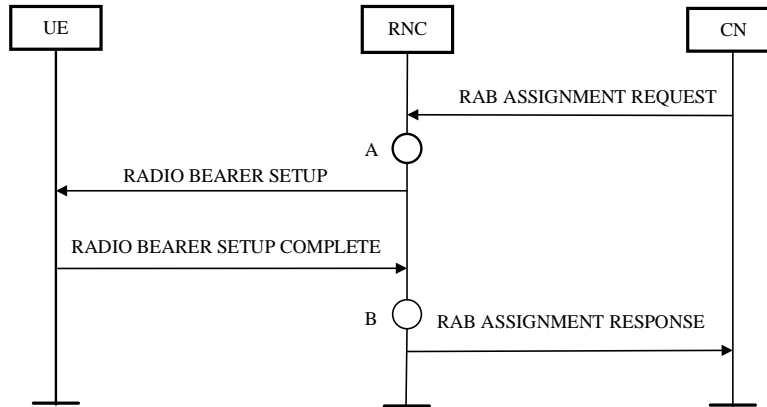


Figure 3-4. Successful RAB setup procedure [32].

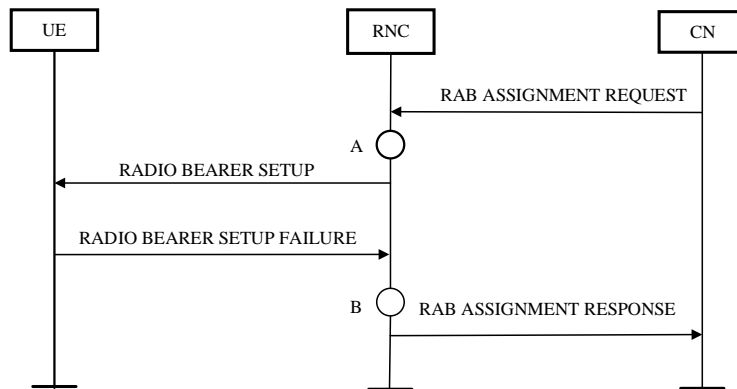


Figure 3-5. RAB setup failure procedure [32]

After getting the number of successful RAB setup and RAB setup attempts, the RAB setup success rate is calculated using Equation (3.2) [31]

$$RAB\ Setup\ Success\ Ratio = \frac{Number\ of\ RAB\ Setup\ Success}{Number\ of\ RAB\ Setup\ Attempt} * 100\% \quad (3.2)$$

Like RRC, different vendors use different counter names for RAB to count the occurrence of these events at point A and B of Figures 3-4 and 3-5. The request for RAB depends on the type of service requested by the CN. The RAB request may be for voice service or for data service, based on the request, the RAB assignment will also vary. In Huawei UMTS network the counter for voice service is “VS.RAB.SuccEstabCS.AMR” at point B in Figure 3-4, Whereas the counter for video phone (VP) at the same point is “VS.RAB.SuccEstCS.Conv.64”.

### 3.1.2.3. Call Setup Success Ratio

Call setup success ratio is the overall success rate during the call setup procedure, where the authentication procedure is assumed to be completed successfully [33]. Therefore call setup success rate is calculated using RRC success rate and RAB setup success rate parameters.

$$CSSR = [(RRC\ success\ Ratio * RAB\ setup\ Success\ Ratio) / 100\%]$$
$$CSSR = \frac{Number\ of\ RRC\ Setup\ Success}{Number\ of\ RRC\ Connection\ Attempts} * \frac{Number\ of\ RAB\ Setup\ Success}{Number\ of\ RAB\ Setup\ Attempt} * 100\% \quad (3.3)$$

Then the value of accessibility will be

$$Accessibility = CSSR \quad (3.4)$$

### 3.1.3. Retainability Performance

Retainability performance is used to assess the performance of a network during transaction procedure. During transaction a call drop may happen due to many reasons, some of these are due to poor coverage, missing neighbor cell, or due to interference both in the uplink and downlink. The call drop happens if the RNC triggers an “IU RELEASE REQUEST” or “RAB RELEASE REQUEST” message to the CN. When the RNC sends IU or RAB release request to the CN, then the counter at point A of Figures 3-6 or 3-7 increments by one. If the request is initiated by the CN, then the counter at point B as shown in Figure 3-8 increments by one and this is a normal procedure to terminate the connection without failure [31].

$$CDR = \frac{Number\ of\ RAB\ Abnormal\ Releases}{Total\ number\ of\ RAB\ Releases} * 100\% \quad (3.5)$$

Where total number of RAB releases is the summation of number of RAB abnormal releases and number of RAB normal releases.

$$CDR = \frac{Number\ of\ RAB\ Abnormal\ Releases}{Number\ of\ RAB\ Abnormal\ Releases + Number\ of\ RAB\ Normal\ Releases} * 100\% \quad (3.6)$$

Then retainability of a system will be calculated using Equation (3.7) [34]

$$Retainability = (100\% - CDR) \quad (3.7)$$

There are different counters used in Huawei system at these points for various service types [31]. For instance, the counters for Huawei UMTS conversational voice service are, “VS.RAB.AbnormRel.CS” for RAB abnormal release, and “VS.RAB.NormRel.CS” for RAB normal release.

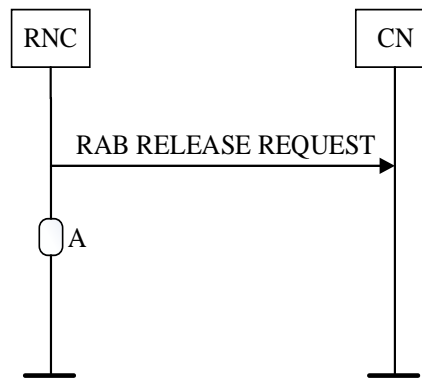


Figure 3-6. RAB release request procedure by RNC [32].

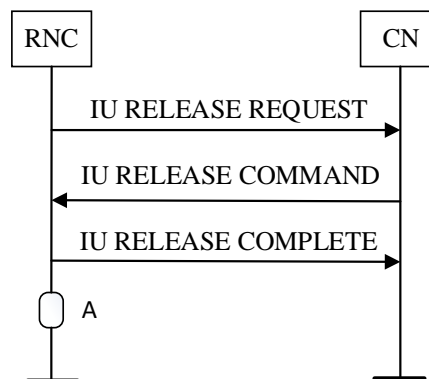


Figure 3-7. Iu connection release request procedure by RNC [32].

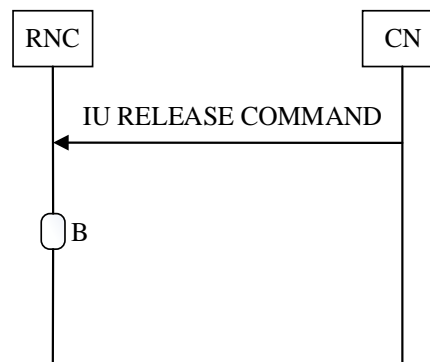


Figure 3-8. Iu release request by CN [32].

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## 4. Markov Chain

### 4.1. Overview of Markov Chain

Markov chain is named after a Russian mathematician Andrey Andreyevich Markov (1856-1922). MC is a stochastic process that satisfies the Markov property [35].

MC is mainly classified into two basic types depending on when the state  $X(t)$  changes, these are DTMC and continuous time Markov chain (CTMC). In the case of DTMC, the transition from one state to another state will take place only at specific instance of time, whereas in the CTMC, the transition between two states could take place at any arbitrary time.

### 4.2. Discrete Time Markov Chain

A Markov process is a stochastic process, characterized by a state space  $X(t)$ , a time  $t$  when  $X(t)$  changes, and a transition probability matrix  $P$  (also called transition probabilities). Markov property states that, next state depends only on the current state [9]. Mathematically

$$\begin{aligned} P(X(n) = i_n | X(n-1) = i_{n-1}, \dots, X(0) = i_0) \\ = P(X(n) = i_n | X(n-1) = i_{n-1}) \end{aligned} \quad (4.1)$$

That is, the state  $X$  at time step  $n$  dependent only on the state  $X$  at time  $n-1$ , due to this an MC is mostly considered as a memoryless discrete time process.

Based on the set of values of the random variables  $X(n)$  an MC could be a discrete state space, in this case the state spaces will be  $\{X_0, X_1, X_2, \dots\}$ , or it is called finite state if the set of values of the random variables are finite set  $\{X_0, X_1, \dots, X_n\}$

An MC is called time-homogeneous if the transition probabilities  $P_{ij}$  are independent of time  $t$ , that is

$$P_{ij} = P(X(n+1) = j | X(n) = i, X(n-1) = i_{n-1}, \dots, X(0) = i_0) \quad (4.2)$$

#### 4.2.1. Elements of Markov Chains

A DTMC is mainly expressed using transition probability matrix  $P$ , transition probability diagram, and steady state vector  $\pi$ .

- **Transition probability matrix**

A transition probability matrix (P) comprises of all the transition probabilities in MC. Each element in the matrix represents the probability of a state moving from one state to another. A movement at each specific instance of time is called transition and the probability of moving from state  $i$  to state  $j$  or the probability of the next state to be in  $j$  given the current state in  $i$ , is expressed by transition probability  $P_{ij}$ . If the state space  $S$  is  $\{1, 2, 3, \dots, n\}$ , then the transition probability matrix will be an  $n \times n$  matrix. Generally,  $P$  is a square matrix with  $n$  rows and  $n$  columns, where  $n$  is the number of states of an MC as shown in Equation (4.3).

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & \dots & p_{1n} \\ p_{21} & p_{22} & p_{23} & \dots & p_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & p_{n3} & \dots & p_{nn} \end{bmatrix} \quad (4.3)$$

An  $n \times n$  transition probability matrix  $P$  must satisfy the following properties.

- The value of each transition probability  $p_{ij}$  must be greater or equal to zero.

$$P_{ij} \geq 0, \text{ for all } i, j = 1, 2, 3, \dots, n \quad (4.4)$$

- The summation of all transition probabilities in a row must be equal to one.

$$\sum_{j=1}^n p_{ij} = 1, \text{ for all } i = 1, 2, 3, \dots, n \quad (4.5)$$

Where in both cases  $p_{ij}$  is the probability of moving to state  $j$  given the current state is in  $i$  [9]

- **Transition probability diagram**

The transition probability matrix could also be represented using a transition probability diagram. In this representation a directed graph is used. In the graph each node represents the state of an MC, and that specific state is represented by a number or letter inside the circle. A directed arrow is used to represent the presence of transition from one state to another, where the tail represents the current state, and the head indicates the next state. On top of this directed arrow there is a number which indicates the probability of moving from the current state to the next state [35].



Figure 4-1. A two-state transition probability diagram of MC

As shown in Figure 4-1 the states of an MC are A and B, hence the state space of MC is  $S = \{A,B\}$  and  $P_{AA}$  is the probability of being in State A given the current state is in A, and  $P_{AB}$  is the probability of being in state B given the current state is in A. As that of the transition probability matrix, the summation of all  $P_{ij}$  starting from any node in the transition probability diagram is one. So, in the Figure 4-1.

$$P_{AA} + P_{AB} = 1 \tag{4.6}$$

Similarly

$$P_{BA} + P_{BB} = 1 \tag{4.7}$$

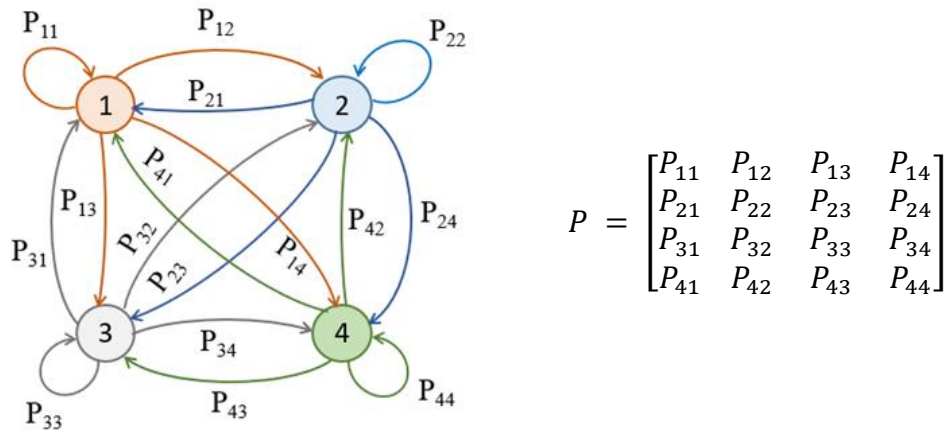


Figure 4-2. A four-state transition probability diagram of MC

In the same way as that of two state transition probability matrix, in a four state transition probability matrix, the summation of all probabilities starting from state i is always one when we see in the transition probability diagram, and the summation of each row in the matrix is also one in the case of transition probability matrix.

Therefore,

$$P_{11} + P_{12} + P_{13} + P_{14} = 1 \tag{4.8}$$

$$P_{21} + P_{22} + P_{23} + P_{24} = 1 \quad (4.9)$$

$$P_{31} + P_{32} + P_{33} + P_{34} = 1 \quad (4.10)$$

$$P_{41} + P_{42} + P_{43} + P_{44} = 1 \quad (4.11)$$

- **Steady state vector**

Once we have a transition probability matrix, given any initial vector  $\pi_0$ , the next state vector will be obtained by multiplying the initial vector  $\pi_0$  and P, thus

$$\pi_1 = \pi_0 * P \quad (4.12)$$

After two state transitions, the resulting probability vector will be

$$\pi_2 = \pi_1 * P \quad (4.13)$$

Substituting the value of  $\pi_1$  in Equation (4.13) by  $\pi_0 * P$  from Equation (4.12) gives

$$\pi_2 = (\pi_0 * P) * P = \pi_0 * P^2 \quad (4.14)$$

Using the same procedure if we continue, we will reach at some point,

where  $\pi_{n-1} = \pi_n$

$$\pi_{n-1} = \pi_0 * P^{n-1} \quad (4.15)$$

$$\pi_n = \pi_0 * P^n \quad (4.16)$$

This value  $\pi_n$  is called the steady state vector  $\pi$ .

Or if we multiply P by itself, that is

$$P^2 = P \times P \quad (4.17)$$

$$P^3 = P^2 \times P \quad (4.18)$$

If we keep on multiplying the transition probability matrix P, then we will reach at some point, where  $P^{n-1} = P^n$

$$P^{n-1} = P^{n-2} \times P \quad (4.19)$$

$$P^n = P^{n-1} \times P \quad (4.20)$$

At this point each row of P will be identical, and the sum of each row will be one.

$$P^n = \begin{bmatrix} \pi_0 & \pi_1 & \pi_2 & \dots & \pi_j \\ \pi_0 & \pi_1 & \pi_1 & \dots & \pi_j \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \pi_0 & \pi_1 & \pi_2 & \dots & \pi_j \end{bmatrix} = \pi_n \quad (4.21)$$

So, if we take one row of  $\pi_n$  of Equation (4.21), then we will get the same value as that of  $\pi_n$  of Equation (4.16) or the steady state vector  $\pi$ . Generally, for MC fulfilling ergodic property (where ergodicity is defined in section 4.2.2.).

$$\lim_{n \rightarrow \infty} P_{xy}^n = \pi_n \quad (4.22)$$

#### 4.2.2. Some Additional Properties of Markov Chain

- **Communicating states:** - Two states are called communicating states, if state  $i$  is accessible from state  $j$ , and state  $j$  is accessible from state  $i$ . In other words, it is possible to travel from state  $i$  to state  $j$  with some probability  $p_{ij}$  greater than zero, and it is possible also to travel from state  $j$  to state  $i$  with some probability  $p_{ji}$  with value greater than zero [36].
- **Irreducibility:** - An MC is called irreducible if it is possible to move from any state  $i$  to any state  $j$  regardless of the number of transitions it takes. Or we call the MC irreducible if all the states of the MC are in one communication class. The MC in Figure 4-3 a) is reducible, because it is impossible to reach state 2 from any state 1, 3, or 4, whereas the MC in Figure 4-3 b) is irreducible since it is possible to travel from any state  $i$  to any state  $j$  within the chain.

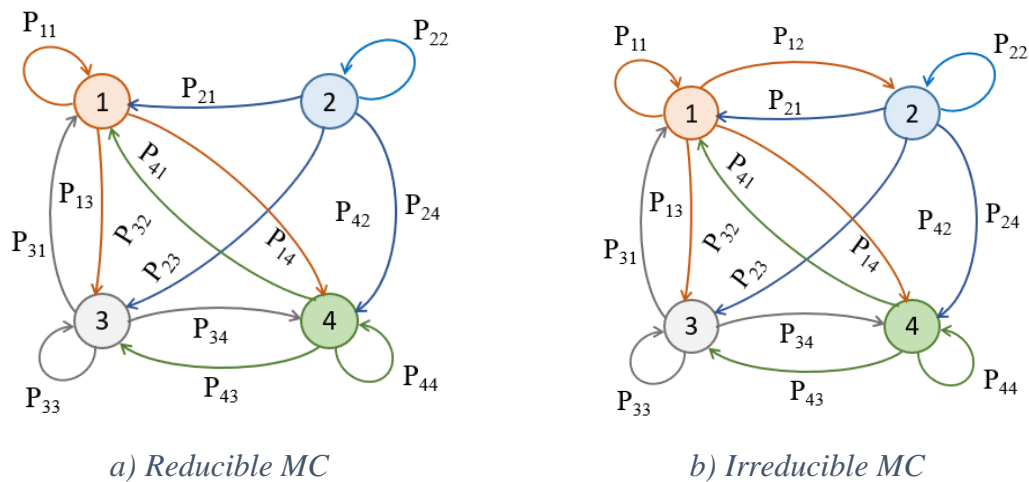
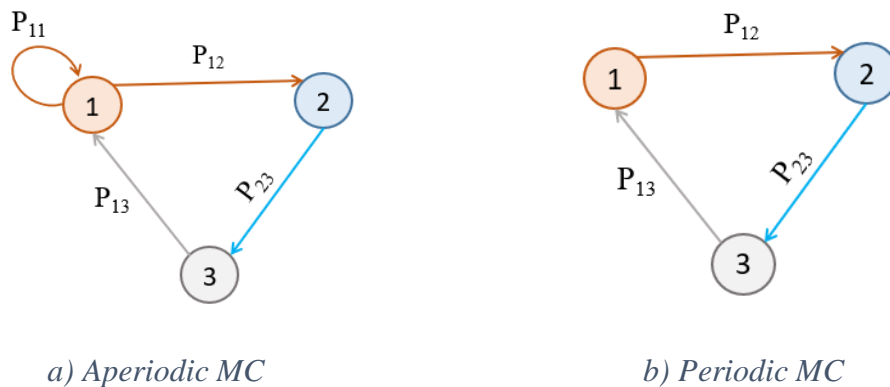


Figure 4-3. Reducible MC vs irreducible MC.

- Aperiodic:** - An MC is called aperiodic if, after departing from state  $i$ , the system can return to it by following different paths as shown in Figure 4-4 a), that is starting from state 2 to return back to the same state (state 2) there are at least two paths, these are path 2-3-1-1-2 and path 2-3-1-2. Otherwise, it is called periodic, and the system returns to its initial state after some multiplication of period  $m$ , where  $m$  is greater than 1, from the Figure 4-4 b) there is only one path that leads from state 2 to state 2, this path is path 2-3-1-2, hence the system is periodic with period 3. All states in a same class could be either periodic or aperiodic and will have the same period. States 1, 2, and 3 of Figure 4-4 a) are all aperiodic with period 1 and states in 1, 2, and 3 of Figure 4-4 b) are all periodic with period 3.



*Figure 4-4. Periodic and aperiodic MC*

- Positive recurrent:** - An MC is called positive recurrent if there is a non-zero probability that after departing from state  $i$ , the process will return to it in a finite time.
- Ergodicity:** - An MC is Ergodic if all its states are aperiodic and positive recurrent.

## 5. Results and Discussions

In this chapter, the processes from data collection to system state prediction of Addis Ababa UMTS network performance in terms of accessibility and retainability using separate four state MC model and prediction of accessibility and retainability using sixteen state MC model will be presented.

For the model, data are collected from ethio telecom UMTS network using NMS per cell level from 1530 cells. The data preprocessing is done after data collection. The data is split into training and test set for model validation. The training dataset is converted into defined states and then transition from state to state is counted and put in matrix form. Then after converting each zero value to one in those rows whose row sum is zero, then the matrix is converted into transition probability matrix. Then using the transition probability matrix, the steady state of the system is computed using MC and the next state of the system is predicted using the current state and the transition probability matrix. Finally, the model is validated using test set data.

### 5.1. Data Collection

The data used for this research work is collected from ethio telecom’s Addis Ababa Arada RNC01 system using Huawei performance report system (PRS) from November 1, 2020, to February 28, 2021, on an hourly basis. From Arada RNC01 1530 cells data is collected, and from each cell, 2880 hours of data have been collected. The data contains counters which help to calculate the accessibility and retainability of UMTS network. The counter values are collected from Huawei adaptive multi rate (AMR) system, R99 system, HSDPA system, and HSUPA systems in CSV format as shown in Table 5-1 for the case of AMR system. The data contains the date, time, cell ID, cells availability rate, and all necessary counters to calculate CSSR and CDR per cell level for both voice and data services.

Table 5-1. Sample date of counters for AMR system

Date	Time	RNC	Cell ID	Cell Name	NodeB Name	Integrity	Cell Availability (%)	RRC.Succ ConnEstab	RRC.Succ ConnEstab	RRC.Attc ConnEstab	RRC.Attc ConnEstab	RRC.Attc ConnEstab	RRC.Attc ConnEstab	RRC.Attc ConnEstab	VS.RAB.S	VS.RAB.A	VS.RAB.N	VS.RAB.A
								EmgCall	vCall	b.OrgCon	onnEstab	onnEstab	onnEstab	onnEstab	CS.AMR	MR	MR	normRe
2/25/2021	0:00	111055.RN	50592	SWAP_11:SWAP_11:		100%	100	0	10	13	13	10	0	0	27	27	29	0
2/25/2021	0:00	111055.RN	30425	SWAP_11:SWAP_11:		100%	100	0	2	2	2	2	0	0	2	2	2	0
2/25/2021	0:00	111055.RN	31435	SWAP_11:SWAP_11:		100%	100	0	8	13	13	8	0	0	23	23	21	0
2/25/2021	0:00	111055.RN	30568	SWAP_11:SWAP_11:		100%	100	0	0	4	4	0	0	0	4	4	5	0
2/25/2021	0:00	111055.RN	53934	SWAP_11:SWAP_11:		100%	100	0	0	0	0	0	0	0	0	0	2	0
2/25/2021	0:00	111055.RN	35437	112082_A_112082_A		100%	100	0	3	3	3	3	0	0	7	7	6	0
2/25/2021	0:00	111055.RN	51041	SWAP_11:SWAP_11:		100%	100	0	4	20	20	4	0	0	24	24	24	0
2/25/2021	0:00	111055.RN	38567	111856_A_111856_A		100%	100	0	4	2	2	4	0	0	7	7	5	0

## 5.2. Data Preprocessing

The data collected from the PRS system can miss counter values for calculating the KPI of a cell. This could happen due to cell outage or connectivity problem between the cell and the central RNC system. The information about the data collected from a cell, that is whether full data is collected, or not in each given time is captured in cell's availability percentage value. If the cell's availability is 100%, then it means full data of that cell is captured in that hour, if the cell's availability is less than 100%, then some or all counter values of that cell are not captured during that hour. For instance, if the cell's availability is 60% as shown in Table 5-2 Row 2, it means that the cell is available, or the cell's data is collected only for 36 minutes in that given hour. If cell's availability is 0.0%, then it means that no data of that cell is collected during that hour. So, after identifying the missing values, the next step will be resolving the problem related to these missing values.

*Table 5-2. Percentage of availability of cell 50524*

Date	Time	Cell ID	Cell Availability (%)
2/26/2021	9:00	50524	100
2/26/2021	10:00	50524	60
2/26/2021	11:00	50524	0
2/26/2021	12:00	50524	0
2/26/2021	13:00	50524	15
2/26/2021	14:00	50524	100

### 5.2.1. Data Cleaning

As we have seen in section 5.2 the data collected from the PRS system is not complete. Some cells contain missing values. One option to resolve this problem is to fill in missing values using different techniques, like interpolation, and padding, and the other option will be deleting the data that contains more missing values [37].

The number of cells in RNC01 in the four months period was 1535 cells, and a total of 4,420,800 hourly data was collected from these cells using PRS system. Of these data 27,105 hours data was collected from cells whose percentage of availability was less than 100%. From 1535 cells, five cells were unavailable for more than 900 hours from the total of 2880 hours data of each cell. So, these cells are removed from the dataset. Then the remaining cell's missed value data is filled

using linear interpolation or padding technique. If the cell's data is missed only for one hour, then the data is filled by interpolating the previous hour and next hour data. But in most cases, the data is missed for more than an hour, in this case, the data is filled by interpolating previous day and next day data of the same hour. If the data is missed for more than 24 hours, in this case the data is filled using padding technique (filled using previous days similar hour data).

### 5.2.2. Future Extraction

After missing values are filled, then the CSSR and CDR of the UMTS system is calculated based on the formula agreed between the vendor and the operator.

- **Call setup success rate:** - Call setup success rate is calculated using the counter values obtained from the four systems, AMR, R99, HSDPA and HSUPA.

$$CSSR = \sum RRC \text{ setup success rate} * \sum RAB \text{ setup success rate} / 100\% \quad (5.1)$$

Where:

$$\sum RRC \text{ setup success rate} = \frac{\sum \text{Number of RRC setup success}}{\sum \text{Number of RRC setup attempt}} * 100\%$$

$$\sum RAB \text{ setup success rate} = \frac{\sum \text{Number of RAB setup success}}{\sum \text{Number of RAB setup attempt}} * 100\%$$

thus

$$CSSR = \frac{\sum \text{Number of RRC setup success}}{\sum \text{Number of RRC setup attempt}} * \frac{\sum \text{Number of RAB setup success}}{\sum \text{Number of RAB setup attempt}} * 100\% \quad (5.2)$$

Where, number of RRC setup success is the summation of the number of RRC setup success of AMR, R99, HSDPA and HSUPA. Similarly, the number of RRC setup attempt is the summation of all attempts of RRC by AMR, R99, HSDPA and HSUPA.

Using the same way, the number of RAB setup success is obtained by adding the number of RAB setup success of AMR, R99, HSDPA, and HSUPA, and RAB setup attempt is obtained by adding the number of RAB setup attempt of AMR, R99, HSDPA, and HSUPA.

The success or attempt of each system is obtained from Huawei PRS counter values. Table 5-3 and Table 5-4 shows counters used in AMR and HSDPA systems, respectively.

Table 5-3. AMR counters for call setup success rate

No.	Counters of AMR	Description
1	RRC.SuccConnEstab.OrgConvCall	Number of Successful RRC Connection Setups for Cell (Originating Conversational Call)
2	RRC.SuccConnEstab.TmConvCall	Number of Successful RRC Connection Setups for Cell (Terminating Conversational Call)
3	RRC.SuccConnEstab.EmgCall	Number of Successful RRC Connection Setups for Cell (Emergency Call)
4	RRC.AttConnEstab.OrgConvCall	Number of RRC Connection Requests for Cell (Originating Conversational Call)
5	RRC.AttConnEstab.TmConvCall	Number of RRC Connection Requests for Cell (Terminating Conversational Call)
6	RRC.AttConnEstab.EmgCall	Number of RRC Connection Requests for Cell (Emergency Call)
7	RRC.AttConnEstab.Rep.OrgConvCall	Number of RRC Connection Repeated Requests for Cell (Originating Conversational Call)
8	RRC.AttConnEstab.Rep.TmConvCall	Number of RRC Connection Repeated Requests for Cell (Terminating Conversational Call)
9	RRC.AttConnEstab.Rep.EmgCall	Number of RRC Connection Repeated Requests for Cell (Emergency Call)
10	VS.RAB.SuccEstabCS.AMR	Number of Successful RAB Connection Setups for AMR
11	VS.RAB.AttEstab.AMR	Number of Requests of RAB Connection for AMR

*Table 5-4. HSDPA counters for call setup success rate*

No.	Counters	Description
1	RRC.SuccConnEstab.OrgInterCall	Number of Successful RRC Connection Setups for Cell (Originating Interactive Call)
2	RRC.SuccConnEstab.TmItrCall	Number of Successful RRC Connection Setups for Cell (Terminating Interactive Call)
3	RRC.SuccConnEstab.OrgBkgCall	Number of Successful RRC Connection Setups for Cell (Originating Background Call)
4	RRC.SuccConnEstab.TmBkgCall	Number of Successful RRC Connection Setups for Cell (Terminating Background Call)
5	RRC.AttConnEstab.OrgInterCall	Number of RRC Connection Requests for Cell (Originating Interactive Call)
6	RRC.AttConnEstab.TmInterCall	Number of RRC Connection Requests for Cell (Terminating Interactive Call)
7	RRC.AttConnEstab.OrgBkgCall	Number of RRC Connection Requests for Cell (Originating Background Call)
8	RRC.AttConnEstab.TmBkgCall	Number of RRC Connection Requests for Cell (Terminating Background Call)
9	RRC.AttConnEstab.Rep.OrgInterCall	Number of RRC Connection Repeated Requests for Cell (Originating Interactive Call)
10	RRC.AttConnEstab.Rep.TmInterCall	Number of RRC Connection Repeated Requests for Cell (Terminating Interactive Call)
11	RRC.AttConnEstab.Rep.OrgBkgCall	Number of RRC Connection Repeated Requests for Cell (Originating Background Call)
12	RRC.AttConnEstab.Rep.TmBkgCall	Number of RRC Connection Repeated Requests for Cell (Terminating Background Call)
13	VS.HSDPA.RAB.SuccEstab	Number of Successful RAB Connection Setups for HSDPA
14	VS.HSDPA.RAB.AttEstab	Number of Requests of RAB Connection for HSDPA

Then the number of attempts and successes will be calculated using counter values of each system (AMR, R99, HSDPA and HSUPA).

For instance, for AMR system from Table 5-3

- The number of RRC setup success is obtained by adding values in No. 1, 2 and 3
- The number of RRC setup attempt is obtained by subtracting the summation of values in No. 4, 5, 6 from the summation of values in No. 7, 8 & 9, that is  

$$\text{number of RRC setup attempt} = (4 + 5 + 6) - (7 + 8 + 9)$$
- The number of RAB setup success is the value in No. 10
- And the number of RAB setup attempt is the value in No. 11

Similarly, for the HSDPA system the values of attempt and success is calculated from Table 5-4

- The number of RRC setup success = 1 + 2 + 3 + 4
- The number of RRC setup attempt = (5 + 6 + 7 + 8) - (9 + 10 + 11 + 12)
- The number of RAB setup success is the value in No. 13
- And the number of RAB setup attempt is the value in No. 14

All numbers in the above indicates the row numbers of each table stated.

Using the same way, the number of attempts and the number of successes of R99 and HSUPA is calculated from the counters of R99 and HSUPA, respectively. Then using Equation (5-2) the CSSR of UMTS system is calculated.

- **Call drop rate:** - Like that of CSSR, the CDR is calculated from the counters obtained from the four systems, AMR, R99, HSDPA and HSUPA.

$$CDR = \frac{\sum \text{Number of Abnormal release}}{\sum \text{Number of RAB Setup Success}} * 100\% \quad (5.3)$$

Where number of abnormal release is the summation of abnormal releases of AMR, R99, HSDPA, and HSUPA systems, and number of RAB setup success is the summation of successes of AMR, R99, HSDPA, and HSUPA systems.

The number of abnormal release and number of RAB setup success of each system is obtained from Huawei PRS counter values. Table 5-5 and Table 5-6 shows counters used for AMR and HSDPA systems, respectively.

*Table 5-5. AMR counters for call drop rate*

No.	Counters	Description
1	VS.RAB.NormRel.AMR	Number of AMR RABs normal released for cell
2	VS.RAB.AbnormRel.AMR	Number of AMR RABs abnormal released for cell

Table 5-6. HSDPA counters for call drop rate

No.	Counters	Description
1	VS.HSDPA.RAB.NormRel	Number of HSDPA RABs normal released for cell
2	VS.HSDPA.HHO.H2D.SuccOutInterFreq	Number of successful Inter-Frequency H2D hard handovers for cell
3	VS.HSDPA.HHO.H2D.SuccOutIntraFreq	Number of successful Intra-Frequency H2D hard handovers for cell
4	VS.HSDPA.H2F.Succ	Number of successful handovers from HS-DSCH to CCH for cell
5	VS.HSDPA.H2D.Succ	Number of successful handovers from HS-DSCH to DCH for cell
6	VS.HSDPA.RAB.AbnormRel	Number of HSDPA RABs abnormal released for cell

The number of abnormal release and the number of RAB setup success of each system will be calculated using counters of each system.

For AMR system the counters are stated in Table 5-5, and the values of abnormal and normal releases will be

- Number of abnormal release = 2
- Number of RAB setup success = 1 + 2

For HSDPA system the counters are stated in Table 5-6, and the values of abnormal and normal releases will be

- Number of abnormal release = 6
- Number of RAB setup success = 1 + 2 + 3 + 4 + 5 + 6

Note that the numbers used here are also used to indicate the row number values in the respective tables.

### 5.2.3. Parameter Selection

After calculating the values of CSSR and CDR, then the correlation between accessibility and retainability is examined. If they are highly correlated, it means using only one of the two parameters, it is possible to predict cell's accessibility and retainability, in this situation one data is sufficient, and data redundancy will be avoided. If they are not highly correlated, then the two parameters are needed to compute the accessibility and retainability.

To compute the correlation between accessibility and retainability different methods are used. The selection of the method depends on the relationship between the datasets. The distribution of the datasets could be linear, nonlinear monotonic, or nonlinear and nonmonotonic and this can be examined using graphical methods like scatter plot, Box plot, histogram plot, and Quantile-Quantile plot or by calculating the significance level alpha ( $\alpha$ ) [38]. Based on the type of distribution the correlation coefficient is examined using different approaches for instance, Pearson correlation is usually used for linearly related datasets, Spearman's rank correlation and Kendall rank correlation are used if the relation is monotonic, and Distance correlation and Hoeffding's D measure are used if the relation is nonlinear and nonmonotonic [39].

As shown in the scatter plot of Figure 5-1, the two parameters (accessibility and retainability) are not linearly related.

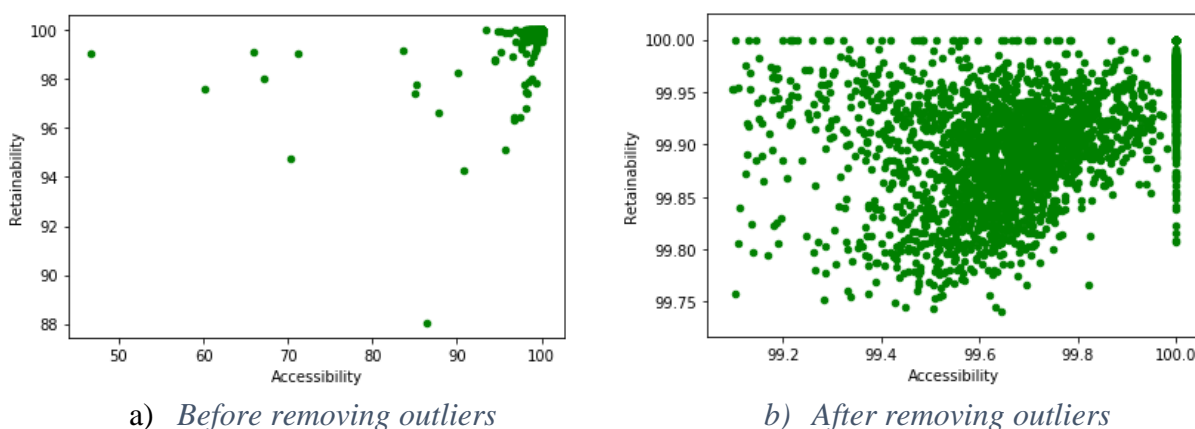


Figure 5-1. Scatter plot of accessibility and retainability of cluster 5 after removing outliers.

Table 5-7. Correlation values of accessibility and retainability before removing the outliers.

Cluster	Pearson's correlation coefficient	Spearman's rank correlation coefficient	Kendall rank correlation coefficient	Distance correlation coefficient
1	0.437328	0.42489	0.313952	0.5397
2	0.38186	0.517197	0.418137	0.4523
3	-0.002178	0.283194	0.204143	0.3338
4	0.198975	0.449764	0.335778	0.4282
5	0.449345	0.421307	0.318798	0.5547
6	-0.008813	0.204028	0.164465	0.086

Table 5-8. Correlation values of accessibility and retainability after removing the outliers.

Cluster	Pearson's correlation coefficient	Spearman's rank correlation coefficient	Kendall rank correlation coefficient	Distance correlation coefficient
1	0.53594	0.424291	0.313487	0.5433
2	0.365653	0.519247	0.419382	0.4532
3	0.016689	0.283955	0.20469	0.3362
4	0.181237	0.452213	0.337048	0.4372
5	0.554295	0.417048	0.315438	0.5044
6	0.069151	0.227977	0.18398	0.1624

The correlation between accessibility and retainability is examined using different approaches and the result is depicted in Table 5-7 and Table 5-8. From the result accessibility and retainability KPIs are not highly correlated (if the correlation coefficient value is near to 1.0 or -1.0 then the correlation is called highly correlated positively or negatively respectively), hence both parameter values are taken for predicting the cells accessibility and retainability.

### 5.3. Clustering

Analyzing the properties of cells individually is time taking. Cells under study will have some common property. If we group those cells which have common property in terms of accessibility and retainability, then it will tell us the general property of cells under that group. Clustering is one method where the algorithm groups similar data points into clusters. In this research k means clustering method is used to cluster 1530 cells. In the clustering algorithm, the value of k is varied from 2 to 18 and a best clustering value of 6 is achieved as shown in Figure 5-2. Therefore, the cells are clustered into 6 clusters based on the clustering algorithm.

Best k = 6

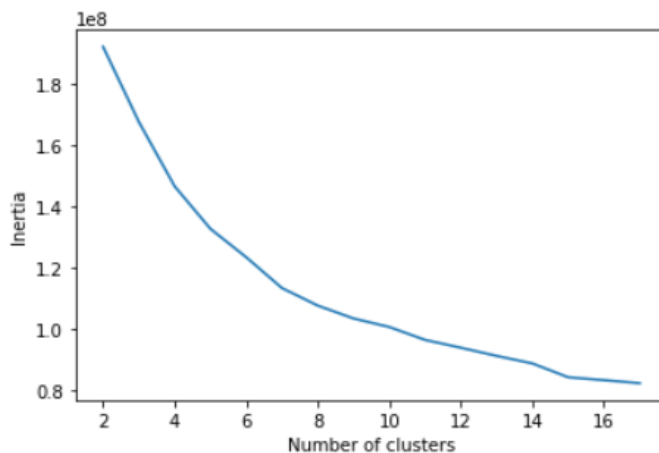


Figure 5-2. Output of K-means clustering

### 5.4. State Formation

Hourly data collected from each cell varies from zero to hundred percent, in addition to this if there is no voice or data service request in a cell for one hour period, then all counter values during that hour will be zero (this happens mostly after mid night) as shown in Figure 5-3, in this case CSSR and CDR will give  $0/0 * 100\%$  value, which is meaningless or division by zero error, so this value should be handled separately. Figure 5-3 shows one week data of RRC attempt and RAB attempt of cluster 6 from 00:00 on January 17, 2021, to 23:00 on January 23, 2021.

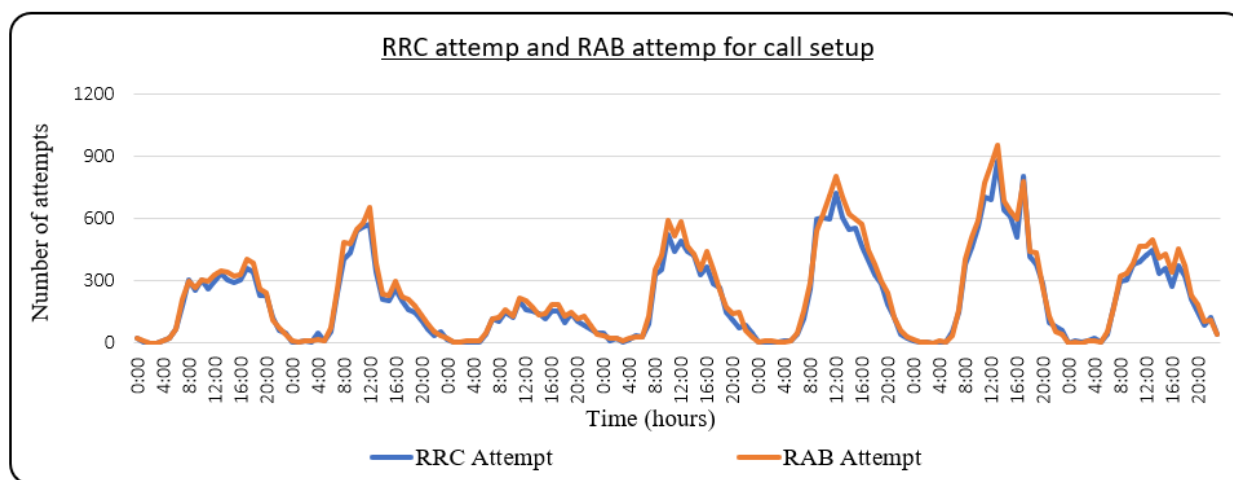


Figure 5-3. RRC and RAB attempts of cluster 6 from January 17, 2021, to January 23, 2021.

Based on the target set by the operators the network is designed and implemented to give service, and one method operators use to control the service they provide to their customers is by setting

and monitoring a set target KPI values. To achieve a highest threshold value, more resource is required. This will be uneconomical for the operators in terms of deploying and managing resources. On the other hand, if the network KPI's are below a certain threshold value, then the customers will fill the problem, and it will bring customer complaints and dissatisfaction from the service they obtained from the operator, and this leads to loss of revenue. So, the threshold value set by operators should consider these factors.

As operator ethio telecom sets a target value every year to achieve the CSSR above a certain threshold value and a CDR below a certain set threshold value. In this year the CSSR is expected to be greater than 98% and the CDR below 1%. Cells' performances vary from time to time. In general, Huawei sets a minimum threshold value to identify the worst cells ration. The minimum acceptable threshold value for CSSR is 95% and the maximum value for CDR is 3% [31].

Based on these values and the values when there is no attempt to make a call setup the following values are set as shown in Table 5-9 and Table 5-10.

*Table 5-9. Possible values of call setup attempt and CSSR*

Call setup attempt	Value	State of a cell
> 0	$CSSR \geq 98\%$	Good (G)
> 0	$95\% \leq CSSR \leq 98\%$	Acceptable (A)
> 0	$0\% \leq CSSR \leq 95\%$	Bad (B)
= 0	-	Idle (I)

*Table 5-10. Possible values of RAB setup success and CDR*

RAB setup success	Value	State of a cell
> 0	$0\% \leq CDR \leq 1\%$	Good (G)
> 0	$1\% \leq CDR \leq 3\%$	Acceptable (A)
> 0	$3\% \leq CDR$	Bad (B)
= 0	-	Idle (I)

To identify this situation the following model is used during state formation using python software, where values of A and B depends on the selected KPI parameter threshold values. For the case of accessibility, the value of A is set to 98% and the value of B is set to 95%. In the case of retainability, the value of A is set to 99% and the value of B is set to 97% as described in Table 5-9 and Table 5-10.

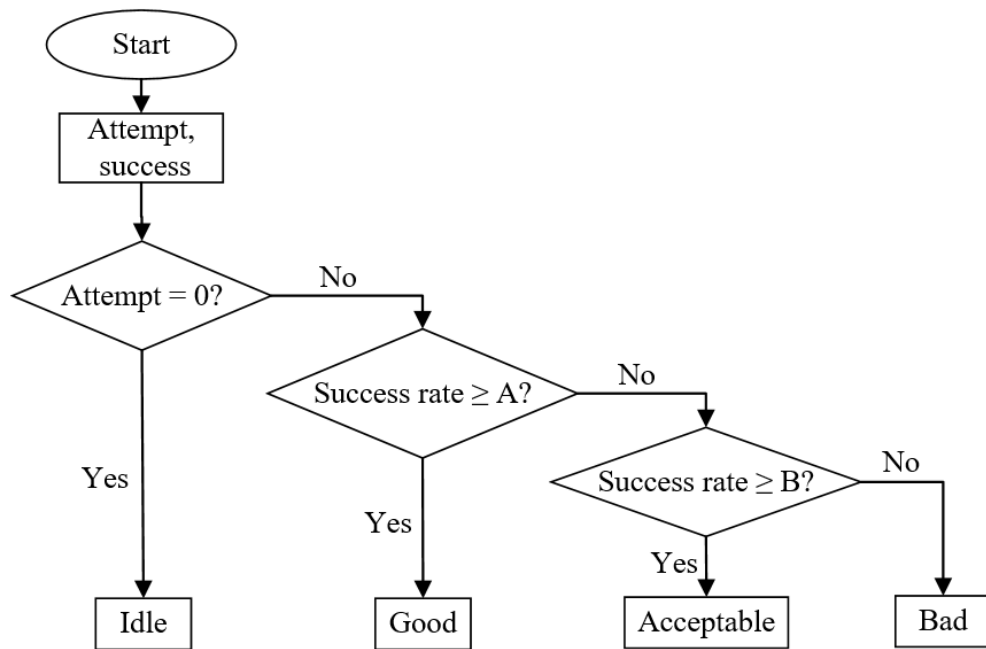


Figure 5-4. Flow chart for state formation.

Based on these set values the state of accessibility and retainability is generated.

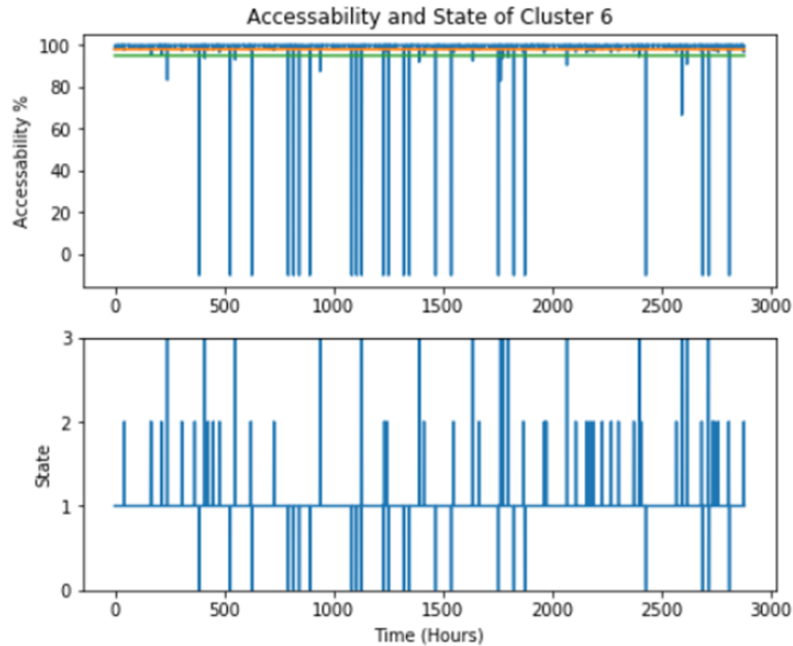


Figure 5-5. Percentage of accessibility and state of accessibility.

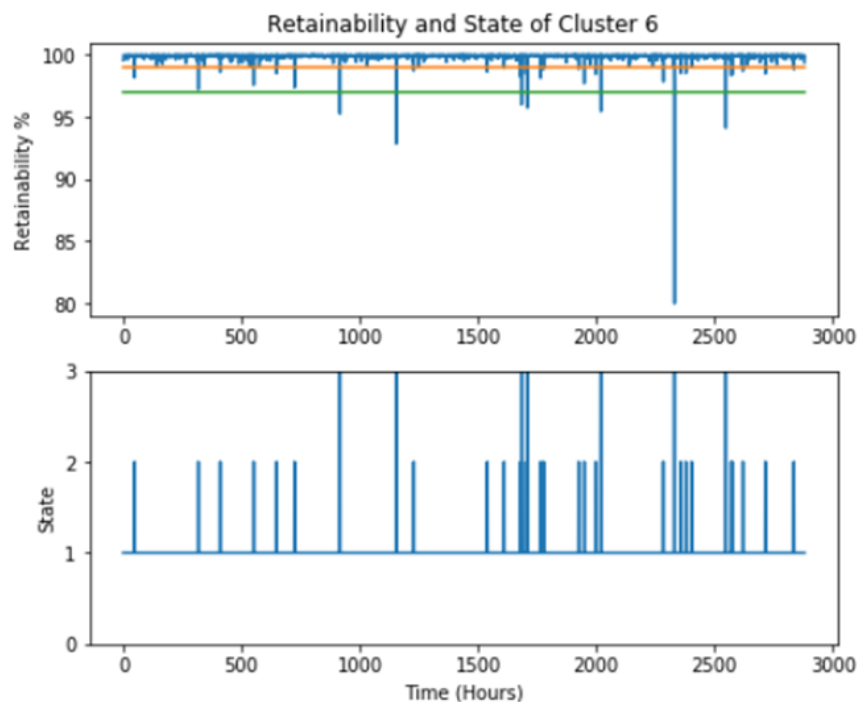


Figure 5-6. Percentage of retainability and state of retainability.

Where in Figure 5-5 and 5-6 state value: 0 means Idle state

1 means Good state

2 means Acceptable state and

3 means Bad state

## 5.5. Transition Matrix Generation

To generate a transition matrix, first the data is divided into training set and test set, so that the transition matrix will be generated using the training set. Model is evaluated using three scenarios. First 60% of the first data is used to generating a transition probability matrix and the remaining 40% is used for model validation, next 70% of the first data is used for transition probability matrix generation and the remaining 30% of the data is used for model validation, and at last 80% of the first data is used for generating the transition probability matrix and the remaining 20% of the last data is used for model validation.

Then after splitting the data into training and test set, the transition from one state to another state is counted from the training set data using python software.

[1.0],  
 [1.0], [1.0], [2.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0],  
 [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [2.0], [1.0], [1.0], [1.0], [1.0],  
 [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [1.0], [2.0]]

Figure 5-7. Sample of state output

From Figure 5-7 the data changes from 1 to 1, then from 1 to 2, then from 2 to 1, then from 1 to 1, and so on. Then these state changes will be counted and put in matrix form.

The matrix to be generated is a 4 x 4 matrix when accessibility or retainability are to be predicted separately or 16 x 16 matrix when both accessibility and retainability are to be predicted at once.

$$\begin{matrix} & \begin{matrix} \text{I} & \text{G} & \text{A} & \text{B} \end{matrix} \\ \begin{matrix} \text{I} \\ \text{G} \\ \text{A} \\ \text{B} \end{matrix} & \begin{pmatrix} \text{N}_{\text{II}} & \text{N}_{\text{IG}} & \text{N}_{\text{IA}} & \text{N}_{\text{IB}} \\ \text{N}_{\text{GI}} & \text{N}_{\text{GG}} & \text{N}_{\text{GA}} & \text{N}_{\text{GB}} \\ \text{N}_{\text{AI}} & \text{N}_{\text{AG}} & \text{N}_{\text{AA}} & \text{N}_{\text{AB}} \\ \text{N}_{\text{BI}} & \text{N}_{\text{BG}} & \text{N}_{\text{BA}} & \text{N}_{\text{BB}} \end{pmatrix} \end{matrix}$$

Figure 5-8. 4 x 4 transition probability matrix

Where:  $N_{xy}$  represents the number of counts of transitions from state x to state y

I represents that the system is in Idle state

G represents that the system is in Good state

A represents that the system is in Acceptable state and

B represents that the system is in Bad state

If both accessibility and retainability are to be predicted at once, then a 16 x 16 matrix will be used.

	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
II	N <sub>IIII</sub>	N <sub>IIIG</sub>	N <sub>IIIA</sub>	N <sub>IIIB</sub>	N <sub>IIIGI</sub>	N <sub>IIIGG</sub>	N <sub>IIIGA</sub>	N <sub>IIIGB</sub>	N <sub>IIIAI</sub>	N <sub>IIIAG</sub>	N <sub>IIIAA</sub>	N <sub>IIIAB</sub>	N <sub>IIIBI</sub>	N <sub>IIIBG</sub>	N <sub>IIIBA</sub>	N <sub>IIIBB</sub>
IG	N <sub>IGII</sub>	N <sub>IGIG</sub>	N <sub>IGIA</sub>	N <sub>IGIB</sub>	N <sub>IGGI</sub>	N <sub>IGGG</sub>	N <sub>IGGA</sub>	N <sub>IGGB</sub>	N <sub>IGAI</sub>	N <sub>IGAG</sub>	N <sub>IGAA</sub>	N <sub>IGAB</sub>	N <sub>IGBI</sub>	N <sub>IGBG</sub>	N <sub>IGBA</sub>	N <sub>IGBB</sub>
IA	N <sub>IAII</sub>	N <sub>IAIG</sub>	N <sub>IAIA</sub>	N <sub>IAIB</sub>	N <sub>IAIGI</sub>	N <sub>IAIGG</sub>	N <sub>IAIGA</sub>	N <sub>IAIGB</sub>	N <sub>IAIAI</sub>	N <sub>IAIAG</sub>	N <sub>IAIAA</sub>	N <sub>IAIAB</sub>	N <sub>IAIBI</sub>	N <sub>IAIBG</sub>	N <sub>IAIBA</sub>	N <sub>IAABB</sub>
IB	N <sub>IBII</sub>	N <sub>IBIG</sub>	N <sub>IBIA</sub>	N <sub>IBIB</sub>	N <sub>IBIGI</sub>	N <sub>IBIGG</sub>	N <sub>IBIGA</sub>	N <sub>IBIGB</sub>	N <sub>IBIAI</sub>	N <sub>IBIAG</sub>	N <sub>IBIAA</sub>	N <sub>IBIAB</sub>	N <sub>IBIBI</sub>	N <sub>IBIBG</sub>	N <sub>IBIBA</sub>	N <sub>IBIBB</sub>
GI	N <sub>GIII</sub>	N <sub>GIIG</sub>	N <sub>GIIA</sub>	N <sub>GIIB</sub>	N <sub>GIIGI</sub>	N <sub>GIIGG</sub>	N <sub>GIIGA</sub>	N <sub>GIIGB</sub>	N <sub>GIIAI</sub>	N <sub>GIIAG</sub>	N <sub>GIIAA</sub>	N <sub>GIIAB</sub>	N <sub>GIIBI</sub>	N <sub>GIIBG</sub>	N <sub>GIIBA</sub>	N <sub>GIIBB</sub>
GG	N <sub>GGII</sub>	N <sub>GGIG</sub>	N <sub>GGIA</sub>	N <sub>GGIB</sub>	N <sub>GGGI</sub>	N <sub>GGGG</sub>	N <sub>GGGA</sub>	N <sub>GGGB</sub>	N <sub>GGAI</sub>	N <sub>GGAG</sub>	N <sub>GGAA</sub>	N <sub>GGAB</sub>	N <sub>GGBI</sub>	N <sub>GGBG</sub>	N <sub>GGBA</sub>	N <sub>GGBB</sub>
GA	N <sub>GAI</sub>	N <sub>GAIIG</sub>	N <sub>GAIIA</sub>	N <sub>GAIIB</sub>	N <sub>GAIIGI</sub>	N <sub>GAIIGG</sub>	N <sub>GAIIGA</sub>	N <sub>GAIIGB</sub>	N <sub>GAIIAI</sub>	N <sub>GAIIAG</sub>	N <sub>GAIIAA</sub>	N <sub>GAIIAB</sub>	N <sub>GAIIBI</sub>	N <sub>GAIIBG</sub>	N <sub>GAIIBA</sub>	N <sub>GAIIBB</sub>
GB	N <sub>GBII</sub>	N <sub>GBIG</sub>	N <sub>GBIA</sub>	N <sub>GBIB</sub>	N <sub>GBIGI</sub>	N <sub>GBIGG</sub>	N <sub>GBIGA</sub>	N <sub>GBIGB</sub>	N <sub>GBIAI</sub>	N <sub>GBIAG</sub>	N <sub>GBIAA</sub>	N <sub>GBIAB</sub>	N <sub>GBIBI</sub>	N <sub>GBIBG</sub>	N <sub>GBIBA</sub>	N <sub>GBIBB</sub>
AI	N <sub>AII</sub>	N <sub>AIIIG</sub>	N <sub>AIIIA</sub>	N <sub>AIIIB</sub>	N <sub>AIIIGI</sub>	N <sub>AIIIGG</sub>	N <sub>AIIIGA</sub>	N <sub>AIIIGB</sub>	N <sub>AIIIAI</sub>	N <sub>AIIIAG</sub>	N <sub>AIIIAA</sub>	N <sub>AIIIAB</sub>	N <sub>AIIIBI</sub>	N <sub>AIIIBG</sub>	N <sub>AIIIBA</sub>	N <sub>AIIIBB</sub>
AG	N <sub>AGII</sub>	N <sub>AGIG</sub>	N <sub>AGIA</sub>	N <sub>AGIB</sub>	N <sub>AGGI</sub>	N <sub>AGGG</sub>	N <sub>AGGA</sub>	N <sub>AGGB</sub>	N <sub>AGAI</sub>	N <sub>AGAG</sub>	N <sub>AGAA</sub>	N <sub>AGAB</sub>	N <sub>AGBI</sub>	N <sub>AGBG</sub>	N <sub>AGBA</sub>	N <sub>AGBB</sub>
AA	N <sub>AAII</sub>	N <sub>AAIG</sub>	N <sub>AAIA</sub>	N <sub>AAIB</sub>	N <sub>AAIGI</sub>	N <sub>AAIGG</sub>	N <sub>AAIGA</sub>	N <sub>AAIGB</sub>	N <sub>AAIAI</sub>	N <sub>AAIAG</sub>	N <sub>AAIAA</sub>	N <sub>AAIAB</sub>	N <sub>AAIBI</sub>	N <sub>AAIBG</sub>	N <sub>AAIBA</sub>	N <sub>AAABB</sub>
AB	N <sub>ABII</sub>	N <sub>ABIG</sub>	N <sub>ABIA</sub>	N <sub>ABIB</sub>	N <sub>ABIGI</sub>	N <sub>ABIGG</sub>	N <sub>ABIGA</sub>	N <sub>ABIGB</sub>	N <sub>ABIAI</sub>	N <sub>ABIAG</sub>	N <sub>ABIAA</sub>	N <sub>ABIAB</sub>	N <sub>ABIBI</sub>	N <sub>ABIBG</sub>	N <sub>ABIBA</sub>	N <sub>ABIBB</sub>
BI	N <sub>BII</sub>	N <sub>BIIIG</sub>	N <sub>BIIIA</sub>	N <sub>BIIIB</sub>	N <sub>BIIIGI</sub>	N <sub>BIIIGG</sub>	N <sub>BIIIGA</sub>	N <sub>BIIIGB</sub>	N <sub>BIIIAI</sub>	N <sub>BIIIAG</sub>	N <sub>BIIIAA</sub>	N <sub>BIIIAB</sub>	N <sub>BIIIBI</sub>	N <sub>BIIIBG</sub>	N <sub>BIIIBA</sub>	N <sub>BIIIBB</sub>
BG	N <sub>BGII</sub>	N <sub>BGIG</sub>	N <sub>BGIA</sub>	N <sub>BGIB</sub>	N <sub>BGGI</sub>	N <sub>BGGG</sub>	N <sub>BGGA</sub>	N <sub>BGGB</sub>	N <sub>BGAI</sub>	N <sub>BGAG</sub>	N <sub>BGAA</sub>	N <sub>BGAB</sub>	N <sub>BGBI</sub>	N <sub>BGBG</sub>	N <sub>BGBA</sub>	N <sub>BGBB</sub>
BA	N <sub>BAII</sub>	N <sub>BAIG</sub>	N <sub>BAIA</sub>	N <sub>BAIB</sub>	N <sub>BAIGI</sub>	N <sub>BAIGG</sub>	N <sub>BAIGA</sub>	N <sub>BAIGB</sub>	N <sub>BAIAI</sub>	N <sub>BAIAG</sub>	N <sub>BAIAA</sub>	N <sub>BAIAB</sub>	N <sub>BAIBI</sub>	N <sub>BAIBG</sub>	N <sub>BAIBA</sub>	N <sub>BAABB</sub>
BB	N <sub>BBI</sub>	N <sub>BBIIG</sub>	N <sub>BBIIA</sub>	N <sub>BBIIB</sub>	N <sub>BBIIGI</sub>	N <sub>BBIIGG</sub>	N <sub>BBIIGA</sub>	N <sub>BBIIGB</sub>	N <sub>BBIIAI</sub>	N <sub>BBIIAG</sub>	N <sub>BBIIAA</sub>	N <sub>BBIIAB</sub>	N <sub>BBIIBI</sub>	N <sub>BBIIBG</sub>	N <sub>BBIIBA</sub>	N <sub>BBIIBB</sub>

Figure 5-9. 16 x 16 transition probability matrix

Where in Figure 5-9, the first letter is for accessibility state and the second letter is for retainability state, for example IG means Idle in accessibility and Good in retainability and the count  $N_{abcd}$  represents the count of transitions from state ab to state cd.

$\begin{bmatrix} 2 & 15 & 0 & 1 \\ 16 & 1647 & 15 & 6 \\ 0 & 15 & 3 & 0 \\ 0 & 7 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1697 & 11 & 4 \\ 0 & 11 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{bmatrix}$
---	---

a) Accessibility

b) Retainability

Figure 5-10. 4 x 4 transition matrix of cluster 6 generated using 60% of the dataset.

After getting the transition matrix as shown in Figure 5-10, the next step is converting the transition matrix to transition probability matrix by dividing each row by its row sum. But before doing this, the row sum must be checked. If the row sum is zero, then each zero value of that row will be converted to value one. This is done for two purposes. First to avoid division by zero, and second when the transition to the new state comes, then that new state will have equal probability to go to the other states in the next transition.

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1697 & 11 & 4 \\ 0 & 11 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{bmatrix} \qquad \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1697 & 11 & 4 \\ 0 & 11 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{bmatrix}$$

a) Before changing row values      b) After changing all zeros by one

Figure 5-11. Cluster 6 Retainability with all first row zero values in a) changed to one in b).

All the first rows of Figure 5-11 a) obtained from cluster 6 are zero, so the first row values are changed to one as shown in Figure 5-11 b) before changing it to transition probability matrix. Then the matrix will be generated by dividing each row element by its row sum and the result obtained for the above matrix will be as shown in Figure 5-12 b).

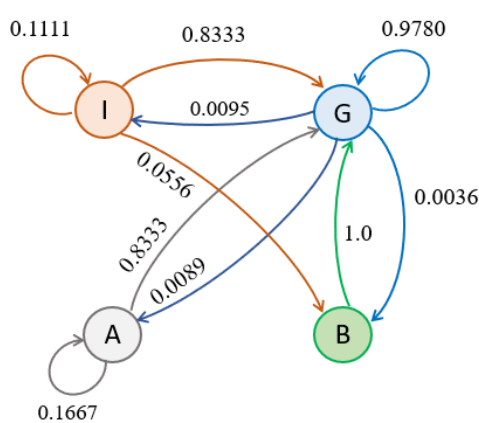
$$\begin{bmatrix} 0.11111111 & 0.83333333 & 0 & 0.05555556 \\ 0.00950119 & 0.9780285 & 0.00890736 & 0.00356295 \\ 0 & 0.83333333 & 0.16666667 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

a) Accessibility transition probability matrix of cluster 6

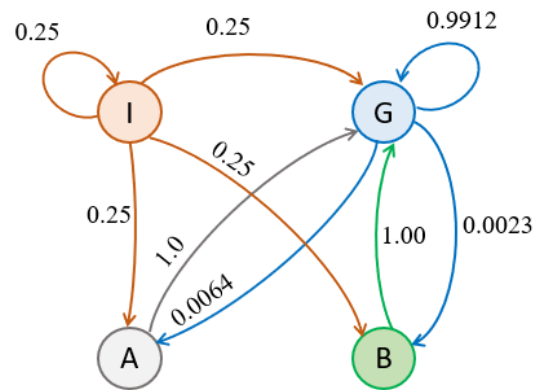
$$\begin{bmatrix} 0.25 & 0.25 & 0.25 & 0.25 \\ 0 & 0.99123832 & 0.00642523 & 0.00233645 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

b) Retainability transition probability matrix of cluster 6

Figure 5-12. Transition Probability matrix of cluster 6



a) Transition probability diagram of accessibility



b) Transition probability diagram of retainability

Figure 5-13. Transition probability diagram of Cluster 6 for accessibility and retainability.

The results of the matrix are also represented using transition probability diagram as shown in Figure 5-13 a) and b). When we see Figure 5-13 b) there is no arrow directing to state I. This tells us, state I does not exist before, meaning there is no Idle state till now, but there is a possibility to happen in the system. If an Idle state happens next to one of the three states, Good, Acceptable, or Bad state, then the probability of moving from an Idle state to the four states including itself will have equal chance.

The states shown in Figure 5-13 are for viewing accessibility and retainability separately. It is possible to identify cells performance separately for detail analysis, but if an overall picture about cells performance is required, then it is easy to handle and visualize if both accessibility and retainability states are predicted together.

	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IG	0	2	0	0	0	13	1	0	0	0	0	0	0	1	0	0
IA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
IB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GG	0	15	1	0	0	1622	8	4	0	15	0	0	0	5	1	0
GA	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0
GB	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AG	0	0	0	0	0	15	0	0	0	3	0	0	0	0	0	0
AA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BG	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
BA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
BB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-14. State transition matrix of cluster 6 for accessibility and retainability

The row values with all zero will first be changed to one for the same reason mentioned previously, so a matrix after changing row values from zero to one is shown in Figure 5-15.

	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
II	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
IG	0	2	0	0	0	13	1	0	0	0	0	0	0	1	0	0
IA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
IB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GG	0	15	1	0	0	1622	8	4	0	15	0	0	0	5	1	0
GA	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0
GB	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
AI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AG	0	0	0	0	0	15	0	0	0	3	0	0	0	0	0	0
AA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BG	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
BA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
BB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 5-15. State transition matrix of cluster 6 after changing the row values.

Then the next step will be generating the state transition probability matrix by dividing all elements of the row by its row sum. The result of the transition probability matrix of Figure 5-15 is given in Figure 5-16 to the nearest four-digit precision value.

	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
II	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
IG	0.0000	0.1176	0.0000	0.0000	0.0000	0.7647	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000	0.0000
IA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
IB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
GI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
GG	0.0000	0.0090	0.0006	0.0000	0.0000	0.9707	0.0048	0.0024	0.0000	0.0090	0.0000	0.0000	0.0000	0.0030	0.0006	0.0000
GA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
GB	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
AG	0.0000	0.0000	0.0000	0.0000	0.0000	0.8333	0.0000	0.0000	0.0000	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AA	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
AB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
BI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
BG	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625

Figure 5-16. State transition probability matrix of cluster 6.

After creating the transition probability matrix, then the next step will be predicting the next state.

## 5.6. Next State Prediction.

If either the transition probability matrix or the transition probability diagram is given, and if the current state is known, then it is simple to predict the possible next state. In Figure 5-12 a) if the current state is in Good state, then the probability of the next state will be the value of the matrix in the next row, that is [ 0.0095 0.9780 0.0089 0.0036 ] to the nearest four-digit precession. This means the system will have 0.95% probability to go to the Idle state, 97.80% probability of staying in Good state, 0.89% probability to go the Acceptable state, and 0.36% probability to go to the Bad state. The result also be obtained by multiplying the current state vector and the transition probability matrix.

$$\begin{aligned}
 & [0 \quad 1 \quad 0 \quad 0] * \begin{bmatrix} 0.1111 & 0.8333 & 0.0 & 0.0556 \\ 0.0095 & 0.9780 & 0.0089 & 0.0036 \\ 0.0 & 0.8333 & 0.1667 & 0.0 \\ 0.0 & 1.0 & 0.0 & 0.0 \end{bmatrix} \\
 & = [0.0095 \quad 0.9780 \quad 0.0089 \quad 0.0036]
 \end{aligned}$$

If the transition probability diagram is given, and if the current state is in Good state, then the next state will be visualized easily from the diagram. That is the next state probabilities are those values starting from state G indicated by a directed arrow and a probability value associated with it as shown in Figure 5-13 a). In both ways the final result is the same.

## 5.7. Prediction Results and Accuracy of the System.

The prediction accuracy of the system is evaluated based on how accurately predict the next state given the current state value. The formula used for accuracy is

$$Accuracy = \frac{Correct\ predictions}{Total\ number\ of\ examples} * 100\% \quad [40] \quad (5.4)$$

Where: “Correct predictions” is the number of counts of correctly predicted states and

“Total number of examples” is the total number of sample states used in the test set

Using Equation (5.4) the accuracy of the six clusters is evaluated. The results obtained are depicted in Table 5-11, where 60%, 70%, and 80% of the first data is used for transition probability matrix generation, and the remaining 40%, 30%, and 20% of the data are used for test purpose.

From the result, a minimum value of 96.09% prediction accuracy is achieved in cluster 2 in predicting accessibility when 60% training set is used, and 96.87% prediction accuracy is achieved in cluster 5 in predicting retainability when 80% training set is used as shown in Table 5-11, and for the case of sixteen state MC 94.61% prediction accuracy is achieved in cluster 6 in predicting both accessibility and retainability when 80% training set is used as shown in Table 5-12.

Table 5-11. Prediction accuracy of four state MC when both accessibility and retainability are predicted separately.

Cluster	Training set	Accessibility accuracy (%)	Retainability accuracy (%)
1	60%	98.78366638	99.13119027
	70%	98.37962963	98.84259259
	80%	98.08695652	98.26086957
2	60%	96.09035621	98.6967854
	70%	96.75925926	98.37962963
	80%	96.17391304	97.73913043
3	60%	98.52302346	100.0
	70%	98.49537037	100.0
	80%	98.60869565	100.0
4	60%	98.52302346	100.0
	70%	98.37962963	100.0
	80%	98.60869565	100.0
5	60%	97.7410947	98.43614248
	70%	97.33796296	97.91666667
	80%	96.17391304	96.86956522
6	60%	96.52476108	98.08861859
	70%	96.875	98.03240741
	80%	96.69565217	97.73913043

The result obtained using both accessibility and retainability with sixteen states is shown in Table 5-12.

Table 5-12. Prediction accuracy of sixteen state MC.

Cluster	Training set	Accuracy (%)
1	60%	97.82797567
	70%	97.10648148
	80%	96.17391304
2	60%	95.56907037
	70%	96.18055556
	80%	95.47826087
3	60%	98.52302346
	70%	98.49537037
	80%	98.60869565
4	60%	98.52302346
	70%	98.37962963
	80%	98.60869565
5	60%	97.04604692
	70%	96.41203704
	80%	94.7826087
6	60%	94.78714162
	70%	95.02314815
	80%	94.60869565

### 5.7.1. Comparison of Four State and Sixteen State Prediction Models.

From the results of Tables 5-11 and 5-12, the prediction accuracy using sixteen state MC is lower than a four state MC with a maximum difference of 3.3015 (98.0886 - 94.7871), this value is obtained when predicting the next state of retainability using four state MC, and accessibility and retainability prediction using sixteen state MC as shown in Table 5-13 in cluster 6. The maximum difference in next state prediction using four state accessibility prediction and sixteen state prediction is 2.0870 (96.6957 - 94.6087) on the same cluster. When we see the difference between the product of prediction accuracy of four states accessibility and retainability and a sixteen state MC, the maximum positive difference is 0.2072 (96.3811 - 96.1739) in cluster 1 and the maximum negative difference is 1.6194 (93.1633 - 94.7826) in cluster 5. This shows with minor difference it is possible to predict the accessibility and retainability of a system using only one state transition probability matrix. In general, for n number of different KPI parameters it is possible to predict the performance using four to the power of n ( $4^n$ ) number of states. For instance, if accessibility or retainability is used n will be 1 and the number of states will be four and if accessibility and

retainability are to be used then n will be two and sixteen states will be used, hence the system is used to predict one or more KPI parameters using one MC model.

*Table 5-13. Comparison of accuracy when four state MC and sixteen state MC are used.*

Cluster	Training set	Accessibility accuracy using four state MC (%)	Retainability accuracy using four state MC (%)	[(column 3 x column 4) / 100] (%)	Accessibility and retainability accuracy using sixteen state MC (%)
1	60%	98.7837	99.1312	97.9254	97.8280
	70%	98.3796	98.8426	97.2410	97.1065
	80%	98.0870	98.2609	96.3811	96.1739
2	60%	96.0904	98.6968	94.8381	95.5691
	70%	96.7593	98.3796	95.1914	96.1806
	80%	96.1739	97.7391	93.9995	95.4783
3	60%	98.5230	100.0000	98.5230	98.5230
	70%	98.4954	100.0000	98.4954	98.4954
	80%	98.6087	100.0000	98.6087	98.6087
4	60%	98.5230	100.0000	98.5230	98.5230
	70%	98.3796	100.0000	98.3796	98.3796
	80%	98.6087	100.0000	98.6087	98.6087
5	60%	97.7411	98.4361	96.2126	97.0460
	70%	97.3380	97.9167	95.3101	96.4120
	80%	96.1739	96.8696	93.1633	94.7826
6	60%	96.5248	98.0886	94.6798	94.7871
	70%	96.8750	98.0324	94.9689	95.0231
	80%	96.6957	97.7391	94.5095	94.6087

## 5.8. Steady State Prediction.

The steady state of MC depends on the transition probability matrix, and it does not depend on where the state begins, but the transition steps to reach the steady state slightly varies on where the initial state starts. This is shown in Table 5-14 for cluster 2 when 60% is used for training set and with initial states being in Idle, Good, Acceptable and Bad state with an accuracy of eight digits between the previous and next states. The next state vector  $S_{(n+1)}$  in each step is obtained by multiplying the current state  $S_{(n)}$  and the transition probability matrix P as explained in Chapter 3.

Table 5-14. Steady state computation of cluster 2 with all possible initial states.

a) Initial state being in Idle (I) state.

States of a vector	I	G	A	B
Initial state (S <sub>0</sub> )	1	0	0	0
S <sub>1</sub>	0.25000000	0.25000000	0.25000000	0.25000000
S <sub>2</sub>	0.06250000	0.76550158	0.06516588	0.10683254
S <sub>3</sub>	0.01562500	0.92593816	0.02378793	0.03464891
S <sub>4</sub>	0.00390625	0.96456910	0.01378000	0.01774465
S <sub>5</sub>	0.00097656	0.97420227	0.01126225	0.01355892
S <sub>6</sub>	0.00024414	0.97661371	0.01063255	0.01250960
S <sub>7</sub>	0.00006104	0.97721655	0.01047516	0.01224725
S <sub>8</sub>	0.00001526	0.97736725	0.01043581	0.01218167
S <sub>9</sub>	0.00000381	0.97740493	0.01042598	0.01216528
S <sub>10</sub>	0.00000095	0.97741435	0.01042352	0.01216118
S <sub>11</sub>	0.00000024	0.97741670	0.01042290	0.01216016
S <sub>12</sub>	0.00000006	0.97741729	0.01042275	0.01215990
S <sub>13</sub>	0.00000001	0.97741744	0.01042271	0.01215984
S <sub>14</sub>	0.00000000	0.97741748	0.01042270	0.01215982
S <sub>15</sub>	0.00000000	0.97741748	0.01042270	0.01215982
S <sub>16</sub>	0.00000000	0.97741749	0.01042270	0.01215982
S <sub>17</sub>	0.00000000	0.97741749	0.01042270	0.01215982

b) Initial state being in Good (G) state.

States of a vector	I	G	A	B
Initial state (S <sub>0</sub> )	0	1	0	0
S <sub>1</sub>	0.00000000	0.97867299	0.01066351	0.01066351
S <sub>2</sub>	0.00000000	0.97735058	0.01043609	0.01221334
S <sub>3</sub>	0.00000000	0.97741668	0.01042198	0.01216133
S <sub>4</sub>	0.00000000	0.97741762	0.01042269	0.01215969
S <sub>5</sub>	0.00000000	0.97741749	0.01042270	0.01215981
S <sub>6</sub>	0.00000000	0.97741749	0.01042270	0.01215981

*c) Initial state being in Acceptable (A) state.*

States of a vector	I	G	A	B
Initial state ( $S_0$ )	0	0	1	0
$S_1$	0.00000000	0.83333333	0.00000000	0.16666667
$S_2$	0.00000000	0.98222749	0.00888626	0.00888626
$S_3$	0.00000000	0.97757098	0.01047399	0.01195503
$S_4$	0.00000000	0.97740566	0.01042434	0.01217000
$S_5$	0.00000000	0.97741747	0.01042257	0.01215996
$S_6$	0.00000000	0.97741751	0.01042270	0.01215979
$S_7$	0.00000000	0.97741749	0.01042270	0.01215981
$S_8$	0.00000000	0.97741749	0.01042270	0.01215981

*d) Initial state being in Bad (B) state.*

States of a vector	I	G	A	B
Initial state ( $S_0$ )	0	0	0	1
$S_1$	0.00000000	1.00000000	0.00000000	0.00000000
$S_2$	0.00000000	0.97867299	0.01066351	0.01066351
$S_3$	0.00000000	0.97735058	0.01043609	0.01221334
$S_4$	0.00000000	0.97741668	0.01042198	0.01216133
$S_5$	0.00000000	0.97741762	0.01042269	0.01215969
$S_6$	0.00000000	0.97741749	0.01042270	0.01215981
$S_7$	0.00000000	0.97741749	0.01042270	0.01215981

In the four cases the steady state is [0.0 0.97741749 0.0104227 0.01215981], though it takes different transition states to reach the steady state, the result of the four steady states is the same. This shows that the steady state is independent of the initial state, but it depends on the transition probability matrix. From this what we observed is that wherever the current state of the network in both performance (accessibility or retainability) is, if other conditions are kept constant, like system failure is not happening, then the system will go after some transitions to its steady state value.

Table 5-15 summarizes the steady state results of the six clusters for both four state and sixteen state MC model for the 70% training set to the four-digit precision value, and almost the same result is obtained for the 60% and 80% training set values.

Table 5-15. Steady state output of each state for the case of 70% training set.

a) Steady state vector of four state MC for accessibility

Cluster	Steady state vector of accessibility			
	I	G	A	B
1	0.0000	0.9926	0.0060	0.0015
2	0.0000	0.9722	0.0149	0.0129
3	0.0000	0.9911	0.0079	0.0010
4	0.0000	0.9782	0.0179	0.0040
5	0.0000	0.9916	0.0055	0.0030
6	0.0109	0.9722	0.0114	0.0055

b) Steady state vector of four state MC for retainability

Cluster	Steady state vector of retainability			
	I	G	A	B
1	0.0000	0.9980	0.0020	0.0000
2	0.0000	0.9955	0.0035	0.0010
3	0.0000	1.0000	0.0000	0.0000
4	0.0000	0.9980	0.0020	0.0000
5	0.0000	0.9965	0.0030	0.0005
6	0.0000	0.9901	0.0079	0.0020

c) Steady state vector of sixteen state MC

Cluster	Steady state vector of accessibility and retainability															
	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
1	[ 0.0000				0.0000					0.0000						0.0000
	0.0000				0.9926					0.0000						0.0000
	0.0000				0.0040					0.0020						0.0000
	0.0000				0.0015					0.0000						0.0000 ]
2	[ 0.0000				0.0000					0.0000						0.0000
	0.0000				0.9692					0.0025						0.0005
	0.0000				0.0144					0.0005						0.0000
	0.0000				0.0119					0.0005						0.0005 ]
3	[ 0.0000				0.0000					0.0000						0.0000
	0.0000				0.9911					0.0000						0.0000
	0.0000				0.0079					0.0000						0.0000
	0.0000				0.0010					0.0000						0.0000 ]
4	[ 0.0000				0.0000					0.0000						0.0000
	0.0000				0.9782					0.0000						0.0000
	0.0000				0.0179					0.0000						0.0000
	0.0000				0.0020					0.0020						0.0000 ]
5	[ 0.0000				0.0000					0.0000						0.0000
	0.0000				0.9906					0.0010						0.0000
	0.0000				0.0050					0.0005						0.0000
	0.0000				0.0010					0.0015						0.0005 ]
6	[ 0.0000				0.0104					0.0005						0.0000
	0.0000				0.9638					0.0065						0.0020
	0.0000				0.0114					0.0000						0.0000
	0.0000				0.0045					0.0010						0.0000 ]

The steady state of MC tells us a more general information about cells. If we see Table 5-15 a), the maximum value of Good state from the six clusters is in cluster 1 with 99.26%, and the minimum value is 97.22% in cluster 2 and 6. The maximum value of Bad state is in cluster 2 with 1.29% and the minimum value is 0.1% in cluster 3. From this cluster 1 cells are performing the top in the Good state and cluster 2 cells are the top in the Bad state. Though cluster 6 cells are the least in the Good state, they are not the top in the Bad state, because next to Good state, cluster 6 cells have high probability (1.09%) of being in the Idle state, so if optimization work or maintenance work is needed the schedule and priority could be given based on the steady state vector values of each cluster.

The steady state vector also tells us about the past performance of clusters. From the same table (Table 5-15 a)) we can say that starting from the generation of the transition matrix, in this case from November 2020 up to January 2021 where the matrix is generated, cluster 1 has spent 0.0% of the time in Idle state or it has no Idle state, 99.26% of the time in Good state, 0.6% of the time in Acceptable state, and 0.15% of the time in the Bad state.

The same logic is applied for the sixteen state MC. Here is the steady state value of cluster 1 with four-digit precision value.

[0.0000 0.0000 0.0000 0.0000 0.0000 0.9926 0.0000 0.0000 0.0000 0.0040 0.0020 0.0000  
0.0000 0.0015 0.0000 0.0000]

The steady state vector tells us the following information. 99.26% of the time accessibility and retainability were both in Good state, 0.4% of the time accessibility was in Acceptable state and retainability was in Good state, 0.2% of the time accessibility and retainability were both in Acceptable state, and 0.15% of the time accessibility was in Bad state and retainability in Good state.

If we compare Bad state of cluster 5 and cluster 6, cluster 5 have 0.3% Bad state in accessibility using four state MC and 0.05% Bad state in retainability using four state MC and 0.05% Bad state in accessibility and retainability using sixteen state MC. This tells us when the performance of the retainability is bad, then the accessibility is also bad during that hour. Whereas cluster 6 have 0.55% Bad state in accessibility using four state MC and 0.2% Bad state in retainability using four state MC and 0.0% Bad state in accessibility and retainability using sixteen state MC. This tells us when accessibility is bad retainability is not bad and when retainability is bad accessibility is not bad, this means Bad state of accessibility and retainability does not occur at the same hour during the time when the data is taken.

Thus, sixteen state MC gives us the occurrence or nonoccurrence of both performance KPI values during same hour, and this information is not obtained in using four state separate MC model as we clearly see in the cases of cluster 5 and cluster 6.

Hence the Table in 5-15 c) gives us or compares cells information related to accessibility and retainability and enables the operators to sort cells that perform bad both in accessibility and retainability easily.

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## 6. Conclusion and Future Works

### 6.1. Conclusion

In this thesis, the two important KPIs namely the service accessibility performance, and the services retainability performance of cells is evaluated and predicted using MC model. Accessibility performance measures the performance of the network, and it indicates how users can easily access the service when they request a connection for voice or data service, whereas retainability performance indicates how users are served by the network without service interruption once they are connected. Most operators set a target value for KPIs and monitor whether the set value is achieved or not on daily basis. Based on the set target value, the cells performance could be good, bad, or acceptable in each hour or it could be idle, mostly during mid night.

For this research a data, which is used to calculate the accessibility and retainability of UMTS network, is collected using Huawei PRS system for a period of four months. The data comprises of AMR, R99, HSDPA, and HSUPA of Addis Ababa Arada RNC01 UMTS network and the cells in this RNC are grouped into six clusters using k means clustering.

After calculating the accessibility and retainability, the performance values are changed into Idle, Good, Acceptable, and Bad states. After counting the occurrence of transitions from state to state in a discrete time of one hour, the transition matrix is generated, then after checking the row values, the transition probability matrix is generated, then using first order MC model the next state and steady state vectors of accessibility and retainability is predicted using two approaches. In the first approach the accessibility and retainability performance of the network is assessed and evaluated using separate four state MC model, and in the second approach the accessibility and retainability performances are predicted using sixteen state MC model. During the experiment 60%, 70% and 80% of the four months data is used for MC transition probability matrix generation and the remaining 40%, 30% and 20% of the data is used for model validation, respectively. During the experiment, in a four state MC a minimum value of 96.09% prediction accuracy is achieved when predicting accessibility and 96.87% prediction accuracy is achieved when predicting retainability, and accuracy of 94.61% is achieved when predicting both accessibility and retainability using sixteen state MC model. From this result, instead of monitoring the network performance of cells

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separately using two separate MC model, it is possible to monitor and predict the cells network accessibility and retainability using single MC model. In addition to this, using the sixteen state MC model it is possible to see the steady state or predict the occurrence of Bad state at the same time in both accessibility and retainability, which we could not visualize using separate four state MC model, for further optimization work. Generally, for n number of KPI parameters it is possible to predict the performance using  $4^n$  states MC, where n starts from one.

## 6.2. Future Works

- As a future work, a general network performance prediction model, which incorporates the service integrity KPI's in addition to accessibility KPI and retainability KPI could be done for 3G, 4G networks.
- The proposed model here is used to predict performance of a network per cells cluster level. The proposed model could be used to assess the overall network performance from the CN side using CN KPI's.

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## References

- [1] GSMA, "The mobile economy 2020," GSM Association, London, 2020.
- [2] N. Marchetti, N. R. Prasad, J. Johansson and T. Cai, "Self-organizing networks: State-of-the-art, challenges and perspectives," *IEEE*, p. 7, 2010.
- [3] A. Asghar, H. Farooq and A. Imran, "Self-Healing in emerging cellular networks: Review, challenges, and research directions," *IEEE communication survey and tutorials*, vol. 20, no. 3, p. 28, 2018.
- [4] Huawei, "Enable autonomous driving network, huawei Network AI Engine (NAIE) white paper," *Huawei Technologies Co., Ltd.*, 2019.
- [5] Rec. CCITT E.800, *Maintenance philosophy for telecommunication networks*, 1993.
- [6] *iManager U2000 unified network management system*, China: Huawei Technologies Co., Ltd, 2016.
- [7] Rec. ITU-T E.804, *QoS aspects for popular services in mobile networks*, 2014.
- [8] Rec. CCITT E.800, *Quality of service and dependability vocabulary*, 1988.
- [9] A. Tolver, *An introduction to Markov Chain*, Copenhagen: University of Copenhagen, November, 2016.
- [10] H. Y. Ng, K. T. Ko and K. F. Tsang, "3G Mobile network call admission control scheme using Markov Chain," *IEEE*, p. 5, 2005.
- [11] K. Mitra, C. Ahlund and A. Zaslavsky, "QoE estimation and prediction using hidden Markov models in heterogeneous access networks," in *2012 Australasian Telecommunication Networks and Applications Conference*, Nov. 2010.
- [12] Q. Wu, M. Zhang, R. Zheng, Y. Lou and W. Wei, "A QoS-satisfied prediction model for cloud-service composition based on a Hidden Markov Model," *Hindawi*, p. 7, 2013.
- [13] V. V. Paranthaman, G. Mapp, P. Shah, H. X. Nguyen and A. Ghosh, "Exploring Markov models for the allocation of resources for proactive handover in a mobile environment," *IEEE*, p. 7, 2015.
- [14] N. A. Amirudin, S. H. S. Ariffin, N. N. N. Abd Malik and N. E. Ghazali, "Mobility prediction via Markov model in LTE Femtocell," *International Journal of Computer Applications*, p. 5, March 2013.
- [15] Y. Wang and Z. Wu, "Evaluating wireless network accessibility performance via clustering based model," *IEEE*, p. 7, 2016.
- [16] Hendrawan, "RRC success rate accessibility prediction on SAE/LTE network using Markov chain model," *IEEE*, p. 5, 2017.
- [17] Hendrawan, "Accessibility degradation prediction on LTE/SAE Network using discrete time Markov chain (DTMC) model," *ITB Journal*, vol. 13, no. 1, p. 18, 2019.

- 
- [18] A. P. Iyer, L. E. Li and I. Stoica, "Automating diagnosis of cellular radio access network problems," *MobiCom*, 2017.
- [19] E. O. Oluwafemi, O. E. Nnonye, U. Okechukwu and A. L. Adewale, "Prediction of call drops in GSM network using artificial neural network," *Jurnal Teknologi dan Sistem Komputer*, p. 10, Jan. 2019.
- [20] J. A. Akanbasiam and D. K. Ngala, "The study of quality of service on a major mobile network operator in Ghana," *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, vol. 12, no. 4, pp. 21-25, Aug. 2017.
- [21] O. O. Olayinka, S. O. Olukemi and O. Chukwuemeka, "Assessment of quality of service of mobile network operators in Akure," *International Journal of Business Administration*, vol. 10, no. 3, p. 14, 2019.
- [22] H. A. Abdulkareem, A. M. S. Tekanyi, A. Y. Kassim, Z. M. Zakariyya, M. D. Almustapha, U. F. Abdu-Aguye and H. Adamu, "Analysis of a GSM network quality of service using call drop rate and call setup success rate as performance indicators," *European Journal of Electrical Engineering*, p. 10, March 2020.
- [23] A. R. Mishra, *Advanced cellular network planning and optimization*, England: John Wiley & Sons Ltd., 2007.
- [24] H. Kaaranen, A. Ahtiainen, L. Laitinen, S. Naghian and V. Niemi, *UMTS networks architecture, mobility and services*, Second ed., England: John Wiley & Sons, 2005.
- [25] H. Holma and A. Toskala, *WCDMA for UMTS radio access for third generation mobile communication*, Third ed., England: John Wiley & Sons, 2004.
- [26] A. R. Mishra, *Cellular technology for emerging markets 2G, 3G and beyond*, United Kingdom: John Wiley & Sons, 2010.
- [27] A. Othman, "3G optimization & drive test analysis," [Online]. Available: [https://www.academia.edu/34137161/3G\\_Optimization\\_and\\_Drive\\_Test\\_Analysis](https://www.academia.edu/34137161/3G_Optimization_and_Drive_Test_Analysis). [Accessed 29 May 2021].
- [28] ETSI TS 123 107, *Digital cellular telecommunications system*, vol. V10.1.0, 2011-06.
- [29] J. Lempiäinen and M. Manninen, *UMTS radio network planning optimization and QoS management*, Dordrecht: Kluwer academic publishers, 2004.
- [30] "Measuring mobile network performance: coverage, quality of service and maps," *Fratel*, p. 36, January 2020.
- [31] *Huawei KPI References*, Shenzhen: Huawei Technologies Co. LTD, 2012.
- [32] Huawei Technology Co, [Online]. Available: <https://fdocuments.in/document/02-wcdma-kpi.html>. [Accessed 10 May 2021].
- [33] *HUAWEI RAN KPI for performance management (RNC V100R006)*, China: Huawei Technologies Co., Ltd, 2006.
- [34] N. O. Chikezie, O. E. Maureen and E. E. Uchenna, "Fuzzy logic implementation for enhanced WCDMA network using selected KPIs," *Advances in science, technology and engineering systems*, vol. 4, p. 11, 2019.
-



- 
- [35] U. Porod, Dynamics of Markov chains for undergraduates, February 19, 2021.
- [36] N. Privault, Understanding Markov chains, Singapore: Springer, 2013.
- [37] C. M. Salgado, C. Azevedo, H. Proença and S. M. Vieira, "Missing data," in *Secondary analysis of electronic health records*, Switzerland, Springer International Publishing, 2016, pp. (pp.143-162).
- [38] W. J. Lammers and P. Badia, Fundamentals of behavioral research, 2021.
- [39] S. S. Santos, D. Y. Takahashi, A. Nakata and A. Fujita, *A comparative study of statistical methods used to identify dependencies between gene expression signals*, Oxford University Press, 2013.
- [40] "Machine Learning Glossary," [Online]. Available: <https://developers.google.com/machine-learning/glossary#multi-class>. [Accessed May 2021].

# Appendex 1.

# Markov Chain for Network Accessibility and Retainability Prediction: An Approach Towards Self Organizing Networks

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**Abstract**—To deliver reliable services to customers, mobile network operators monitor performance of their radio access network (RAN) and core network using different performance parameters or indicators. A typical mobile network has hundreds of counters. However, collecting and analyzing all parameters is a resource (in time, manpower, computational capacity, and cost) intensive undertakings. So, operators monitor selected key performance indicators (KPIs) and monitor them on daily, weekly, or monthly bases, to identify faults or anomalous events that can significantly degrade quality of service delivery and end-users experience. KPIs are clustered to measure network performance like accessibility, retainability, mobility, integrity, and availability. Moreover, taking corrective actions based on monitored parameters is a reactive approach and contributes to network and service degradations until corrective actions are taken. With huge investment mobile network operators implement network management systems (NMS) that monitor network performance data, and with of upgrade can analyze possible trends and patters about the network and services. So, a systematic way of monitoring and predicting the network performance status is required to guaranty service quality. In this work, we propose Markov chain to predict network accessibility and retainability, two important RAN performance parameters. The steps involved in this work are comprised of collecting real time KPI data for four months in hourly basis of a major mobile network operator and then designing a probabilistic cells state prediction model. The results demonstrate that the proposed methods can achieve 94.61% prediction accuracy. The approach can be extended to predict other network performance parameters and can serve as an input towards developing self organizing radio access network system.

**Keywords**— *Accessibility, Retainability, Markov chain*

## I. INTRODUCTION

Nowadays the demand for reliable mobile network services is increasing, and it is expected to increase in the coming years. To accommodate this increasing demand and keep up with reliable service requirements, network operators expand their networks and monitor the radio access network (RAN) and core network with centralized network management system (NMS). NMS is a collection of tools for network monitoring and control. While the actual functionalities of NMS are requirement and vendor dependent, fault management and performance management are two critical aspects of the system, so as to achieve error free network and keep up with service requirements. Fault management enables fault detection (by generating alarms), isolation of the rest of the network from the failure so that it can continue to function without interference, and correction

of abnormal operation by repairing or replacing the failed components.

Performance management of a network comprises of monitoring and controlling. Monitoring is the function that tracks activities on the network. The controlling function enables performance management to make adjustments to improve network performance. Some of the performance issues of concern to the network manager are: identifying level of capacity utilization, traffic monitoring, status of throughput, status of response time and the like.

Though the NMS provides necessary information using different management subsystems, managing the data obtained from the system and taking remedial actions on time is the challenging problem for most operators. So, operators monitor selected key performance indicators (KPIs) and monitor them on daily, weekly or monthly bases, to identify faults or anomalous events that can significantly degrade quality of service delivery and end-users experience. KPIs are clustered to measure network performance like accessibility, retainability, mobility, integrity, and availability.

Advancements in data mining techniques contribute to analyze possible trends and patters from historic network performance data collected via NMS. So a systematic way of monitoring and predicting the network performance status is required to guaranty service quality.

In this work, we propose Markov chain (MC) to predict network accessibility and retainability, two important RAN performance parameters. According to International Telecommunication Unions' (ITU) definition service accessibility performance is defined as "The ability of a service to be obtained, within specified tolerances and other given conditions, when requested by the user", and service retainability performance as "The ability of a service, once obtained, to continue to be provided under given conditions for a requested duration"[1].

Markov model is a powerful statistical tool that could be applied to component diagnostics, prognostics, and maintenance optimization in the telecom industry [2]. Many researchers have used Markov model to optimize the network service and operation and maintenance (O&M) activities. There are many processes in communication system that can be modeled and studied with the help of Markov model. Some application areas of Markov model includes like call admission control [3], quality of experience (QoE) prediction [4], quality of service (QoS) prediction [5], efficient resource utilization [6], and mobility prediction [7].

The main objective of this paper is to use real time data available from a major network operator to predict the accessibility and retainability state of Universal Mobile Telecommunication System (UMTS) network. MC is used for network status prediction, and the approach is generalizable to other generation of networks. In order to arrive at the task, here are the specific tasks that are performed.

- Identify and collect relevant key network parameters for accessibility and retainability data from NMS.
- Taking ITUs recommendations on different states of accessibility and retainability, we identified the states and state transitions and then computed the state transition matrix (TM) from the collected data. The MC formulation is per cell level and separate matrices are formulated for the accessibility and retainability. Given the initial distribution of the states (which could mean the current state of the network), subsequent transitions of the states indicate the status of the network in the subsequent time slots. The state transitions help to assess network performance or predict worst performing cells in terms of accessibility and retainability for close monitoring and future actions like fault diagnosis, optimization or network expansion.
- Scaling the MC formulation to analyze multiple cells was an issue. Instead of replicating the operation as much the number of cells, K-mean clustering is used to identify related cells. Then the MC is formulated per cluster level.
- Finally, both the accessibility and retainability are formulated at once. This approach helps to provide the status of both via a single operation.

We hope that the results of this research output provide significant insight on the predicted performance of the network from accessibility and retainability point of view. Specifically, given the current state of the network, the model can help to predict, in probability sense, the state/health/dynamics by identifying cells that perform below the expected threshold value during the subsequent time slots until steady state is reached. The results can help to take corrective actions for maintenance team, which reduces the workload on employees, or are good inputs to take further optimization or expansion work.

The remaining of the paper is organized as follows. Section II will present review of related works. Section III discusses basic concepts and formulas used in accessibility and retainability. Section IV presents the methodology used. Section V introduces some basic concepts of MC. Section VI presents the results obtained and discussion part. Finally, section VII concludes this paper.

## II. RELATED WORKS

To evaluate the accessibility performance of a network clustering based method is proposed in [8]. It is used to identify a comfortable zone where accessibility is high, and this enables to detect when accessibility begins to degrade. The aim is to predict the performance of cells in cluster, and performance per cell level is not considered, in addition radio access bearer (RAB) performance is used where the effect of radio resource controller (RRC) is not considered to predict the accessibility performance. To predict RRC setup success

rate of Long-term Evolution (LTE) network a discrete time MC (DTMC) model is proposed in [9]. RRC success rate of cells is categorized into Good, Moderate, and Bad state and the state of a cell will be predicted using DTMC. In [10] a DTMC model is used to predict accessibility of LTE network using call setup success rate (CSSR) KPI. The states of cells are categorized into High, Acceptable, and Low state. In [9] & [10] three state MC is used, and the model is developed considering these three states are existed. The presence of Idle state which could exist in some cells mostly during non-busy hours (after mid night ) in addition to these three states is not considered. A cell could have a minimum of one state and a maximum of four states, but the author does not show how to handle these different situations. After classifying RAN performance parameters into event based and non-event or volume based metrics, the work in [11] uses bearer level RAN parameters to predict the performance of a network. In the work, decision tree is used for event based metrics, and regression model is used for non-event based metrics. The model helps to predict the performance of a network after the establishment of a bearer, in addition only access network problems are taken whereas user equipment (UE) related problems are not considered. In [12] artificial neural network (ANN) is used to predicts the call drops in Global System for Mobile (GSM) network using five QoS parameters. Since frame error rate (FER) and Timing advance parameters are related to GSM network, the system is applicable only to GSM network, in addition, the system predicts the occurrence and non-occurrence of a call drop for a specific UE based on the selected five parameters. Network capacity, CSSR, call drop rate (CDR), and bet error rate (BER) parameters are used in [13] to evaluate second generation (2G) and third generation (3G) network performance of a network. To evaluate and compare the performance of 2G service provided by different operators, RxLevel, RxQuality, CSSR, CDR, and handover success rate performance parameters are used in [14]. In addition to these five parameters, questioner is also used to assess users' level of satisfaction, then the effect of QoS on the customers satisfaction is examined using regression analysis method. In [15] CSSR and CDR KPIs are used to evaluate 2G network in different geographical areas. The aim of [13], [14], and [15] is only to assess the performance of the network from accessibility, retainability and other performance parameters, hence prediction of performance is not done.

In this work we propose a model to predict accessibility or retainability of a network using four state (Idle, Good, Acceptable and Bad) MC. The model also enables to predict the performance of n number of KPI parameters using  $4^n$  state MC. The  $4^n$  state MC handles all possible scenarios starting from a cell having only one state to a maximum of  $4^n$  states of a cell.

## III. ACCESSABILITY AND RETAINABILIT KPI'S

### A. Accessibility

To manage and follow the performance of a network, KPIs could be categorized into accessibility, retainability, integrity, mobility and likes [16]. Accessibility measures the network performance during a call setup procedure or before a bearer is established [17]. RRC, RAB, and Enhanced-Universal Terrestrial RAN RAB (ERAB) and CSSR are essential accessibility parameters and are presented below.

- RRC setup success rate (RRC SSR) evaluates the call success rate in a cell or cluster. The formula for this KPI is shown as.

$$RRC\ SSR = (a/b) * 100\% \quad (1)$$

where  $a = \sum$  Number of RRC setup success

$b = \sum$  Number of RRC connection attempt

" $\sum$ " is used to represent the summation of voice and data service counter values.

- RAB setup success rate (RAB SSR) evaluates the success rate of assigning a RAB during a call setup procedure. The formula for this KPI is given as.

$$RAB\ SSR = (c/d) * 100\% \quad (2)$$

where  $c = \sum$  Number of RAB setup success

$d = \sum$  Number of RAB setup attempt.

- CSSR is used to evaluate the call setup success at the cell or cluster level. This KPI is calculated based on RRC SSR and RAB SSR for the case of 3G and ERAB SSR for the case of LTE.

$$CSSR = (a/b) * (c/d) * 100\% \quad (3)$$

$$Accessibility = CSSR \quad (4)$$

#### B. Retainability

- Retainability performance measures the performance of a network after RAB is established. It indicates the percentage of calls that serve the requested service without call drop.
- CDR is used to measure the percentage of calls dropped after a RAB is established.

$$CDR = (e/f) * 100\% \quad (5)$$

where  $e = \sum$  Number of RAB abnormal release

$f = \sum$  Total number of RAB release

$$Retainability = (100\% - CDR) \quad (6)$$

#### IV. METHODOLOGY

The methodology used for accessibility and retainability state prediction is shown in Fig. 1.

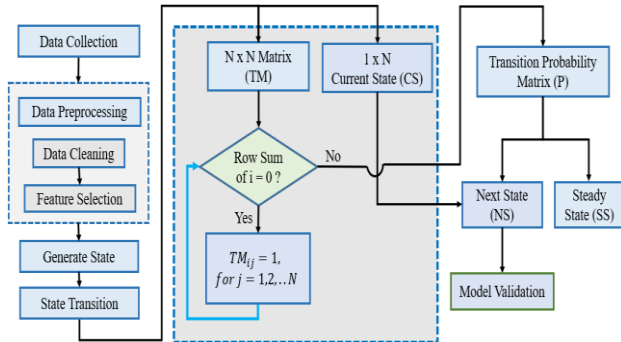


Fig. 1. System model for state prediction.

Real time data is collected from NMS per cell level and the data is preprocessed before state formation. The processed data will then be first converted into defined state, then these

states and the transition from one state to another state is counted, then the counted states will then be transformed into TM, then after converting each zero value to one in those rows whose row sum is zero, then the TM is changed into transition probability matrix (TPM), then using MC model, the next state will be predicted, and the steady state of the system is also calculated. Finally, the model is validated based on the accuracy of the system to predict the next state.

#### V. MARKOV CHAIN

MC is named after Andrey Andreyevich Markov (1856-1922), a Russian mathematician. MC is a stochastic process satisfying Markov property.

MC is mainly classified into two based on when the state  $X(t)$  changes, these are DTMC and continuous time MC (CTMC). In the case of DTMC the transition from one state to another state will take place only at specific instance of time, whereas in the CTMC the transition between two states could take place at any arbitrary time.

##### A. Discrete time Markov chain

A DTMC is characterized by a state space  $X(t)$ , a time  $t$  when  $X(t)$  changes, and a TPM  $P$  (also called transition probabilities). Markov property states that, next state depends only on the current state [2]. Mathematically

$$P(X(n) = i_n | X(n-1) = i_{n-1}, \dots, X(0) = i_0)$$

$$P(X(n) = i_n | X(n-1) = i_{n-1}) \quad (7)$$

Based on the set of values of the random variables  $X(n)$ , an MC could be discrete state space, in this case the state spaces will be  $\{X_0, X_1, X_2, \dots\}$ , or it is called finite state if the set of values of the random variables are finite set  $\{X_0, X_1, \dots, X_n\}$

An MC is called time-homogeneous if the transition probabilities  $P_{ij}$  are independent of time  $t$ , that is

$$P_{ij} = P(X(n+1) = j | X(n) = i, X(n-1) = i_{n-1}, \dots, X(0) = i_0)$$

$$P_{ij} = P(X(n+1) = j | X(n) = i) \quad (8)$$

##### B. Elements of Markov chains

A DTMC is mainly expressed using TPM, transition probability diagram (TPD), and steady state vector  $\pi$ .

- Transition probability matrix

A TPM  $P$  comprises of all the transition probabilities in the MC. Each element in the matrix represents the probability of a state moving from one state to another.

If the state space  $S$  is  $\{1, 2, 3, \dots, n\}$ , then the TPM  $P$  will be an  $n \times n$  square matrix, where  $n$  is the number of states of an MC. Fig. 2 shows TPM of four state MC.

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}$$

Fig. 2. Four state TPM

An  $n \times n$  TPM  $P$  must satisfy the following properties [2].

- i) The value of each transition probability  $p_{ij}$  must be greater or equal to zero.

$$P_{ij} \geq 0, \text{ for all } i, j = 1, 2, 3, \dots, n \quad (9)$$

- ii) The summation of all transition probabilities in a row must be equal to one.

$$\sum_{j=1}^n p_{ij} = 1, \text{ for all } i = 1, 2, 3, \dots, n \quad (10)$$

- *Transition probability diagram*

A TPM could also be represented using a TPD. In this representation a directed graph is used as shown in Fig. 6 a). In the graph each node represents the state of an MC, and that specific state is represented by a number or letter inside a circle. A directed arrow is used to represent the presence of transition from one state to another, where the tail represents the current state, and the head indicates the next state. On top of this directed arrow there is a number which indicates the probability of moving from current state to next state [18].

- *Steady state vector*

Once we have a TPM, given any initial vector  $\pi_0$ , the next state vector  $\pi_1$  will be obtained by multiplying the initial vector  $\pi_0$  and  $P$ .

$$\pi_1 = \pi_0 * P \quad (11)$$

After two state transitions,

$$\begin{aligned} \pi_2 &= \pi_1 * P \\ \pi_2 &= (\pi_0 * P) * P = \pi_0 * P^2 \end{aligned} \quad (12)$$

If we continue, we will reach at some point, where  $\pi_{n-1} = \pi_n$

$$\pi_{n-1} = \pi_0 * P^{n-1} \quad (13)$$

$$\pi_n = \pi_0 * P^n \quad (14)$$

This value  $\pi_n$  is called the steady state vector  $\pi$ .

## VI. RESULTS AND DISCUSSIONS

In this section, the processes from data collection to system state prediction of accessibility or retainability using four state MC model and prediction of accessibility and retainability using sixteen state MC model will be presented.

### A. Data collection

To evaluate the model a real world four months data are collected using performance report system (PRS) from 1530 cells of ethio telecom Addis Ababa RNC01 UMTS network on hourly basis from Nov. 2020 to Feb. 2021. The data contain counter values to calculate accessibility and retainability of UMTS network. The counters are collected from adaptive multi rate (AMR), release 99 (R99), high speed downlink packet access (HSDPA), and high speed uplink packet access (HSUPA) systems in CSV format. Per cell level data contains date, time, cell ID, cell availability rate, and all necessary counters to calculate accessibility and retainability.

The data collected from PRS system can miss values, this could happen due to cell outage or connectivity problem between a cell and central radio network controller (RNC). Missing values are filled using linear interpolation or padding technique.

### B. Accessibility and retainability

After missing values are filled, then accessibility is calculated using (4) and retainability is calculated using (6).

In the case of accessibility, number of RRC setup success and attempt values are the summation of AMR, R99, HSDPA, and HSUPA values. Similarly, number of RAB setup success and attempt values are the summation of AMR, R99, HSDPA, and HSUPA values.

In the case of retainability, the number of RAB abnormal release and total number of RAB release values are the summation of AMR, R99, HSDPA, and HSUPA values.

### C. State formation

Hourly data of accessibility or retainability will have a value from zero to hundred percent. In addition to this, if there is no voice or data service attempt in a cell for one hour period, then all counter values during this period will be zero as shown in Fig. 3, as a result the values in (4) and (6) will give division by zero error value, hence this situation is handled separately, and the state of accessibility or retainability in this case will be Idle without calculating (3) and (5) for CSSR and CDR values respectively as shown in Fig. 4.

One week RRC attempt and RAB attempt values of cluster 6 is shown in Fig. 3, and both values will have zero value during mid-night.

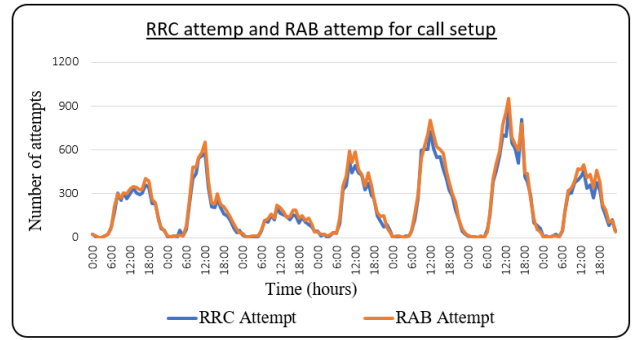


Fig. 3. One week RRC and RAB attempt of cluster 6

Operators set threshold values for different KPI parameters considering different conditions. Capital expenditures (CAPEX) and operational expenses (OPEX) on one side, and QoS and satisfaction of customers on the other side are some of the two extreme conditions to be considered, so operators should set a threshold value considering at least these two scenarios.

Table I and Table II shows a threshold value used for accessibility and retainability of the operator.

TABLE I. POSSIBLE VALUES OF CALL SETUP ATTEMPT AND CSSR

Call setup attempt	Value	State of a cell
> 0.0	CSSR $\geq$ 98.0%	Good (G)
> 0.0	95.0% $\leq$ CSSR $\leq$ 98.0%	Acceptable (A)
> 0.0	0.0% $\leq$ CSSR $\leq$ 95.0%	Bad (B)
= 0.0	-	Idle (I)

TABLE II. POSSIBLE VALUES OF RAB SETUP SUCCESS AND CDR

RAB setup attempt	Value	State of a cell
> 0.0	0.0% $\leq$ CDR $\leq$ 1.0%	Good (G)
> 0.0	1.0% $\leq$ CDR $\leq$ 3.0%	Acceptable (A)
> 0.0	3.0% $\leq$ CDR	Bad (B)
= 0.0	-	Idle (I)

A model shown in Fig. 4 is used for state formation, where values of A and B depend on KPI values. For instance in the case of accessibility, the value of A is set to 98.0% and the value of B is set to 95.0%, and for retainability the value of A is set to 99.0% and the value of B is set to 97.0% as depicted in Table I and Table II.

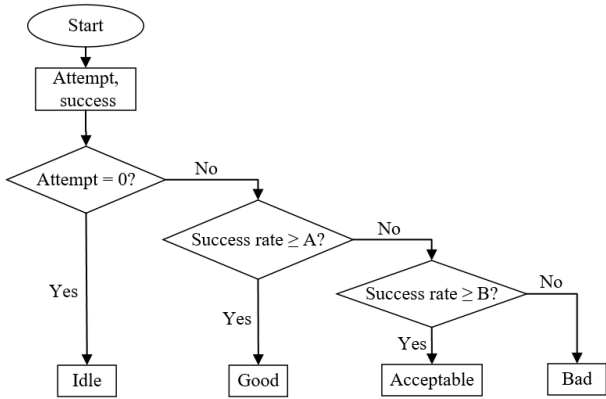


Fig. 4. Flow chart for state formation

Based on these set values the state of accessibility and retainability is generated. State formation of accessibility of cluster 6 is shown in Fig. 5. Here values with zero attempt are first changed to -10% before calculating the accessibility value, so that the state of -10% will be Idle.

In the state value of Fig. 5, state value 0 is used for Idle state, 1 for Good state, 2 for Acceptable state, and 3 for Bad state.

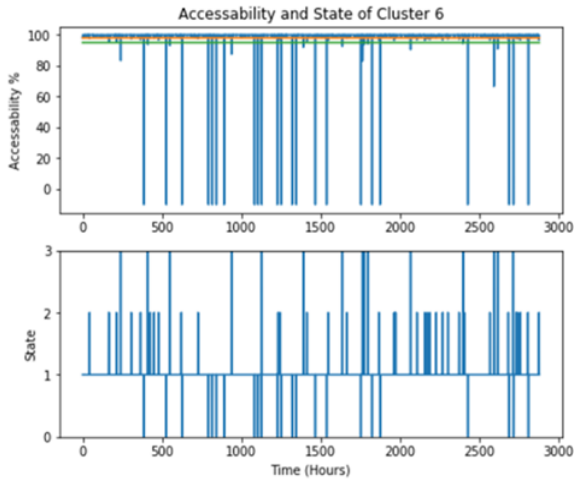


Fig. 5. Percentage of accessibility and state of accessibility

#### D. Transition probability matrix

To generate a matrix, the data is first divided into training set and test set. That is first 60%, 40% data separation is used, meaning 60% of the data is used to generate a TPM and the remaining 40% is used for model validation. Next 70%, 30% combination is used and last 80%, 20% combination is used.

The TM is generated by counting the transition from one state to another in the training data, then a four state MC is generated to predict accessibility or retainability separately using separate MC model and a sixteen state MC is used to predict accessibility and retainability together. A matrix of four state MC is shown in Fig. 6 b).

After creating a matrix as shown in Fig. 7, the next step will be checking the summation of each row. As shown in Fig. 7 b), the summation of the first row is zero. Therefore all zero values of that row must be converted to one as shown in Fig. 8 b). This is done for two purposes. First to avoid division by zero, second when a transition to the new state comes, then it will have equal probability to go to the other states in the next transition.

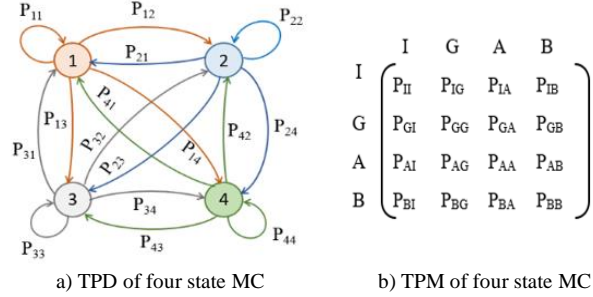


Fig. 6. Four by four transition matrix

$\begin{bmatrix} 2 & 15 & 0 & 1 \\ 16 & 1647 & 15 & 6 \\ 0 & 15 & 3 & 0 \\ 0 & 7 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1697 & 11 & 4 \\ 0 & 11 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{bmatrix}$
a) TM of accessibility	b) TM of retainability

Fig. 7. 4 x 4 matrix of cluster 6 generated using 60% training date.

$\begin{bmatrix} 2 & 15 & 0 & 1 \\ 16 & 1647 & 15 & 6 \\ 0 & 15 & 3 & 0 \\ 0 & 7 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1697 & 11 & 4 \\ 0 & 11 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{bmatrix}$
a) Accessibility	b) Retainability

Fig. 8. Values of Fig. 7 b) with all zero row value changed to one.

Then a matrix is generated by dividing each row value by its row sum and the result obtained for the above matrix rounded to the fourth decimal place is shown in Fig. 9.

$\begin{bmatrix} 0.1111 & 0.8333 & 0.0000 & 0.0556 \\ 0.0095 & 0.9780 & 0.0089 & 0.0036 \\ 0.0000 & 0.8333 & 0.1667 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 & 0.0000 \end{bmatrix}$	$\begin{bmatrix} 0.2500 & 0.2500 & 0.2500 & 0.2500 \\ 0.0000 & 0.9912 & 0.0064 & 0.0023 \\ 0.0000 & 1.0000 & 0.0000 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 & 0.0000 \end{bmatrix}$
a) Accessibility	b) Retainability

Fig. 9. TPM of cluster 6

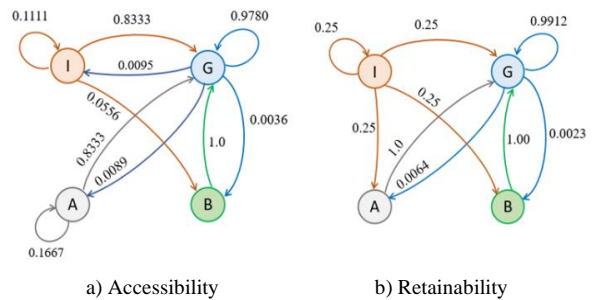


Fig. 10. TPD of cluster 6

The result of the matrix could also be presented using TPD as shown in Fig. 10. In the case of Fig. 10 b) there is no arrow directing to state I, this tells us, state I does not exist, meaning there is no Idle state till now, but there is a possibility to happen in the system. If an Idle state happens next to one of the three states, Good, Acceptable, or Bad state, then the

probability of moving from an Idle state to the four states including itself will have an equal chance.

The matrix shown in Fig. 9 is for TPD of four state MC to predict accessibility or retainability separately. Using this method, it is not possible to visualize the occurrence of both states, for instance the occurrence of Bad state in accessibility and Bad state in retainability at the same time. Using sixteen state MC model as shown in Fig. 12 this problem is resolved and the overall performance of a cell in terms of accessibility and retainability is visualized.

### E. State prediction

After creating the TPM and knowing the current state, the next state as well as the steady state is predicted using (11).

If the current state is in Good state, then the value of  $\pi_0$  will be

$$\pi_0 = [I \ G \ A \ B] = [0 \ 1 \ 0 \ 0]$$

Then using (11), the next state  $\pi_1$  is computed, the result is shown in Fig. 11.

$$\begin{aligned} [0 \ 1 \ 0 \ 0] * \begin{pmatrix} 0.1111 & 0.8333 & 0.0000 & 0.0556 \\ 0.0095 & 0.9780 & 0.0089 & 0.0036 \\ 0.0000 & 0.8333 & 0.1667 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 & 0.0000 \end{pmatrix} \\ = [0.0095 \ 0.9780 \ 0.0089 \ 0.0036] \end{aligned}$$

Fig. 11. Next state of accessibility of cluster 6 when current state is in Good state

From the result the system will have 0.95% probability to go to the Idle state, 97.80% probability of staying in Good state, 0.89% probability to go the Acceptable state, and 0.36% probability to go to the Bad state as shown in Fig. 11.

The steady state is obtained using (11) and computing iteratively until the next state value and previous state value are equal as stated in (13) & (14). In the experiment python software is used to iterate till the next state and the previous state values are equal to the eighth decimal place. The result of the steady state for the case of four state MC is shown in Table III for accessibility and Table IV for retainability,

	II	IG	IA	IB	GI	GG	GA	GB	AI	AG	AA	AB	BI	BG	BA	BB
II	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
IG	0.0000	0.1176	0.0000	0.0000	0.0000	0.7647	0.0588	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000	0.0000
IA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
IB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
GI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
GG	0.0000	0.0090	0.0006	0.0000	0.0000	0.9707	0.0048	0.0024	0.0000	0.0090	0.0000	0.0000	0.0000	0.0030	0.0006	0.0000
GA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
GB	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
AG	0.0000	0.0000	0.0000	0.0000	0.0000	0.8333	0.0000	0.0000	0.0000	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AA	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
AB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
BI	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
BG	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BA	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BB	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625

Fig. 12. Sixteen state TPM of cluster 6

whereas Table V shows the steady state of cluster 1 using sixteen state MC. The results in Table III, Table IV, and Table V are given to the fourth decimal place and the TPM is generated using 70% training set.

The steady state of MC tells us a more general information about cells. If we see Table III, the maximum value in Good state from the six clusters is 99.26% in cluster 1, and the minimum value is 97.22% in cluster 2 and 6. The maximum value of Bad state is 1.29% in cluster 2 and the minimum value is 0.1% in cluster 3. From these cluster 1 cells are the top in the Good state and cluster 2 cells are the top in the Bad state. Though cluster 6 cells are the least in the Good state, they are not the top in the Bad state, because next to Good state, cluster 6 cells have high probability (1.09%) of being in the Idle state, so if optimization work or maintenance work is needed the schedule and priority should be given based on the steady state vector values of each cluster.

The steady state vector also tells us about the past performance of each cluster. For instance, from Table III, when we see the first 70% of the data set were the TPM is generated, in this case from Nov. 2020 up to Jan. 2021, cluster 1 has spent 0.0% of the time in Idle state or it has no Idle state, 99.26% of the time in Good state, 0.6% of the time in Acceptable state, and 0.15% of the time in the Bad state.

The same logic is applied for the 16 state MC. The steady state result of cluster 1 is shown in Table V. The first letter represents for accessibility and the second for retainability. From the result, 99.26% of the time accessibility and retainability were both in Good state, 0.4% of the time accessibility was in Acceptable state and retainability was in Good state, 0.2% of the time accessibility and retainability

TABLE III. STEADY STATE VECTOR OF ACCESSIBILITY USING 4 STATE MC

Cluster	Steady state vector of accessibility			
	I	G	A	B
1	0.0000	0.9926	0.0060	0.0015
2	0.0000	0.9722	0.0149	0.0129
3	0.0000	0.9911	0.0079	0.0010
4	0.0000	0.9782	0.0179	0.0040
5	0.0000	0.9916	0.0055	0.0030
6	0.0109	0.9722	0.0114	0.0055

TABLE IV. STEADY STATE VECTOR OF RETAINABILITY USING FOUR STATE MC

Cluster	Steady state vector of retainability			
	I	G	A	B
1	0.0000	0.9980	0.0020	0.0000
2	0.0000	0.9955	0.0035	0.0010
3	0.0000	1.0000	0.0000	0.0000
4	0.0000	0.9980	0.0020	0.0000
5	0.0000	0.9965	0.0030	0.0005
6	0.0000	0.9901	0.0079	0.0020

TABLE V. STEADY STATE VECTOR OF CLUSTER 1 USING SIXTEEN STATE MC

Cluster	Steady state vector			
	[ II IG IA IB GI GG GA GB AI AG AA AB BI BG BA BB ]			
1	[ 0.0000 0.0000 0.0000 0.0000			
	0.0000 0.9926 0.0000 0.0000			
	0.0000 0.0040 0.0020 0.0000			
	0.0000 0.0015 0.0000 0.0000 ]			

were both in Acceptable state, and 0.15% of the time accessibility was in Bad state and retainability in Good state. Hence the table gives us or compares the cells information related to accessibility and retainability and enables the operators to sort cells that perform bad both in accessibility and retainability or any combination of accessibility and retainability easily.

#### F. Evaluation Metrix

Using (15) [19] the accuracy of a model is evaluated based on the percentage of accurately predicting the next state given the current state. From the result a minimum value of 96.09% prediction accuracy is achieved in cluster 2 in predicting accessibility when 60% training set is used, and 96.87% prediction accuracy is achieved in cluster 5 in predicting retainability when 80% training set is used, and for the case of sixteen state MC 94.61% prediction accuracy is achieved in cluster 6 in predicting both accessibility and retainability when 80% training set is used as shown in Table VI.

$$Accuracy = \frac{Correct\ predictions}{Total\ number\ of\ examples} * 100\% \quad (15)$$

TABLE VI. PREDICTION ACCURACY

Cluster	Training set	Accuracy of accessibility using 4 state MC (%)	Accuracy of retainability using 4 state MC (%)	Accuracy of accessibility and retainability using 16 state MC (%)
1	60%	98.7837	99.1312	97.8280
	70%	98.3796	98.8426	97.1065
	80%	98.0870	98.2609	96.1739
2	60%	96.0904	98.6968	95.5691
	70%	96.7593	98.3796	96.1806
	80%	96.1739	97.7391	95.4783
3	60%	98.5230	100.0000	98.5230
	70%	98.4954	100.0000	98.4954
	80%	98.6087	100.0000	98.6087
4	60%	98.5230	100.0000	98.5230
	70%	98.3796	100.0000	98.3796
	80%	98.6087	100.0000	98.6087
5	60%	97.7411	98.4361	97.0460
	70%	97.3380	97.9167	96.4120
	80%	96.1739	96.8696	94.7826
6	60%	96.5248	98.0886	94.7871
	70%	96.8750	98.0324	95.0231
	80%	96.6957	97.7391	94.6087

#### VII. CONCLUSION

In this thesis, two important KPI's states are predicted using four state MC and sixteen state MC model. A state is created based on threshold values set by operators. Cells performance state could be Good, Bad, or Acceptable in each hour or it could be Idle, mostly during mid-night, based on set value of operators.

Four months UMTS network data is collected and grouped into six clusters. Using MC model next state and steady state of six clusters is computed separately using four state MC and together using sixteen state MC. During the experiment, in a four state MC a minimum value of 96.09% prediction accuracy is achieved in predicting accessibility and 96.87% prediction accuracy is achieved in predicting retainability, and accuracy of 94.61% is achieved in predicting both accessibility and retainability using sixteen state MC. From this it is possible to monitor and predict any combination of KPIs using 4<sup>n</sup> states, where n is the number of KPIs. This helps to see every combination of states and sort out cells which perform worst in terms of these n KPI values easily.

Though the model is tested using UMTS network, it is applicable to predict the state of other generation of networks.

#### REFERENCE

- [1] International Telecommunication Union, "Quality of service and dependability vocabulary," The International Telegraph and Telephone consultative Committee, vol. E.800, no. ITU, p. 16, 1988.
- [2] A. Tolver, An introduction to Markov Chain, Copenhagen: University of Copenhagen, November, 2016.
- [3] H. Y. Ng, K. T. Ko and K. F. Tsang, "3G Mobile network call admission control scheme using Markov Chain," IEEE, p. 5, 2005.
- [4] K. Mitra, C. Ahlund and A. Zaslavsky, "QoE estimation and prediction using hidden Markov models in heterogeneous access networks," in 2012 Australasian Telecommunication Networks and Applications Conference, November, 2010.
- [5] Q. Wu, M. Zhang, R. Zheng, Y. Lou and W. Wei, "A QoS-satisfied prediction model for cloud-service composition based on a Hidden Markov Model," Hindawi, p. 7, 2013.
- [6] V. V. Paranthaman, G. Mapp, P. Shah, H. X. Nguyen and A. Ghosh, "Exploring Markov models for the allocation of resources for proactive handover in a mobile environment," IEEE, p. 7, 2015.
- [7] N. A. Amirrudin, S. H. S. Ariffin, N. N. N. Abd Malik and N. E. Ghazali, "Mobility prediction via Markov model in LTE Femtocell," International Journal of Computer Applications, p. 5, March 2013.
- [8] Y. Wang, "Evaluating wireless network accessibility performance via clustering based model," IEEE, p. 7, 2016.
- [9] Hendrawan, "RRC success rate accessibility prediction on SAE/LTE network using Markov chain model," IEEE, p. 5, 2017.
- [10] Hendrawan, "Accessibility degradation prediction on LTE/SAE Network using discrete time Markov chain (DTMC) model," ITB Journal, vol. 13, no. 1, p. 18, 2019.
- [11] A. P. Iyer, L. E. Li and I. Stoica, "Automating diagnosis of cellular radio access network problems," MobiCom, 2017.
- [12] E. O. Oluwafemi, O. E. Nnonye, U. Okechukwu and A. L. Adewale, "Prediction of Call Drops in GSM Network using Artificial Neural Network," Jurnal Teknologi dan Sistem Komputer, p. 10, Jan. 2019.
- [13] J. A. Akanbasiam and D. K. Ngala, "The study of quality of service on a major mobile network operator in Ghana," IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), vol. 12, no. 4, pp. 21-25, Aug. 2017.
- [14] O. O. Olayinka, S. O. Olukemi and O. Chukwuemeka, "Assessment of quality of service of mobile network operators in Akure," International Journal of Business Administration, vol. 10, no. 3, p. 14, 2019.
- [15] H. A. Abdulkareem, A. M. S. Tekanyi, A. Y. Kassim, Z. M. Zakariyya, M. D. Almustapha, U. F. Abdu-Aguye and H. Adamu, "Analysis of a GSM network quality of service using call drop rate and call setup success rate as performance indicators," European Journal of Electrical Engineering, p. 10, March 2020.
- [16] ETSI TS 132 410 version 9.0.0 Release 9, ETSI, 2010.
- [17] HUAWEI RAN KPI for Performance Management (RNC V100R006), China: Huawei Technologies Co., Ltd, 2006.
- [18] U. Porod, Dynamics of Markov chains for undergraduates, February 19, 2021.
- [19] "Machine Learning Glossary," [Online]. Available: <https://developers.google.com/machine-learning/glossary#multi-class>. [Accessed May 2021].