ANALYSIS AND MODELING OF INTERCONNECTION COSTS IN TELECOMMUNICATIONS BASED ON A CASE STUDY OF TANZANIA

John Andrew Mpapalika

A thesis submitted in partial fulfillment of the requirements of London Metropolitan University

for the degree of

Doctor of Philosophy

December 2012

Declaration

This thesis was written to support my Doctor of Philosophy (Ph.D) research degree studied at the London Metropolitan University in the United of Kingdom (U.K). It does not support any other degree or qualification of this or any other university, or other institution of learning.

The ideas and work developed in this thesis were originated by the author and represent his own thinking and not any other person or position of the organization he works for.

Acknowledgements

I wish to thank first and foremost to my Director of studies Professor AlgirdasPakstas for his directions, valuable discussions and co-operation throughout this research.I also wish to thank my 1st supervisor Dr. RomasMikusauskas and 2nd supervisor Dr. Dimitrious Stasinopoulos for their valuable discussions and lastly, I wish to thank to my wife Gladness and children Jane, Andrew, Joshua and Robinson for their patience and understanding during all the time that I spent working on this research.

The Author

In 1983, John Andrew Mpapalika, graduated his B.Sc. in Electronic and Communications Engineering from the London Metropolitan University (then North London Polytechnic). He has achieved a wide range of work experience and professional training in the field of telecommunications engineering, policy and regulations. He worked with the Tanzania Telecommunications Company Limited (TTCL) in his country (Tanzania) for 17 years. In September 1998, he joined the Tanzania Communications Regulatory Authority (TCRA) as the Director of Telecommunications Development. In November 2004, he left Tanzania for London and enrolled as a student on an MPhil/PhD programme in the field of telecommunications engineering with the London Metropolitan University. In December 2006, he completed successfully his MPhil programme and upgraded to Ph.D. In May 2011, he got a job with the International Telecommunication Union (ITU) as a Senior Advisor for the Southern Africa based in Harare ITU Area Office.

Abstract

This PhD thesis is concerned with research for the analysis and modeling of interconnection costs in telecommunications based on a case study of Tanzania. The research formed the basis for recommending the review of the current interconnection charges. Chapter 1 of the thesis started to introduce the United States of America's (USA) Reform Act of 1996,which was the first Act in the world that liberalised the telecommunications markets and opened them up to competition in the USA. The competition brought up interconnection of telecommunications networks and associated costs, which is the focus of the research. Chapter 2 provided for the design and architecture of the interconnection of telecommunications networks in the liberalized and competitive telecommunications markets in terms of types of interconnection models, interconnection components, types of services, interconnection costs and call route types and factors. In chapter 3 the thesis presented the telecommunications development in Tanzania from 1888 to date covering the period of the monopoly era where there was no interconnection of the telecommunications networks and the post-monopoly era where there is interconnection of the telecommunications networks.The chapter also presented the growth of the mobile networks over time in terms of number of mobile phones and mobile density. Chapter 4 discussed charging principles, call routing and operations of the international roamingand non-international roaming servicesreferred to as the One Network concept, which was launched simultaneously in East Africa (Tanzania, Kenyaand Uganda) by the Zain GSM mobile network operator for the first time in the world on 26th September, 2006. Review of the existing generic interconnection cost models developed by the British Telecommunications Company Limited and Europe Economics'Consulting Firm was presented in Chapter 5. The review formed the basis for collecting data from Tanzania. Chapter 6 presented the analysis of the data collected from Tanzania.The analysis revealed that the interconnection costs per minute for the five competitive telecommunications network operators for 2007-2009 were far below the interconnection charges per minute set by the Tanzania Communications Regulatory Authority for the same period. Chapter 7 concluded that the interconnection charges per minute for the telecommunications industry in Tanzania for2007-2009 have been set over and above the interconnection costs per minute obtained from the analysis of the collected data. The research reviewed the existing generic interconnection cost models mentioned above and identified the interconnection cost estimation methods. The research then collected audited operators' accountsand traffic throughput in minutes from the five competitive telecommunications network operators in Tanzania for 2007-2009. It analysed the dataand gave results,which showed a big percentage difference of an average of at least 300% between the interconnection costs obtained from the analysis of the collected data and the interconnection charges set by the Regulator. The research results have justified insufficient interconnection regulations currently used by the Regulator in Tanzania. Hence, the need for the objective and accurate interconnection cost estimation methodology for setting up the cost based interconnection charges have been confirmed by this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Abbreviations

AIM	Adaptable Interconnection Model
ASL	Application Service Licence
AT&T	American Telegraph and Telephone
AUC	Authentication Centre
BOT	Bank of Tanzania
BSC	Base Station Controller
BT	British Telecommunications
BTS	Base Transceiver Station
CAMEL	Customized Application for Mobile network Enhanced Logic
CAPEX	Capital Expenditure
CAPM	Capital Asset Pricing Model
CCK	Communications Commission of Kenya
CCSS No.7	Common Channel Signaling System No.7
CCTLD	Country Code Top Level Domain
CDMA	Code Division Multiple Access
CEIR	Central Equipment Identification Register
CERT	Computer Emergency Response Team
CLF	Converged Licence Framework
CSL	Content Service Licence
EAC	East African Community
EACO	East African Communications Organisation
EACSO	East African Common Services organisation
EAP&TC	East African Posts and Telecommunications Corporation
EASSy	East African Submarine cable System
EC	European Commission
EDGE	Enhanced Data rate for GSM Evolution
EIR	Equipment Identification Register
EPOCA	Electronic Postal and Communications Act
ERG	European Regulatory Group
ERP	Economic Recovery Programme
EU	European Union
FAC	Fully Allocated Costs
FCi	Fixed Call initiator/originator

FCr	Fixed Call recipient/terminator
FDC	Fully Distributed Costs
FO1	Fixed Operator network 1
FO2	Fixed Operator network 2
GATS	General Agreement on Trade in Services
GDP	Growth Domestic Product
GPRS	General Packet Radio Services
GSM	Global System for Mobile communications
HSPDA	High Speed Packet Downlink Access
ICASA	Independent Communications Authority for South Africa
ICT	Information and Communications Technology
IMT-2000	International Mobile Telecommunication-2000
IN	Intelligent Network
IP	Internet Protocol
IRP	Integrated Road Project
ISD	International Subscriber Dialing
ITU	International Telecommunication Union
LE	Local Exchange
(LE-TE)le	Local Exchange to Tandem Exchange transmission length
(LE-TE)li	Local Exchange to Tandem Exchange transmission link
LRIC	Long Run Incremental Costs
MCi	Mobile Call initiator/originator
MCr	Mobile Call recipient/terminator
MDF	Main Distribution Frame
MEA	Modern Equivalent Asset
MMS	Multimedia Message System
MO1	Mobile Operator network 1
MO2	Mobile Operator network 2
MSC	Mobile Switching Center
MSI	Mobile System International
NFL	Network Facility Licence
NMS	Network Management System
NRA	National Regulatory Authority
NTP	National Telecommunication Policy

OPEX	Operating Expenditure
PCS	Personal Communications System
PDH	Pleiosynchronous Digital Hierarchy
PMG	Postal Master General
PSTN	Public Switched Telephone Network
RDF	Rural Development Fund
RON	Rest of Other Networks
RSU	Remote Switching Unit
(RSU-LE)le	Remote Switching Unit to Local Exchange Transmission length
(RSU-LE)li	Remote Switching Unit to Local Exchange Transmission link
SAC	Stand Alone Costs
SMP	Significant Market Power
SMS	Short Message System
SMSC	Short Message System Controller
TCC	Tanzania Communications Commission
TCRA	Tanzania Communications Regulatory Authority
TCW	Twisted Copper Wires
(TE-TE)le	Tandem Exchange to Tandem Exchange Transmission length
(TE-TE)li	Tandem Exchange to Tandem Exchange Transmission link
TP&TC	Tanzania Postal and Telecommunications Corporation
TPC	Tanzania Postal Corporation
TRAI	Telecommunications Regulatory Authority of India
TTCL	Tanzania Telecommunications Company Limited
UCAF	Universal Communications Access Funds
USA	United States of America
VHE	Virtual Home Environment
VLR	Visitor Location Register
VMS	Voice Mail System
WACC	Weighted Average Cost of Capital
WLL	Wireless Local Loop
WTO	World Trade Organisation

Chapter1. Introduction

The Telecommunications Reform Act of 1996 in the United States of America (USA) [FCCO1996] resulted in liberalization and deregulation of the USA telecommunications markets. Most other countries around the world followed it. The telecommunications markets have changed with new entrant operators (often mobile) and incumbent fixed telecommunications network operators by having obligations to interconnect their networks [FCCO].

1.1. Telephone Calls Involving Interconnections and Related Issues

Call scenario involving interconnection and associated costs between a new entrant operator's mobile network and incumbent fixed operator's network is shown in Fig. 1.1. At first, a person from the new entrant operator's mobile network makes a call to a person who is a subscriber of another operator of the incumbent fixed network. The call is sent from the new entrant operator's mobile network to the incumbent fixed operator's network via the *interconnection link*. The calling person pays the new entrant mobile network operator a *retail tariff* for originating and sending a call to the person belonging to the incumbent fixed network operator. At second, the new entrant mobile network operator pays the incumbent fixed network operator part of the retail tariff received from the calling person as interconnection charges for *terminating* the call.

This scenario shows only one possible mobile to fixed interconnection known as *fixed termination*from Mobile Call initiator/originatorto Mobile Operator network1 to Fixed Operator network1 to Fixed Call recipient/terminator (MCi → MO1 → FO1 → FCr); that is;the fixed network operator charges the mobile network operator for terminating a call from the mobile network on the fixed network.Even if the scenario presents on new mobile operators (service providers), it is not only Mobile to Fixed interconnection, but also Fixed to Mobile interconnection, Mobile to Mobile interconnection and fixed tofixed interconnection:

- Fixed to mobile interconnectionknown as *mobile termination,*this scenariomeans the interconnection from Fixed Call initiator/originator to Fixed Operator network1 to Mobile Operator network1 to Mobile Call recipient/terminator(FCi → FO1 → MO1 → MCr);that is, the mobile network operator charges the fixed network operator for terminating a call from the fixed network on the mobile network;

- Mobile to mobile interconnectionknown as *mobile termination,*this scenario means the interconnection from the Mobile Call initiator/originator to Mobile Operator network1to Mobile Operator network2to Mobile Call recipient/terminator (MCi $\rightarrow$ Mo1 $\rightarrow$ Mo2 $\rightarrow$ MCr); that is, the mobile network operator charges another mobile network operator for terminating the call from the mobile network on the mobile network;

- Fixed to fixed interconnection known as *fixed termination,* this scenario means the interconnection from the Fixed Call initiator/originator to Fixed Operator network1 to Fixed Operator Network2 to Fixed Call recipient/terminator (FCi $\rightarrow$ FO1 $\rightarrow$ FO2 $\rightarrow$ FCr); that is,the fixed network operator charges another fixed network operator for terminating a call from the fixed network on the fixed network.

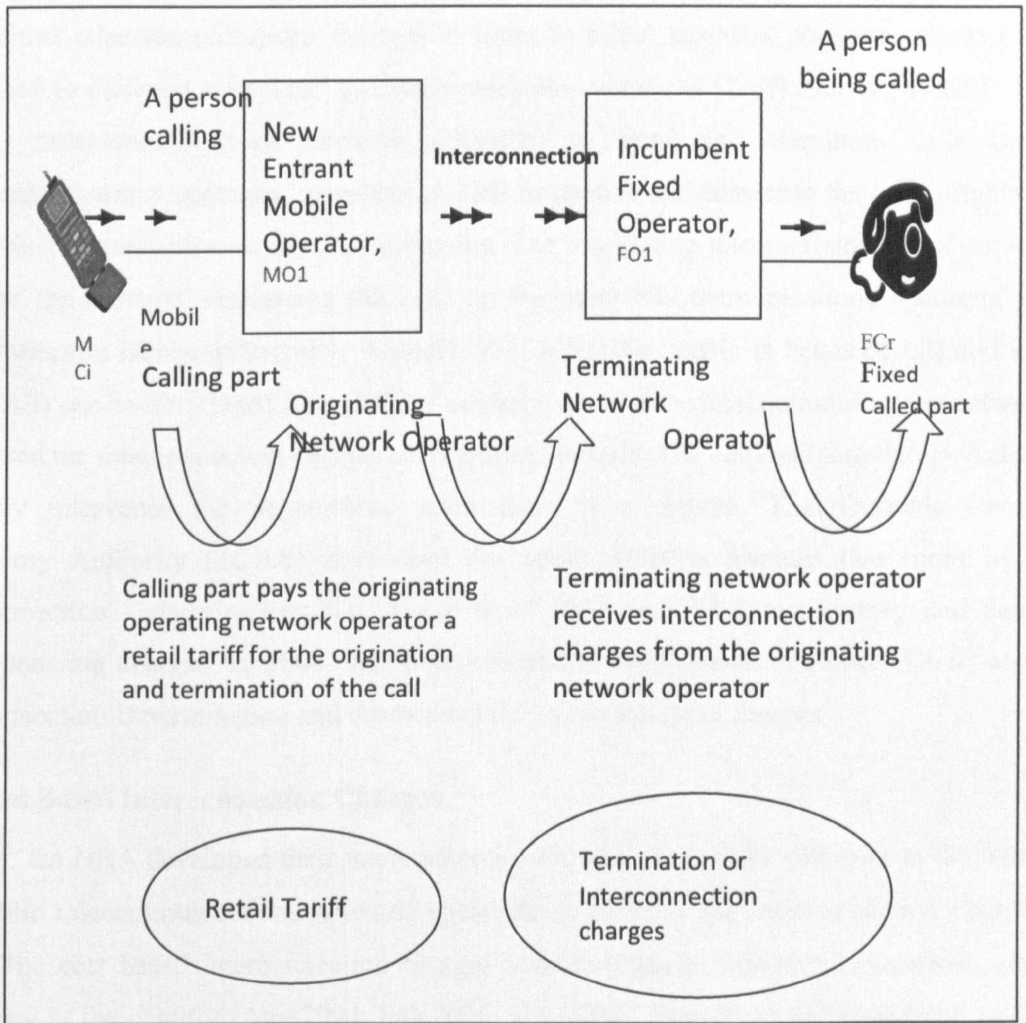


Figure 1.1. Calls involving interconnection scenario between a new entrant operator's mobile network and incumbent fixed operator's network.

The following notations are defined below:

MCi -Mobile call initiator/originator;

MO1- Mobile operator network 1;

Mo2 – Mobile operator network 2;

MCr – Mobile call recipient/terminator;

FCi – Fixed call initiator/originator;

FO1 – Fixed operator network 1;

FO2 – Fixed operator network 2;

FCr – Fixed call recipient/terminator.

The calls involving the interconnection scenarios are therefore essential in the liberalized and competitive telecommunications markets in order to allow seamless communications of subscribers connected to different operators' telecommunications networks [Laff1996, Lapu1999]. This scenario enables telecommunications network operators to send and terminate calls on the other telecommunications operators' networks as well as receive and terminate the calls originated from the other telecommunications operators' networks. The originating telecommunications network operator pays for the costs of terminating the calls on the other telecommunications operators' networks as *interconnection charges*[Cart1999, Walker1997]. When the traffic is balanced bill and keep (Sender Keeps All) can be introduced [Jong2008].Currently, most of the telecommunications network operators negotiated the interconnection charges on commercial basis. The National Regulatory Authority (NRA) normally intervenes the negotiation, when there is a dispute. The Tanzania Communications Regulatory Authority (TCRA) intervened the interconnection disputes two times by issuing the Interconnection Determinations No. 1 and 2 of 2004 and 2007 respectively and determined the interconnection charges. In 2004, the Communications Commission of Kenya (CCK) also issued the Interconnection Determination and determined the interconnection charges.

1.2. Cost Based Interconnection Charges

Usually, the NRA developed their interconnection regulations in most countries in the world requiring the public telecommunications network operators to estimate the interconnection charges based on costs. The cost based interconnection charges usually promote effective competition and economic efficiency in the country [Anyi2004, Falc2004, Stov2004]. The effective competition ensures that the new telecommunications network entrants access the existing network facilities on conditions that enable them to compete effectively with the incumbent telecommunications network operators with the *Significant Market Power (SMP)* [Grube1999, Falch2004].

However, the methodology for estimating the cost based interconnection charges in the most part of the world is still subjective. This indicates that most of the National Regulatory Authorities in the world have been experiencing difficulties to address the question of how to estimate the interconnection charges based on the costs [Arms1998, Gill2004]. In February 1998, the World Trade Organization (WTO) issued the Fourth Protocol of the General Agreement on Trade in Services (GATS), which required the fixed Public Switched Telephone Network (PSTN) operators with the Significant Market Power to address the question of estimating the cost based interconnection charges in their networks on the basis of transparency [Melo2002, Cave2004].

The European Commission (EC) issued the directive requiring the European Union (EU) Member States to estimate accurately and reliably the cost based interconnection charges in their networks as specified by the World Trade Organisation [Euec2002]. In 2002, the European Commission also issued to the European Union Member States the "best practice" cost based interconnection charges (see Table 1.1), which benchmarked the interconnection charges from the three lowest charged EU Member States. The EU Member States adopted them as an interim solution pending for the completion of the interconnection cost studies in the European Union Member States.

Table 1.1.The EU best practice benchmarked interconnection charges for 2002 for the fixed PSTN.

Interconnection services	Interconnection charges in euro per minute
Local level	0.40-0.70
Single tandem	0.70-1.20
Double tandem	1.20-1.44

There are three categories of fixed interconnection (traffic termination) over Public Switched Telephone Networks:

- **Local level**: when the Point of Interconnection is in the local exchange to which the destination end-User is directly connected;
- **Single Tandem:** when the Point of Interconnection is in the Tandem (Transit) exchange, to which the local switch of the end User is directly connected;
- **Double Tandem:** when the Point of Interconnection is in a Tandem (Transit) exchange that does not interconnect to the local switch to which the destination end User is directly connected. The Traffic must be routed over (at least) another Tandem or Transit exchange before being

sent to the destination local exchange.

The EC commissioned the consulting firm from the United Kingdom (UK) called the Europe Economics to conduct the interconnection cost study for the PSTN in the EU Member States.

The consulting firm conducted the interconnection study and developed an Adaptable Interconnection Model (AIM) for the EU member States. This model estimated the Long Run Incremental Costs (LRIC) of fixed interconnection services for the PSTN in the EU Member States [Euec2002]. These costs as presented in Chapter 5 formed the basis to replace the EU best practice benchmarked interconnection charges in Table 1.1. The British Telecommunications Company Limited developed a top-down LRIC model for her own internal use [Brte2005].

1.3. Aim and Objectives of this Research Project

The aim of this research project is to adapt the chosen existing interconnection cost model to the Tanzania case study by specifying the following particular objectives:

- Identifyaccurate interconnection cost estimation methods;
- Establish cost based interconnection charges;
- Introduce effective and reliable interconnection charges.

1.4. Research Questions and Hypotheses

This project focused on the following sets of research questions relating to the objectivity, reliability, transparency, competitiveness, effectiveness and universality of the current interconnection charges:

- How objective and effective are the current interconnection charges in Tanzania?
- Are they based on costs?
- Can they be applied universally?
- What changes should be applied, if any, for the interconnection charge estimation method to particular regions/ market situations?
- How to develop the objective interconnection cost estimation methods with the use of field data in a focused case study?

The following hypotheses guided this research to achieve the said above objectives:

- Interconnection cost estimation methodsdrive down interconnection charges;
- Network related costs form cost based interconnection charges;

- Interconnect traffic throughput in minutes is attributed to the interconnection cost estimation methods.

1.5. Research Methodology and Case Study in Tanzania

The research used the top-down cost modeling and forward looking Long Run Incremental costing (LRIC) methodologies to estimate the interconnection costs. The top-down cost modeling methodology referred to the use of the company's actual cost data for determining the interconnection costs. The LRIC methodology referred to the use of the directly attributable network related costs. The network related costs include the following:

- Network related Capital Expenditure (CAPEX);
- Network related Operating Expenditure (OPEX);
- Weighted Average Cost of Capital (WACC).

These expenditures were sourced from annual audited accounts for 2007-2009 from four competitive GSM mobile network operators (Vodacom, Zain, TIGO and Zantel) and one fixed telecommunications network operator called the Tanzania Telecommunications Company Limited (TTCL) and presented in Chapter 6.

The annual audited accounts were collected from the Tanzania Communications Regulatory Authority (TCRA).

The forward looking refers to the use of current costs of the modern efficient available technology. In Tanzania, the Second Generation (2G) Global System for Mobile (GSM) communications technologies operating at the 900MHz and 1800MHz for voice traffic is still the modern efficient mobile technology in the country and its current costs are taken as part of the forward looking costs.

The interconnect traffic throughput in minutes for the five competitive telecommunications network operators for 2007-2009 were calculated by dividing the interconnection revenue sourced from the operators' audited accounts by the interconnection charges per minute set by the regulator of the corresponding year and presented in Chapter6. The costs per minute interconnect traffic throughput known as unit interconnection costs for the same competitive telecommunications network operators of the same period (2007-2009) were estimated and presented in Chapter6. The unit interconnection costs for 2007-2009 were then compared by the interconnection charges per minute set by the Regulator for the same period and found that they were far below the interconnection charges per minute set by the Regulator.

Subscriber data, which is the main driver for the traffic throughput was collected from the Regulator TCRA. The number of mobile subscriptions increased rapidly from 110,518 in 2000 to 17,469,486 in December 2009(see Fig.37). The fixed line subscriptions increased gradually from 173,663 in 2000 to 172,922 in December 2009. [TCRA2011]. The growth of the mobile networks in terms of the number of mobile phones was analyzed mathematically by using the Gompertz model. The analysis finds that the growth of the mobile networks will overtake the population of Tanzania in January 2021 when the number of the mobile phones is 55,840,060.

The analysis of the growth of the mobile phones also shows that the potential mobile market will be reached at the mobile- density 112% in January 2035 when the number of mobile phones is 79,736,619. The analysis intends to inform policy makers, regulators, operators and other stakeholders in Tanzania to prepare appropriate contingent network roll-out plan to match with the growth of the mobile networks.

The mobile-density rose from 0.33% at a population of 33,463,388in 2000 to 40.01% at a population 43,476,204in December 2009(see Fig.3.8). The share of the mobile market in Tanzania; that is, the number of mobile phones to total phones (fixed and mobile) was 99.2% in December 2010. This means, the mobile phones in Tanzania have been becoming increasingly the dominant means for accessing the communications.

The study reviewed the existing generic interconnection cost models developed by the British Telecommunications Company Limited, and the Europe Economics' Consulting Firm. The review identified the analysis of the framework, components and design details for the interconnection cost models.

1.6. Delimitations of Scope and Key Assumptions

This research focuses on the interconnection cost estimation methods for only voice traffic throughput which is routed through the Public Switched Telephone Networks (PSTN) using circuit switched technology. The interconnection cost estimation methods for the data traffic throughput is outside the scope of this research because it assumed that in the case of Tanzania the data traffic throughput is still routed separately in a private Internet Protocol (IP) based packet switched network technology using traffic delayed system when the circuits are busy. The research also assumed that the Third Generation (3G)mobile technologies carrying both voice and data traffic throughput is still at the early deployment phase; hence, the data traffic throughput is assumed negligible.

1.7. Conclusions

Foundations of the thesis have been set out by this Chapterby introducing schematically with detailed explanations on an interconnection scenario, involving a voice call between a new entrant operator's mobile network and incumbent fixed operator's network. The Chapter also introduced different types of the interconnection models and charges used by the EU countries, which had some problems of inaccuracy and subjectivity. These problems were addressed by the European Commissionby issuing directives to the EU Member States to adopt the best practice benchmarked interconnection charges as an interim solution pending for the cost study.

The aim of the research has been presented by adapting the chosen existing British telecom's cost model to the Tanzania case study by specifying the objectives mentioned on page 5.

The research questions have been set out by relating objectivity, reliability, transparency, competitiveness, effectiveness and universality of the current interconnection charges. The research hypotheses have been formed byguiding the research to achieve the objectives. The research limitations have been presented by excluding the Internet and data related traffic. On these foundations, the detailed descriptions of the research have been presented by the thesis.

1.8. Thesis Organization

The rest of the thesis is organized as follows:

- Chapter2presents in details architecture and topology of interconnection of operators' telecommunications networks;
- Chapter 3 presents in details the Tanzania telecommunications development;
- Chapter 4 presents from international roaming to non-international roaming in Tanzania;
- Chapter5presents review of existing interconnection cost models in Europe;
- Chapter6 presents analysis of interconnection cost models using historical data in Tanzania;
- Chapter7presents the conclusions.

Chapter 2.Design and Architecture of Interconnection of Telecommunications Networks

This Chapter builds on the introduction given in Chapter 1. The aim of this Chapter is to present in details design and architecture of interconnection telecommunications networks. These details form the basis for the analysis of development of the interconnection of the telecommunications networks in Tanzania during the post monopoly erain the next Chapter. The details are relevant for the estimation of the interconnection costs, which include the following:

- Key definitions;
- Fixed and mobile interconnection components;
- Fixed and mobile interconnection services;
- Interconnection cost methodology,
- Interconnection of competing telecommunications networks,
- Defining call route types, and
- Defining route factors.

2.1. Key Definitions

This Section presents some key definitions related to networks and interconnection.

2.1.1. Network related definitions

The network related key definitions include the following:

- *Conveyance (core) networks* means the part of the telecommunications network, which transport the traffic through the switching and transmission components.

- *Access networks* means the part of the telecommunications network, which connects the subscribers to the local telephone exchanges of the conveyance networks.

- *Fixed wireless access* means the radio signals in the access networks used to access the local telephone exchanges for communications with the subscribers [IECO2004,Dias2004].

- *Wire line* means the local loop in the access networks such as pairs of copper wires used to access the local telephone exchanges for communications with the subscribers.

- *Call route factors* means a measure of intensity or utilization factors of the network components of the core network by calls of different types.

2.1.2. Interconnection related definitions

The interconnection related definitions include the following:

- *Interconnection* means as defined by the ITU as a set of physical and logical linkage between the two telecommunications networks as indicated in Fig.2.1 [ITEU2003]. This linkage facilitates customers of one network operator to communicate seamlessly with the customers of another network operator and use the products and services of the other network operator [ITEU2003,Mpap2006,TCRA2005,Sama2008]. The physical and logical linkage refers to the transmission and switching networks respectively. The operator pays the interconnection charges for the use of the products and services of the other network operator.

- *Point of Interconnection*(PoI)means a location where the competing switched telecommunications networks link together to provide seamless communications of subscribers connected to different operators' telecommunications networks.

- *Local level interconnection* means the interconnection with the point of interconnection (PoI) between the two switched telecommunications networks being located at the local telephone exchanges with the call origination and termination remain in the same local switching area The services utilize resources of the remote concentrator units, the remote concentrator unit to local telephone exchange transmission links and the local telephone exchanges.

- *Single tandem interconnection* means the interconnection with the PoI between the two-switched telecommunications networks being located at the tandem telephone exchanges with the call origination and termination remains in the same tandem switching area. The services utilise the tandem telephone exchanges and the local telephone exchange to the tandem telephone exchange transmission links besides the resources of the local level interconnectionservices. This is what has been used in Tanzania.

- *Double tandem interconnection* means the interconnection with the PoI between the two-switched telecommunications networks being located at the tandem telephone exchanges with the call origination and termination in different tandem switching areas. The services utilise extra tandem telephone exchanges and tandem-to-tandem telephone exchange transmission links beside the resources of the single tandem interconnection

2.2. Fixed and Mobile Interconnection Components

This Section presents the components associated with the fixed and mobile interconnection models.

2.2.1. Fixed Interconnection Components

In keeping with the international standards, the fixed interconnection components assumes a relatively modern equivalent flat and fixed switching network of two level hierarchy of standalone digital local and tandem exchanges complemented by the remote switching units (see Fig.2.1).

The fixed interconnection also assumes the PoI is located only to the conveyance networks in the case of Tanzania (see Fig.2.2). Based on the location of the points of interconnection, three different categories of fixed interconnections are formed: local level, single tandem and double tandem as defined in sub-section 2.1.2.

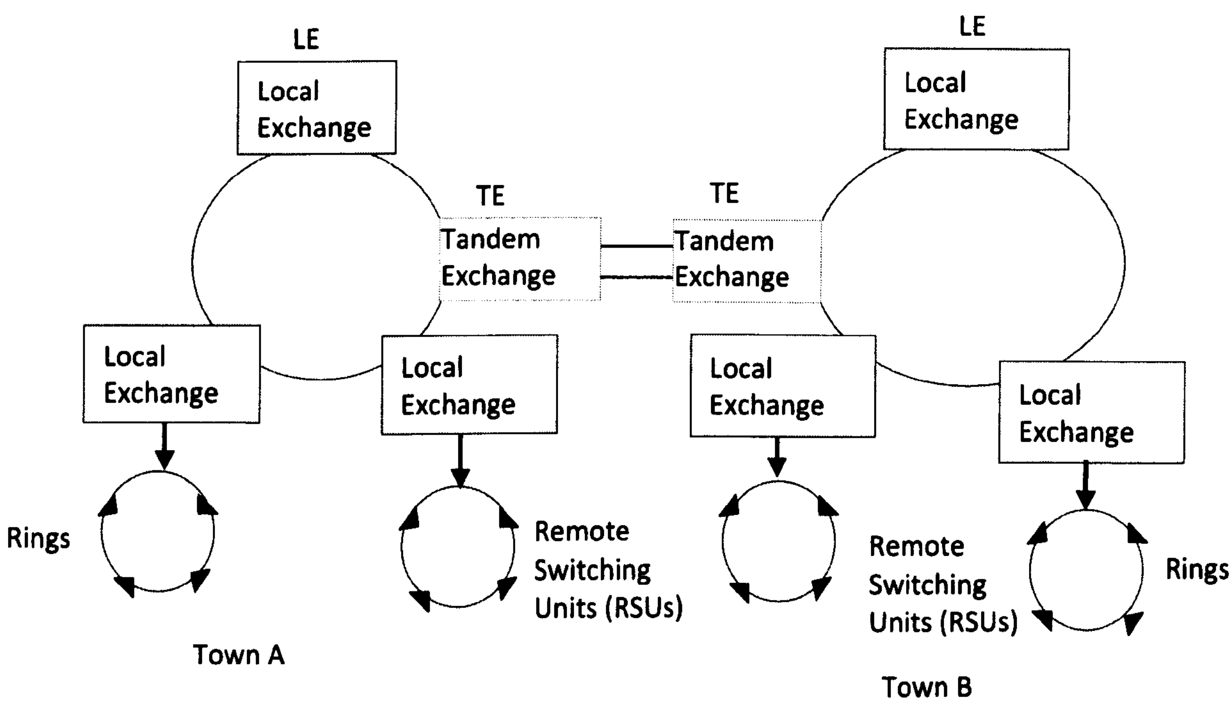


Figure 2.1.The modern equivalent fixed switching network hierarchy [EUEC2002]

Table 2.1. An example of network components associated with the fixed interconnection

No.	Network component	Definition
1	Remote Switching Units (RSU)	An end of office switch with at most 1,000 subscribers in the case of Tanzania and has no transit capability
2	Local Exchange (LE)	A stand alone switch with at least 1,000 subscribers and has no transit capability
3	Tandem Exchange (TE)	A stand alone switch without subscribers, but it has a transit capability.
4	RSU – LE transmission	Transmission links between Remote Switching Unit (RSU) and Local Exchange (LE)
5	LE-TE transmission	Transmission links between the Local Exchange (LE) and Tandem Exchange (TE)
6	TE –TE transmission	Transmission links between Tandem Exchanges (TEs) or inter-Tandem Exchange transmission links

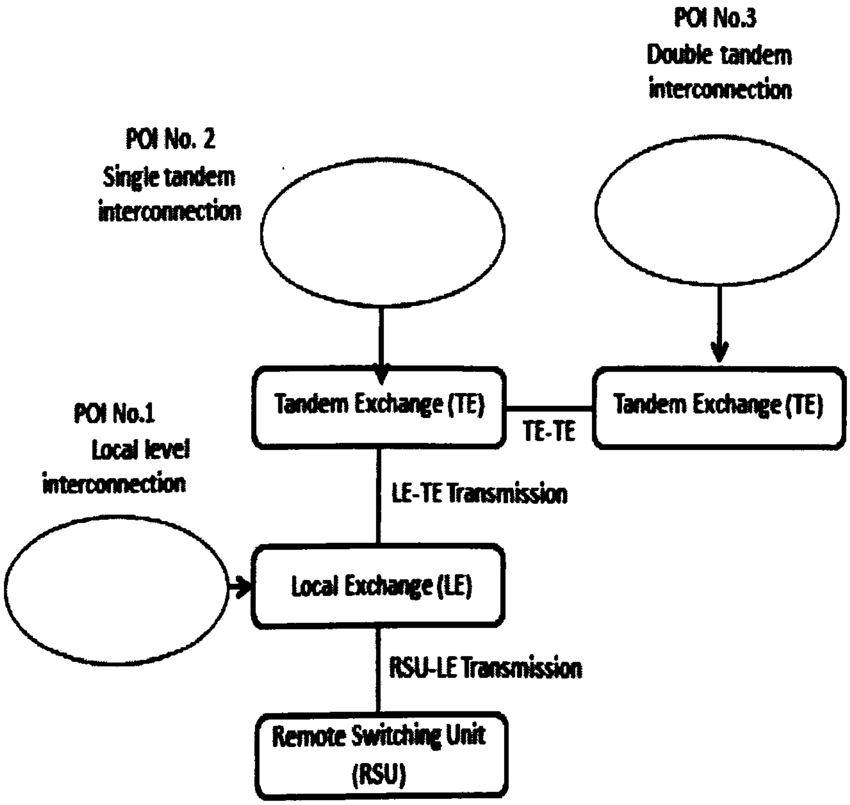


Figure 2.2. Locations of points of interconnection in the conveyance network [Thom2003]

2.2.2. Mobile Interconnection Components

The mobile interconnection model assumes the GSM network architecture of a single tier of standalone Mobile Switching Centre (MSC) connected by Base Station Sub-systems(BSS) (seeFig.2.3) and all abbreviations of the network components of the GSM mobile interconnection are defined in Table 2.2. The mobile interconnection assumes the PoI is located to the MSC and forms a single mobile interconnection (termination) in the case of Tanzania [TCRA2005]. The components of the mobile interconnection include:

- MSC+GMSC+BSC+BTS+ (BTS-BSC) + (BSC-MSC) + (MSC-MSC) + (GMSC-MSC) + common network components (HLR+VLR+EIR+AuC+NMC).

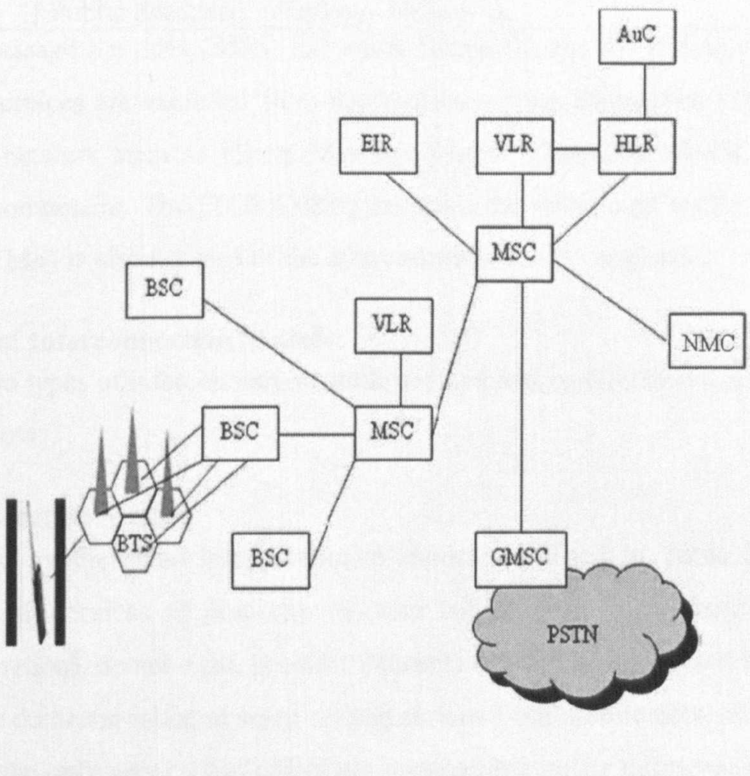


Figure 2.3. The GSM network architecture [GSMA2009]

Table 2.2. Definition of terms associated with the mobile interconnection model.

Network components	Definition
Base Station Subsystem (BSS)	This subsystem consists of Base Transceiver Station (BTS) and Base Station Controller (BSC)
BSC-MSC transmission	Transmission from Base Station Controller to Mobile Switching Centre
• MSC • GMSC	• Mobile Switching Centre (MSC), • Gateway Mobile Switching Centre
• MSC-MSC transmission • MSC-GMSC transmission	• Transmission links between Mobile Switching Centre • Transmission link between the Mobile Switching Centre (MSC) and Gateway Mobile Switching Centre (GMSC)
BTS-BSC transmission	Transmission links between Base Transceiver Station and Base Station Controller
Voice Mail System (VMS)	A system handles voice mail traffic
Value added and non-voice networks	Short Message System Controller (SMSC): packet switched network and associated networks
Common network components	Home Location Register (HLR), Visitor Location Register (VLR) Equipment Identification Register (EIR) and Authentication Centre (AuC) and Network Management Centre (NMC).
PSTN	Public Switched Telephone Networks

In Tanzania, Short Message Services (SMS) fall under Sender Keeps All (SKA) charge arrangement. Therefore, the SMS services are excluded from the interconnection framework [TCRA2005], and the associated non-voice network such as (Short Message Service Controller (SMSC is not part of the interconnection cost component. The [TCRA2005] excludes the voice mail traffic, and the associated Voice Mail System (VMS) is also not part of the interconnection cost component.

2.3. Different Types of Interconnection Models

Basically, there are two types of interconnection models: fixed and mobile. Services provided by each model are detailed below.

2.3.1. Fixed Interconnection Models

The services provided by the fixed interconnection model are listed in Table 2.3. In the case of Tanzania, the voice call services of domestic inbound calling from other fixed networks to fixed networks (fixed termination), do not exist, because Tanzania has still a single fixed telecommunications network operator. The domestic inbound voice calling service from mobile networks to fixed networks (fixed termination) is the only service that offers the interconnect traffic throughput.The costs incurred to build capacity to terminate this traffic throughput are called *fixed interconnection costs* and are presented in Chapter 6.

Table 2.3.An example of services provided by the fixed interconnection model (own work).

Services	Retail	Wholesale
Domestic	Pay phone calling, national operator assisted calling, national calls (fixed to own fixed i.e. "on-net" calling), local calls (fixed to own fixed i.e. "on-net" calling), fixed to own mobile (on-net) calling, fixed to other mobile (off-net) calling, voicemail calling, emergency calling, dial-up Internet.	• Inbound calling from other mobile networks to fixed network (fixed termination). • Inbound calling from other fixed networks to fixed network (also fixed termination). • Fixed transit calling.
International	Outgoing payphone calling, International Subscriber Dialing (ISD) outgoing calling, outbound operator assisted calling.	Inbound calling from overseas countries, inbound transit calling to other mobile networks in the country, inbound transit calling from other mobile networks in the country.

2.3.2. Mobile Interconnection Models

The services provided by the mobile interconnection models are listed in Table 2.4.

Table 2.4. An example of voice calling services provided by the mobile interconnection model.

Services	Retail	Wholesale
Domestic	Voicemail, Short Message Systems (SMS), Multimedia Message Systems (MMS), mobile data, mobile to own mobile (on-net) calling, mobile to other mobile (off-net) calling, mobile to fixed (off-net) calling.	• Inbound calling from other fixed networks to mobile network (mobile terminations). • Inbound calling from other mobile networks to mobile network (mobile terminations). • Inbound roaming calling.
International	Outbound international calling.	Inbound roaming calling.

The following voice calling services offer the mobile interconnect traffic throughput:

- Domestic inbound voice calling from fixed to mobile networks (mobile terminations);
- Domestic inbound voice calling from other mobile networks to mobile networks (also mobile terminations).

The costs incurred to build capacity to terminate this interconnect traffic throughput are called *mobile interconnection costs* and are presented in Chapter 6.

2.4. Interconnection Costing Methods

This Section presents methods that are used commonly for estimating interconnection costs:

- Marginal Costs;
- Stand Alone Costs (SAC);
- Fully Distributed Costs (FDC) or Fully Allocated Costs (FAC);
- ForwardLooking-Long Run Incremental Costs (FL-LRIC).

Tanzania Communications (Interconnection) Regulations, 2005 specified for the use of the Fl-LRIC methodology for estimating the interconnection costs. The FL-LRIC methodology promotes effective competition and economic efficiency.

2.4.1. Marginal Costs

This methodology measures the costs of a service provided by the operator in a perfect competition and reflects only the utilization of an existing network [ITEU2010a]. Therefore, the marginal Costs include only the variable cost component of the direct and attributable cost category (see the shaded part of Fig.2.4) [ITEU2010a].

It is caused by the provisioning of one additional unit of service and be used to remedy a competition problem for a short term. Practically, it cannot be used for price determination. With the marginal costs, only variable costs get allocated to a single service to be measured.

2.4.2. Stand Alone Costs (SAC)

This methodology measures the costs of providing a service by the operator in isolation from other services of the company [ITEU2010a]. Therefore, SAC includes variable and fixed cost components of the direct and attributable cost category, joint and common costs (see the shaded part of Fig.2.5). The SAC cost standard does not lead to economic efficiency. However, it provides useful information about the highest costs National regulatory Authority (NRAs) might consider in the wholesale price regulation, since the costs obtained by means of this standard define the upper limit (ceiling) of the attributable costs. With SAC all joint and common costs get allocated to a single service to be measured i.e. the assumption is that the regulated company produces a single service.

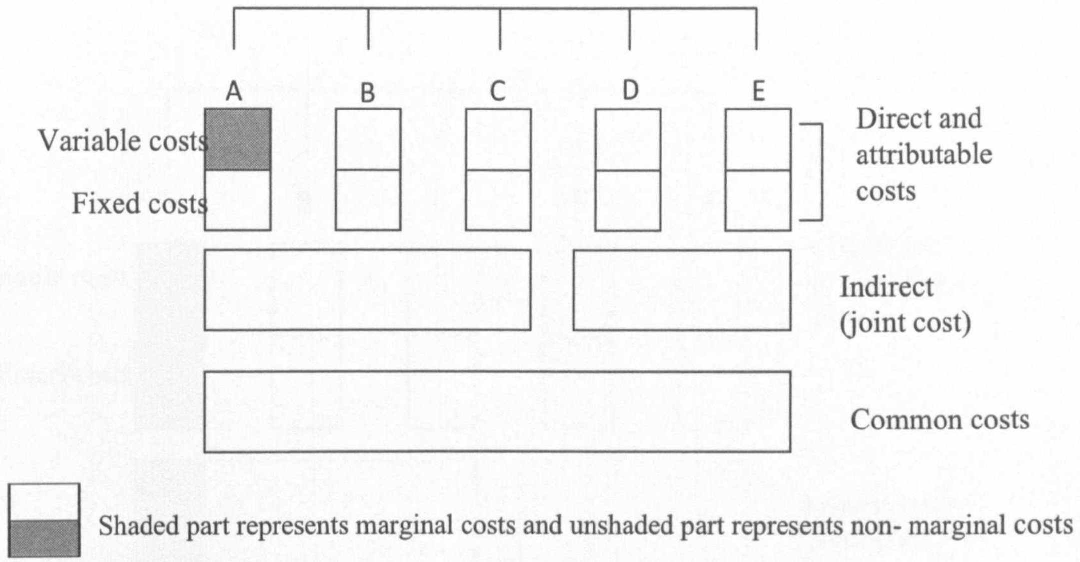


Figure 2.4. An example of Marginal Costs. Here A to E are various services.

2.4.3. Fully Distributed Costs

This methodology uses historical costs; of the existing networks. It allocates a portion of joint (shared) and common costs to the interconnection in addition to the wholly allocation of the direct costs (see the shaded part of Fig.2.6) [ITEU2010a]. With the FAC, all costs get allocated to all services. The drawback is that the interconnection charges derived from the Fully Distributed Costs (FDC), sometimes known as Fully Allocated Costs (FAC) methodology tends to reinforce inefficiencies. Hence, this method is not recommended for the regulatory interconnection costing.

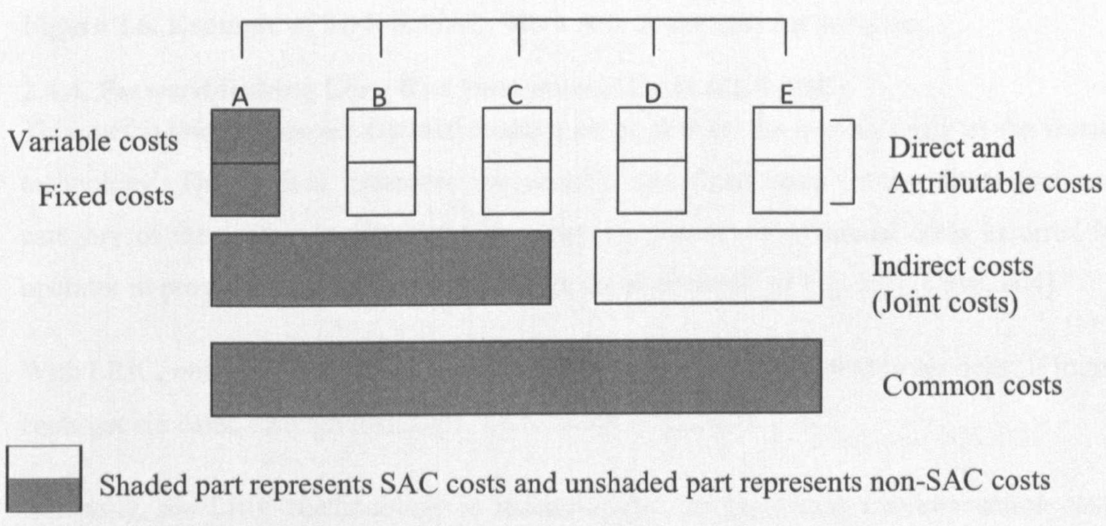


Figure 2.5. Example of SAC costs. Here A to E are various services.

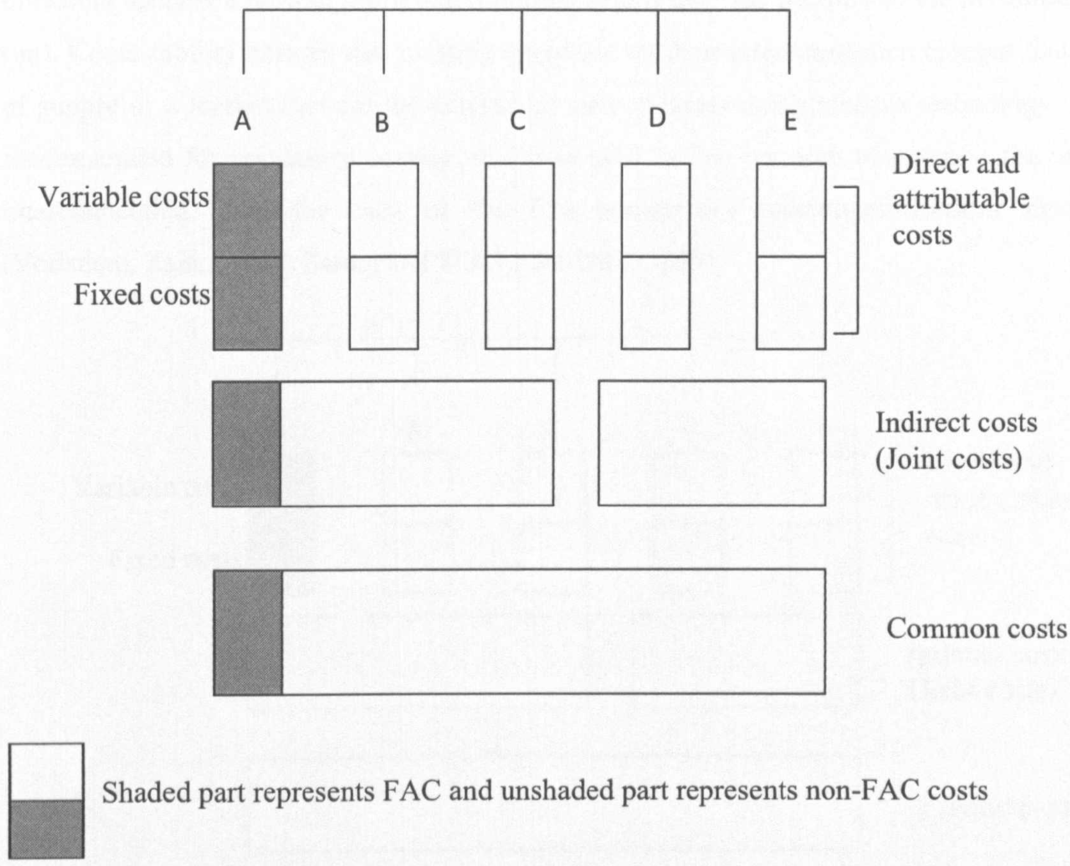


Figure 2.6. Example of FDC or FAC. Here A to E are various services.

2.4.4. Forward-looking Long Run Incremental Costs (FL-LRIC)

This methodology uses the forward looking costs; that is, the current costs of the modern equivalent technology. The method estimates the variable and fixed costs of the direct and attributable cost category of the modern equivalent technology on present value annual costs incurred by an efficient operator in providing the interconnection (see the shaded part of Fig. 2.7) [Cave2004].

With LRIC, only service specific variable and fixed costs get allocated to services. If joint and common costs get allocated through mark-ups, LRIC starts to resemble FAC.

Generally, the LRIC methodology is recommended for regulatory interconnection costing. In many jurisdictions around the world, set the interconnection charges based on the LRIC methodology [Falc2004]. These jurisdictions include Tanzania, the United Kingdom, Denmark, Australia and the United States of America. The interconnection charges based on the LRIC methodology reflect the levels of costs that would occur in a competitive and contestable market. Competitionensures that operators achieve a normal profit and a normal return over the lifetime of the investment (i.e. the long run). Contestability ensures that existing operators set their interconnection charges that reflect the cost of supply in a market that can be entered by new entrants using modern technology. This method is recommended for regulatory costing, and it is used in this research to estimate the unit and average interconnection costs for each of the five competitive telecommunications network operators (Vodacom, Zain, TIGO, Zantel and TTCL) for 2007-2009.

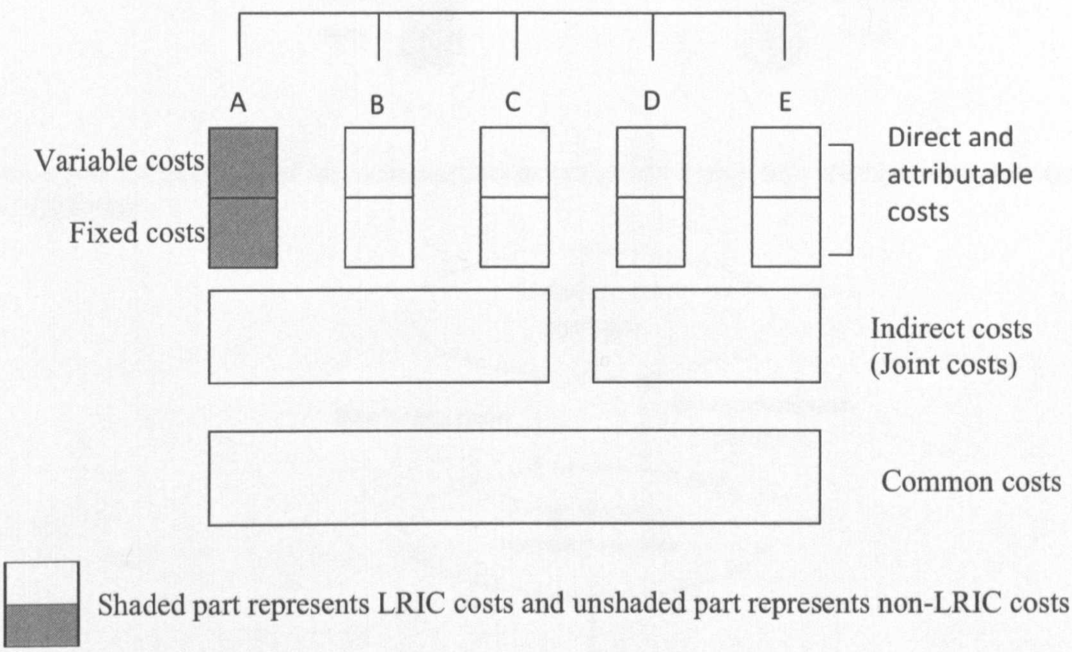


Figure 2.7. Example of LRIC. Here A to E are various services.

2.5. Interconnection BetweenCompeting Telecommunications Networks

This Section presents the interconnection used between the competing telecommunications networks in Tanzania. This interconnection connects the competing telecommunications networks (facilities) such that customers of one network can call seamlessly customers served by other networks and vice versa. Fig.2.8 provides an illustrative example.

The interconnection between the non- competing telecommunications networks is not used in Tanzania and in Africa. This interconnection connects the non-competing telecommunications networks such that one network obtains inputs from another network in order to offer services to its customers (Fig. 2.9 provides an illustrative example).

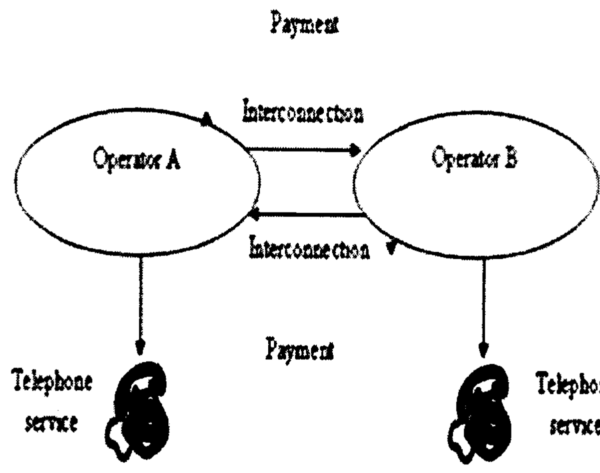


Figure 2.8. An example of interconnection between the competing telecommunications networks [ITEU2010b].

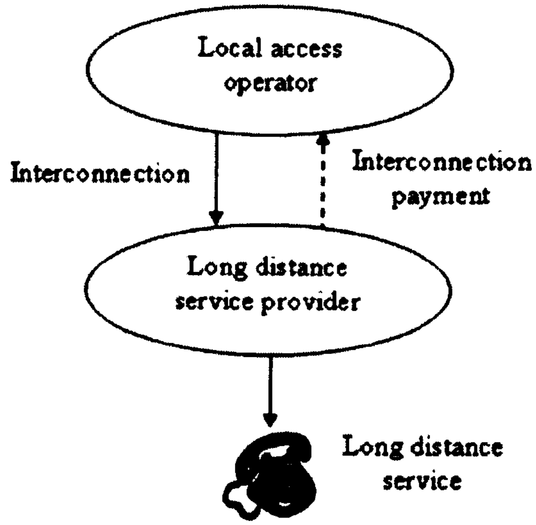


Figure 2.9. An example of interconnection between non-competing telecommunications networks [ITEU2010b].

For example, prior to 1996, local exchange carriers in the United States of America (USA) were prohibited from offering long distance calls [Fcco1996]. Long distance carriers such as AT&T, Sprint and MCI obtained access from these local exchange carriers to offer long distance calls to customers on the local exchange networks.

Payment for the interconnection between non-competing telecommunications networks is always done from the interconnecting operator (in the example above, the long distance carrier) to the interconnection provider (the local exchange carrier) [ITEU2010b]. Therefore, the interconnection between the competing telecommunications networks as introduced in Chapter 1 includes the following:

- Fixed-to- mobile interconnection (mobile interconnection);
- Mobile- to- fixed interconnection (fixed interconnection);
- Mobile-to- mobile interconnection (mobile interconnection);
- Fixed-to-fixed interconnection (fixed interconnection).

2.5.1. Fixed-to-Mobile Interconnection (Mobile Interconnection)

A mobile network terminates a call from a fixed network. The call might originate from a local fixed network operator, a domestic long distance operator, or an international operator (Fig.2.10 provides the illustrative example).

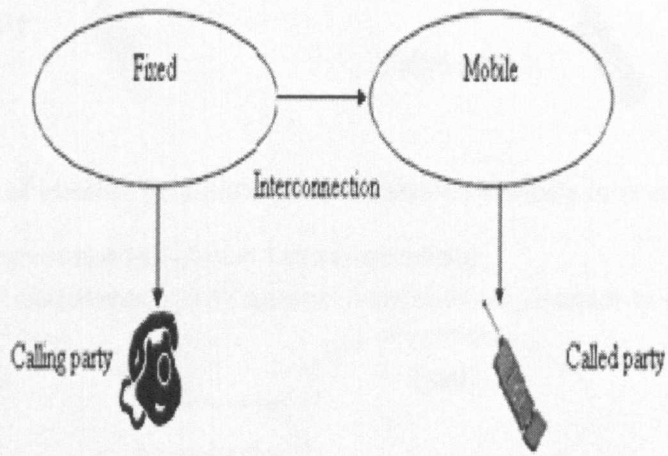


Figure 2.10.An example of fixed- to-mobile interconnection (mobile interconnection)

2.5.2. Mobile-to-Fixed Interconnection (Fixed Interconnection)

A mobile network operator interconnects with the fixed network in order to complete calls for the mobile network operator's customers. (seeFig.2.11provides the illustrative example).

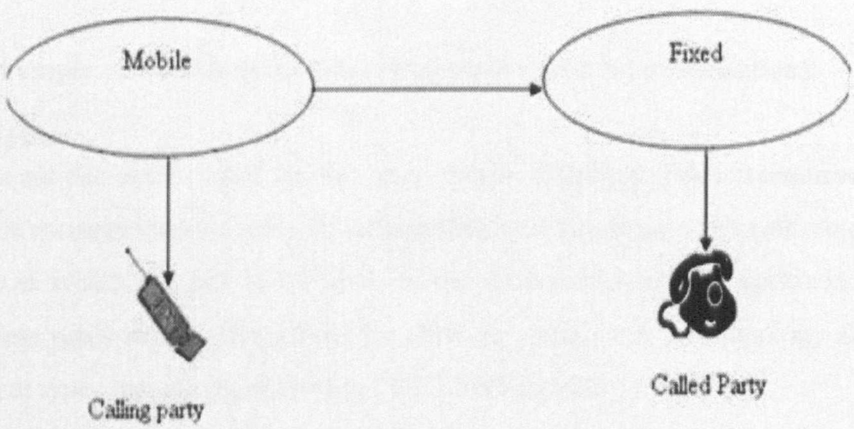


Figure 2.11. An example of mobile-to-fixed interconnection (fixed interconnection).

2.5.3. Mobile-to-Mobile Interconnection (Mobile Interconnection)

A mobile network terminates a call from another mobile network (see Fig.2.12 provides the illustrative example).

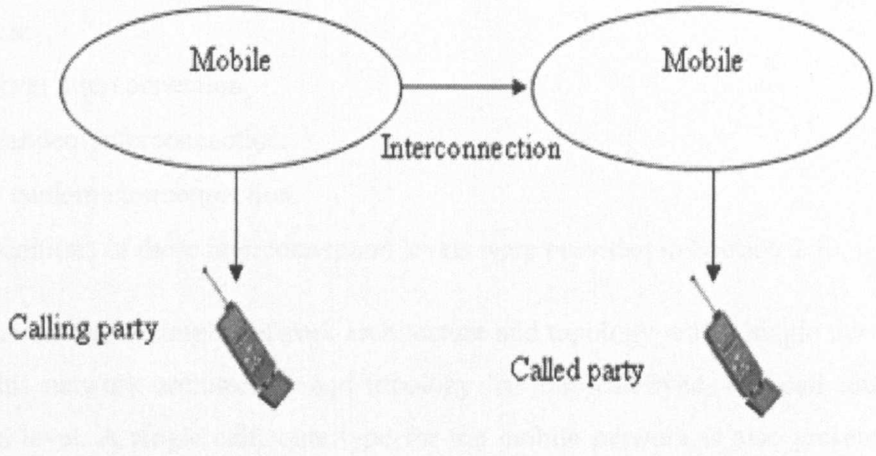


Figure 2.12.An example of mobile- to-mobile interconnection (mobile interconnection).

2.5.4. Fixed-to-Fixed Interconnection (Fixed Interconnection)

A fixed network operator interconnects with another fixed network operator to complete the calls (see

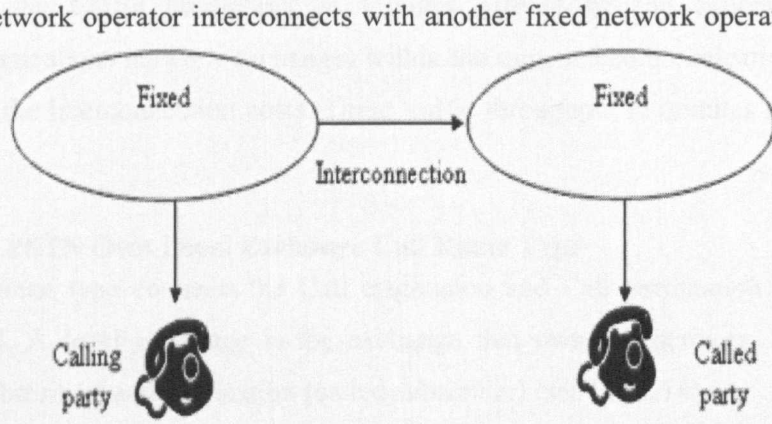


Fig.2.13).

Figure 2.13.An example of fixed-to fixed interconnection (fixed interconnection).

2.6. Call Route Types

This Section presents call route types for the fixed Public Switched Telecommunications Networks (PSTN) and mobile communications network architectures and topologies. The call route type gives the connection(route) in which the call is switched in the telecommunications networks. For the fixed PSTN, the call route types were derived from the network architecture and topology shown in Figure 2.1. These call route types include the following [Wick1997,Brte2005]:

- Own local exchange,
- Adjacent local exchange,
- Single tandem exchange,
- Double tandem exchange.

The call route types that terminate the incoming calls from other operators' telecommunications networks can be referred to as *interconnect based call route types.* These call route types in the fixed telecommunications network architecture and topology form the following levels of the fixed interconnections:

- Local level interconnection,
- Single tandem interconnection,
- Double tandem interconnection.
- The definitions of these interconnection levels were provided in Section 2.1.

The mobile network has a simple network architecture and topology with a single tier (level) as shown in Fig. 2.3. This network architecture and topology has one call type, one call route type and one interconnection level. A single call route type for the mobile network is also presented based on the architecture and topology shown in Fig. 2.3.

Although the research is about interconnection between telecommunications networks of different operators, the traffic throughput in minutes offered by the callconnections between different telecommunications network exchanges within the same telecommunications network operator have an impact on the interconnection costs. These traffic throughput in minutes are presented and analyzed in Chapter 6.

2.6.1. The PSTN Own Local Exchange Call Route Type

This call route type connects the Call origination and Call termination on the same *local exchange* [Brte2005]. A local exchange is the exchange that owns subscribers. Normally, a call has source (calling subscriber) and destination (called subscriber) (see Fig.2.14).

A Call Origination refers to a source of the call, and a Call Termination refers to a destination of the call. In the own local exchange call route type, the source and destination of the call reside on the same local exchange. Therefore, the local exchange routes the call originated from the calling subscriber and terminates the call to the called subscriber connected on the same local exchange. The call route also uses the termination side of the local exchange to connect the national calls, international calls, and other calls from different networks and operators. This termination side of the local exchange serves as a local level interconnection for the incoming calls from other operators.

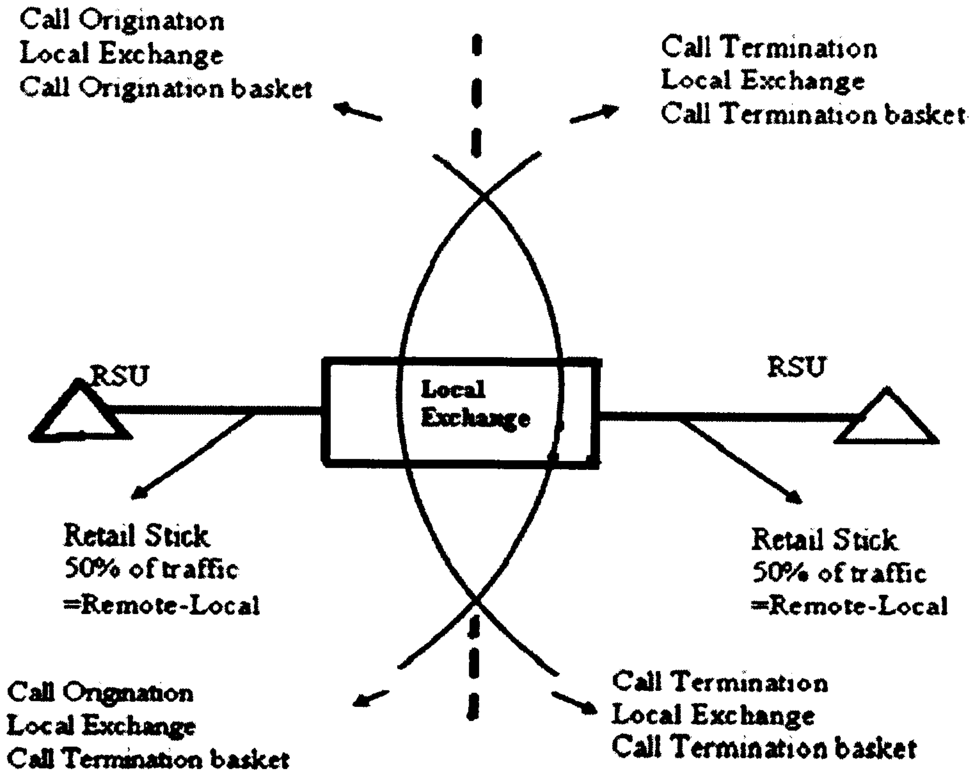


Figure 2.14. The PSTN own local exchanges call route type [Brte2005].

The Call Origination side consists of components of half of the local exchange, local exchange to Remote Switching Unit (RSU) transmission link and RSUs. The remote-local exchange components of the Call Origination are referred to as a *retail stick* or retail leg, which forms a portion of the retail tariff. Similarly, the components of the Call Termination form another portion of the *retail stick.* The Call Origination basket and Call Termination basket are referred to a set of tariff entries of different types of calls [Trab2008].

2.6.2. The PSTN Adjacent Local Exchange Call Route Type

This type of the call route uses the origination and termination sides to connect the calls originating at one local exchange and terminating at another adjacent local exchange within the same local area (see Fig. 2.15) [Brte2005]. Here adjacent local exchanges are always connected directly without passing through *tandem exchange.* A tandem exchange is the exchange, which does not own subscribers; it only transits traffic. In some cases, the adjacent local exchanges are connected via the tandem exchange and form a *local-tandemretail stick.* A local-tandem retail stick is a portion that contributes to the retail tariff of the local call.

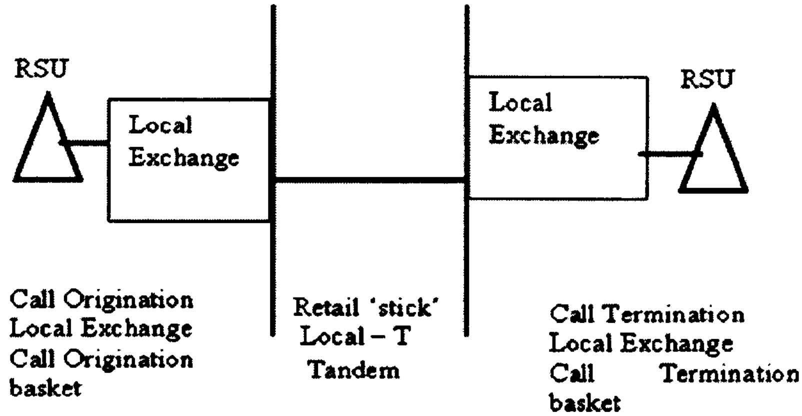


Figure 2.15.Adjacent local exchanges call route type [Brte2005].

2.6.3 The PSTN single tandem exchange call route type

This call route type uses the origination and termination sides to connect the national calls involving a single tandem exchange (see Fig.2.16) [Brte2005]. This call route type consists of the components of the tandem exchange; tandem-local exchange transmission link, local exchange and RSUs. The components of the tandem and tandem-local exchange transmission link contribute to the *Tandem layer Basket*, which are the tariff entries for the local to tandem conveyance [Trab2008]. The call route also uses the termination side to connect the national calls, international calls, and other calls from different networks and operators and provides *single tandem interconnection.*

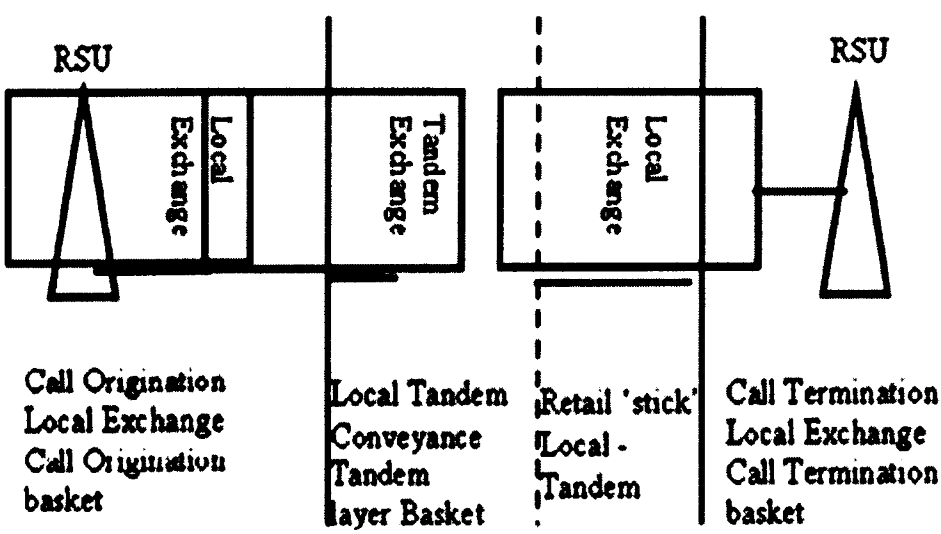


Figure 2.16. The single tandem exchange call route type [Brte2005].

2.6.4. The PSTN Double Tandem Exchange Call Route Type

This call route type uses the origination and termination sides to connect the national calls involving two tandem exchanges (see Fig.2.17) [Brte2005]. The call route type consists of the *Inter-Tandem Conveyance,* which has an extra tandem exchange and tandem to tandem transmission link beside the components of the single tandem exchange route type. The components of the inter-tandem conveyance contribute the *Safeguard Cap,* which is the maximum limit of the retail tariff entries [Trab2008]. The call route type also uses the termination side to connect the national calls, international calls, and other calls from different networks and operators, and it provides the *double tandem interconnection.*

2.6.5. The Mobile Own MSC Call Route Type

In contrast, the mobile telephone network has only one call route type i.e. own mobile switching center route type (see Fig.2.18), which connects the originating and terminating calls on the same MSC. The call route type also uses the termination side to connect the international calls and other calls from different operators' networks.

2.7. Call Route Factors

Call route factors are important factors for the interconnection cost models. These factors indicate the average usage (weighted) of a network component by a specific service. The

matrix of the average usage of different network components by different services in the conveyance network is called a *routing table.* The call route factor of the network component in the core network can be derived from the *factored component volume*[Brte2005].

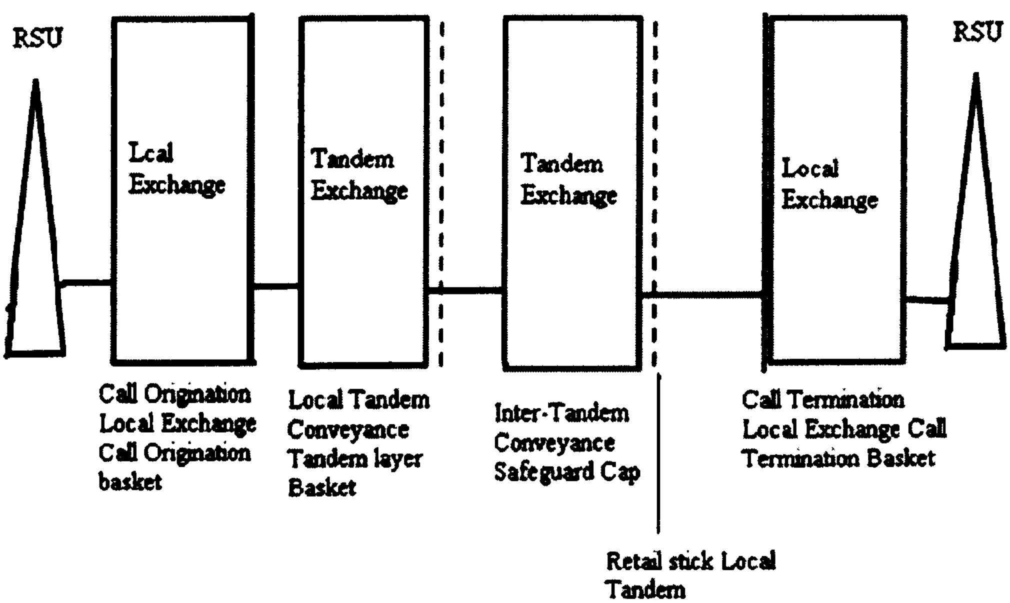


Figure 2.17.Double tandem exchange call route type [Brte2005].

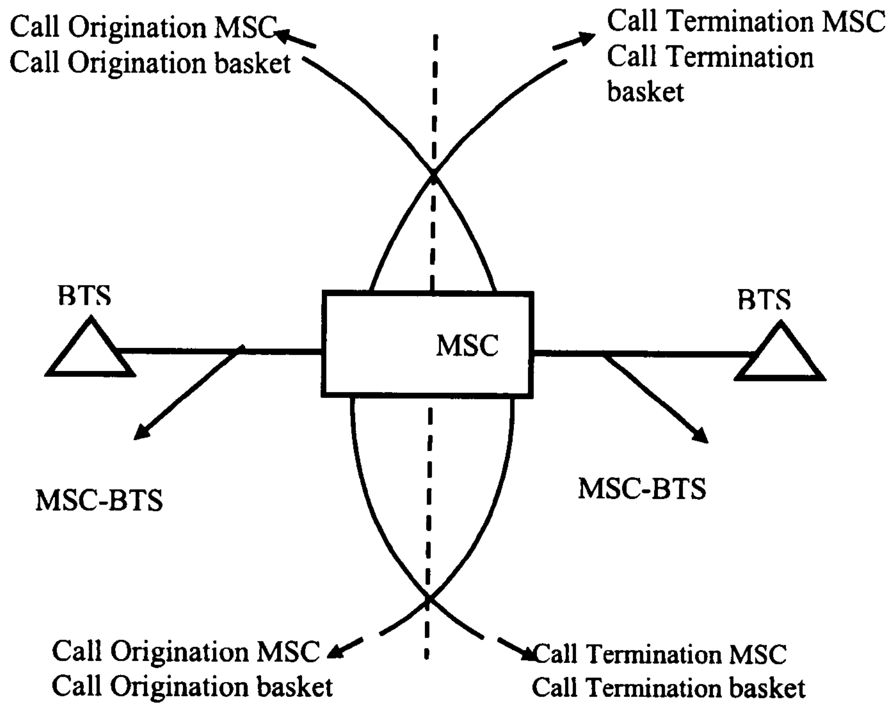


Figure 2.18 . Own MSC call route type [Gill2003].

The factored component volume is the volume of traffic carried or conveyed by a particular network component in the core network by a call type [Brte2005]. The ratio of the factored component volume to the total volume of the traffic of the same call type carried in the core network gives the *component utilization factor.*

The total volume of the traffic carried by the component by all call types in the core network gives the *total factored component volume.* The ratio of the total factored component volume to the total volume of traffic carried in the core network by all call types gives the *total component utilization factor*known as the*call route factor.*Therefore, this Section presents the call route factors of different components in the fixed and mobile interconnection cost model.

Table 2.5 provides the call route factors of different components in the fixed interconnection cost model. Table 2.6 also provides the call route factors of different components for the mobile interconnection cost model for the 2-G mobile networks (abbreviations used in Table 2.6. are defined previously in Table 2.2).

Table 2.5.An example of routing factors for fixed interconnection cost model [ITUD2010].

Network component	Local level interconnection	Single tandem interconnection	Double tandem interconnection
Remote Switching Units (RSU) with subscribers	0.9	0.9	0.9
Local Exchange (LE) with subscribers	1	1	1
Tandem Exchange (TE) without subscribers, but has transit capability	0	1	2
RSU-LE transmission link	0.9	0.9	0.9

Table 2.6.An example of route factors for different components in the mobile interconnection cost model for the 2-G mobile networks [ITUD2010].

Voice Services	BTS	BTS - BSC	BSC	BSC - MSC	MSC	MSC-GMSC	GMSC	NMS	HLR	IN
On-net calls	2	2	2	2	1.66	0.27	0.27	1	1	1
Off-net incoming calls	1	1	1	1	1		1	1	0	0.9
Off-net outgoing calls	1	1	1	1	1	1	1	1	1	0.1

2.8. Conclusions

In this Chapter, fixed and mobile telecommunications network design and architecturehave beenanalysed by presenting in details , different types of the interconnection models,levels of the switching network hierarchy, call route types and factors, points of interconnection, network components and services, key terminologies related to the telecommunications networks and interconnection. The Chapter also analyseddifferent types of interconnection cost methodologies (marginal costs, stand alonecosts, fully allocated costs and forward looking- Long Run Incremental Costs (LRIC)) by using cost structure, categories and components. The LRIC methodology has been recommended for regulatory costing and was used to analyze the costs for fixed and mobile interconnection models in Chapter 6.

Based on the analysis of the telecommunications network design and architecture the next Chapter presents in details the telecommunications development in Tanzania by analyzing background, history, deployments and operations of the telecommunications networks during the monopoly and post-monopoly era.

Chapter 3.Analysis of the Telecommunications Developments in Tanzania

The United Republic of Tanzania is located in the Eastern Africa between longitude 290 and 410 East and Latitude 10 and 120 South (see Fig.3.1). The United Republic of Tanzania is made up of a union of two formerly independent countries: Tanganyika (on the mainland) and the islands of Zanzibar and Pemba in the Indian Ocean [URTA1999]. This union was formed on 26th April, 1964. The aim of this chapter is to present the telecommunications development in Tanzania during the monopoly era where there was no interconnection of telecommunications networks and post monopoly era where there is the interconnection of the telecommunications networks.

Figure 3.1. The map of Tanzania[URTA2005].

Tanzania is the biggest of the East Africa countries (i.e. Kenya, Uganda and Tanzania). The size of the country is 945,087 square kilometers. Tanzania mainland(formerly Tanganyika) has an area of at most 942,000 square kilometers of which about 20,000 square kilometers are covered by lakes

[URTA2005].The islands ofZanzibar and Pemba have a combined area of 2,500 square kilometers. Almost one third of the country area is reserved as national parks: the Serengeti and Ngorongoro crater in Arusha Region are most famous national parks. The highest mountain in Africa is Mount Kilimanjaro (with snow) in Tanzania, and its height is 5895 meters above the sea level. The country has a spectacular landscape of mainly three physiographic regions; namely the Islands and the coastal plains to the east; the inland saucer-shaped plateau, and the highlands. The Great Rift Valley that runs from north east of Africa through central Tanzania is another landmark that adds to the scenic view of the country. It is important to know the size and terrain of the country for the telecommunications network planning and designs.

The Tanzania population has grown from 12,313,469 persons in the first post-independence census in 1967 to 34,569,232 persons counted in the census held in August 2002. Over the period from 1967 to 2002 the population of Tanzania has almost tripled. The rate of population growth during the last ten years has been around 1.95%. According to the 2002 Census (34,564,230 persons), the male to female distribution was 49%:51%, urban to rural distribution was 23.1%:79.9% and almost 80% of the population live in rural areas. The population density, in Tanzania varies considerably from region to region. People are particularly concentrated in Dar es Salaam Region (1793 persons per square kilometer) and Urban West (1700 persons per square kilometer). The other four Regions of Zanzibar and Mwanza are also relatively densely populated. The population growth is important for the research because it increases subscriber penetration rate as well as traffic and drives down the interconnection costs.

As by now 2009, Tanzania's economic prospects depended significantly on the development of agriculture, mining resources mainly gold and diamonds and tourism [URTA1998]. The Growth Domestic Product (GDP) of the country is about USD 14,000.00 million with GDP per capital of about USD 400.00 at inflation rate of 7.2% [URTA2005]. Tanzania is one of a few African countries with a stable and peaceful socio-political environment. The political landscape in Tanzania changed dramatically in 1992 with the introduction of multiparty democracy. By the time the first election under multipart was held in 1995, thirteen (13) political parties were registered. Indeed the 1995, 2000 and now 2005 parliaments began with 43 (18.5%) in 1995 opposition members of parliament. The subsequent elections reduced the number to 35 in 2005. The political stability attracted foreign investment in the telecommunications sector development in the country.

3.1. Background and History of the Telecommunications Development in Tanzania

Tanganyika (the mainland part of Tanzania) was a German colony for 30 years up to 1918, the end of the First World War. From 1918 to 1961 Tanganyika was ruled by the Great Britain as a Trustee Territory of the League of Nations (1918-1945) and of the United Nations (1945-1961). Tanganyika obtained her independence from the Great Britain in 1961 and became a republic in 1962. Zanzibar obtained her independence from the Great Britain in 1963. The background and history of the telecommunications development in Tanzania could be explained in three time periods: the German colonial rule, the Great Britain colonial rule, and post colonial rule and monopoly situation. The history of the telecommunications development in the country is important to know the growth of the telecommunications networks.

3.1.1. Telecommunications Development DuringThe German Colonial Rule (1888-1918)

Before the Germans came into the country, slave trades and missionaries established routes and centers to conduct their businesses. These routes and centers were used by the Germans to provide and construct the Postal and Telecommunications networks under the Tanganyika Posts and Telegraph Administration. Thus, the spread of the postal and telegraph facilities during the German colonial rule followed the pattern of the slave trade and missionary routes and centers [TTCL2009].

3.1.2. Telecommunications Development DuringThe Great Britain Colonial Rule (1918-1961)

In 1933, the Great Britain colony amalgamated the previous independent Postal, Telegraph, and Telephone facilities in the then Tanganyika, Kenya and Uganda resulting into the formation of a company known as the East African Posts and Telegraph Company, which became a self contained service with its own capital account and operated under the East African High Commission [EACO2009]. In 1951, the Great Britain colony enacted the East African Posts and Telecommunications Act, which provided a legal instrument covering all Postal and Telecommunications services and formed the East African Posts and Telecommunications Administration.

In 1961, when Tanganyika became independent, the East African High Commission gave way to a new organisation, the East African Common Services Organization (EACSO). The Head of the Posts and Telecommunications under the EACSO was designated Postmaster General, abbreviated as PMG.

3.1.3. Telecommunications Development during ThePost ColonialRule and Monopoly Situation (1961-1993)

On 1st December, 1967 the three East African countries, namely Kenya, Tanzania and Uganda established the East African Community (EAC), and its headquarters were in Arusha in Tanzania

[EACO2009]. The EAC came officially into operation from 1st January, 1968. The EAC replaced the then EACSO and brought certain changes in the operation of Posts & Telecommunications Administration. The name of the Administration was changed to "Corporation". Therefore, the EAC operated the postal and telecommunications services on commercial basis under a single corporation for the three East African countries called the East African Posts and Telecommunications Corporation (EAP&TC). The headquarters of EAP&TC was in Kampala in Uganda. The EAP&TC was providing only domestic telecommunications services in the region. A different company called External Telecommunications Company provided international telecommunications services.

The EAC lasted for a period of 10 years (1967-1977). The EAP&TC ceased its operations when the EAC collapsed in 1977. However, each member state of the defunct community established immediately the Posts and Telecommunications organization after the collapse of the EAC.In 1978, Tanzania established the Tanzania Posts and Telecommunications Corporation (TP&TC) and operated monopoly the postal and telecommunications services in the country until 1993 when it was split up into three entities. These entities included: the Tanzania Telecommunications Company Limited (TTCL), the Tanzania Postal Corporation (TPC),andThe Tanzania Communications Commission (TCC). The split of the TP&TC was part of the government's reform to liberalize the telecommunications sector and bring it to competition as presented in details in the macro-economic reform in Section 3.2.

On 7th July, 2000, Kenya, Tanzania and Uganda revived officially the EAC. This time, the EAC included two new additional member countries, Burundi and Rwanda making a total of five countries. However, each member state still operates her own Posts and Telecommunications organizations. We learned from the history that during that time, there was no need for the interconnection of the telecommunications network because of the monopoly situation.

3.2. Macro-economic Reforms

Tanzania has been undergoing social economic and political reforms for the past 20 years, which have re-oriented the economy from a government-led to a private-sector-led one. Tanzania has made significant progression in the formulation, implementation and performances of social economic policies intending to empower Tanzanian in managing own social economic activities, [Semb2000]. The reforms and changes in policies have resulted in the privatization of formal public sectors and liberalization of various sectors for competition including the telecommunications. The liberalization and competition in the telecommunications sub-sector brought the interconnection of networks, and its architecture and topology was presented in Chapter2. The first and second generation macro reforms were pursued since early 1980s and are explained in details below.

3.2.1. First Generation Macro-economic Reform

In mid 1980s, Tanzania introduced a social economic and political reforms to restore macro economic balance, stimulate econmic growth and facilitate social and political development [Semb2000,URTA2005].These reforms brought a paradigm shift of the economy from a public and government led to amarket oriented environmentand private sector led one. Experience with the first generation reforms in 1986-1996 indicated that individual initiative and market-oriented economic systems made higher growth rates than centrally planned economic systems [Tesk1990,Worl2000].

In 1986, Tanzania launched the Economic Recovery Programme (ERP), one of the main programmes of the first generation macro-reform [Semb2000]. Under the ERP, the Government formed the Integrated Road Programme (IRP) and Telecommunications Restructuring Programme (TRP). The IRP rehabilitated and expanded the road networks in the country.

The TRP contained two components: the Investment Part and the Institutional Development. The Investment Part rehabilitated and expanded the telecommunications networks as follows [TTCL2009]:Manually operated and electromechanical analogy switching systems were phased out and replaced by digital switching systems; Analogy transmission systems were also phased out and replaced by digital transmission systems.

The Institutional Development embarked on capacity building of the telecommunications sector. In 1993, the Institutional Development embarked on the splitting up of the former state owned monopoly Tanzania Posts and Telecommunications Corporation (TP&TC) [Semb2000]. In this context, the TP&TC was split into three separate entities:

- The Tanzania Telecommunications Company Limited (TTCL). This entity is responsible for operating the telecommunication services;
- The Tanzania Postal Corporation (TPC). This entity is responsible for operating the postal services;
- The Tanzania Communications Commission (TCC). This entity was responsible for regulating the postal and telecommunications services.

In 2003, TCC merged with the Tanzania Broadcasting Corporation (TBC) and formed the Tanzania Communications Regulatory Authority (TCRA). TCRA is responsible for regulating the posts, telecommunications and broadcasting services.

3.2.2. Second Generation Macro-economic Reforms

The second generation macro economic reform occurred between 1996 and 2006, when Tanzania, like other Sub-Saharan African economies was facing huge debt problems making poverty an important policy issue. These reforms embarked on formulation and implementation of a series of broad based national development policies related to poverty reduction and sector specific and macro-economic policies [URTA2005]. The following broad-based national development policies are related directly to poverty reduction: National Poverty Eradication Strategy [URTA1998] and National Development Vision 2025 [URTA1999]. These policies are not the focus of this research.The most relevant sector specific national development policies related directly to the telecommunications sector include the The National Telecommunication Policy of 1997 and The National Information and Communications Technologies Policy of 2003.

These policies are important for the research because they liberalized the telecommunications markets and brought them up to competition. The competition brought/started the interconnection of the telecommunications networks. The policies can be explained in details:

3.3. Policy Framework

Currently, Tanzania uses two sector specific national development policies for governing the telecommunications sector; namely, the National Telecommunications Policy of 1997 and the National Information and Communications Technologies Policy of 2003. These policies played a very important role in the liberalization of the telecommunications sector and opening it up to the competition [Semb2005].

3.3.1. National Telecommunications Policy

In 1997, the government launched the National Telecommunications Policy (NTP 1997), which set up the vision, objectives and target for the telecommunications sector in Tanzania [MOCT1997].The vision of the NTP 1997 for the sector is for the "accelerated development of an efficient telecommunications network that can provide a national info-communication infrastructure and access to present day telecommunication technologies by all sectors of the economy and all segments of the population, including universal access".

The overall policy objective is to ensure that telecommunication services are provided in a liberalized and competitive manner. Specific objectives include the following [MOCT1997]:

- To provide modern, efficient and reliable telecommunications networks that can meet requirements of the present info-communication infrastructure;

- To ensure provision of adequate, sustainable, efficient and affordable telecommunication services in all sectors of the economy.

The overall target for the sector was to achieve a fixed tele-density of 6 telephones per 100 inhabitants by 2020. In 1997, the fixed tele-density was estimated as 0.32 telephones per 100 inhabitants.

The NTP 1997 provided for liberalization and deregulation of the telecommunications markets only in the value added services such as mobile telephones, data communications, radio paging, the Internet, and customer premises equipment. The value added services were opened fully to competition. The NTP97 left the basic telecommunications and leased line services (fixed telephones) monopoly to the Tanzania Telecommunications Company Limited (TTCL). Thus, in Tanzania, the TTCL is the incumbent fixed telecommunications network operator.The NTP 1997 also provided for partial privatization of the TTCL with possibility of certain exclusivity period on basic telecommunications and leased line services. It further provided for the establishment of the Rural Telecommunications Development Funds (RTDF) in order to promote universal access provision in the rural areas.

3.3.2. National Information and Communications Technology Policy

In 2003, the Government launched the National Information and Communications Technologies Policy (ICT 2003) with its vision for the "accelerated development of the Tanzanian telecommunications infrastructure and enhancement of the sustainable socio-economic development and accelerated poverty reduction both nationally and globally" [MOCT2003]. The overall mission of this ICT 2003 is "to enhance nation-wide economic growth and social progress by encouraging beneficial ICT activities in all sectors through providing a conducive framework for investments in capacity building and in promoting multi-layered co-operation and knowledge sharing locally as well as globally".

The ICT 2003's broad objectives include the following [MOCT2003]:

- To provide a national framework that will enable ICT to contribute towards achieving national development goals;
- To transform Tanzania into a knowledge-based society through the application of ICT;
- To provide a national framework that accommodates the convergence of information, communications and technology including media.

The ICT 2003 articulates ten main areas of focus in harnessing ICT towards development. These areas are strategic ICT leaderships, ICT infrastructure, ICT industry, human capital, legal and regulatory framework, productive sectors and service sectors. Others are public services, local content and universal access.

3.3.3. Privatization of the Tanzania Telecommunications Company Limited

On 23rd February, 2001, the Government privatized partially the TTCL, by selling its 35% of shares to strategic investors called the Mobile System International (MSI) of the Netherlands and Detecon Consulting of German) [PSRC1998,Hagg2000]. As an incentive to the investor, the sale was guaranteed with an Exclusivity Period of 4 years on basic telecommunications and leased line services from 23rd February, 2001 to 22nd February, 2005. In addition, they were given the Board and Management control.

Following the partial privatisation, the former Tanzania Communications Commission issued to TTCL five operating licences: fixed telecommunications services, mobile communications services, data communications services, the Internet service provision, and radio paging. The licences for the fixed telecommunications services, data communications services, and radio paging were operated directly by the TTCL. TTCL formed two subsidiary companies of Celtel Tanzania Limited and SimuNet to operate the mobile and the Internet service provision licences respectively. In 2007, Celtel Tanzania was then sold to Zain Company.

On February 23rd, 2005, the Government liberalized fully the telecommunications markets and opened them up to competition following the expiry of the Exclusivity Period of TCCL on fixed telecommunications and leased line services on 22nd February, 2005 [TCRA2009,TTCL2009]. This Exclusivity did not improve the financial, commercial and technical performance of the TTCL.

In February 2007, the Government ceased the Board and Management control of TTCL, by the strategic investors and awarded the Canadian firm SaskTel a three-year contract to manage TTCL. On 1st July, 2007, SaskTel started its operations to manage TTCL. In this contract, SaskTel was responsible for managing all aspects of the TTCL, operations, maintenance and expansion of the company in order to improve its financial, commercial and technical performance. The financial, commercial and technical performance of TTCL, could not improve probably because of stiff competition that TTCL was facing with the mobile network operators. The two policies ceased the telecommunications monopoly era and brought up effective competition in the telecommunications sector.

3.4. Legal and Regulatory Framework

Currently in Tanzania, the Tanzania Communications Regulatory Authority Act No.12 of 2003 (TCRA, Act 12/2003) and the Electronic and Postal Communications Act No. 3of 2010 (EPOCA Act 3/2010 define the legal and regulatory framework for regulating the postal, telecommunications and broadcasting services as detailed below.

3.4.1. Legal Framework

From 1994 to 2003, the communications sector was regulated by the former Tanzania Communications Commission (TCC) under the Tanzania Communications Act no. 18 of 1993 (TCC Act no. 18/1993) [TCCO1993]. In 2003, the government merged two independent separate regulatory bodies the TCC and the Tanzania Broadcasting Commission (TBC) and formed the Tanzania Communications Regulatory Authority (TCRA) under the Tanzania Communications Regulatory Authority Act no. 12 of 2003 (TCRA Act 12/2003) [TCRA2003]. TCRA is responsible for regulation of postal, telecommunications and broadcasting sectors.

In November 2006, a Bill for an Act of Parliament to establish the Universal Communication service Access Fund (UCAF) was passed by the Parliament [MOCT2006]. The Act enables accessibility and participation of private sectors in communications sector to extend communication services to rural and underserved areas so as to promote social, education and economic development. The Act puts in place the legal framework for designated operators to meet the supply of communications and quality of services in rural areas to the communities of Tanzania. The general objective of the Act is to provide enabling environment for promoting the provision of communications in rural and under-served areas.

In January, 2010, the Tanzania Parliament passed the Electronic and Postal Communications Act No. 3 of 2010 (EPOCA Act 3/2010). Beside the postal and electronic communications regulations, the EPOCA deals with new developments in the communications sector including SIM card registration, establishment of the Central Equipment Identification Register (CEIR), Computer Emergence Response Team (CERT), Digital Broadcasting, Postcodes and oversight of the Country Code Top level Domain (CCTLD).

3.4.2. The Regulatory Framework

In February 2005, after the expiry of the TTCL's Exclusivity Period on basic telecommunications and leased line services, the regulatory framework changed by liberalizing fully the communications sector. Following the full liberalization of the communications sector, Tanzania through the TCRA introduced the new Converged Licensing Framework (CLF) [TCRA2005] with four licence categories:

- Network Facilities;
- Network Services;
- Application Services;
- Content Services.

Each category is available in four market segments; namely (see Table 3.1):

- District;
- Regional;
- National;
- International.

Table 3.1.A Matrix of LicenceCategory and Market Segment in the CLF in Tanzania [TCRA2005].

License category	**District market segment**	**Regional market segment**	**National market segment**	**International market segment**
Network Facility License (NFL)	Network Facility Licence-District	Network Facility Licence-Regional	Network Facility Licence-National	Network Facility Licence-International
Network Service License (NSL)	Network Service Licence-District	Network Service Licence-Regional	Network Service Licence-National	Network Service Licence-International
Application Services License (ASL)	Application Service Licence-District	Application Service Licence –Regional	Application Service Licence-National	Application Service Licence-International
Content Service License (CSL)	Content Service Licence-District	Content Service Licence-Regional	Content Service Licence-National	Content Service Licence-International

The four license categories are defined as follows [TCRA2005]:

- Network facilities. This licence category entitles the holder of the licence to construct, maintain, own and make available one or more network facilities, which are "*any element, or combination of elements, of physical infrastructure used principally for, or in connection with, the provision of one or more network services, but not including customer premise equipment*".
- Network services. This licence category *"entitles the holder of the licence to provide a service for the carrying of information in the form of speech or other sound, data, text or images, by means of guided or unguided electromagnetic energy but does not include services provided solely on the customer side of the network boundary"*. The network boundary refers to as the *Main Distribution Frame (MDF),* where it terminates the external line plant of the copper access network on the customer side and core networks on the exchange side.

- Application services. This licence category *"entitles the holder of the licence to provide a service provided by means of one or more network services but does not include such a service provided solely on the customer side of the network boundary"*. The network boundary refers to as the *Main Distribution Frame (MDF),* where it terminates the external line plant of the copper access network on the customer side and core networks on the exchange side.
- Content services. This licence category *"entitles the holder of the licence to provide Television and radio broadcasting services"*.

Table 3.1 shows possibility of 16 possible combinations but in reality only 7 distinctive multiple interconnections of the telecommunications networks exists what can be explained as follows:

1 licence category has 4 different market based licences and 4 licence categories have 16 different market based licences, which formed 7 different types of multiple interconnections of the telecommunications networks. The table is relevant for the research, because it gives different types of multiple interconnections of the telecommunications networks of the CLF.

The CLF is technology and service neutral, and it enshrines effective competition in all market segments. The CLF represented a fundamental shift away from the traditional licensing regime in which the regulator grants licences to provide dedicated services over a given technological platform. Under the CLF, the operators can now apply for different categories licences and market segments to provide different facilities and services as shown in the matrix of the licence category and market segment.

Table 3.2. Number ofLicensesIssued as in December 2010 [TCRA2011].

License category	Market segment	Number of licenses issued
Network Facilities (NF)	International	5
	National	10
Network Services (NS)	International	5
	National	9
Application Services (AS)	International	13
	National Regional	45 4
Content Services (CS)	National Television / Radio	4 / 5
	Regional Television / Radio	5 / 7
	District Television / Radio	27 / 35

The current licensing framework and procedures issued a large number of licences, promoted investment in the communications sector, and ensured that many more customers have access to telecommunications services. However, it is clear that this framework using a sequential licensing approach of the "first come, first served" has a big problem and cannot be sustained because of the scarcity of radio frequency spectrum for future applicants. Table 3.3 presents the current demand and supply of the radio frequency spectrum in Tanzania. It is also clear that the demand for the radio frequencies in almost all competitive radio frequency bands exceeds the supply as the number of operators requesting frequency assignments exceeds the available space. It is suggested that the current sequential licensing framework should be reviewed by introducing spectrum auctioning in order to meet the demand and supply for the radio frequency spectrum.

Table 3.3.Radio Frequency Spectrum Demand and supply in Tanzania (as in December 2010) [TCRA2011].

Frequency band in MHz	Technology	Number of frequency bandwidths assigned to applicants	Number of available frequency bandwidths	Number of requested frequency bandwidths
450	CDMA	1	0	0
800	CDMA	4	0	0
900	GSM	4	0	3
1800	PCS	5	1	2
1900	PCS	2	1	3
2100	3G/UMTS/IMT-2000	1	1	4
2300	WiMAX	3	1	3
2500	WiMAX	4	2	6
3300	WiMAX	4	0	0
3500	WiMAX	13	0	2
4900	WiMAX	1	2	0

Other problems of the current licensing framework in Tanzania are the following:

- It does not match with interest of the telecommunications network operators. Although there are four licence categories most of the telecommunications network operators use everything. In situation, the telecommunications network operators build their own networks and provide services to wholesale and retail customers over them making it difficult to understand the distinction between the owner of the Network Facility and Network Service Licence;
- The CLF has a number of contradictions in its operations such as many Internet Service Providers (ISPs) with application licences hold spectrum, especially in the WiMAX band; thus, requiring radio communications transmitters (this require Network Facility Licence);

- There is no clear distinction between content services and network services. This confusion will be become more difficult when telecommunications network operators provide the Internet Protocol Television (IPTV) services and interactive games and television companies provide the Internet services.

In general the current licensing framework needs to be reviewed in order to match with the interest of the telecommunications network operatorsand the business model they like most. The main fundamental telecommunications business models are the following:

- Network build and operate.Where operators build their own networks and provide services to wholesale and retail customers over them.
- Service provision. Where operators rent networks from other operators, and provide services to retail customers.
- Content creation and its distribution. Where licensees create content and distribute through the telecommunications and broadcasting networks.

The research focused for the telecommunications network build and operate business model, which is the interest of the most of the telecommunications network operators.

3.4.3. Examples of LicensingFrameworksFromOtherCountries

Malaysia was the country, which provided the template of the licensing framework in Tanzania. The Malaysian licensing framework has four different license categories called Network Facilities, Network Services, Application Services, and Content [MCMC1998] Services. The license categories have no market segment. This is one of the major differences between the Tanzanian and Malaysian licensing frameworks.

The Malaysian licensing framework opted initially to issue licenses either on a class or an individual basis depending on a situation. However, in 2005, Malaysia stopped issuing the individual licences (licenses issued on beauty contest) for the application services and introduced class licences (authorisationlicences without evaluation). The number of licenses issued under the CLF in Malaysia at the start of 2009 (see Table 3.4).

Table 3.4.Number of LicencesUnder the CLF in Malaysia at the Start of 2009 [MCMC1998].

License category	Individual	Class
Network Facilities	70	15
Network Services	82	392
Application Services	0	19
Content	23	428

Some countries developed their licensing frameworks at least matched with the interest of some of the telecommunications network operators.

For example, **in Saudi Arabia,** a distinctionis drawn between facility based providers (defined as a service provider who builds, owns and operates a public telecommunications network) and service based providers (defined as a service provider who does not build or own a public telecommunications network and utilises the network of the facility based provider in order to offer services. Licences are provided to the facility based provider on an individual basis and to the service based provider on a class licence basis.

In **Kenya,** there are two main licence categories. Individual network operator (major) licences are available to operators who need access to scarce resources (spectrum and numbering). They are issued on an individual licence basis. The non-facility based operators (minor) licences are available to operators who do not need access to scarce resource. They are issued on a class licence basis.

In 2006, **Uganda** adopted a new licensing regime using two licensing categories:

- Infrastructure (the provision of plant and equipment associated with the sending of telecommunications signals);
- Service (the sending of telecommunications signals between a sender and a receiver).

In addition, operators wishing to use scarce resources (defined as spectrum, short numbers and international gateway facilities) have to obtain an essential resources authorisation.

In South Africa, the Independent Communications Authority for South Africa (ICASA) implemented a two tier structure. An Electronic Communications Network Service licence permits the construction of a network and the provision of network services. An Electronic Service Licence permits the provision of services, but the licensee must use the network (including numbers from the national numbering plan) provided by a holder of an Electronic Network Service Licence. A separate broadcasting licence is also made available. These licenses are both available as individual and class licenses.

In 2004, the **Telecommunications Regulatory Authority of India (TRAI)** introduced a new licensing framework with three main license categories [TRAI2003]:

- Unified licence.This licence category covers all public communications networks, irrespective of media and technology, capable of offering voice and /or non-voice (data services). The unified licence allows operators to offer both fixed, mobile and broadcasting services within a single licence.The licence category is in line with the convergence of the information and communications technologies that merge the services together to form broadband and multimedia services.

- Class licence. This licence category covers all services including satellite services, which do not provide both way connectivity with the public communications networks.
- Authorisationlicence.This licence category covers mainly the services for the provision of passive infrastructure and bandwidth services to the service providers.

3.4.4. The Impact of the Converged Licensing Framework OnIndustry and Economy In Tanzania

The introduction of the converged licences promoted effective competition and increased rapidly the number of mobile phones. The rapid growth of the mobile phones generated additional volume of traffic in minutes. The increase of volume of the traffic drives down the interconnection charges. The mobile interconnection charges per minute dropped from US cents 10.00 in 2005 to US cents 7.89 in 2010 [TCRA2011].

Retail tariffs dropped down as operators compete for market share with promotions. Employment and investment levels increased as new operators roll out their networks. In 2006 the total number of jobs created by the mobile telecommunications industry in Tanzania was 125, 000.

3.4.5. Interconnection Regulations

In 2005, TCRA prepared and issued the Tanzania Communications (Interconnection) Regulations, 2005 [TCRA2005] in order to promote effective competition in all market segments under the current CLF. These regulations impose an obligation on licensees to enter into interconnection agreements with each other on "reasonable terms and conditions" within three months of a request by a licensee for interconnection with another. The interconnection agreements must be negotiated on transparent in a non-discriminatory manner and comply with among other criteria the following.

- Methods to be adopted to establish and maintain the connection;
- Connecting points of the network in which the connection is to be made;

- Necessary capacity to ensure reasonable quality of the signal, taking into account the overall capacity of the interconnecting network;
- Form in which signals must be transmitted and received at the terminal points of the network, including numbering arrangements and signalling methods;
- Way to ensure that any signal is received with a quality consistent with the recommendations of the International Telecommunications Union (ITU);
- Interconnection tariff be based on costs.

The interconnection regulations require the telecommunications network operators to negotiate on a price for the delivery of an electronic service based on a forward looking Long Run Incremental Costing (LRIC) methodology [TCRA2005].

On 30th September, 2004, Tanzania through the Tanzania Communications Regulatory Authority issued the Interconnection Determination No. 1 of 2004 on cost based interconnection charges for fixed and mobile telecommunications networks in the United Republic of Tanzania following the interconnection studyconducted by the Analysis Consulting Limited from the United Kingdom [TCRA2005].

The mobile interconnection charges per minute for 2005 was US Dollar 0.10 [TCRA2005]. The fixed interconnection charges per minute for single and double tandem 2005 were US Dollar 0.039 and 0.054 respectively. This Determination was reviewed in March 2006 and the mobile interconnection charge per minute was capped at US Dollar 0.080 from 1st March 2006 until 31st December 2007. Similarly, the fixed single and double tandem interconnection charge per minute was also capped at US Dollar 0.038 and 0.053 from 1st March until 31st December 2007.

On 31st December, 2007, TCRA issued another Interconnection Determination No. 2 of 2007 that aligned fixed and mobile interconnection charge per minute into one mobile interconnection charge per minute from 1st January, 2008 to 31st December, 2012 (see table 3.5). This alignment of the fixed and mobile interconnection charge per minute was due to low traffic (less than 3%) terminating on the fixed telecommunications networks. The alignment removed the single and double-tandem interconnection charge per minute for the fixed telecommunications networks. The current interconnection charge per minute for mobile and fixed dropped from USD 0783 in 2008 to USD 0.0716 in 2012.

Table 3.5.Aligned Voice Call Interconnection Charges per Minute from 1.1.2008 to 31.12.2012.

Year	1.1.2008	1.1.2009	1.1.2010	1.1.2011	31.12.2012
Interconnection charges per minute in USD	0.0783	0.0765	0.0749	0.0732	0.0716

3.5Competitive Telecommunications Network Deployment and Operations

This Section presents telecommunications network deployment and operations for five competitive licensed operators. These operators include the following:

- Tanzania Telecommunications Company Limited;
- Vodacom;
- Zain;
- TIGO;
- Zantel.

The Capital Expenditures (CAPEX) and Operating Expenditures (OPEX) for 2007-2009 for the most competitive telecommunications network companies were sourced from the operators' annual audited accounts and analysed them to get their interconnection costs. The interconnection costs were presented in Chapter 6.

3.5.1. Tanzania Telecommunications Company Limited

TTCL is still the only fixed telecommunications network operator in the country [TTCL, 2009]. Most of the access networks were constructed by the Twisted Copper wires (TCW). In 2000, the company complemented the TCW based access networks by the Wireless Local Loop (WLL) in some areas of Arusha, Morogoro and Tanga regions. Deployment of the WLL based access networks in these regions increased subscriber connections and solved problems of vandalism and sabotage of the copper wires. TTCL looses over USD 1.0 million a year through the theft of copper telephone wires and fibre optical cables [TTCL, 2009].

TTCL's **backbone transmission** systems are still predominantly microwave radio with a combination of Pleiosynchronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH) technologies, which are limited in capacity. Fibre optic is prevalent technology in Dar es Salaam city. Lack of adequate backbone transmission capacity owned by TTCL in the country made some of the mobile operators to construct their own backbone microwave transmission systems.

In 2001, immediately after privatization, the TTCL made a substantial investment. The company expanded, upgraded and modernized the fixed telecommunications networks by replacing the traditional circuit switched systems by the InternetProtocol (IP) based packet switched systems at the core networks. TTCL also upgraded the radio networks by deploying 34Mbits/s and Synchronous Transport Mode 1 (STM-1) microwave radio equipment and linking them to the newly installed IP based packet switched systems and Intelligent Network (IN) platform. The TTCL's upgrading of the radio networks provided cost effective digital leased lines to mobile network operators as compared to the expensive leased lines via satellites.

TTCL planned to deploy the National Information and Communications Technology (ICT) backbone of optical fiber cable system of about 6,200 kilometers, which was estimated to cost USD 64.00 million into 4 phases (see Fig. 3.2):

- Phase 1, 2006;
- Phase 2, 2007;
- Phase 3, 2008;
- Phase 4, 2009.

The backbone optical fiber system was completed and commissioned successfully. It is now in good operation.

In 2007, TTCL decided to deploy mobile services using the CDMA 2000 mobile network technologies. It is the fifth mobile market entrant and has not yet made significant impact in the market. By December 2010, TTCL had 86,965 mobile subscribers holding the fifth position by acquiring 0.4% of the shares in the mobile market and 159,054 fixed line subscribers. The deployment of the CDMA mobile networks has boosted the overall subscriber base of TTCL to 315, 0871. TTCL operates its own international gateway to provide the international services. Some of the international services are routed through the sub-marine cable installed by the Seacom Limited Company.

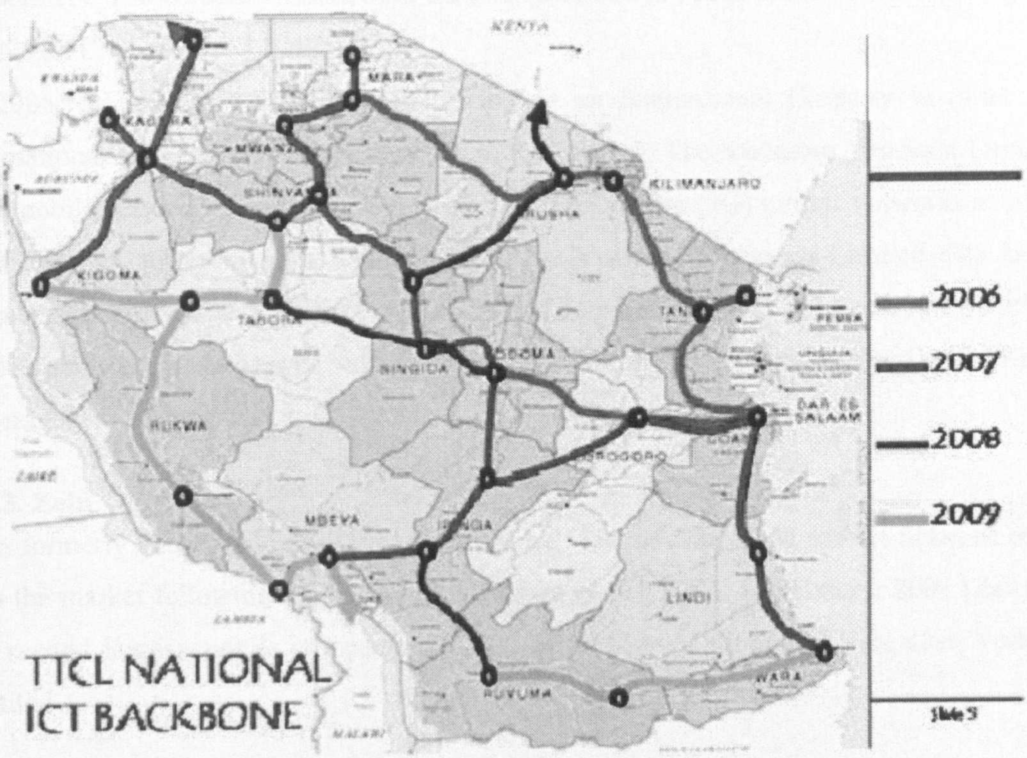


Figure 3.2.A map of Tanzania showing routes of the planned National ICT backbone optical fiber cable system [TTCL,2009]

3.5.2. Vodacom

In December 1999, the Vodacom Tanzania Limited was licensed to provide and operate the GSM mobile services in the country. The Vodacom Tanzania Limited was the fourth company to enter into the mobile market in the country [Voda, 2009]. The Vodacom Tanzania Limited rolled out aggressively the GSM mobile networks within the first three years of operations 2000-2003. The company acquired quickly wide network coverage with presence in almost all headquarters of the administrative regions and districts including rural areas in both the Tanzania Mainland and Zanzibar Islands. Services provided include national and international voice services, Short Message Services (SMS), Multimedia Message Services (MMS), General Packet Radio Services (GPRS), High Speed Packet Downlink Access (HSPDA), video and sound streaming. The Vodacom Tanzania Limited has a total number of the mobile subscribers of 8,670,536as December 2010. The company holds the first position by acquiring the 41% the shares of the mobile markets in the country in terms of the number of the subscribers. The company offers both the post-paid and pre-paid international roaming as explained in details on Chapter 4.

In 2006, the company was licensed to operate an International Gateway in order to provide the international telecommunications services in the country. The Vodacom Tanzania Limited became the first mobile network operator to deploy the third Generation (3G) mobile networks using the WCDMA 2000 network technology. In January 2007, the Vodacom Tanzania Limited also launched the 3G mobile services. in March 2007, the company commenced their commercial operations of the 3G mobile services in the Dar es Salaam region. The Vodacom Tanzania Limited's GSM mobile network coverage was not provided.

3.5.3. Zain

Zain formerly known as Celtel Tanzania Limited was the fifth GSM mobile network operator to enter into the market following the partial privatisation of the TTCL in February 2001 [Zait, 2009]. Zain is the second largest mobile company in terms of number of mobile phones after Vodacom Tanzania Limited.

Zain expanded and upgraded its GSM mobile networks significantly covering almost the entire country including some rural areas. Zain has become the second position by acquiring 28.69% shares of the mobile markets in the country in terms of the number of the connected subscribers of 6,021,091 as in December 2010.

In 2006, Zain deployed the Enhanced Data rates for GSM Evolution (EDGE) and General Packet Radio System (GPRS) services in the country. The GPRS services are available throughout the entire country while the EDGE services are limited to some areas of the country. Zain offers both post paid and pre-paid international roaming as explained in details on Chapter 4. The pre-paid roaming is offered to 16 different countries in Africa and Middle East under the concept of One Network explained in details onChapter 4.

3.5.4. TIGO

Milcom Tanzania Limited (MIC (T) trading as TIGO, was the first mobile communications company in Tanzania. TOGO was licensed in 1993 as joint venture between Milcom International cellular company based in Luxemburg [TIGO, 2009], Ultimate Security Company and Tanzania Posts and Telecommunications Corporation (TP&TC).

TIGO started operations of the mobile networks using the analogy Total Access Communications Systems (TACS) mobile technology. In 2001, the company changed the operations of networks from the analogy TACS to digital GSM mobile technology. Although TIGO was the first company licensed to provide and operate mobile networks in the country, their network coverage is still concentrated mainly in urban areas leaving most of the rural areas uncovered (see Fig.3.3). Following the limited supply of the mobile network coverage, TIGO Limited has been relegated to the third position by holding 21.33% of the shares in the mobile market in terms of the number subscribers of 4,477,510 as in December 2010.

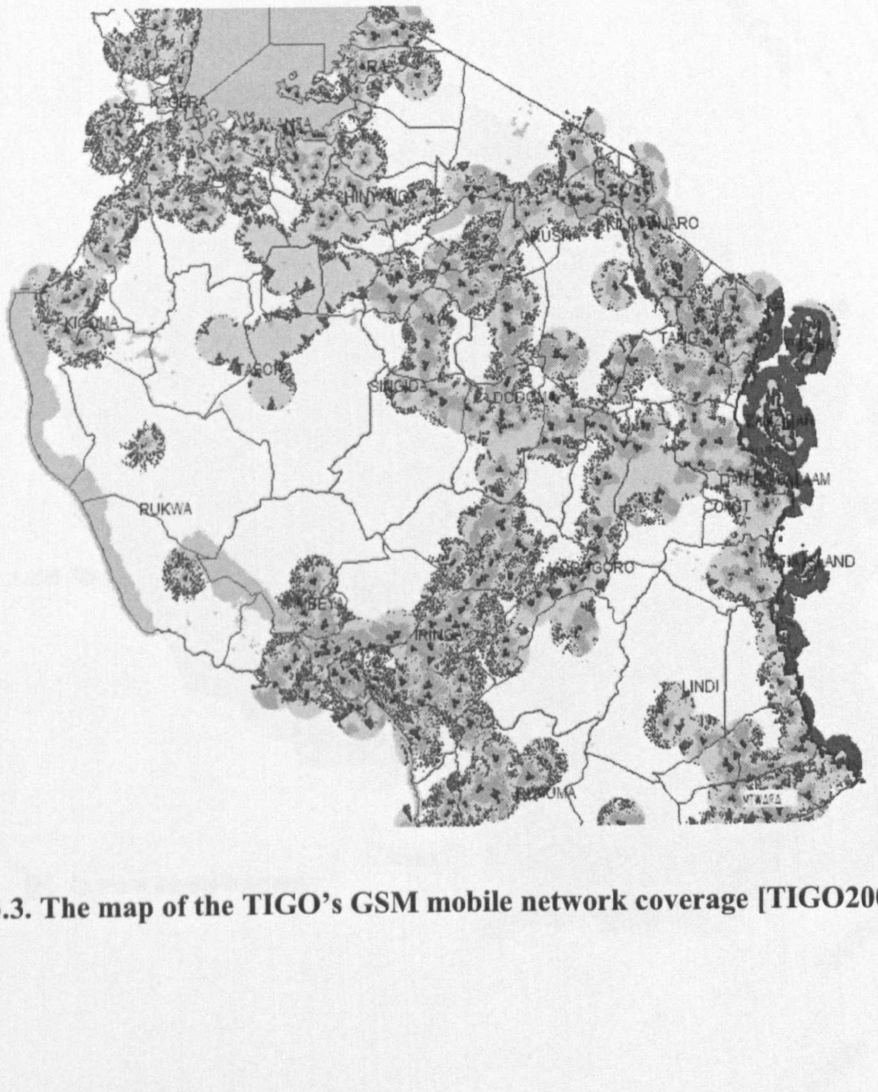


Figure 3.3. The map of the TIGO's GSM mobile network coverage [TIGO2009]

3.5.5. Zanzibar Telecommunications Limited

In 1997, Zanzibar Telecommunications Limited (Zantel) was licensed to provide and operate fixed and mobile telecommunications services and international gateway only in the Zanzibar Islands [Zant, 2009]. Zantel was the third company to enter into the mobile market in the country. The company was not allowed to use their international gateway in the Zanzibar Islands to route the international traffic from/to Tanzania Mainland, because the fixed telecommunications services were still monopoly to TTCL in the Tanzania Mainland. However, the Government allowedTTCL and Zantel to operate the fixed telecommunications services in the Zanzibar Islands on duopoly basis.Following the full liberalization of the telecommunications sector on 23rd February, 2005, Zantel was allowed to provide and operate their telecommunications networks in the whole country (see Fig.3.4)

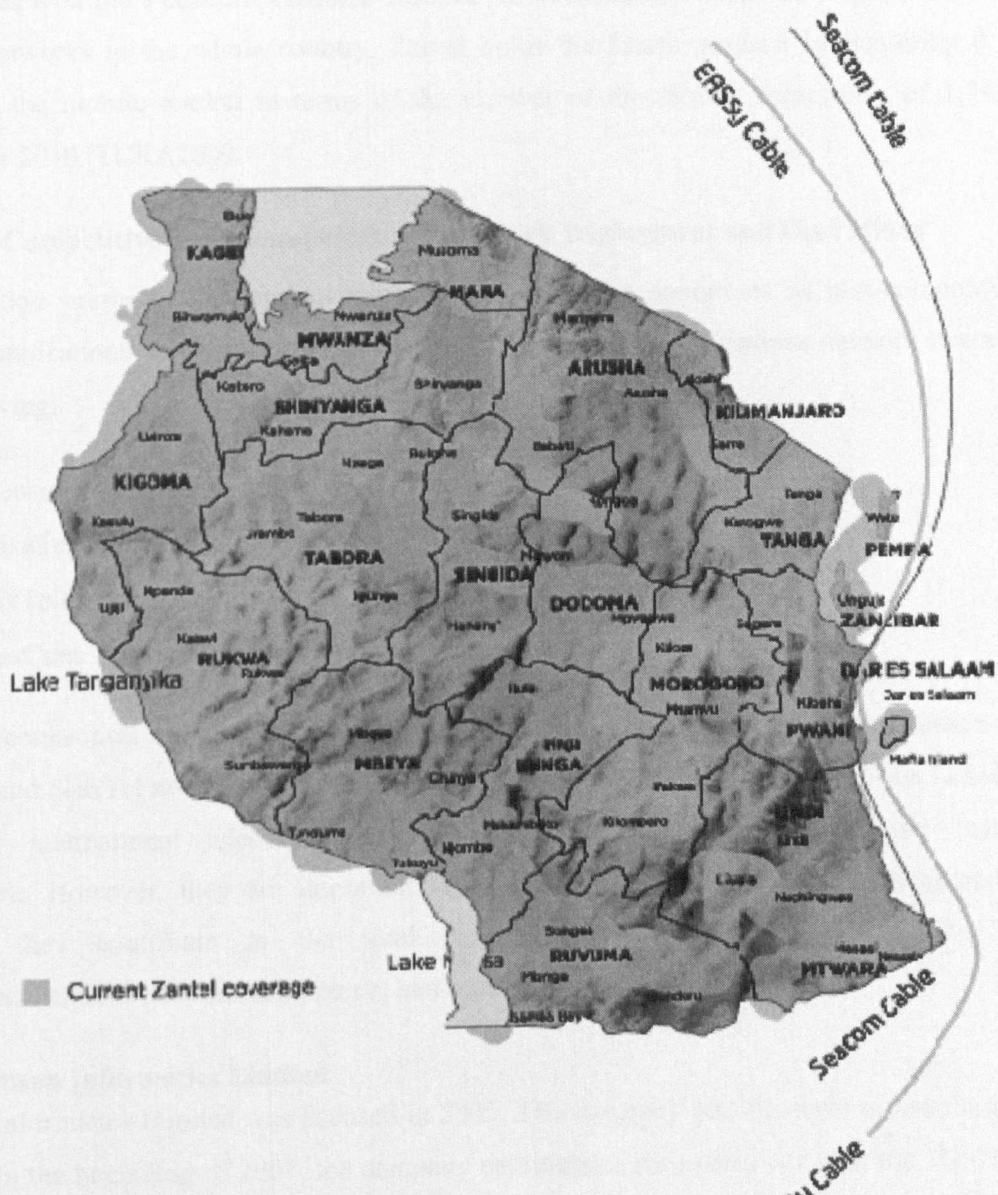


Figure 3.4.The Map of Zantel's GSM mobile network coverage [ZANT,2009]

Following the full liberalization of the telecommunications sector on 23rd February, 2005, Zantel was allowed to provide and operate their telecommunications networks in the whole country. In July 2005, Zantel crossed to the Tanzania Mainland offering the mobile communications services [Zant, 2009]. The company started their operations in the Tanzania Mainland through entering national roaming agreements with the Vodacom Tanzania Limited. In 2007, Zantel started rolling out their own CDMA mobile networks in the whole country. Zantel holds the fourth position by acquiring 8.18% of the shares in the mobile market in terms of the number of the mobile subscribers of 1,715,985 as in December 2010 [TCRA2009

3.6. Non-Competitive Telecommunications Network Deployment and Operations

This Section presents telecommunications deployment and operations of non-competitive licensed telecommunications network operators. These licensed telecommunications network operators include the following:

- Benson Informatics Limited,
- SasaTel Company Limited,
- SixTelecoms Company Limited, and
- SeaCom Tanzania Limited.

The interconnection costs of these companies have not been estimated because Benson Informatics Limited and SasaTel are small and non-competitive companies. SixTel and SeaCom Tanzania Limited deployed international telecommunications networks, which are outside the interconnection framework. However, they are important telecommunications network deployment and operations because they contribute to the total interconnect traffic throughput to the competitive telecommunications network deployment and operations.

3.6.1. Benson Informatics Limited

Benson Informatics Limited was licensed in 2005. The company was the sixth to enter into the mobile market. In the beginning of 2007, the company commenced the operations with the 3G CDMA–based networks. The company concentrated offering the mobile services in only Dar es Salaam region. In December 2010 the company had mobile subscriptions 2,396 and acquired 0.01% of the shares in the mobile markets. The GSM mobile network coverage map was not provided.

3.6.2. SasaTel Company Limited

In 2007, SasaTel Company Limited was also licensed to provide and operate the mobile services. The company was the seventh to enter into the mobile market.

In 2009, the company commenced the operations with the 3G CDMA broadband based networks. The company concentrated offering the broadband mobile services in only Dar es Salaam region. In December 2010, the company had mobile subscriptions 24,827 and acquired 0.12% of the shares in the mobile markets. SasaTel also could not provide the GSM mobile network coverage map.

3.6.3. Six Telecoms Company Limited

Six Telecoms Company Limited operates an international gateway. The company serves as a carrier of carriers in handling outgoing and incoming international voice calls. In December 2005, the Six Telecoms Company Limited commenced commercially the operations of the international gateway. The company does not have subscribers.

3.6.4. SeaCom Tanzania Limited

In September 2008, Tanzania licensed the SeaCom Tanzania Limited to provide, install and operate a submarine cable system branching from the main submarine cable system to the landing point station in Dar es Salaam [Seac2009]. The branch submarine cable crossed the Tanzanian territorial waters of about 12 nautical miles (22.22 kilometers) and terminated to the Dar es Salaam landing point station. The sub-marine cable is not considered for the calculations of the interconnection costs because it is not part of the interconnection network components. The costs of the submarine cable (the international network component) are usually recovered bilaterally between international carriers through settlement of accounts.

The main submarine cable system has a length of about 15,000 kilometers passing through the international waters of the Indian Ocean and connecting South Africa, Mozambique, Madagascar, Tanzania, Kenya and India with options to extend the same to Fujairah, Kingdom of Saudi Arabia and Egypt. The installation and commissioning of the SeaCom Limited's submarine cable system project made Tanzania connected to the rest of the world by the submarine cable systems offering the broadband communications services. Another big submarine cable project formed by multi-national companies and governments of Eastern African countries is called the East African Submarine cable System (EASSy). The EASSy project intends to provide, install and operate the submarine cable along the coast of the East of Africa. The cable is expected to be ready for services before 2012.

Thus, there will be two submarine cable systems along the coast of East of Africa operating by two companies on duopoly basis.

Other submarine cable networks in Africa (see Fig.3.5) include the following:

- In the West of Africa, the SAT-3/WASC submarine cable connected from Gibraltar in Spain and crossed the Atlantic Ocean to South Africa;
- The South Africa and Far East (SAFE) submarine cable connected the SAT-3/WASC submarine cable from South Africa and crossed the Indian Ocean to Malaysia.
- In the North Africa, the submarine cable connected from Gibraltar in Spain crossed the Mediterranean Sea to India and Far East.

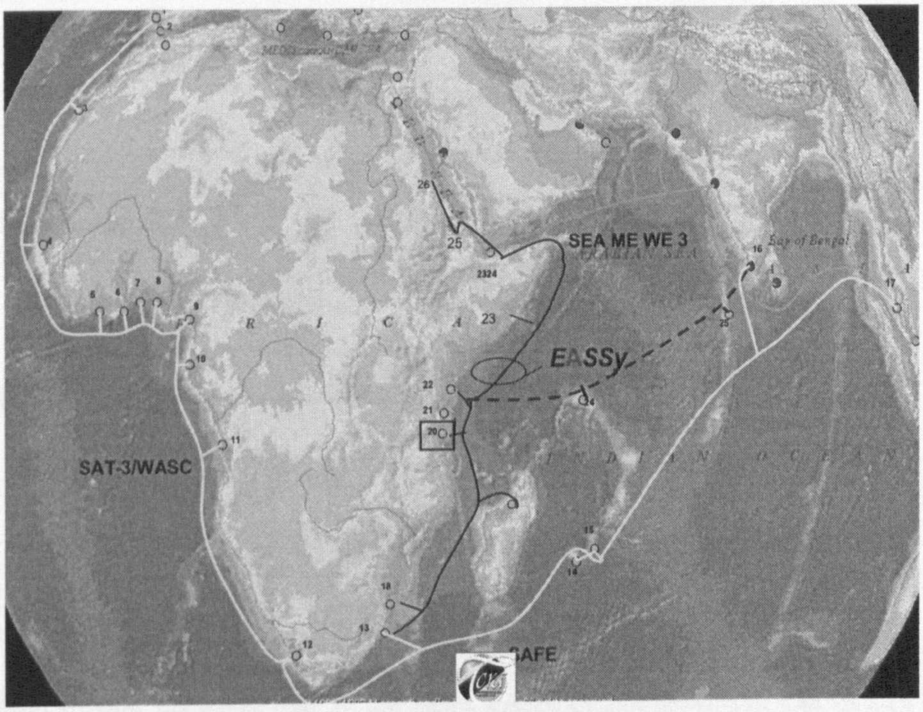


Figure 3.5.The African submarine cable networks [Seac2009]

3.7. Analysis of the Growth of Mobile Networks in Tanzania

This Section presents the analysis of the growth of mobile networks in Tanzania in terms of number of mobile phones and density using the diffusion theory of innovations [Riff1995,Jukic2004,]. The growth of the mobile phones normally drives down the interconnection costsbecause of the increase of utilization of the telecommunications network due to the increase of traffic throughputs. The Section starts by presenting the underlying the diffusion theory of the innovations and causes of the rapid growth of the mobile phones in the developing countries like Tanzania. The Section analyzes mathematically empirical data of mobile phones collected from Tanzania from 2000 to 2009. This analysis attempts to obtain the growth phenomenon of the mobile phones in Tanzania, which can be used by telecoms operators and policy makers to plan well the mobile networks to meet the demand.

3.7.1. The Diffusion Theory of Innovation

The theory of diffusion of innovation relies on the concept that many past innovations like mobile phones exhibited a non-linear shaped penetration from the innovation is launched to that point in time when the innovation reaches the end of its product cycle and is fully adopted (see Fig. 3.6) [Mead2004, Gree2002]

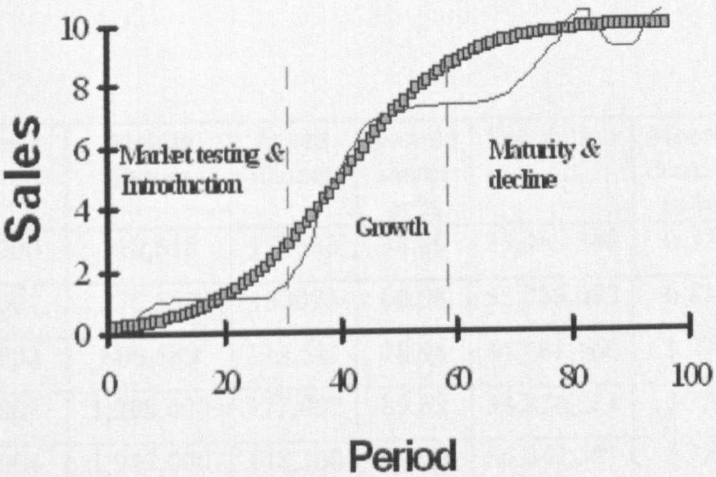


Figure3.6. The non-linear curved penetration [Filde2007]

The logic behind of this theory is that at the early stages of the launch of the mobile phones *early adopters (the innovators)* come to market, possibly drawn in by marketing hype, and test the product. At this time, many others remain outside of the market looking in, uncertain of the products reliability, features and final real costs. Many others within the economy may not even know of the mobile products existence or care for its application. As the innovators test the product they describe its value to those looking in. This activity may take place between friends, family, neighbours and work colleagues as well as via media sources reporting successes. If the innovation is useful, critical mass is achieved that speeds up adoption growth, i.e. the curve ramps upwards (i.e. the middle part of Fig. 3.6).

Eventually the product lifecycle ends as the entirety of the population now has the mobile phone.

The rapid growth of the mobile phones in Tanzania was due to late adoption of telephones. Late adopters of telephones have less reliance on fixed telephones [Jame2004,Sing2008]. In 1995, the mobile technology was introduced for the first time in Tanzania, and it penetrated rapidly into the population in accordance with the diffusion theory of innovation.

3.7.2. Fixed and Mobile Phone Data Collected from Tanzania

The total number of fixed and mobile phones was collected from the Tanzania Communications Regulatory Authority (TCRA) in Tanzania from 2000 to December 2009 (see table 3.6). Annually and monthly data was collected from 2000 to 2006 and from 2007 to 2009 respectively.

Table 3.6. Cumulative Growth of Fixed and Mobile Phones in Tanzania from 2000-2009

Year	Mobile phones	Fixed phones	Mobile shares in %	Population	Mobile density in %
2000	110,518	173663	38.89	33,463,388	0.33
2001	275,557	183093	60.08	33,756,093	0.81
2002	606,589	173,591	78.94	34,161,166	1.77
2003	1,298,000	177,802	89.83	34,876,231	3.72
2004	1,942,000	148,360	92.90	36,049,581	5.38
2005	2,963,737	154,420	95.04	37,267,530	7.95
2006	5,614,922	151,644	97.37	38,523,907	14.57
Jan07	5,715,089	154,865	97.36	38,548,278	14.82
Feb07	5,941,784	152,547	97.49	38,572,649	15.40
Mar07	6,140,532	154,141	97.55	38,597,020	15.90
Apr07	6,304,151	158,138	97.55	38,621,391	16.32
May07	6,488,744	161,926	97.56	38,645,762	16.79
Jun07	6,720,072	169,135	97.54	38,670,133	17.38
Jul07	6,975,930	188,786	97.36	38,694,504	18.03
Aug07	7,217,010	202,852	97.26	38,718,875	18.63
Sep07	7,489,901	233,890	96.97	38,743,246	19.33
Oct07	7,687,906	225,141	97.15	38,767,617	19.83
Nov07	8,018,016	230,545	97.20	38,791,988	20.66

Dec07	8,252,281	236,493	97.21	38,816,363	21.26
Jan08	8,647,863	279,406	96.87	39,010,523	22.17
Feb08	8,920,709	286,942	96.88	39,204,683	22.75
Mar08	9,225,345	294,047	96.91	39,398,843	23.41
Apr08	9,504,318	280,026	97.10	39,593,003	24.00
May08	9,838,924	155,451	98.44	39,787,163	24.73
Jun08	10,272,792	155,251	98.51	39,981,323	25.69
Jul08	10,576,519	156,285	98.54	40,175,483	26.33
Aug08	10,831,633	155,787	98.58	40,369,643	26.83
Sep08	11,563,309	156,320	98.66	40,563,803	28.50
Oct08	11,937,170	169,640	98.59	40,757,963	29.28
Nov08	12,340,040	168,966	98.65	40,952,123	30.13
Dec08	13,014,337	116,265	99.11	41,146,284	31.63
Jan09	13,317,093	171,299	98.73	41,340,444	32.21
Feb09	13,595,696	170,688	94.55	41,534,604	32.73
Mar09	13,896,555	170,021	98.79	41,728,764	33.30
Apr09	14,047,092	169,688	98.80	41,922,924	33.50
May09	14,327,249	166,126	98.85	42,117,084	34.02
Jun09	14,736,645	166,379	98.88	42,311,244	34.83
Jul09	15,224,976	181,167	98.82	42,505,404	35.81
Aug09	15,666,077	181,172	98.82	42,699,564	36.69
Sep09	16,051,647	181,671	98.88	42,893,724	37.42
Oct09	16,229,706	137,433	99.16	43,087,884	37.66
Nov09	16,642,748	173,264	98.96	43,282,044	38.45
Dec09	17,469,486	172,922	99.01	43,476,204	40.01

The cumulative number of mobile phones and mobile density were plotted against time (see Fig.3.7 and 3.8 respectively). The figures show that the diffusion of the mobile phone took place essentially after 2005 when Tanzania liberalized fully the communications sector and introduced the Converged Licensing Framework (CLF). In the following years the mobile phones continued growing rapidly in number of mobile phones, pushing it from 5,765,819 in 2006 to 17,642,408 mobile phones in December 2009.

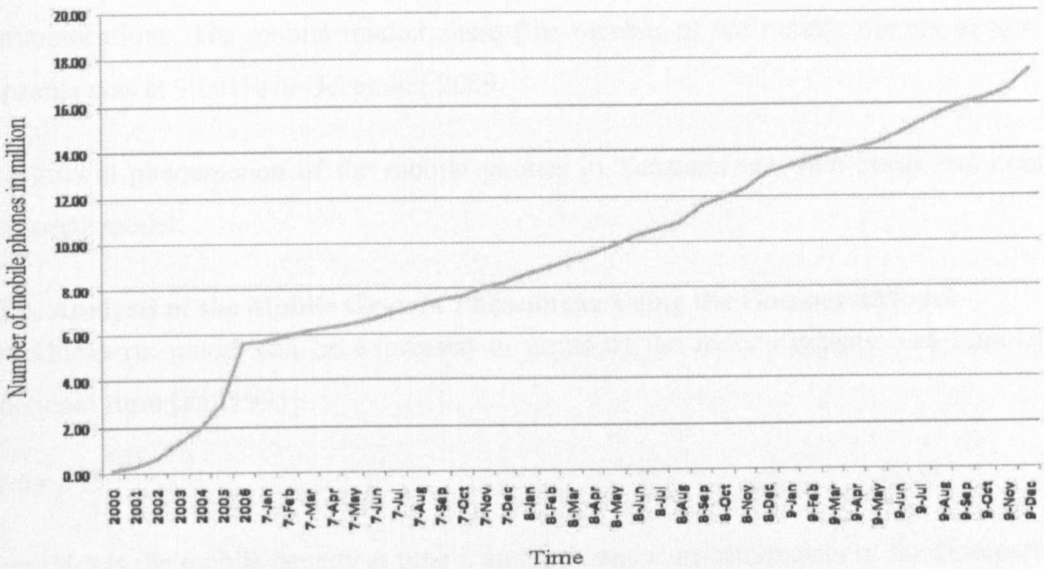


Figure 3.7. Cumulative Growth of Mobile Phones AgainstTime

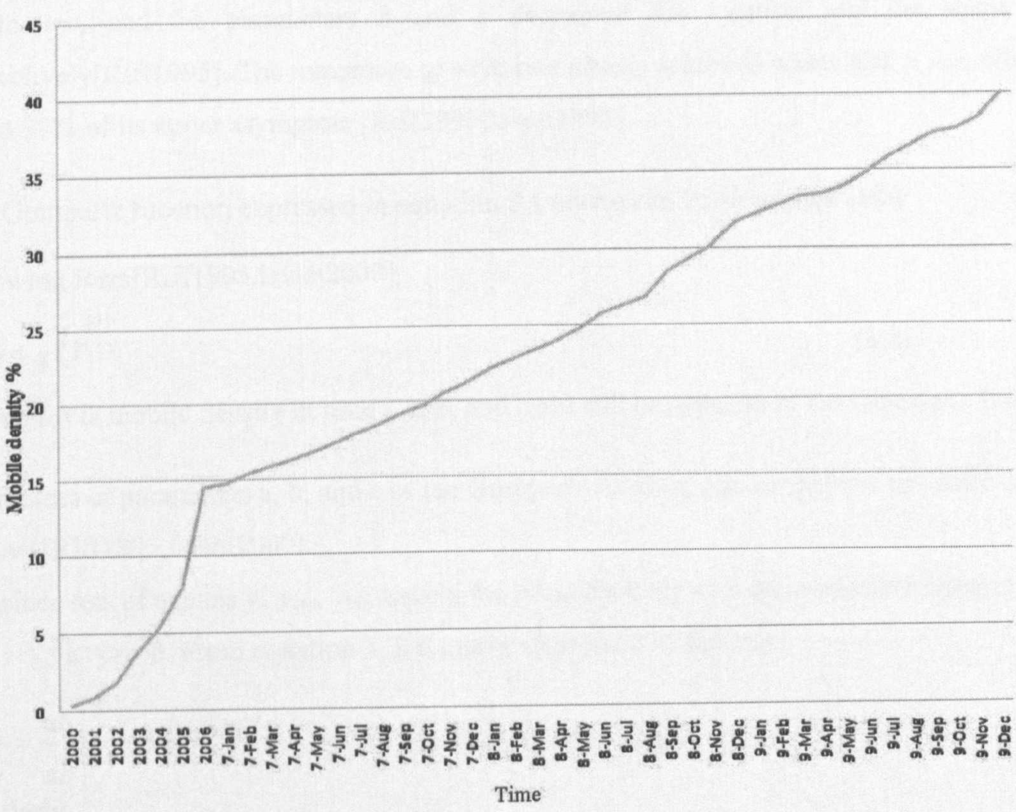


Figure 3.8. Mobile Density AgainstTime

In Tanzania, the mobile phones have been becoming the dominant means for accessing communications. The mobile market share (the number of the mobile phones to total telephones) in Tanzania was at 99.01% in December 2009.

The growth phenomenon of the mobile phones in Tanzania was non-linear and consistent with the Gompertz model.

3.7.3. Analysis of the Mobile Growth Phenomena Using the GompertzModel

The Gompertz model can be expressed in terms of the mobile density and time by the following functional form [Riff1995]:

$$Mdt = a\,e^{-be^{-ct}} \qquad (3.1)$$

where*Mdt* is the mobile density at time *t*, and *a*, *b*, and *c* are parameters of the Gompertz function to be estimated. The parameter *a*, represents the saturation level, which is the upper asymptote. The Gompertz function ranges from a lower asymptote of zero to the upper asymptote of *a* as t ranges from -∞ to +∞, and the parameters *b* and *c* determine the location and the shape of the curve respectively[Riff1995]. The maximum growth rate *ab/e* is achieved when *Mdt* = *a/e*, when *Mdt* reaches about 37% of its upper asymptote [Riff1995,Islam1995].

The Gompertz function expressed in equation 3.1 above can be simplified inthe

following form[Riff1995,Islam2000]:

$$Mdt = a\,b^{c^{t}} \qquad (3.2)$$

where*Mdt* is mobile density at time t, a, b, and c are still parameters of the Gompertz function.

Estimators of parameters a, b, and c of the Gompertz function can be derived basically as follows[Riff1995,Islam2000].

Consider sets of triplets y_i, y_{j+j}, y_{i+k} having the property k=2j with the respective integral t-values, i, i+j and i+k, k>j>i>0. From equation 3.2, it can be expressed as follows:

$$\frac{y_{i+k}}{y_{i+j}} = \frac{ab^{c^{i+k}}}{ab^{c^{i+j}}} = b^{c^i(c\,k - c^j)} \qquad (3.3)$$

Similarly,

$$\frac{y_i + j}{y_i} = b^{c^i(c^j - 1)} \qquad (3.4)$$

Then in general,

$$\frac{\log\dfrac{y_i+k}{y_i+j}}{\log\dfrac{y_i+j}{y_i}}=\frac{c^i(c^k-c^j)\log b}{c^i(c^j-1)\log b}=((c^k-c^j)(c^j-1)^{-1} \tag{3.5}$$

Usuaally, k can be chosen such that k=2j, in this case

$$C^j=\frac{\log\dfrac{y_i+k}{y_i+j}}{\log\dfrac{y_i+j}{y_i}} \tag{3.6}$$

Equations 3.5 or 3.6 can be used to solve for c, since the left-hand side of the equation is a numerical value. In general, $0<c<1$.

The estimate for c can be substituted for c in the following equations to obtain an estimate for b. In general,

$$\frac{\log^2\dfrac{y_i+k}{y_i+j}}{\log\dfrac{y_i+j}{y_i}}=\frac{c^{2i}(c^k-c^j)^2\log^2 b}{c^i(c^j-1)\log b}=\frac{c^i(c^k-c^j)^2\log b}{c^j-1} \tag{3.7}$$

or

$$\log b=\frac{(c^j-1)\log^2\dfrac{y_i+k}{y_i+j}}{c^i(c^k-c^j)^2\log\dfrac{y_i+j}{y_i}} \tag{3.8}$$

In the special case in which k=2j,

$$\log b=\frac{\log^2\dfrac{y_i+k}{y_i+j}}{c^{i+k}(c^j-1)\log\dfrac{y_i+j}{y_i}}=\frac{\log\dfrac{y_i+k}{y_i+j}}{c^{i+k}(c^j-1)} \tag{3.9}$$

$$\log b=\frac{\log\dfrac{y_i+k}{y_i+j}}{c^{i+k}(c^j-1)} \tag{3.10}$$

An estimate of b can be obtained from Equations 3.8 or3.9. In general $0<b<1$.

The estimate for c and b can now be substituted for c and b in the following equations to obtain an estimate for a.

$$\log(y_i+y_{i+j}+y_{i+k})=\log a+\log(b^{c^i}+b^{c^{i+j}}+b^{c^{i+k}}) \tag{3.11}$$

$$\log a=\log(y_i+y_{i+j}+y_{i+k})-\log(b^{c^i}+b^{c^{i+j}}+b^{c^{i+k}}) \tag{3.12}$$

From Equations 3.11 and 3.12 an estimate for a can be found; hence, all estimates for a,b and c can now be found.

Given that the data for the whole 2000-2009 period as shown in Table 3.6 are on different frequency, only monthly data from January 2007 to December 2009 was used to estimate parameters for the Gompertz Growth curve. It is the more recent monthly observations that are of utmost important for estimating the level of saturation of the mobile-density, which is considerable interest in this analysis. Moreover, inclusion of the annual observations do not alter any conclusion reached, and by discarding them for estimation purposes, it is avoided making unduly assumptions concerning the monthly evolution of the market from 2000 until the last month of December 2007.

From Table 3.6, three monthly observations are chosen arbitrarily, y_i, y_{j+j}, y_{i+k} having the property that k = 2j.

Let i=5 and j=14 (3.13)

The three monthly observations from Table 3.6 have the following data points:
(5,16.79), (19,26.73), (33,37.42). From equation 3.6,

$$C^{14} = \frac{\log\frac{37.42}{26.33}}{\log\frac{26.33}{16.79}} = \frac{\log 1.4212}{\log 1.5681} = \frac{0.1526}{0.1953} = 0.7813 \qquad (3.14)$$

$$Logc = \frac{1}{14}\log 0.7813 = -0.00076 \qquad (3.15)$$

$$c = 0.9825 \qquad (3.16)$$

From equation 3.10,

$$\text{Log b} = \frac{\log\frac{y_{33}}{y_{19}}}{C^{33} - C^{19}} = \frac{0.1526}{0.5584 - 0.7150} = -0.9744 \qquad (3.17)$$

$$b = 0.10592 \qquad (3.18)$$

From equation 3.12,

$$\log a = \log(\, y_5 \square y_{19} + y_{33}\,) - \log(0.10592^{0.9825^5} + 0.10592^{0.9825^{19}} + 0.10592^{0.9825^{33}}\,) \qquad (3.19)$$

$$\log a = \log 80.54 - \log(0.72) \qquad (3.20)$$

$$\log a = \log\frac{80.54}{0.72} = 111.86 = 112 \qquad (3.21)$$

$a = 112$ (3.22)

The projection of the mobile density in Tanzania will primarily be based on the estimated Gompertz model using the equation 3.23 below.

$$Mdt=112(0.10592^{0.9825^t}) \quad (3.23)$$

where Md is the mobile density, the parameter 112 represents the level of saturation of the mobile density, 0.9825 represents the adoption rate, in this case of Tanzania the adoption rate is fast, 0.10592 represent the shape of the curve and t represents period of time in months from January 2007. The inflection point based on the

Gompertz model is rotationally asymmetrical to the level of the saturation of the mobile-density, and it occurs at 37% of the level of the saturation of the mobile-density [Islam2004]:

37% x 112 = 41.44 (3.24)

Therefore, the inflection point will occurs at mobile density of 41.44%. The time t in months from January 2007corresponds to the inflection point can be calculated as follows:

$$41.44 = 112\,(0.10592^{0.9825^t} \quad (3.25)$$

$$\text{Log } 41.44 = \log 112 + 0.9825^t \log 0.10592 \quad (3.26)$$

$$\text{Log } 41.44 - \log 112 = 0.9825^t \times (-0.9750) \quad (3.27)$$

$$\text{Log } \frac{41.44}{112} = 0.9825^t\,(-0.9750) \quad (3.28)$$

$$\text{Log } 0.37 = 0.9825^t(-0.9750) \quad (3.29)$$

$$\frac{-0.4317}{-0.9750} = 0.4427 = 0.9825^t \quad (3.30)$$

$$\text{Log } 0.4427 = t\,(\log 0.9825) \quad (3.31)$$

$$\frac{-0.3539}{-0.00766} = t \quad (3.32)$$

$$t=46.2 \quad (3.33)$$

This means that the inflection point of the curve will occur at 46.2 months after January 2007; that is, October 2010 (when the mobile-density and number of mobile phones will be around *41.44* mobile phones per 100 inhabitants and *17,855,619* mobile phones respectively).

The time at which the number of the mobile phones exceeds the number of people in Tanzania can be forecasted as follows. This time will occur when the mobile- density will be at least 100%. Therefore, this time can be represented by the following equation:

$$100=112(0.10592)^{0.9825^t} \quad (3.34)$$

$$0.89285=0.10592^{0.9825^t} \quad (3.35)$$

$$\text{Log } 0.89285= 0.9825^t \log 0.10592 \quad (3.36)$$

$$\frac{-0.04939}{-0.9750} = 0.9825^t \quad (3.37)$$

$$0.050656 = 0.9825^t \quad (3.38)$$

$$\text{Log } 0.050656 = t \log 0.9825 \quad (3.39)$$

$$\frac{\log 0.050656}{\log 0.9825} = t \quad (3.40)$$

$$\frac{-1.29542}{-0.00766} = t \quad (3.41)$$

$$t = 169.1 \text{ months from January 2007} \quad (3.42)$$

The number of mobile phones will just exceed the number of people in Tanzania by January 2021; that is, 169.1 months from January 2007 when the mobile density is 100% and the number of mobile phones will be at least 55,840,060 based on the population projection (see Table 3.7).

The mobile density Mdt near to the level of saturation of the mobile density can be estimated by taking Mdt near to 112 let say t= 111. The corresponding estimated time t can be calculated as follows:

$$111 = 112(0.10592)^{0.9825^t} \quad (3.43)$$

$$\log(0.9910) = 0.9825^t \log(0.10592) \quad (3.44)$$

$$\frac{\log 0.9910}{\log 0.10592} = 0.9825^t \quad (3.45)$$

$$0.9825^t = 0.004026 \quad (3.46)$$

$$t \log 0.9825 = \text{Log } (0.004026) \quad (3.47)$$

$$t = \frac{\log(0.004026)}{\log(0.9825)} = 312.67\,months \quad (3.48)$$

Therefore the level of saturation of the mobile density will be reached in the year 3035 (312.67months (27 years) from January 2007).

The mobilemarket potential (the number of mobile phones at the level of saturation of mobile-density) is based on the saturation level of mobile –density and population of the country at that time. Projection of the population of Tanzania 2003- 2035
taken from the Tanzania National Bureau of Statistics (TNBS) is presented (see Table 3.7)

Table 3.7. Projection of population in Tanzania: 2003 – 2035 [tnbs2009]

Year	Population
2003	34,719,999
2004	35,731,938
2005	36,784,149
2006	37,869,275
2007	38,983,135
2008	40,127,136
2009	41,302,284
2010	42,509,480
2011	43,746,911
2012	45,010,906
2015	48,919,824
2020	55,840,060
2025	63,516,735
2035	71,193,410

The number of mobile phones at the market potential (level of saturation of mobile-density of 112%) in 2035 can be calculated as follows:

$$71{,}193{,}410 \times \frac{112}{100} = 9{,}736{,}619 \qquad (3.49)$$

The number of mobile phones at the potential market (112%) in 2035 will be *79,736,619.*

3.8. Conclusion

Details of telecommunications development in Tanzania have been presented in this chapter by explaining the background and history of the telecommunications development in the country during the German and Great Britain colonial rule from 1888 to 1961 and post-colonial rule from 1962 up to 1994. During this period, the telecommunications networks were operated on monopoly basis where there was no interconnection of networks. The Telecommunications developments in Tanzania from 1994 to date have been presented by explainingreforms that took place in the telecommunications industry. These reforms resulted in the liberalisation of the telecommunications markets and opening them up to competition. The competition brought up the interconnection of telecommunications networks, which is important to the research.The competitive and non-competitivecompanies have been discussed by presenting their telecommunications network deployments and operations.Growth of the mobile networks over time in terms of number of mobile phones and mobile density has been modeled and forecasted by using the Gompertz models. The results showed that the growth of the mobile networks would reach the saturation level at the mobile density 112% in 2035 and the number of the mobile phones of 79,736,619. The mobile phones have been becoming increasingly a dominant means for accessing the communications in Tanzania.

Chapter 4.From International Roaming To Non-international Roaming In Tanzania

This Chapter aims to go into detail here on about international roaming explained on Chapter 3 on page 61 by presenting its implementation in Tanzania as follows [Zait2009].

- Post-paid international roaming,
- Pre-paid international roaming, and
- Non- international roaming sometimes is known as the One Network Concept.

4.1. Post-paid International Roaming

This Section presents the post-paid international mobile roaming calling using the ITU-T Common Channel Signaling Systems No. 7 (ITU-T CCSS No.7). These calls are part of the call types included in the mobile interconnection cost models analyzed in Chapter 6. The calls are provided by All GSM mobile network operators in the country. The post-paid international mobile roaming calls enable only the post-paid customers to make and receive calls on a foreign network while travelling outside their home country. The post-paid international roaming calls ensure that the post-paid customers are always connected with their home networks when they are outside the country as detailed below [GSMA2007,GSMA2009] .

4.1.1. Post-paid InternationalRoaming: Target Customers

The post-paid international roaming calling was developed to serve for customers with contract with the home mobile network operator; that is, post paid customers who pay bills after using the GSM services. This roaming service enables the post-paid customers to make and receive calls on foreign GSM mobile networks while they are in the foreign countries.

4.1.2. Post-paid International Roaming:Scenario

The post-paid roaming customer can use their GSM phones on a foreign network in a foreign country. The Interconnection Regulation 2005 does not regulate the international roaming calling. The international calls originating from Tanzania and terminating on the networks of other countries and vice versa are outside scope of the Interconnection Regulation 2005. Normally, the costs of terminating these calls are recovered through special procedures of international settlement of accounts between the international carriers of the two countries. However, the traffic throughput in minutes offered by the post-paid international roaming are included in the mobile interconnection cost models as presented in Chapter 6. Hence, the international roaming callingis relevant to this research. The services offered to the post-paid international GSM mobile roaming include the following:

- Making calls;

- Receiving calls at their home GSM numbers while roaming;
- Sending fax and data;
- Receiving fax/data at their home GSM numbers;
- Sending and receiving Short Message Services (SMS);
- Billing by the home network operator.

The post-paid roaming customers are visited customers on the foreign networks, and they are not connected as home customers. That is, when they make and receive local calls on the visited foreign country, they pay the roaming tariffs and not the standard local call charge.

4.1.3. Post-paid InternationalRoaming:Operations

The post paid international roaming calling operates with the following technical and commercial arrangements:

- Own an operational network with the ITU-T CCSS no.7;
- Signing bilateral roaming agreements;
- Own a billing system capable of generating and receiving *Transferred Account Procedure* (TAP) files. The TAP is a procedure by which the GSM network operators exchange international roaming call data records for the use of the GSM networks and services for billing purposes [GSMA2009] ;
- Conclude roaming agreements with other operators.

4.1.4. Post-paid InternationalRoaming:ChargingPrinciples

Charging principles for the post-paid roaming customers in a foreign country include the following:

- A roaming customer receiving an international call from the home network in a foreign country pays an international call charge from the home network to the foreign network;
- The calling part from the home network pays a local call charge;
- A roaming customer originating and sending an international call from the foreign networks pays the foreign network operator's roaming tariffs;
- A roaming customer making and receiving local calls on a foreign network in a foreign country also pays the foreign network operator's roaming tariffs, which are higher than the local call standard charges.

In this situation, the roaming customer pays on receiving local calls.

4.2. Pre-paid International Roaming

Zain and Vodacom Tanzania Limited GSM mobile network operators introduced the pre-paid international roaming services using the Customized Application for Mobile network Enhanced Logic (CAMEL) Phase I. These services are included in the mobile interconnection cost models analyzed in Chapter 6. The services offer the traffic throughput in minutes defined in Chapter 6. The pre-paid international roaming services enable the pre-paid customers to make and receive calls on foreign GSM mobile networks while travelling outside their home country [GSMA2009,Zait2009].

4.2.1. Pre-paid InternationalRoaming:TargetCustomers

The pre-paid international roaming services were developed to serve for *top up customers*; that is, the customers who pay bills as they use the GSM services. These roaming services enable the pre-paid customers to make and receive calls on a foreign GSM mobile network while travelling outside their home country.

4.2.2. Pre-paid InternationalRoaming:Scenario

The pre-paid roaming customers can use their GSM phones on a foreign network in a foreign country as follows:

- Making calls;
- Receiving calls at their home GSM numbers while roaming;
- Sending fax and data;
- Receiving fax/data at their home GSM numbers;
- Sending and receiving Short Message Services (SMS);
- Billing by the foreign network operator (not by the home network like the post-paid roaming). This is an area that differs from the post paidinternational roaming.The pre-paid roaming customers are visited customers on the foreign networks, and they are connected as home customers enjoying the Virtual Home Environment (VHE) [Roam2009,Gsma2009]. The VHE provides the local network environment for the international roaming subscribers on the foreign networks.

4.2.3. Pre-paid InternationalRoaming:Operations

The pre-paid international roaming operates with the following technical and commercial arrangements:

- Own an operational network with the Customized Application for Mobile network Enhanced Logic (CAMEL) Phase 1;

- Signing bilateral roaming agreements;
- Own a billing system capable of generating and receiving transferred account procedures;
- Conclude roaming agreements with other Operators.

4.2.4. Pre-paid InternationalRoaming:ChargingPrinciples

Charging principles for the pre-paid roaming customers in the foreign country on the foreign visited mobile networks include the following [GSMA2009,Roam2009]:

- A roaming customer receiving an international call from the home network in a foreign country pays an international call charge from the home network to the foreign network. The calling part from the home network pays a local call standard charge (the same as post-paid international roaming charging principles);
- The pre-paid international roaming subscriber does not need to register the service to the home network when travels outside the country for billing purposes.

4.3. Non- international Roaming (One Network Concept)

Zain has the GSM mobile network installations in 23 different countries in Africa and Middle East [Zait2009]. The GSM mobile network installations of 16 out of 23 different countries have been linked together by a single Intelligent Network (IN) platform using the CAMEL Phase 2 to form a *One Network* [GSMA2009]. The non-international roaming network, [Roam2009] expanded the customers' coverage and service experience from 1 country to 16 countries in Africa and Middle East in the Zain'sGroup networks. The traffic throughput in minutes offered by the one network is included in the mobile interconnection cost model and defined on Chapter 6.

4.3.1. Non-international Roaming:One NetworkConcept

The concept of the non-international roaming introduced by the Zain Group is the creation of *borderless mobile network coverage* across the zain Group's mobile network installations of different countries in Africa and Middle East [Zain2009]. The borderless mobile network coverage enables customers to enjoy the Pan-African/Middle East community and *move freely between the countries* (now 16 countries) *in which the Zain Group operates,* and be treated as *"virtual"*local customers of the visited network in terms of pricing, while retaining their home network service functionality.

4.3.2. Non-international Roaming: Networkroll-out plan

On 27th September, 2006, Zain Group introduced simultaneously the non-internationalroaming network in East Africa (Kenya, Tanzania and Uganda) as Phase 1 for the first in the world [Zait2009]. Phase 2 of the non-international roaming network roll-out plan expanded to three countries in Africa, namely

Democratic Republic of Congo (DRC), Congo Brazzaville and Gabon. This phase was commissioned on 8th June, 2007. On 22nd November, 2007, Zain Group commissioned Phase 3, which expanded further the non-international roaming network to 6 more countries in Africa, namely Nigeria, Niger and Chad. Other countries are Burkina Faso, Malawi and Sudan.

Phase 4 of the non-internationalroaming network roll-out expanded the coverage and services to 3 countries in the Middle East, namely Bahrain, Jordan, Iraq (the Middle East) and Sudan (Africa). The non-international roaming network covers a total of 13 countries in Africa and 3 countries in the Middle East.

4.3.3. TechnicalIntegrationOfThe Non-international Roaming

Technically, the non-international roaming is supported by a single Intelligent Network (IN) platform using the CAMEL Phase 2 for mobile. The CAMEL Phase 2 is a network solution that offers a Virtual Home Environment (VHE) for the GSM international roaming services. The VHE for the international roaming services using the General Packet Radio Services (GPRS) and Enhanced Data for GSM Evolution (EDGE)technologies is offered by the CAMEL Phase 3. The VHE enables the roaming customers to use directly the services in the visited foreign mobile networks with real time billing as if they were in their home mobile networks. The software for the CAMEL Phase 2 has the following main service functionalities:

- Local Recharge.This service allows in-roamers to use Prepaid Airtime vouchers of visiting network to top-up their balance. The service also manages currency exchange rates between various countries. It provides detailed reports of voucher usage for accurate financial reconciliation within operations;
- Short Message System Billing in Camel 2 destinations.This service does bills all Short Message Systems (SMS) sent by prepaid out-roamers. The SMS Service of CAMEL Phase 2 out-roamers are usually barred as it cannot bill them for SMS sent while roaming. The SMS Billing solution thus enables SMS service for prepaid out-roamers, and if the out-roamer runs out of balance while roaming, the SMS service is barred on the HLR for that out-roamer;
- Boarder Roaming Gateway service (BRGW)in order to manage cross border spill over effect.Normally, when the international roaming customers come close to international borders sometimes log onto the network across the border even though they are in the home network. The BRGW services will process such a situation so that customer comes back to home network to avoid roaming charges;

- Smart call assistant.In-roamers often have difficulty dialing home numbers from their phone book, which are usually stored in local format. Smart Call Assistant (SCA) intelligently provides the correct format in order to support national format dialing for the roamer;
- Optimal routing.This service allows calls made to an in-roaming customer by a local subscriber to be routed locally instead of using the international gateway. The optimal routing reduces load and dependency on the international links. It improves connection time and voice quality by avoiding routing of calls through the home networks. In the absence of the CAMEL Phase 2, the calls from the local subscribers to the in-roaming customer, should be routed back to the international gateway of the home network of the in-roaming customer and then sent back to the international gateway and local exchange of the visited foreign network of the in-roaming customer. This type of routing delays the calls in terms of time, and it uses unnecessary two outgoing and incoming international legs;

- Accurate financial reconciliation. This reconciliation details reports of voucher usage enables for accurate financial reconciliation within operations;

- SMS Billing in Camel 2 destinations.This service does billing of all SMS sent by prepaid out-roamers. The SMS Service of CAMEL Phase 2 out-roamers are usually barred as it cannot bill them for SMS sent while roaming. The SMS Billing solution thus enables SMS service for prepaid out-roamers, and If the out-roamer runs out of balance while roaming, the SMS service is barred on the HLR for that out-roamer;
- 4.3.4 The No Roaming cost effective and user-friendly solutions

4.3.4. Non-international Roaming: Cost Effective and User-friendly Solutions

The non-international roaming is cost-effective and user-friendly solutions; it is designed to meet customers' requirements for affordable communications services in Africa and Middle East by serving them as local customers when they are travelling across any country in which the Zain'sGroup is present as follows [Zait2009]:

- Customers can place calls at local rates;
- Customers can receive incoming calls for free;
- Customers can re-charge the telephone using locally-purchased top up scratch cards, or those brought from their home country;Customers can use any existing Zain SIM card across One Network countries

- Customers can access home country services (voice mails and customer care) in any No roaming country.

- Customers use all existing tariff plans and apply them automatically to all prepaid and post-paid customers throughout the region.

4.3.5. The Impact of the Non-International Roaming

Following the successful completion of the non-international roaming network roll-out plan, Zain Group announced proudly the achievement of the *world's first and largest borderless mobile network coverage.*The coverage of the non-international roaming network is 2.5 times the size of the European Union, with the coverage of 16 countries. Following this coverage, the non-internationalroaming network is accessible to *450 million people* andpresently it is available to more than *35 million Zain's customers.*The large coverage and customer base increased tremendously the traffic and revenue collection of the company.

4.4. Conclusion

In this Chapter, the implementation of the post-paid, pre-paid and non-international roaming servicesby the Zain's Group has been presented by explaining in details technical integration, operations and charging principles. The non-international roaming services have been proved cost effective and relevant to the research due to the use of the Virtual Home Environment (VHE) for making and receiving local calls on foreign networks which reduce the usage of the network elements; hence, reduction of the interconnection costs.

Chapter5.Review OfThe Existing Generic Interconnection Cost Models

This Chapter presents review of the existing generic interconnection cost models. The British Telecom's top-down Long Run Incremental Cost (LRIC) model;

- Europe Economics' bottom- up LRIC model.

These models are chosen because of the British and German history and background of the telecommunications development in Tanzania. There is no interconnection cost model from Africa.
The Chapter also presents comparison of the top-down and bottom-up cost modelingapproaches and selects a the top-down cost modeling approach, which is used for the research.

5.1. The British Telecom's Top-down Long Run Incremental CostModel

This Section presents the following:

- The BT telecommunications business model,
- The network increment and components of the BT telecommunications business model,
- Cost modelling approach used by the BT cost model,
- Types of costs being calculated, and
- Interconnection costs estimation using the BT's top-down LRIC model.

5.1.1. The BT TotalTelecommunicationsNetworkBusinessModel

The British Telecommunications Company Limited's total telecommunications network business model consists of the following main increments:

- core (conveyance) network,
- International network, and
- Access networks.

The boxes and circles above the dotted lines in Fig.5.1 represent the increments and network elements being modeled respectively. The directly attributable network related costs of the increments form the LRIC. The shaded boxes below the dotted line in the figure represent areas where fixed common costs exist across the increments. However, the BT used the LRIC methodology to estimate the costs of the interconnection [Brte2005].

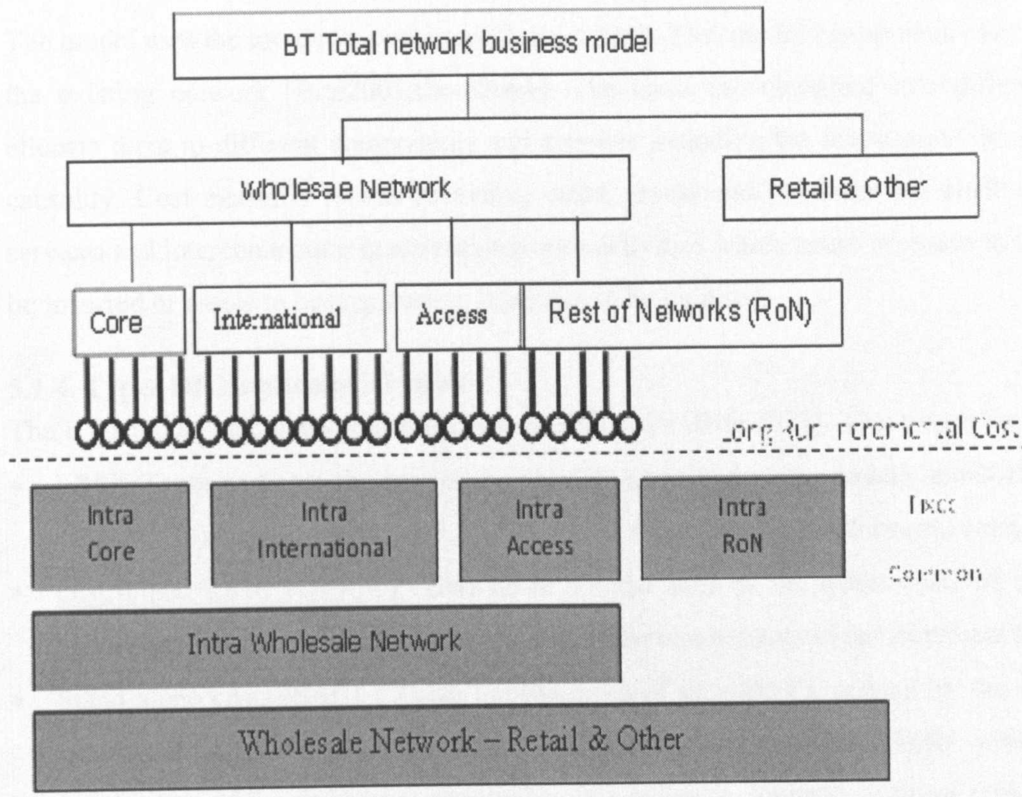


Figure 5.1. The BT total network business model [Brte, 2005]

5.1.2. The NetworkIncrement to be Mmodelled

The core network is the increment to be modeled and its architecture can be explained as follows:

- Switching network hierarchy. The core network increment has a flat switching network hierarchy of two levels of standalone digital local and tandem exchanges complemented by remote switching units as per Fig. 2.1 on page 13.

Network elements.Based on the switching network hierarchy, the BT top- down LRIC model uses 9 types of the network elements[Brte2005]. These types of the network elements are the following: remote concentrator units, local exchanges, tandem exchanges, remote to local transmission links, and remote to local transmission length. Others are local to tandem transmission links, local to tandem transmission length, intra-tandem transmission links, and intra-tandem transmission length. The network element "length" refers to infrastructure such as cables and ducts.

- Technology. All the transmission links in the core networks use the synchronous digital hierarchy (SDH) technology over the fibre optical cables. The fibre optical cables connect the digital local exchanges and remote concentrator units in rings.

5.1.3. Cost ModelingApproaches

The model uses the top-down cost modelingapproach. This modelingapproach uses the cost structure of the existing network [Brte2005,Cave2004]. The costs are classified into different categories, and allocate them to different components and services including the interconnection on the basis of cost causality. Cost causality means revenues, costs, assets and liabilities are attributed to components, services and interconnection in accordance with activities which cause revenues to be earned or costs to be incurred or assets to be acquired or liabilities to be incurred.

5.1.4. Types OfCostsBeingCalculated

The BT's model calculates four different types of costs [Brte,2005]. These costs include:

- LRIC. These costs are the sum of the variable and fixed of the directly attributable network related costs of the increment (see Fig.5.2). The LRIC forms the floor (minimum) costs.
- Distributed LRIC (DLRIC).These costs are the sum of the direct costs of the components and apportionments of the joint (indirect) costs of the components of the increment (see Fig.5.2).
- Stand-alone costs (SAC). These are the costs of providing a service by the operator in isolation from other services of the company. Therefore, SAC includes wholly variable and fixed cost components of the direct and attributable cost category, jointand common costs (see Fig.5.3). The SAC forms the ceiling (maximum) costs.
- Distributed SAC (DSAC). These are the sum of the direct costs and the apportionments of the joint and common costs of the components of the increments (see again Fig.5.3). The DSAC forms between the floor and ceiling costs.

5.1.5. Interconnection CostEstimationUsing The BT's Top-down LRIC Model

The BT adopted a detailed Accounting Separation [Brte2005] in which the total operating costs per network element, total capital costs per network element, total costs per network element and total traffic throughput in minutes per network element are presented. Then the costs of each network element per minute in pence (unit component costs) are also presented (see Table 5.1). The model aggregates the appropriate unit component costs and forms the costs in pence per minute of the three different types of fixed interconnection:

- local level;
- single tandem;
- double tandem.

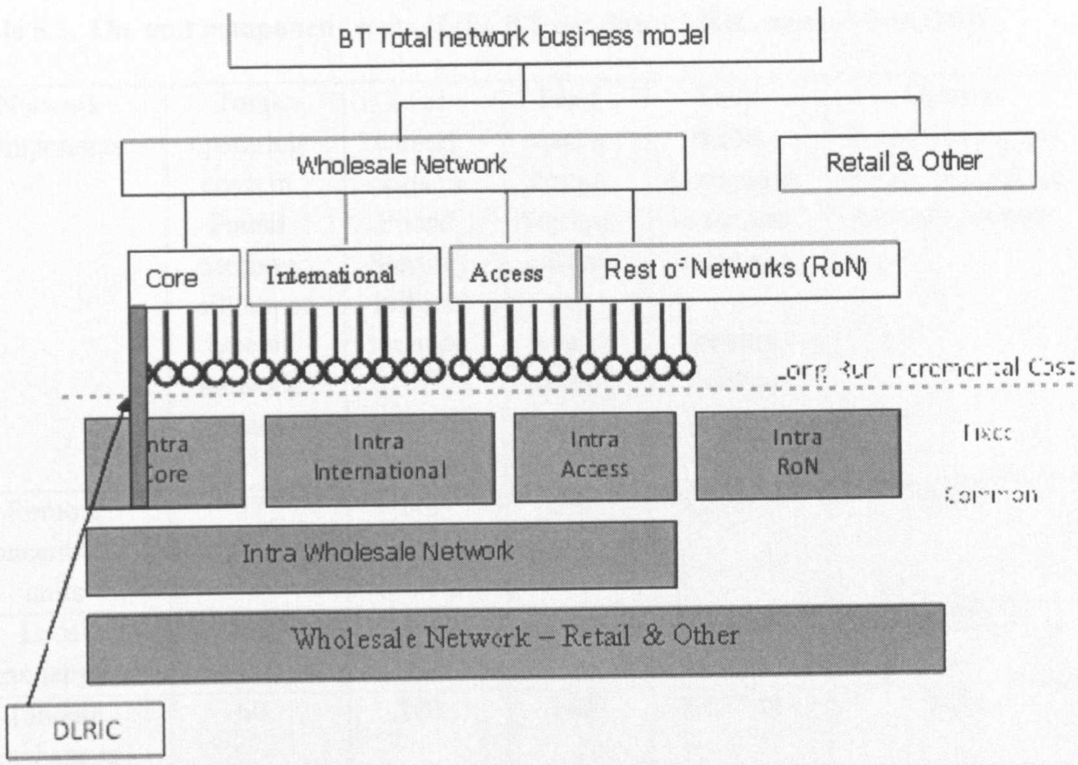


Figure 5.2. Use of the components of the BT networks for the LRIC and DLRIC costs Brte, 2005]

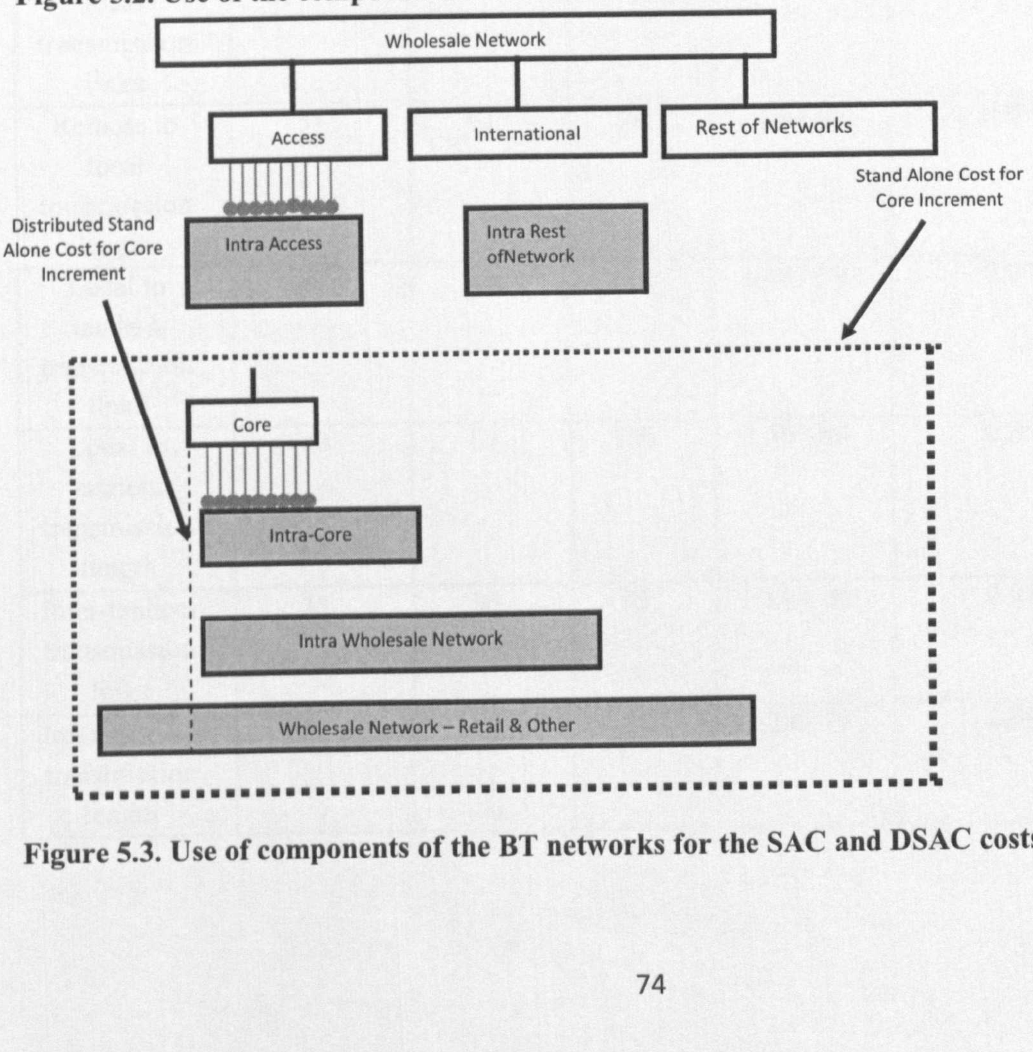


Figure 5.3. Use of components of the BT networks for the SAC and DSAC costs [Brte2005]

Table 5.1. The unit component costs of the BT top down LRIC model [Brte, 2005]

Network components	Total operating costs in Pound Sterling millionper type of network element	Total capital costs in Pound Sterling million per type of network element	Total costs in Pound Sterling million per type of networ k element	Total traffic throughput in million minutes per network element	Costs in PoundSterling per minute per type of network element
Remote concentrator units	57	146	203	3,256.72	0.062
Local exchanges	64	179	243	3,348.15	0.073
Tandem exchanges	60	180	240	2,357.88	0.101
Remote to local transmission links	40	103	143	2,118.82	0.067
Remote to local transmission length	51	95	146	1,567.65	0.093
Local to tandem transmission links	49	72	121	1,687.99	0.072
Local to tandem transmission length	40	60	100	1,567.85	0.064
Inter-tandem transmission links	35	50	85	1,146. 86	0.074
Inter-tandem transmission length	31	46	77	1,240.79	0.062

Table 5.2. Interconnection costs per minute of the BT network for 2005 [Brte2005]

Types of interconnection	Unit interconnection cost component equation	Unit interconnection costs in Pound Sterling	Unit interconnection costs in Euro at exchange rate of 1 Pound Sterling to Euro 1.64719
Local level	LE+RCU+(LE-RCU)li+(L-RCU)le	0.295	0.486
Single Tandem	TE+(TE-LE)li+(TE-LE)le+	02	0.876
Double Tandem	TE+(TE-TE)li+(TE-TE)le +TE+(TE-LE)li+(TE-LE)le+LE+RCU+(LE-RCU)li+(LE-RCU)le	0769	1.27

The interconnection costs per minute for the local level, single tandem and double tandem matched withthe EU recommended benchmarked interconnection rates as per table 1.1.

The data in Table5.1 show cost structure of the BT's network and unit component costs for 2005. The BT's model notations for the 9 network elements for cost modeling include the following:

- RCU Remote concentrator units;
- LE local exchanges;
- TE Tandem exchange;
- LE-RCU(li) Local exchange to remote concentrator unit transmission links;
- LE-RCU(le) Local exchange to remote concentrator unit transmission length;
- TE-LE(li) Tandem exchange to local exchange transmission links;
- TE-LE(le) Tandem exchange to local exchange transmission length;
- TE-TE(li) Tandem exchange to tandem exchange transmission links;
- TE-TE (le) Tandem exchange to tandem exchange transmission length.

The BT's model notations distinguish the transmission component between link and length. The length (le) refers to infrastructure such as cables and ducts and the link (li) refers to electronic equipment such as radio and multiplexers. Therefore, the BT' top-down LRIC model gives the accurate interconnection costs due to detailed cost modeling using 9 network elements.

5.2. The Europe Economics' Bottom-up Long Run Incremental Cost Model

This Section presents the following:

- The network increment to be modeled;
- The network components being included in the model
- Cost modeling methodology used by this model
- Interconnection cost estimation using the Europe Economics' bottom-up LRIC model.

5.2.1. Network Increment ToBe Modeled

The increment being used in the model is the core network of the modern fixed PSTN with a topology of a flat switching hierarchy network as per Figure 2.1 on page 13.

5.2.2. NetworkComponentsBeingModeled

The network components being included in the model are six: remote concentrator units, local exchanges, and tandem exchanges. Others are the remote to local transmission links, local to tandem transmission links, and inter-tandem local transmission links.

5.2.3.Cost Modeling Approach

The Europe Economics used the bottom-up cost modeling methodology. The costs are derived from the cost structure of a hypothetical efficiently designed new entrant network [Cave2004]. The costs of the individual network component are calculated, annualized and finally allocated to various components, services including the interconnection[Floo1975].

In 2000, the Europe Economics' Consulting Firm conducted the interconnection cost study for the British telecommunications networks using the bottom-up LRIC model. The model calculates the total operating costs per component; total capital costs per component, total costs per component and total traffic throughput per component and unit component costs in euro per minute (see Table5.3). All costs were in Euros. The model aggregated appropriately the unit component costs in euro per minute andformed threedifferent categories of interconnection costs(see Table5.4)

Table 5.3.Unit component costs in cents of euro per minute [Euec2002]

Network components	Total operating costs per network element in euro million	Total capital costs per network element in euromillion	Total costs per network element in euromillion	Traffic through put in million minutes per network element	Unit component costs in euro per minute
Remote switching units (RSU)	154	255	409	2,555.36	0.16
Local exchanges (LE)	185	255	440	2,607.83	0.17
Tandem exchanges (TE)	51	94	145	1,606.71	0.09
Remote to local transmission links(RSU-LE)	280	387	667	3,557.81	0.19
Local to tandem transmission links (LE-TE)	135	176	311	2,774.56	0.12
Inter-tandem transmission links (TE-TE)	150	279	429	1,021.43	0.42

Table 5.4.Average interconnection costs in euro per minute [Euec, 2002]

Typesof interconnection	Unit interconnection cost equations	Interconnection costs in euro per minute
Local level	LE+(LE-RSU)+RSU	0.52
Single tandem	TE+(TE-LE)+LE+(LE-RSU)+RSU	0.73
Double tandem	TE+(TE-TE)+TE+(TE-LE)+LE+(LE-RSU) +RSU	1.24

The interconnection costs per minute for the local level, single tandem and double tandem also matched withthe EU recommended benchmarked interconnection rates as per table 1.1.

The Europe Economics' model notations for the network components are different from the BT's model notation. The Europe Economics' model notation does not distinguish the transmission component costs between the link and length because the length costs is assumed negligible. The notations combine together the transmission length and link into one transmission cost component. As a result, the Europe Economics' model used only six components:

- RCU Remote concentrator units;
- LE local exchanges;
- TE Tandem exchange;
- LE-RCU Local exchange to remote concentrator unit transmission links;
- TE-LE Tandem exchange to local exchange transmission links;
- TE-TE Tandem exchange to tandem exchange transmission links.

The interconnection costs derived from the Europe Economics' bottom-up LRIC model were not transparent and detailed as compared to BT's model.

5.3.Comparison OfBottom-up and Top-down Cost Modeling Approaches

This Section presents comparison of advantages and disadvantages between the bottom-up and top-down cost modelingapproaches(see Table5.5). These are the two currently used cost modeling approaches.

Table 5.5. Comparison of bottom-up and top-down cost modeling approaches

	Top-down modeling	**Bottom-up modeling**
Advantages	• Can model costs that an efficient entrant would face; • Flexible- can change assumptions readily; • Transparent-much of the information used is publicly available.	• Incorporâtesactualcosts; • Useful for testing results from bottom –up model; • May be faster and less costly to implement.
Disadvantages	• May optimise "to much" or omit costs; • Modelling of Operating Expenditure (OPEX) is usually based on simple margin; • The modelling process can be time-consuming and expensive.	• Includes the firm actual costs and so are likely to incorporate inefficiencies; • Less transparent-Confidentiality issues mean other stakeholders may not have access to information used; • Data may not exist in the required form.

5.4. Conclusion

The existing generic bottom-up and top-down LRIC models developed by the Europe Economics and British Telecommunications Limited Company respectively have been reviewed by identifyingmore accurate methodsforthe interconnection cost estimation. The analysis of the framework, relevant cost components and design details for the interconnection cost models have been identified by reviewing of these generic cost models. The top-down and bottom-up cost modelingapproaches have been presented and compared with each other.

The BT top-down LRIC modelingapproachhas been selected as a suitable cost model for the case study based on the results obtained from the comparative analysis of the above mentioned generic cost models and formed basis for collection of the data required for the case study.

Chapter 6.Analysis Of Interconnection Cost ModelsFor Tanzania

This Chapter presents the analysis of the interconnection cost models that can be adapted and applied in the Tanzania telecommunications markets. These models intend to serve as tools for enabling telecommunications regulators and operators in Tanzania to estimate efficiently the fixed and mobile interconnection costs. The analysis of the interconnection cost models includes the following:

- Adaptation of the interconnection cost model;
- Defining Traffic throughput; ;
- Network costing;
- Traffic throughput calculations;
- Interconnection cost modeling;

6.1. Adaptation Of The Interconnection CostModel

This Sectionexplains adaptation of the interconnection cost model suitable to the Tanzania case study:

- The adapted interconnection cost model;
- Components of the adapted interconnection cost model;
- The cost function of the adapted interconnection cost model;

6.1.1. The Adapted Interconnection Cost Model

The BT's telecommunications network design and architecture of a two level switching network hierarchy, interconnection models and components and services delivery are similar or very close as in Tanzania. Therefore, the BT's interconnection cost models can be used and adapted to the Tanzania case study.

6.1.2. Components OfThe AdaptedInterconnectionCostModels

The Tanzania telecommunications networks were mostly designed by microwave radio links and not optical fiber systems like in the case of the BT's telecommunications networks. The Tanzania telecommunications networks lack of infrastructural related components (ducts, trenches) of optical fiber installations. Therefore, only sixout of nine components of the BT's interconnection cost models can be used and adapted to the Tanzania case study. The rest of the three components are related to infrastructure,andthey cannot be used and adapted to the Tanzania case study (see Table 6.1).

Table 6.1. Adapted components to the Tanzania case study

TANZANIA CASE STUDY: ADAPTED COMPONENTS	BT's Interconnection cost model components
RSU Remote Switching Units; LE Local Exchange; TE Tandem Exchange; LE-RSU(li) Local Exchange to Remote Switching Unit transmission link; TE-LE(li) Tandem Exchange to Local Exchange transmission link; TE-TE(li) Tandem Exchange to Tandem Exchange transmission link.	RSU Remote Switching Units; LE Local Exchange; TE Tandem Exchange; LE-RSU(li) Local Exchange to Remote Switching Unit transmission link; TE-LE(li) Tandem Exchange to Local Exchange transmission link; TE-TE(li) Tandem Exchange to Tandem Exchange transmission link LE-RSU(le) Local Exchange to Remote Switching Unit transmission length; TE-LE(le) Tandem Exchange to Local Exchange transmission length; TE-TE(le) Tandem Exchange to Tandem exchange transmission length.

6.1.3. Cost FunctionOf The Adapted Interconnection Cost Model

The interconnection costs are a function of the direct and attributable network related costs, cost of capital (Weighted Average Cost of Capital abbreviated as WACC) and duration of services in terms of traffic throughput in minutes [ITEU2006]. This function can be expressed mathematically as follows:

- **ICm** f**(NRC, WACC,TTm)** **(6.1)**

whereICm is the interconnection costs per minute, NRC is the network related costs, WACC is the Weighted Average Cost of Capital and TTm is the Traffic Throughput in minutes. The details of analysis of the interconnection costsarepresented from Sections 6.2-6.4 below:

6.2. Defining TrafficThroughputs

This Section defines the traffic throughputs offered by different services. These definitions form the basis to estimate the interconnection costs. The definitions include the following:

- Current traffic throughput in calls,
- Current traffic throughput in minutes,
- Expected traffic throughput in calls,

- Expected traffic throughput in minutes
- Interconnect traffic throughput in calls,
- Interconnect traffic throughput in minutes,
- Total traffic throughput in calls, and

By defining the traffic throughput, the interconnect traffic throughput can be expressed as a proportion of the total traffic throughput[Thom2003]. This proportion can be used to find the additional costs incurred to build the physical components (switching and transmission) required to handle the interconnect traffic throughput [Jung,2007] as presented in this Chapter. The additional costs (avoidable costs) required per minute interconnect traffic throughput is referred to as the interconnection costs [Jung,2008]. These costs for the five competitive operators are calculated and presented in this Chapter.

6.2.1. Current Traffic Throughput in Calls

Definitions for the formulae describing current traffic throughput in calls are taken from [Euec, 2002]. Current traffic throughput in calls on the conveyance network is equal to total number of call attempts that engage the conveyance network. Total call attempts is the sum of successful and billed calls, and unsuccessful calls.

The current traffic throughput in calls can be defined as follows:

$$\mathbf{CTc} = \sum_{i=1}^{m} \mathbf{Sci} + \sum_{j=1}^{n} \mathbf{Ucj} \qquad \mathbf{(6.2)}$$

where CTc is the current traffic throughput in calls, Sc is the successful and billed calls, Uc is the unsuccessful calls, i is a call type, m is number of successful calls and n is number of unsuccessful calls. Successful and billed calls i=1 to m clergy number of successful calls; j=1 to n number of unsuccessful calls.

Unsuccessful calls Uc can be expressed as a proportion of successful and billed calls Sc as follows

$$\mathbf{Uc = kSc} \qquad \mathbf{(6.3)}$$

where k is a factor of unsuccessful calls.

Therefore, the current traffic throughput in calls, CTc is defined by the following formulae:

$$CTc = \sum_{i=1}^{m} (Sci + kSci) \qquad (6.4)$$

$$CTc = \sum_{i=1}^{m} Sci\,(1+k) \qquad (6.5)$$

K depends on number of successful calls i.e. how large iis.

6.2.2. Current TrafficThroughput in Minutes

The current traffic throughput in minutes can be defined in terms of successful and billed calls (in minutes), unsuccessful calls in minutes plus holding time (call set up) (in minutes) as follows [Euec, 2002]

$$CTm= \sum_{i=1}^{n} (Smi+ Umi+Hmi) \qquad (6.6)$$

where CTm is current traffic throughput in terms of minutes switched, Sm is successful and billed calls in minutes switched , Um is unsuccessful calls in minutes, Hm is holding time (in minutes).

The current traffic throughput in minutes can be expressed in terms of successful and billed calls as follows

$$CTm= \sum_{i=1}^{n} Smi+ pSm+qSm \qquad (6.7)$$

wherepSm is unsuccessful call attempts in minutes expressed as proportion of successful and billed minutes; qSm is holding time in minutes expressed as proportion of successful and billed minutes.p and q depend on i a time n

6.2.3. Expected TrafficThroughput in Calls

Expected traffic throughput in calls, ETc, is defined as the current traffic throughput in calls plus margin for growth Mc for the operator's own traffic [Euec,2002]. During the state owned Posts, Telephones and Telegraph (PTT) monopoly era, the telecommunications networks were defined to carry only the expected traffic throughput. That is, to carry the traffic throughput belonged to the state owned telecommunication networks, because there was not any other operator in the market.

With the advent of the liberalization of the telecommunications market, more telecommunications network operators came in the market; therefore, interconnection of telecommunications networks was necessary and the state owned telecommunications networks had to define additional traffic throughput apart from the expected traffic throughput to handle the traffic throughput from other telecommunications network operators. The additional traffic throughput is now referred to as the interconnect traffic throughput. Therefore, the expected traffic throughput does not include the interconnect traffic throughput. The expected traffic throughput in calls can be expressed in terms of the current traffic throughput in calls as follows

$$ETc = CTc + Mc \qquad (6.8)$$

whereETc is the expected traffic throughput in calls ,Mc is margin of growth and it can be expressed as a proportion of expected traffic throughput in calls as follows

$$Mc = wCTc \qquad (6.9)$$

where w is a factor of the margin of growth of calls.

$$ETc = CTc + wCTc \qquad (6.10)$$

Therefore, the expected traffic throughput in calls ETc, can be expressed as follows

$$ETc = CTc\ (1+w) \qquad (6.11)$$

6.2.4. Expected TrafficThroughput in Minutes

Similarly, the expected traffic throughput in minutes can be expressed as follows;

$$ETm = CTm\ (1+z) \qquad (6.12)$$

Where z is a factor of the margin for growth in minutes.

6.2.5. Interconnect TrafficThroughput in Calls

The interconnect traffic throughput in calls ITc is a proportion (variation) of the expected traffic throughput in calls ETc [Thom, 2003] and can be expressed as follows:

$$ITc = pETc \qquad (6.13)$$

where p is a factor of the interconnect traffic throughput in calls and ITc is the interconnect traffic throughput in calls.

6.2.6. Interconnect TrafficThroughput in Minutes

Similarly, the interconnect traffic throughput in minutes is also a proportion of the expected traffic throughput in minutes ITm and can be expressed as follows:

$$ITm = qETm \qquad (6.14)$$

where q is a factor of the interconnect traffic throughput in minutes and ITm is the interconnect traffic throughput in minutes. The constant proportionality (q factor) of the interconnect traffic throughput can be expressed in terms of interconnect and expected traffic throughput as follows:

q =ITm/ETm **(6.15)**

6.2.7. Total TrafficThroughput in Calls

The total traffic throughput in calls is the sum of the expected traffic throughput in calls ETc, and interconnect traffic throughput in calls ITc. It can be expressed in terms of expected traffic throughput in calls as follows:

TTc = ETc +pETc **(6.16)**

TTc = ETc (1+p) **(6.17)**

whereTTc is the total traffic throughput in calls

6.2.8. Total TrafficThroughput in Minutes

The total traffic throughput in minutes is the sum of the expected traffic throughput in minutes ETm, and the interconnect traffic throughput in minutes ITm. It can be expressed in terms of the expected traffic throughput in minutes as follows:

TTm = ETm+qETm **(6.18)**

TTm = ETm (1+q) **(6.19)**

whereTTm is the total traffic throughput in minutes

6.3. Network Costing

This Section shows the analysis of the total direct and attributable annual costs, which represent the LRIC value and forms the basis for estimating the interconnection costs. The Tanzania Communications (Interconnection) Regulations [TCRA2005] require the interconnection charges be based on LRIC.This analysis includes the following:

- Network related costs,
- Weighted Average Cost of Capital (WACC),
- Total direct annual costs.

6.3.1. Network Related Costs

The Network Related Costs (NRC) can be calculated by adding the annualized network related Capital Expenditures (CAPEX) and network related Operating Expenditures (OPEX) per year and can be expressed as follows [EURG2008]:

NRC = Annualized CAPEX +network related OPEX per year **(6.20)**

where CAPEX is the Capital Expenditures and OPEX is Operating Expenditures per year. The CAPEX is a *stock entity* whose value is used over several financial years

[Olse1996,Cric2007]. Therefore, the CAPEX values should be annualized to obtain the annualized CAPEX (annual capital cost).

The annualized CAPEX is obtained by multiplying the CAPEX by the by the annualization factor using the following formula [NITA2007a,NITA2007b]:

$$\textbf{Annualized CAPEX} = \textbf{CAPEX} \times \frac{i(1+i)^n}{(1+i)^n - 1} \qquad \textbf{(6.21)}$$

where $\frac{i(1+i)^n}{(1+i)^n - 1}$ represents the annualization factor, i is the market interest rate

and n is the useful working life of the asset. In this case, the assets considered are traffic sensitive, which have maximum useful working life n of 15 years [Gill et al 2004]. The average market interest rate i for 2007, 2008 and 2009 taken from the central Bank of Tanzania is i=5.92% [Bota2011]. Therefore, the value of the annualization factor is given below:

$$\frac{0.0592(1.0592)^{15}}{(1.0592)^{15} - 1} = \mathbf{0.102425}$$

The annualized CAPEX can be calculated by multiplying the CAPEX by the annualization factor 0.102425. It takes into account of the opportunity cost of CAPEX and depreciation of assets. The CAPEX sourced from the five competitive operators' annual audited accounts (Vodacom, Zain, TIGO, Zantel and TTCL) for 2007, 2008 and 2009 are annualized to get the annualized CAPEX (see Table6.2). Details of the calculations of the annualized CAPEX are presented in Appendix C. However, the operators' annual audited accounts are consolidated (not in details)unlike the accounts from the British Telecommunications Company Limited showing the costs and traffic throughput in minutes per component as presented in Table 5.1.

The network related OPEX is a *flow entity* whose value is used within the financial year[Bare2004]. The network related OPEX includes operation and maintenance costs. These
costs are added wholly to the annualized costs. The operational costs are those costs, which are necessary to run the network:

- Electricity, network monitoring and control functions.

The maintenance costs are costs that keep the network running:

Site visits, Repair, replacement parts and Vehicles for inspection trips.

Data collection was difficult exercise.

Table 6.2.Annualized CAPEX for the five competitive operators

Operator	Year	CAPEX in Tanzania shillings (million) sourced from the operator's audited annual accounts	Annualized CAPEX = CAPEX 0.102425 Tanzania shillings (million)
Vodacom	2007	302,133	30,945.97
Vodacom	2008	364,052	37,288.03
Vodacom	2009	491,689	50,361.23
Zain	2007	342,404	35,070.73
Zain	2008	511,882	52,418.35
Zain	2009	525,098	53,783.16
TIGO	2007	151,773	15,545.35
TIGO	2008	317,028	32,471.59
TIGO	2009	415,236	42,530.54
Zantel	2007	33,303	3,411.06
Zantel	2008	103,493	10,600.28
Zantel	2009	116,204	11,902.19
TTCL,	2007	134,030	13,728.02
TTCL,	2008	117,407	12,025.41
TTCL,	2009	99,102	10,150.52

One of the most delicate areas is the estimation of the network related OPEX. The model suggests the application of the international best practice proportion (factor) of the annualised CAPEX to represent the OPEX as follows:

OPEX = k x AnnualizedCAPEX **(6.22)**

where k is a proportion of the annualised CAPEX.

The international best practice proportion of the efficient network related OPEX ranges from 3% to 5 % of the annualized CAPEX [Gill2004 et al,Jain2006]. This model takes the highest international best practice proportion of the network related OPEX of 5% of the annualized CAPEX in order to recover back the high running costs of the sites in the rural areas.

In Tanzania, most of the sites in the rural areas lack electricity from the national grid, and they run on diesel generators, which increase the operating costs. The maintenance costs of the sites in the rural areas are also high. The network related OPEX can be calculated by multiplying 5% by the annualized CAPEX of each of the five competitive telecommunications network operators for 2007-2009 (see Table6.3)

Then, the Network Related Costs (NRC) can be calculated by adding the annualised CAPEX to the Network related OPEX and can be expressed as follows:

NRC = Annualised CAPEX + Network related OPEX **(6.23)**

Table 6.3. Network related OPEX derived from the annualized CAPEX

Operator	Year	Annualized CAPEX in Tanzanian shillings (millions)	Network related OPEX in Tanzanian shillings (millions) =5% multiply by the annualised CAPEX
Vodacom	2007	30,945.97	1,547.30
Vodacom	2008	37,288.03	1,864.40
Vodacom	2009	50,361.23	2,518.06
Zain	2007	35,070.73	1,753.54
Zain	2008	52,418.35	2,620.92
Zain	2009	53,783.16	2,689.16
TIGO	2007	15,545.35	777.27
TIGO	2008	32,471.59	1,623.58
TIGO	2009	42,530.54	2,126.53
Zantel	2007	3,411.06	170.55
Zantel	2008	10,600.28	530.01
Zantel	2009	11,902.19	595.11
TTCL	2007	13,728.02	686.40
TTCL	2008	12,025.41	601.27
TTCL	2009	10,150.52	507.53

From equation 6.3 and 6.4, the NRC can be expressed in terms of annualised CAPEX as follows:

NRC = Annualised CAPEX +k annualised CAPEX **(6.24)**

NRC = Annualized CAPEX (1+k) (6.25)

Given k =5%, the network related annual costs for the five competitive network operators for 2007-2009 are calculated (see Table6.4)

Table 6.4.Network related annual costs for the five competitive telecommunications network operators for 2007- 2009

Operator	Year	Annualized CAPEX in Tanzania shillings (millions)	Network related annual costs=105% multiply by the annualized CAPEX in Tanzania shillings (millions)
Vodacom	2007	30,945.97	32,492.25
Vodacom	2008	37,288.03	39,152.43
Vodacom	2009	50,361.23	52,879.29
Zain	2007	35,070.73	36,824.26
Zain	2008	52,418.35	55,039.26
Zain	2009	53,783.16	56,472.32
TIGO	2007	15,545.35	16,322.62
TIGO	2008	32,471.59	34,095.17
TIGO	2009	42,530.54	44,657.06
Zantel	2007	3,411.06	3,581.61
Zantel	2008	10,600.28	11,130.29
Zantel	2009	11,902.19	12,497.30
TTCL,	2007	13,728.02	14,414.42
TTCL,	2008	12,025.41	12,626.68
TTCL,	2009	10,150.52	10,658.05

6.3.2. The Weighted Average Cost of Capital (WACC) Evaluation

The major sources of the operators' capital are shareholders' equity and debt [Gill et al2004]. These two major sources of capital are weighted together to get the Weighted Average Cost of Capital (WACC) for the company. This WACC is the minimum return to the shareholders' equity and interest on debts. The WACC contributes directly to the provision of the components. Therefore, it is an input to the interconnection costs beside the network related costs calculated in Table 6.4. The current regulations [Tcra2005] specify for the use of the pre-tax Weighted Average Cost of Capital (WACC) to regulate the interconnection costs. Thepre-tax is calculated as follows[NITA2007a,NITA2007b]:

Pre-tax WACC= $C_d \times \frac{D}{D+E} + C_e \times \frac{E}{D+E}$ **(6.26)**

where:

- C_d = Cost of debt),
- C_e = cost of equity,
- E = Equity,
- D = Debt,
- D/(D+E) = percentage of debt financing (Gearing),
- **E/(E+D)**= percentage of equity financing.

Operators' financing structure in terms of equity and debt sourced from five competitive operators' annual audited accounts for 2007-2009 (see Table 6.5)

Generally, the demand for return on equity capital is higher than the demand for return on debt capital. An increasing gearing will lead an increasing debt risk premium as creditors demand a higher interest rate if there is less certainty in getting repaid.

Therefore, in financial theory it is assumed that an optimum financing structure, that minimizes the cost of capital, actually exists [Dimson et al 2002]. This is called target gearing. The international best practice target gearing is 40% [Gill et al 2004]. The model takes the international best practice target gearing (% debt financing) of 40%.

Table 6.5.Operators' financing structure in terms of equity and debt for 2007-2009

Operator	Year	Total Equity (E) in TZS million	Total Debt(D) in TZS million	Total Capital (D+E) in TZS million	% of debt financing $(\frac{D}{D+E})$	% of equity financing $(\frac{E}{D+E})$
Vodacom	2007	166435	142594	309029	46	54
Vodacom	2008	191144	88924	280068	32	68
Vodacom	2009	158454	160207	318661	50	50
Zain	2007	153124	46216	199340	23	77
Zain	2008	201271	269915	471186	57	43
Zain	2009	194714	264071	458785	58	42
TIGO	2007	44855	40507	85362	47	53
TIGO	2008	45662	209556	255218	82	18

TIGO	2009	52527	261609	314136	83	17
Zantel	2007	21,239	51,532	72,771	71.0	29.0
Zantel	2008	1,700	160,601	162,301	99.0	1.0
Zantel	2009	(58,440)	265,063	206,623	128.3	-28.3
TTCL	2007	99685	4250	103935	4.0	96.0
TTCL	2008	58393	5123	63516	8.0	92.0
TTCL	2009	39343	6128	45471	13.0	87.0

The cost of debt Cdcan be expressed as follows [Gille et al 2004]:

Cd = (1-Tc) x (Rf + Rd) **(6.27)**

whereTcis the corporate tax, Rfis the risk free rate of return, and Rd is the company's debt premium.

the Tanzanian corporate tax (Tc)is 30% [Trev006]. The risk free interest rate Rfisusually taken of that of a long-term government treasury bond. In this study a ten-year government treasury bond issued by the Bank of Tanzania (BoT)with a risk-free interest rate of 7.75% has been used [Bota2011]. Generally, the debt premium Rdincreases with the rate of gearing. The debt risk premium increases to around 2-3% at a gearing of 40%. Therefore, the study has used the debt risk premiumRdof 2.5% at a gearing of 40%.

Based on equation 6.27 the cost of debt Cdcan be estimated as follows [Gille2004 et al]:

Cd = (1 – 0.3) x (7.75%+2.5%) = 7.18%

The cost of equity, Cecan be calculated using the Capital Asset Pricing Model (CAPM) as follows [Gille et al 2004]:

Ce = Rf + β x Re **(6.28)**

where β is the risk factor of the telecommunications sector and Re is the equity risk premium.

The last interconnection cost study considered the funding risk perspective and chose the β value of 1.2 for all companies in Tanzania. The choice was made by evaluating several studies done by the European Regulatory Group (ERG) that the value of the beta varies quite widely in the world, ranging from 0.8 to 1.6 [EURG2008]. Therefore, this study adopted the beta value of 1.2; that is, the middle point of the range (0.8-1.6).

No operator provided the equity risk premium, Re,in the annual audited accounts. However, the most recent studies done by Dimson in 2002of investment returns over 101 years from 1900 to 2000 estimated that the forward-looking equity risk premium, Refor the world is equal to 3% (geometric mean) and a little bit than 4% (arithmetic mean). This study used the equity risk premium, Reof 3.75% within the range of the result of the Dimson's study.

Based on equation 6.28, the cost of equity, Cecan be calculated as follows:

Ce = 4.15% + (1.2 x 3.75%) = 8.65%

Based on equation 6.26, the pre-tax WACC for the five competitive telecommunications network operators for 2007-2009 can be calculated (see Table6.6)

Table 6.6.Pre-tax WACC for the five competitive telecommunications network operators for 2007-2009.

Operator	Year	Pre-tax WACC= $C_d \times \frac{D}{D+E} + C_e \times \frac{E}{D+E}$
Vodacom	2007	7.97%
Vodacom	2008	8.18%
Vodacom	2009	7.91%
Zain	2007	8.3%
Zain	2008	7.81%
Zain	2009	7.79%
TIGO	2007	7.95%
TIGO	2008	7.44%
TIGO	2009	7.43%
Zantel	2007	7.61%
Zantel	2008	7.19%
Zantel	2009	6.76%
TTCL	2007	8.59%
TTCL	2008	8.53%
TTCL	2009	8.46%

The WACC can be expressed as a proportion of the annualized CAPEX as follows:

WACC = p AnnualisedCAPEX **(6.29)**

where p is a constant of proportionality or coefficient of the annualized CAPEX

6.3.3 Total direct Annual Costs

The total direct annual cost is the sum of the network related costs and the pre-tax WACC. From equation 6.5, 6.6 and 6.10 the total direct annual cost can be expressed in terms of the annualized CAPEX as follows:

$$\textbf{TDAC=AnnualizedCAPEX +} \qquad \textbf{(6.30)}$$

$$\textbf{TDAC= (1+k+p) x AnnualizedCAPEX} \qquad \textbf{(6.31)}$$

where TDAC is the total direct annual costs, p represents different values of the WACC, k is 5% from equation 6.6.The TDAC is calculated and presented (see Table6.7 and Fig. 6.1).

Table 6.7.Total direct annual costs for the five competitive telecommunications network operators for 2007-2009

Operator	Year	Annualized CAPEX in TZS (millions)	WACC (p)	Total direct annual costs (TDAC) in TZS (million) = (1.05 +p) of the annualized CAPEX
Vodacom	2007	30,945.97	7.97%	34,959.66
Vodacom	2008	37,288.03	8.18%	42,202.59
Vodacom	2009	50,361.23	7.91%	56,862.86
Zain	2007	35,070.73	8.3%	39,735.14
Zain	2008	52,418.35	7.81%	59,133.14
Zain	2009	53,783.16	7.79%	60,662.03
TIGO	2007	15,545.35	7.95%	17,558.47
TIGO	2008	32,471.59	7.44%	36,511.06
TIGO	2009	42,530.54	7.43%	47,817.09
Zantel	2007	3,411.06	7.61%	3,841.19
Zantel	2008	10,600.28	7.19%	11,892.45
Zantel	2009	11,902.19	6.76%	13,301.89
TTCL,	2007	13,728.02	8.59%	15,593.66
TTCL,	2008	12,025.41	8.53%	13,652.45
TTCL,	2009	10,150.52	8.46%	11,516.78

6.4. Traffic Throughput Calculations

This Section shows the calculations of the following:

- Interconnect traffic throughput in minutes;
- Total traffic throughput in minutes offered by all call types supported by the telecommunications conveyance network.

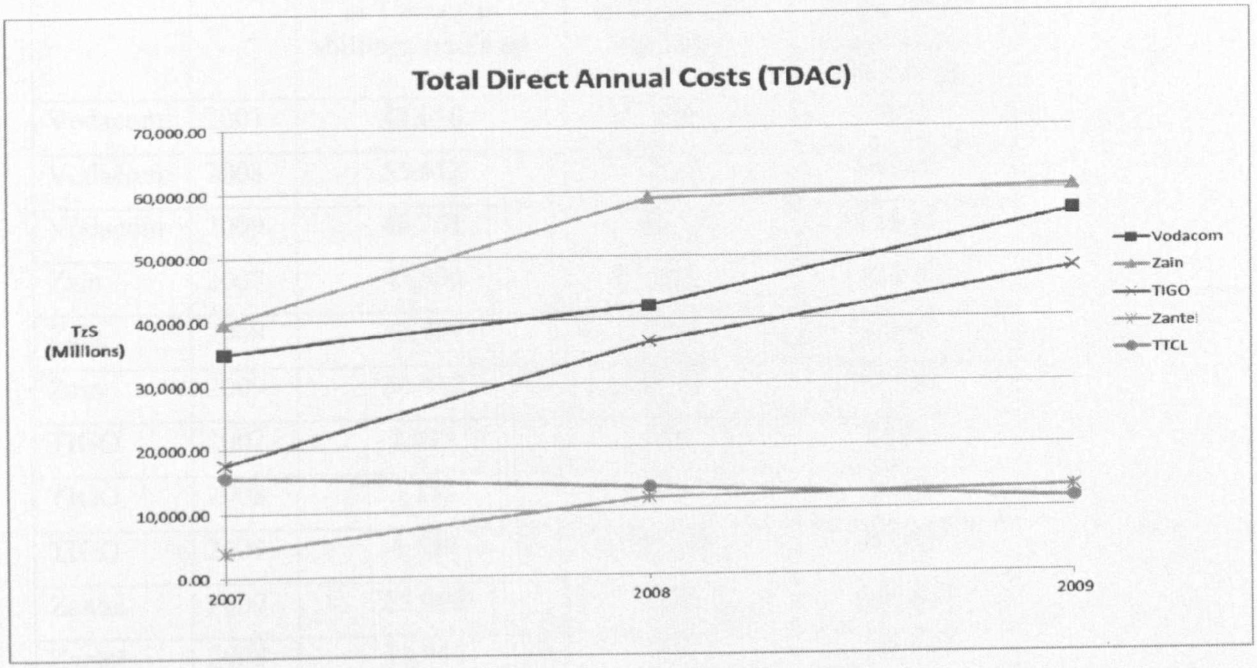


Figure 6.1. Total direct annual costs for five competitive operators for 2007-2009

6.4.1. Interconnect TrafficThroughputin Minutes Calculations

The British Telcoms in the United Kingdom report their annual financial statements with traffic throughput including interconnection. In the case of Tanzania, the telecoms operators report their annual financial statements without the traffic throughput. Therefore, it is not possible to get directly the interconnect traffic throughput from the financial statements. In this situation, the research suggests to calculate the interconnect traffic throughput by dividing the interconnect annual revenue sourced from the operators' annual audited accountsfor 2007-2009 by the interconnection chargesper minute set by the

Regulator (see Table 6.8).Figure 6.2 presents the annual interconnect traffic throughput for the five competitive telecommunications network operators for 2007-2009

Table 6.8.Annual interconnect traffic throughput in minutes for five competitive telecoms network operators for 2007-2009.

Operator	Year	Interconnect annual revenues sourced from operators' annual audited accounts in Tanzanian shillings (million)	Interconnection charges per minute collected from the Regulator in Tanzanian shillings	Interconnect traffic throughput (ITm) in minutes (million) per operator for 2007-2009
Vodacom	2007	42,610	100	426.10
Vodacom	2008	55,512	97.8	567.61
Vodacom	2009	48,751	91.25	534.25
Zain	2007	43,530	100	435.30
Zain	2008	42,707	97.8	436.67
Zain	2009	30,467	91.25	333.88
TIGO	2007	2,021	100	20.21
TIGO	2008	3,151	97.8	32.22
TIGO	2009	4,554	91.25	49.90
Zantel	2007	15,948	100	159.48
Zantel	2008	14,948	97.8	152.84
Zantel	2009	12,469	91.25	136.64
TTCL,	2007	3,481	100	34.81
TTCL,	2008	5,525	97.8	56.49
TTCL,	2009	1,943	91.25	21.29

6.4.2. Total TrafficThroughputin Minutes Calculations

It should be noted that the TCRA (Regulator) started collecting the traffic throughput in minutes only from 2007 by the request of this research project, when started the data collection. Since 2007, all operators have been reporting to the Regulator on quarterly basis the traffic throughput in minutes per call type and published in the TCRA, website (http//www.tcra.go.tz). From this website, the total traffic throughput for all call types per operator for 2007-2009 were collected and presented (see Table 6.9 and Figure 6.3).

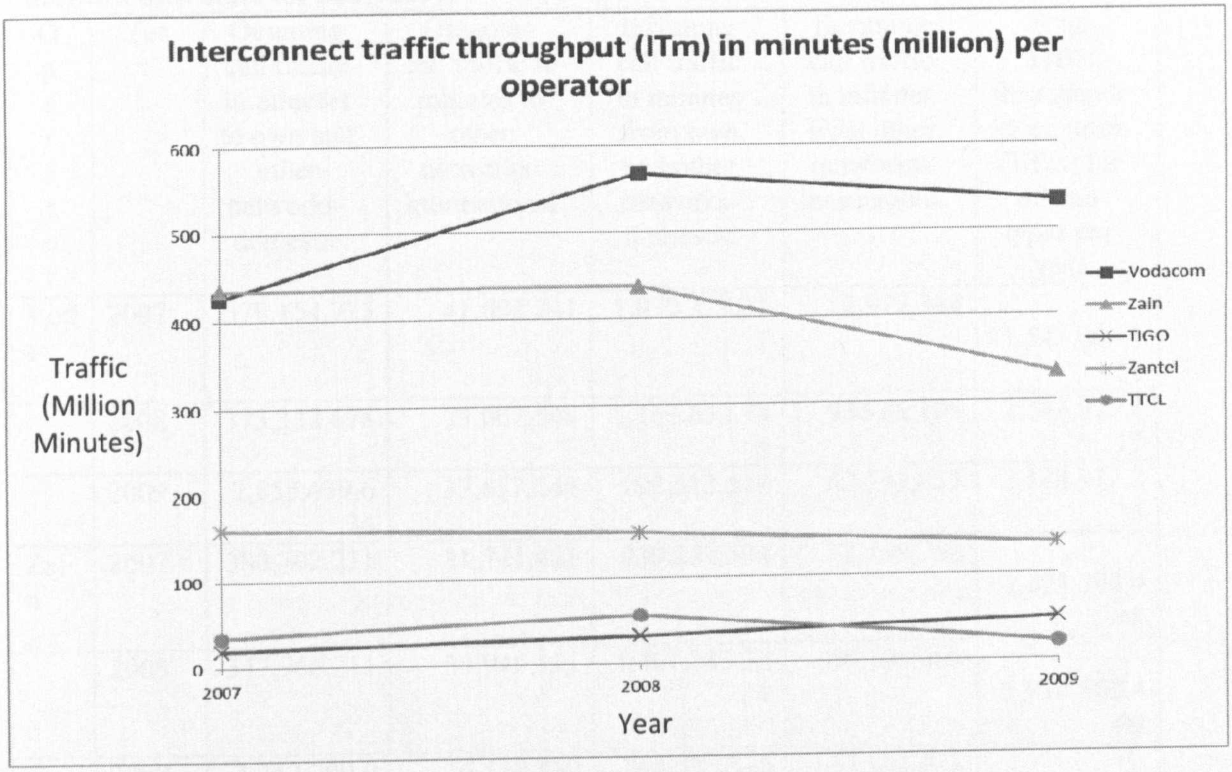


Figure 6.2. Annual interconnect traffic throughput in minutes for five competitive telecoms network operators for 2007-2009

6.5. CostEstimation

This section estimates the following:

- Interconnection costs;
- Unit interconnection costs.

6.5.1. Interconnection cost estimation

In essence, the interconnection costs, are the costs incurred to provide physical network capacity (switching and transmission components) of the core telecommunications networks required to terminate (handle) the interconnect traffic throughput[Thom, 2003]. We suggest estimating the interconnection costs from the cost to volume of traffic functional relationship (as expressed mathematically in equation 6.32) as a proportion to the total direct annual costs, where the constant of proportionality is the ratio of the interconnect traffic to the total traffic (ITm/TTm) (see equation 6.32).

Table 6.9. Total traffic throughput in minutes for the five competitive telecommunications network operators for 2007-2009.

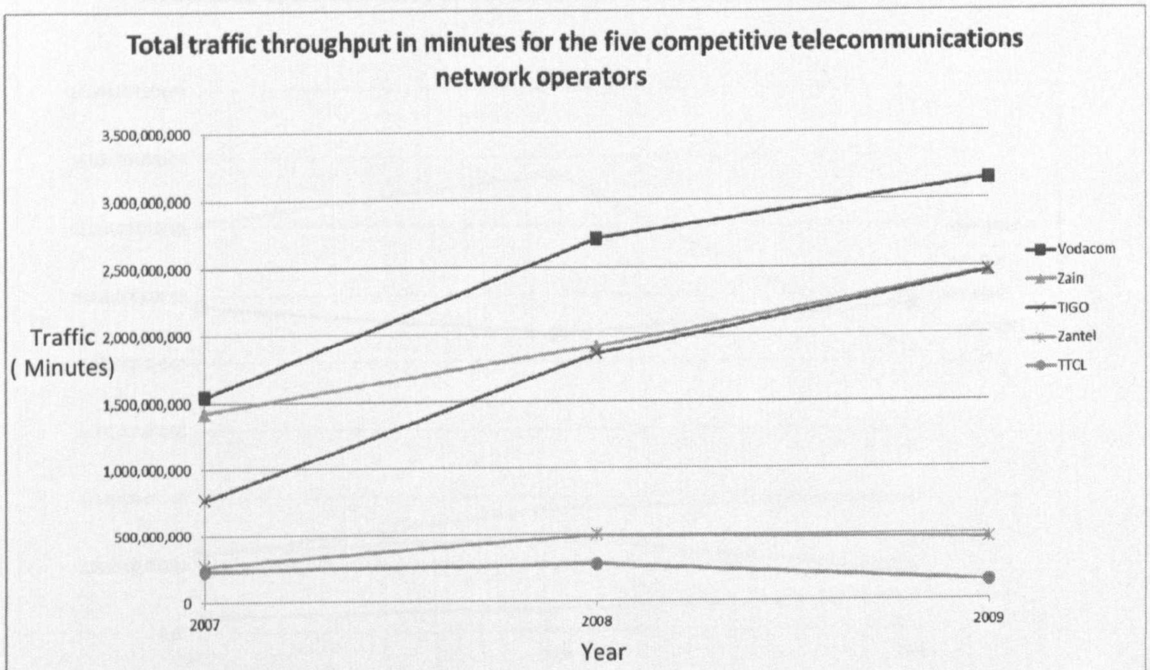
Operator	Year	Outgoing call traffic in minutes to own and other networks-domestic	Outgoing call traffic in minutes to other networks-International	Incoming call traffic in minutes from own and other networks-domestic	Incoming call traffic in minutes from other networks-International	Total traffic throughput in minutes (TTm) for all call types per year
Voda	2007	378,154,725	41,694,741	1,070,377,311	52,977,344	1,543,204,121
	2008	373,332,678	79,007,548	2,167,652,786	93,986,105	2,713,979,117
	2009	2,855,439,634	37,837,248	192,513,518	63,181,835	3,148,972,235
Zain	2007	380,702,211	31,721,421	939,231,534	72,139,782	1,423,794,948
	2008	347,966,211	34,946,811	1,461,743,321	66,146,066	1,910,802,409
	2009	2,242,709,015	26,539,869	161,285,578	37,962,912	2,468,497,374
TIGO	2007	178,864,162	10,591,068	570,641,747	7,289,577	767,386,554
	2008	215,054,418	13,638,750	1,622,360,051	5,796,883	1,856,650,102
	2009	2,277,959,331	12,012,641	144,865,412	29,799,583	2,464,636,967
Zantel	2007	80,454,687	11,398,013	172,747,197	5,870,407	270,470,304
	2008	100,728,824	17,434,537	363,782,617	16,137,833	498,083,811
	2009	412,177,788	9,763,219	30,621,782	15,801,378	468,364,167
TTCL	2007	111,910,911	16,517,033	23,664,379	78,787,682	230,880,005
	2008	129,741,697	15,171,255	43,325,245	89,153,974	277,392,171
	2009	78,512,224	9,818,442	15,825,876	41,967,653	146,124,195

Table 6.9shows that there was tremendous increase of domestic outgoing call traffic in minutes to all mobile operators in 2009 due to reduction of tariffs through marketing promotion caused by stiff tariff competition.The reduction of the tariffs in the mobile communications networks enabled people to communicate more in the mobile communications networks than in the fixed telecommunications networks and caused decrease of the domestic outgoing call traffic in minutes in the fixed telecommunications market.

$$\mathbf{IC = TDAC} \quad \left(\frac{ITm}{TTm}\right) \qquad \mathbf{(6.32)}$$

Where ICis the interconnection costs, TDAC is the total direct annual costs, ITmis the interconnect traffic throughput in minutes and TTmis the total traffic throughput in minutes.Based on the equation 6.32, the interconnection costsper operator for the five

competitive operators for 2007-2009 are calculated and presented (see Table6.10 and Figure 6.4).



.

Figure 6.3. Total traffic throughput in minutes for all call types per operator telecommunications network operators for 2007-2009

Table 6.10.Interconnection costs for the five competitive operators for 2007-2009.

Operator	Year	Interconnection costs in Tanzanian shillings
Vodacom	2007	9,652,845,611
Vodacom	2008	8,826,380,409
Vodacom	2009	9,647,269,232
Zain	2007	12,148,312,840
Zain	2008	13,513,520,880
Zain	2009	8,327,798,499
TIGO	2007	462,422,330.5
TIGO	2008	633,606,920.3
TIGO	2009	968,123,428.7
Zantel	2007	2,264,917,709
Zantel	2008	3,649,269,496
Zantel	2009	3,880,677,425
TTCL,	2007	2,351,071,088
TTCL,	2008	2,780,276,378
TTCL,	2009	1,677,971,579

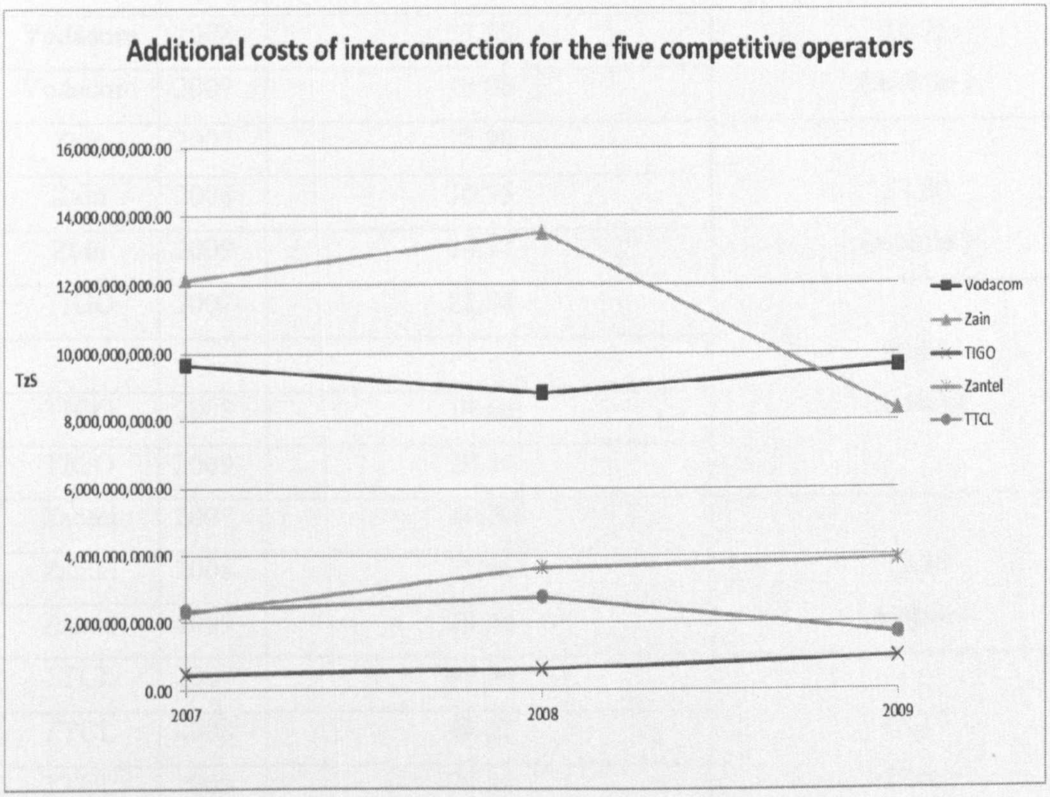


Figure 6.4. Interconnection costs per operator for 2007-2009

6.5.2. Estimation of Unit and AverageInterconnectionCosts

The unit interconnection costs per operator is obtained by dividing the interconnection costs by the interconnect traffic throughput in minutes (see Table 6.11 and Figure 6.5). The average unitinterconnection costs per operator for three years for the five competitive operators for 2007-2009 were calculated and presented (see also Table6.11 and Figure 6.)

Table 6.11.Unit interconnection costs per operator per year in TZS and average unit interconnection costs for three years in TZS for the five competitive operators for 2007-2009

Operator	Year	Interconnection costs per minute per operator per year in TZS for 2007-2009	Average unit interconnection costs per operator in TZS for 2007-2009
Vodacom	2007	22.65	18.75 (mobile)
Vodacom	2008	15.55	
Vodacom	2009	18.05	
Zain	2007	27.90	27.80 (mobile)
Zain	2008	30.95	
Zain	2009	24.57	
TIGO	2007	22.88	20.65 (mobile)
TIGO	2008	19.66	
TIGO	2009	19.40	
Zantel	2007	14.20	22.16 (mobile)
Zantel	2008	23.88	
Zantel	2009	28.40	
TTCL	2007	67.54	65.19 (Fixed
TTCL	2008	49.22	
TTCL	2009	78.82	

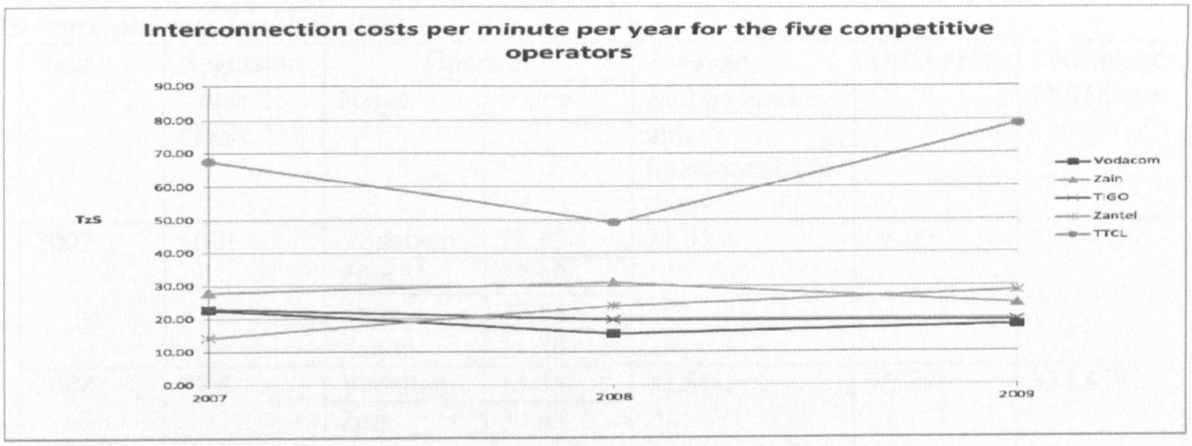


Figure 6.5. Unit interconnection costs per operator per year in TZS for 2007-2009

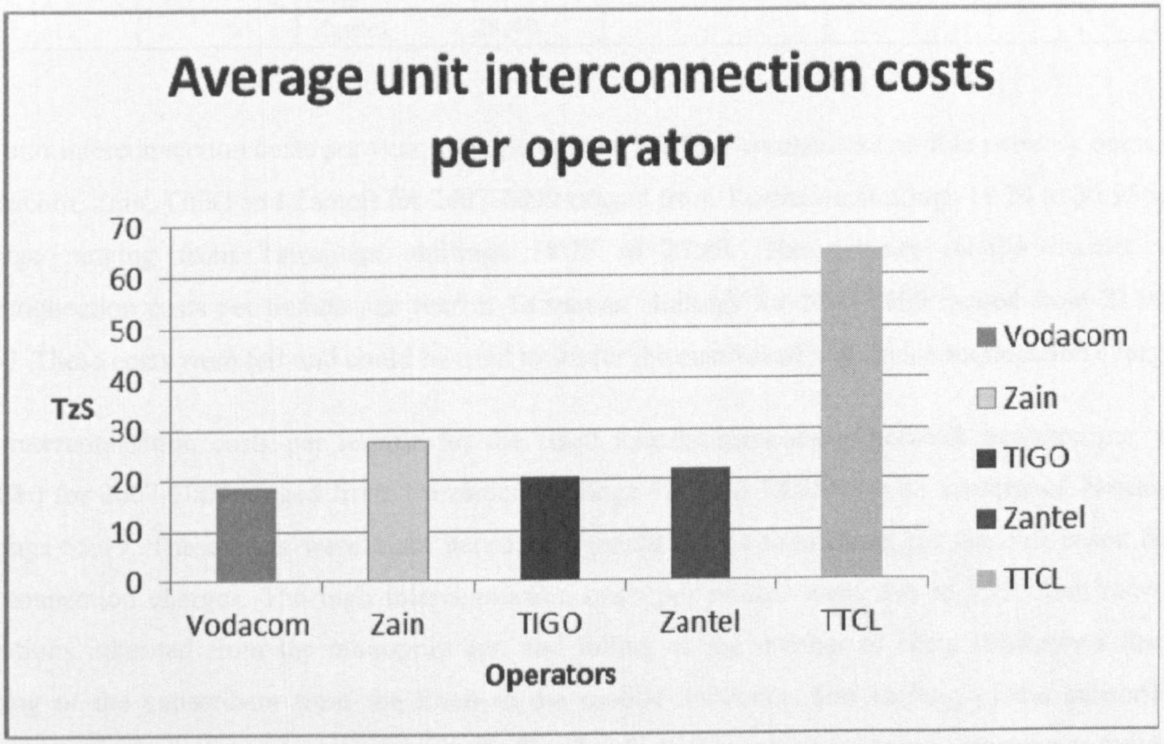


Figure 6.6. Average unit interconnection costs per operator in TZS for 2007-2009

The average mobile market unit interconnection costs and its percentage difference per year for 2007-2009 were calculated and presented (see Table 6.12)

Table 6.12. Average mobile market unit interconnection costs in TZS and its percentage difference per year for 2007-2009.

Year	Regulator Value (TzS)	Operator		Average Mobile market unit interconnection costs	Difference	Percentage Difference
		Name	Value			
2007	100	Vodacom	22.65	21.91	78.09	356.41%
		Zain	27.90			
		Tigo	22.88			
		Zantel	14.20			
2008	97.8	Vodacom	15.55	22.51	75.29	334.47%
		Zain	30.95			
		Tigo	19.66			
		Zantel	23.88			
2009	91.25	Vodacom	18.05	22.61	68.65	303.60%
		Zain	24.57			
		Tigo	19.40			
		Zantel	28.40			

The unit interconnection costs per year, per operator for the four competitive mobile network operators (Vodacom, Zain, TIGO and Zantel) for 2007-2009 ranged from Tanzanian shillings 14.20 to 30.95 with average ranging from Tanzanian shillings 18.75 to 27.80. The average mobile market unit interconnection costs per minute per year in Tanzanian shillings for 2007-2009 ranged from 21.90 to 22.60. These costs were fair and could be used to set for the cost based mobile interconnection charges.

The interconnection costs per minute for the fixed telecommunications network operator per year (TTCL) for 2007-2009 ranged from Tanzanian shillings 49.22 to 78.82 with an average of Tanzanian shillings 65.19. These costs were high; hence, they could not be used to set for the cost based fixed interconnection charges. The high interconnection costs per minute were due to inefficient network operations inherited from the monopoly era, and falling of the number of fixed subscribers due to shifting of the subscribers from the fixed to the mobile networks. The shifting of the subscribers resulted in the fixed networks with low traffic.The fixed interconnection costs per minutewere replaced by the mobile interconnection costs per minute for setting the fixed interconnection charges per minute. In fact, in January 2008, Tanzania replaced the high fixed interconnection costs by the competitive mobile interconnection costs per minute for setting the fixed interconnection charge per minute. Hence, the fixed and mobile interconnection charges per minute are aligned into single mobile interconnection charges per minute. This means that Tanzania use the same interconnection charges per minute for both fixed and mobile terminations.The regulation in fact was setting the interconnection charges per minute in Tanzanian shillings as the following:

- 2007 100.00
- 2008 97.8
- 2009 91.25

As can be seen, it was set far above the interconnection costs per minute obtained from the analysis of the collected data as shown in Table6.11 and its percentage difference is too big as shown in table 6.12.

The Interconnection Regulations require the interconnection charges should be based on costs [TCRA2005]. Although the Interconnection Regulations require the cost based interconnection charges, the methodology to establish the required cost based interconnection charges is not yet developed. As a result, the interconnection charges per minute were set arbitrarily far above the actual costs. Therefore, this research provides the methodology to set the interconnection charges per minute based on the costs. This methodology provides an additional knowledge to the field of telecommunications regulations, which is a new field in telecommunications. Tanzania will review the current interconnection charges in January 2013. Luckily, the process for the review has been started using the knowledge acquired from this research project.

6.6. Conclusion

The chosen top down LRIC models developed by the British Telecommunications Company Limited have been adapted to the case study by considering similarity of the telecommunications network design and architecture. The total traffic throughputs in calls and minutes have been determined by defining the current, expected and interconnect traffic throughput in calls and minutes. Calculation of the annual interconnect traffic throughput in minutes per operator for 2007-2009 has been suggested in this Chapter by dividing the interconnection revenue sourced from the operators' annual audited accounts by the interconnection charges per minute set by the Regulator and presented in Table 6.8. The total traffic throughput in minutes for all call types per operator has been calculated by adding the historical traffic throughput in minutes for each call type collected from the Regulator as shown in Table 6.9. The total direct annual costs have been calculated by adding the network related direct costs and weighted average cost of capital. The interconnection costs for five competitive telecommunications network operators for 2007-2009 have been estimated by using the cost to volume of traffic functional relationship as presented in table 6.10. This relationship estimates the interconnection costs as a proportion of the total direct annual costs and the ratio of the interconnect traffic to the total traffic throughput in minutes is the constant proportionality (coefficient) of the relationship.

The interconnection costs per minute per operator for 2007-2009 and the average interconnection costs per minute per operator for the same period for the five competitive telecommunications network operators have been calculated and presented as shown in Table6.11. The average mobile market interconnection costs per minute and its percentage difference for the four competitive mobile network operators for 2007-2009 have been also calculated as shown in Table 6.12. The average mobile market interconnection costs per minute per year for 2007-2009have been compared with the interconnection charges per minute set by the Regulator for the same period and found that the Regulator has been setting the interconnection charges over and above the average mobile interconnection costs obtained from the analysis of the collected data.

Chapter 7.Conclusions

In conclusion, the research has achieved the following:

- Current insufficient situation in interconnection regulations in Tanzania has been identified by comparing the interconnection costs per minute obtained from the analysis of the collected data and the interconnection charges set by the regulator and found a very big percentage difference;
- Architecture and topology of the interconnection of telecommunications networks in Tanzania have been presented by identifying relevant interconnection types, interconnection components, call types, and call route types and factors, which can be used for the interconnection cost estimation methodology;
- Telecommunications developments in Tanzania have been described, by presenting historical and current situations in terms of telecommunications network design and architecture, operations, policies and regulations, which have not been stated earlier;
- Implementation of non-internationalroaming for the first time in Africa and Middle East has been described by presenting its charging principles, cost effectiveness, user-friendliness and impacts on coverage expansion and subscriber penetration;
- The existing generic top-down LRIC cost models developed by the British Telecommunications Limited Company have been reviewed and adapted to the Tanzania case study by considering similarity of their telecommunications network design and architecture and interconnection models and components;
- Conveyance's traffic throughputs have been modeled by defining current, expected, interconnect and total traffic throughput measured in calls and minutes;
- The traffic throughputs for all call types measured in minutes (see table 6.9)have been suggested to the Regulator in Tanzania for the first time by collecting them for the use of this research and regulatory purposes;
- Interconnection cost estimationmethod has been suggested from the cost to volume of traffic functional relationship by estimatingthe interconnect costs as a proportion of the total direct annual costs where the constant proportionality is the ratio of the interconnect traffic throughputin minutes to the total traffic throughput in minutes (see equation 6.32);
- Calculation of the interconnect traffic throughput has been suggested by dividing the interconnection revenue sourced from the operators' annual audited accounts by the interconnection charges set by the regulator;

- The interconnection costs obtained from the research have been compared with the interconnection charges set by the Regulator for 2007-2009 and found a big percentage difference of greater than 300%;
- Research results have shown that the interconnection charges in Tanzania have been set over and above the actual interconnection costs obtained from the collected data;
- The aim and objectives (see page 16) of this research project have been achieved by adapting the chosen existing interconnection cost models to the Tanzania case study and specifying the following particular objectives: identify accurate interconnection cost estimation methods; establish cost based interconnection charges; introduce effective and reliable interconnection charges.
- The 3 hypotheses (see page 17) have been proved "true":for the "hypothesis of the interconnection cost estimation methods driving down interconnection charges" it was confirmed true based on the results of the big percentage difference obtained from the comparison between the interconnect costs obtained from the collected data and interconnection charges set by the Regulator (see Section 6.5); for the "network related costs formingthe cost based interconnection charges" it was also confirmed true by showing that the network related costs are function of the interconnection costs (see Section 6.1); for the "interconnect traffic throughput in minutes attributing to the interconnection cost estimation methods" it was confirmed true; by using it in the equation 6.32 for estimating the interconnection costs (see Section 6.5);
- All 5 questions have been answered correctly as follows: "how objective and effective are the current interconnection charges in Tanzania?" This question has been answered that they are not objective and effective (see Section 6.5); "are they based on costs?" This question has been answered that they are not based on costs (see also Section 6.5); "Can they be applied universally?" This question has been answered that they cannot be applied universally (see Section 6.1); "what changes should be applied, if any, for the interconnection charge estimation method to particular regions/ market situations?" This question has been answered that changes should be applied are telecommunications network design and architecture, interconnection models and components (see Section 6.1); "How to develop the objective interconnection cost estimation methods with the use of field data in a focused case study?"This question has been answered to use the network related costs and interconnect traffic throughput in minutes (see Section 6.3 and 6.5);
- Cost analysis and modeling of the Internet Protocol (IP) based packet switched Next Generation Network (NGN) has been identified for further work of study

REFERENCES

Anyi, A. and Falch, M. [2004]. Telecommunications development in Africa: Fill the gap, *Telematics and Informatics Journal,* Volume 21; Issue No. 1, 2004, pp.1-9

Arms, M.A. [1998]. Network Interconnection in Telecommunications, *TheEconomic Journal,* Volume 108, Issue No. 448, May 1998, pp 545-564

Bank of Tanzania (BOTA). [2011]. www.bot-tz.orgviewed on 20th June, 2011

Bare, A. B. [2004]. Innovative Regulatory and Policies Initiatives at Increasing ICT Connectivity in South Africa, *Telematics and Informatics Journal,* Volume 21, No. 1, 2004, pp 49-66 (18)

Bote, A. and Pinto, L. [2004]. The Diffusion of Mobile Phones in Greece, *Telecommunications Policy,* Volume 28, Issues 5-6, 2004, pp 427-437

British Telecoms (BRTE) [2005].Regulatory Financial Statements, Published by the BT Group in conjunction with the Xansa plc

Cave, M. [2004]. Cost Analysis and Cost Modeling for Regulatory Purposes in U.K and Experience, Telecom Reform, Principles, Policies and Regulatory Practices

Carter, M. and Wright, J. [1999]. Interconnection in Network Industries, *Review of Industrial Organization,* Volume 14, Issue No. 1, February 1999, pp1-25

Cricelli, F., Cric L. and Levialdi, T. [2000]. Could Asymmetric Regulation of Access Charges Improve the Communications Networks?

Dias, K. Fernandes, S., and Sadok, D. [2004]. A Call Admission Control Scheme for Next Generation Wireless Networks

Dimson, M., and Staunton, K. [2002].Trimph of the Optimists: 101 Years of Investment Returns. *Princeton University Press, Princeton, New Jersey and Oxford*

East African Community (EACO), [2009].www.eachq.orgviewed on 15th July, 2009

Europe Economics (EUEC), [2002]. Study on the Preparation of an Adaptable Bottom-up Costing Model for Interconnection and Access Pricing in European Union Countries, *The European Commission,* April 2000

European Regulatory Group (EURG), [2008]. Regulatory Accounting in Practice, September 2008

Falch, M. [2004]. Cost Based Interconnection Charges as a Way to Induce Competition, 2004

Federal Communications Commission (FCCO), [1996]. The Telecommunications Reform Act of 1996

Fildes, R., Robertson, A. and Soopramanien, D. [2007]. Segmental New-Product Diffusion of Residential Broadband Services, *Telecommunications Policy,* 2007

Flood, J. [1975]. Telecommunications Networks: *IEE Telecommunication's series 1, IEE, 1975*

Gille, L., Noumba, P., Simon, L., and Rudelle, C. [2004].A model for Calculating Interconnection Costs in Telecommunications, The World Bank, 2004

Gizeli, C., and Vergados, D. [2005]. Interconnection Between Mobile Providers and The SLA-Pricing Policy, *Vehicular Technology Conference,* Volume 4, 30 May –1 June 2005, pp 2142-2146

Green, J. [2002]. Forecasting Market Demand for New Telecommunications Services: An Introduction, *Telematics and Informatics Journal,* Volume 19, No. 3, 2002, pp 225-249 (25)

Grubber, H. [1999]. An Investment View of Mobile Telecommunications in the European Union, TelecommuniationsPolicy,Volume 23, Issues 7-8, 1999, pp521-538

Global System for Mobile Association, (GSMA). [2007]: Taxation and the Growth of Mobile Services in East Africa, page 56

Global System for Mobile Association, (GSMA). [2009]. The GSM Association for Mobile Communications, www.gsmworld.com, viewed on 1st March, 2009

Haggart, L., Mgombello, H., and Semboja, H. [2000].Privatisation of Telecommunications Industry in Tanzania

International Engineering Consortium, (IECO). [2004]. Wireless local loop

Islam, T., and Meade, N. [1995]. Forecasting with the Growth Curves: An Empirical Comparison, *International Journal of Forecasting,* Volume 11, 1995, pp 199-215

Islam, T., and Meade, N. [2000]. Modeling Diffusion and Replacement, *European Journal of Operational Research*, Volume 125, 2000, pp 551-570

Islam, T., and Hamoudia, M. [2004]. Examining Forecasting Methodologies to Assist and Support Operators in the Transition from a Regulated Environment to Deregulated Markets, *ITU/IIF Conference,*25-26 October, 2004

International Telecommunication Union, (ITEU). [2003]. Trends in Communications Reforms; Promoting Universal Access to ICTs, Geneva, Switzerland

International Telecommunication Union, (ITEU). [2006] International Telecommunication Union Trends in Economic and Finance: *Use of Economic Modeling in Telecommunications,* Volume II, November 2006

International Telecommunication Union, (ITEU). [2010a] Cost Accounting models, www.ictregulationtoolkit.org viewed on 20th February, 2010

International Telecommunication Union, (ITEU). [2010b] Competition and Price Regulation, www.ictregulationtoolkit.org viewed on 20th February, 2010

Jain, R. [2006]. Interconnection Regulation in India. Lessons for Developing Countries, *Telecommunications Policy Journal,* Volume 30, Issues No. 3-4, April-May 2006, pp. 183-200

James, J. [2008]. Leapfrogging in Mobile Telephony: A Measure for Comparing Country Performance, *Technological Forecasting and Social Change, 2008*

Jongyong, L. [2008]. Possibility of Bill &Keep in the Mobile Termination Market of Korea, *Management of Engineering & Technology, Portlar*27-31 July 2008, pp. 2613-2622

Jung-Eun, K., Choi, S., Lee, S., and Tchanghee, H. [2007]. Interconnection Scenario and Regulation under NGN Environment, *Third International Conference on Networking and Services,* on 19-25 June 2007 pp 37-37

Jung-Eun, K and Lee, S [2008]. Study on Access Charge Method between Fixed and the Internet Phone, *Advanced Communications Technology,* Volume 3,17-20 February, 2008, pp 1658-1663

Jukic, D., Kralik, G., and Scitovski, R, [2004].Least-squares Fitting GompertzCurve, *Journal of Computational and Applied Mathematics,* Volume 169, 2004, pp. 359-375

Laffont, J. Tirole, J. [1996]. Creating Competition through Interconnection: Theory and practice, *Journal of Regulatory Economics,* Volume 10, Issue No.3, November 1996, pp 227-256

Lapuerta, C. and Tye, W. [1999] Promoting Effective Competition through Interconnection Policy, *Telecommunications Policy Journal,* Volume 23, Issue No.2, March 1999, pp 129-145.

Malaysian Communications and Multimedia Commission, (MCMC). [1998].Converged Licenses under the Communications and Multimedia Act 1998.

Meade N. [2004]. Applications of Diffusion Models in Telecommunications, *ITU/IIF Conference,* 25-26 October 2004

Melody, W. and Samarajiva, R. [2002] Briefing Paper on Fixed to Mobile Interconnection Workshop, *ITU,* Geneva, 20-22 September 2002

Ministry of Communications and Transport (MOCT), [1997]. The National Telecommunications Policy, 1997

Ministry of Communications and Transport (MOCT), [2003]. National Information and Communications Technologies Policy, 2003

Ministry of Communications and Transport (MOCT), [2006]. Universal Communications service Access Fund, 2006

Mpapalika, J., Pakstas, A., and Mikusauskas, R. [2006].Interconnection Costing in the Fixed Public Switched Telephone Network Based on the Wireless Local Loop System, *IEEE 10th International Conference on Intelligent Network Engineering System,* London, 26-28 June, 2006, pp 264-269

National Information and Telecommunications Agency (NITA), [2007a].Denmark's LRAIC Model of Mobile Terminations: Specifications Consultation Paper for Industry

National Information and Telecommunications Agency, (NITA). [2007b]. Denmark's Mobile LRAIC model-Final version 4 cost model

Network Telecommunications at Africa, (NETA). [2004]. Wireless Local Loop, Training, TR 502, 2004, Chapter 8, Module 7, pp 71-87
Olsen, B., Stordahl, K. and Zaganiaris, A. [1996]. Techno-economic Evaluation of Narrowband and Broadband Access Network Alternatives and Evaluation Scenario Assessment," *IEEE Journal on Selected Areas in Communications,* Volume 14, Issue No.6, 1996, pp 1184-1203]
Presidential Parastatal Sector Reform Commission [PSRC], [1998]. The Tanzania Telecommunications Company Limited's Privatization Information Memorandum, 1998
Riffenburg, R H [1995] A New Method for Estimating Parameters for the Gompertz Growth Curve
Samanta, S., Woods, J., and Ghanbari, M. [2008]. Network Design and Interconnection Pricing in A Heterogeneous Terrain, *IEE International Symposium onTelecommunications,* 27-28 August 2008, pp 515-520
SeacomLimited [Seac2009],www.seacom.com viewed 25th March 2009
Semboja, H. [2000]. Review of Legal, Regulatory and Judiciary Framework affecting Industry and Business Activities in Tanzania
Semboja, H. [2005]. Generating African Competitiveness for Sustainable Market Access: The Case of Tanzania
Singh, S. [2008]. The diffusion of mobile phones in India, *Telecommunications policy,* Volume 32, Issues 9-10, October-November 2008, pp 642-651
Storving, J. [2004]. The Washington Consensus' in relation to the telecommunication sector in Africa developing countries," *Telematics and Informatics Journal,* Volume 21, No. 1, 2004, pp 11-24 (14)
Tanzania Communications Commission, (TCCO). [1993]. The Tanzania Communications Commission Act no. 18, 1993
Tanzania Communications Regulatory Authority, (TCRA). [2003]. The Tanzania Communications Regulatory Authority Act no.12, 2003
Tanzania Communications Regulatory Authority, (TCRA). [2005]. The Tanzania Communications (Interconnection) Regulations, 2005
Tanzania Communications Regulatory Authority, (TCRA). [2011], www.tcra.go.tz viewed on 1st March, 2011
Teske, P., and Wilson, R. [1990]. Telecommunications and Economic Development, *The State and Local Role Economic Development Quarterly,* Vol. 4, No. 2, 1990, 158-174
Tigo Company Limited, (TIGO). [2009]. www.tigo.co.tz, viewed on 12th July,2009
Thomas, C. [2003]. Proposed modification to the TAL interconnect cost model, 2003
Tanzania Bureau of Statistics, (TNBS). [2009], www.nbs.go.tz viewed on 12th July, 2009

Telecommunications Regulatory Authority Kingdom of Bahrain, (TRAB). [2008]. Benchmarking Methodology for the Telecoms Price Benchmarking Study for Arab Countries
Tanzania Revenue Authority, (TREV). [2006]. Tanzania Revenue Authority 2006/2007.
Telecommunications Regulatory Authority of India, (TRAI). [2003]. Unified Licensing Regime, 2003
Tanzania Telecommunications Company Limited, (TTCL). [2009]. www.TTCL.co.tz, viewed on 12th July,2009
United Republic of Tanzania, (URTA). [1998]. National Poverty Eradication Strategy, 1998
United Republic of Tanzania, (URTA). [1999]. United Republic of Tanzania. Development Vision 2025, 1999
United Republic of Tanzania, (URTA). [2005]. United Republic of Tanzania. The Economic survey, 2005
Vodacom Tanzania Limited, (Voda). [2009]. www.vodacm.co.tz viewed on 20th April, 2009
Walker, P. [1997]. How to Complete and Connect: Setting The Business And Regulatory Context, *IEE,* London, UK, 1997
Wickenden, S. [1997]. Interconnect Routing and Traffic Routes, *IEE* London, UK
The World Bank, (Wolb). [2000]. Telecommunication Regulatory Handbook, infoDev.

Zain Tanzania Limited, (Zait). [2009]. www.tz.zain.com, viewed on 20th April,2009
Zanzibar Telecommunications Limited, (Zant). [2009]. www.zantel.co.tz, viewed on 20th April, 2009

Appendix A.Network Costing

This Appendix shows calculations of the network related costs spread out over time through the economic lifetime of the investment. These costs are calculated in present (current) value terms using the discounted cost method[Gill2004]. The discounted cost method provides the present value of annual costs from the base year of the component up to the end of the costing period. The costs for each year are discounted to give the present value of annual costs of the component at the base year. The algebraic sum of the discounted annual costs (annualized costs) gives the total discounted costs of the component.

The total discounted costs of using the component for Nyears in the absence of technical progress can be derived in terms of the discounted sum of the original investment, residue (resale) value, and operating-maintenance cost as follows [Gill2004]:

$$C_N = I_0 + \sum_{n=1}^{N} \frac{f_n}{(1+i)^n} - \frac{V_N}{(1+i)^N} \qquad \text{(A.1)}$$

where $C_N$is the total discounted costs of the component with the economic life of N years, n is the current year, $I_0$is costs of the component paid in year 0 or the discounted sum in year 0 of the component costs if they are spread over several years, $f_n$is the operating-maintenance costs of year n, n=1,2,..., N and f_n is assumed constant and equal at f_0, and V_N is the resale or residue value in year N, and $V_0 = I_0$.

Replacing the sum of the discounted factor $\sum_{1}^{N} \frac{1}{(1+i)^n}$ by ω^{N_i} to get the following formula [Gill2004]:

$$\omega^{N_i} = \sum_{1}^{N} \frac{1}{(1+i)^n} = \frac{(1-i)^N - 1}{i(1+i)^N} \qquad \text{(A.2)}$$

Retaining the operating-maintenance cost f_n constant and equal at 0, C_N can be simplified in terms of $f_0$and N_i as follows:

$$C_N = I_0 + \sum_{n=1}^{N} \frac{f_0}{(1+i)^n} - \frac{V_N}{(1+i)^N} \qquad \text{(A.3)}$$

$$C_N = I_0 + f_0 \sum_{1}^{N} \frac{1}{(1+i)^n} - \frac{V_N}{(1+i)^N} \qquad (A.4)$$

Substituting $\sum_{1}^{N} \frac{1}{(1+i)^n}$ by ω^{N_i} giving the following formula:

$$C_N = I_0 + f_0\, \omega^{N_i} - \frac{V_N}{(1+i)^N} \qquad (A.5)$$

The simplified C_N is divided by the sum of the discounted factor $\sum_{1}^{N} \frac{1}{(1+i)^n}$ to get the average discounted annual costs, which is known as the long run average incremental cost (LRAIC) as expressed as follows[Gill2004]:

$$X_N = \frac{C_N}{\sum_{1}^{N} \frac{1}{(1+i)^n}} = \frac{C_N}{\omega^{N_i}} = \frac{I_0}{\omega^{N_i}} + f_0 - \frac{V_N}{(1+i)^N} \frac{1}{\omega^{N_i}} \qquad (A.6)$$

where the X_N is the long run average incremental cost.

The X_N can be expanded and simplified as shown in equations A.7 and A.8 respectively:

$$X_N = \frac{I_0}{\omega^{N_i}} + f_0 - \frac{V_N}{(1+i)^N} \frac{1}{\omega^{N_i}} \qquad (A.7)$$

$$X_N = \frac{1}{\omega^{N_i}} \left(I_0 - \frac{V_N}{(1+i)^N}\right) + f_0 \qquad (A.8)$$

The average discounted annual costs correspond to LRAIC of the component in the absence of the technical progress as stated in equation A.7 is the sum of the total investment less discounted residue value, the whole discounted by phi (N,i), and the annual operating-maintenance cost [Gill2004].

When the technical progress is considered, the component is renewed or replaced before the economic lifetime. The technical progress alters the component its initial costs, level of operating costs, and service provision in terms of capacity and functionality. The replacement cost of the component is based on the cost of the modern equivalent asset (MEA) with the same level of capacity and functionality. The replacement cost factor of the component over time (every Nyears) can be expressed as follows [Gill2004]:

$$D_N = C_N + \frac{C_N}{(1+i)^N} + \frac{C_N}{(1+i)^{2N}} + \ldots + \frac{C_N}{(1+i)^{kN}} \quad \text{(A.9)}$$

whereD_N is the replacement cost factor of the component with the technical progress. The expression of the $D_N$indicates the sum of a geometric series, which can be simplified as follows:

$$D_N = \frac{C_N}{1 - \frac{1}{(1+i)^N}} \quad \text{(A.10)}$$

The expression of the D_N can be further simplified as:

$$D_N = \frac{(1+i)^N C_N}{(1+i)^N - 1} \quad \text{(A.11)}$$

The expression of the D_N can be presented in terms of the annual discounted cost of the component in the absence of the technical progress as:

$$D_N = X_N / i \quad \text{(A.12)}$$

Procuring the component of identical age, or procuring a new component straight away can replace the old component. The extra cost of renewing or replacing the old component by identical component of the same age and characteristics before the economic lifetime N at year n and operating it at the same discounted cost price from year n+1 to year N can be expressed as follows [Gill2004]:

$$\frac{U_n}{(1+i)^n} + \sum_{k=n+1}^{N} \frac{f_k}{(1+i)^k} - \frac{V_N}{(1+i)^N} = \sum_{k=n+1}^{N} \frac{X_N}{(1+i)^k} \quad \text{(A.13)}$$

whereU_n is the discounted usage value before the renewal of the component, and it acts as the discounted initial investment after the renewal of the component, f_k is the discounted operating cost after the renewal of the component, V_N is the discounted resale value of the renewed component, and X_N is the annual equivalent cost of the renewed component.

The replacement cost can be presented in terms of economic depreciation as:

$$\frac{U_n}{(1+i)^n} = \sum_{k=n+1}^{N} \frac{a_k}{(1+i)^k} + \frac{V_N}{(1+i)^N} \quad \text{(A.14)}$$

[THE END]