INFRASTRUCTURE SHARING BY MOBILE OPERATORS IN ZAMBIA: A GAME THEORETICAL APPROACH

By

Lennox Richard Sitoloma
(513809857)

A dissertation submitted to University of Zambia in partial fulfilment of the requirements for the degree of Master of Engineering in Telecommunication Systems

THE UNIVERSITY OF ZAMBIA

LUSAKA

DECLARATION

I, Lennox Richard Sitoloma do hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication.

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CERTIFICATE OF APPROVAL

This dissertation of Lennox Richard Sitoloma has been approved as fulfilling partial fulfilment of the requirements for the award of the degree of Masters in Telecommunication Systems by the University of Zambia.

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ABSTRACT

The problem of infrastructure sharing among competing agents, each hoping to maximize its utility, is a daunting task for regulators and policy makers at large. This study used a game theoretical analysis of how a Network infrastructure as a Service (NaaS) company can optimize its utilities or payoff given strategic moves of other users. It set out some of the key themes, under factors of willingness to pay regulatory factor and price, with infrastructure investment by network operators and thereafter conclude with benefits it would bring to the service providers, (provision of network as a service) subscribers and the regulators. Utility-based decision rules are defined for competing mobile providers under varying regulatory, price and willingness to pay requirements. An adapted model of utility was used under information asymmetry and information symmetry game environment.

Simulation analysis was done to determine the effects of such factors on infrastructure investment. This study used the adapted model for infrastructure sharing and we present the following results:

The simulations results showed that the willingness to pay factor has positive contribution to the provider of Network as a Service (NaaS). Additionally, an increased investment in infrastructure coupled with positive response in willingness to pay from users, increases the NaaS's utility. It was further deduced that investment in infrastructure alone when other factors are constant reaches an optimal point or maximum point at which it starts to reduce negatively.

In conclusion, willingness to pay, price and regulatory factor plays an important role on whether the provider of NaaS should invest in the provision of network infrastructure as a service to the country.

Keywords: Infrastructure sharing, active sharing, passive sharing, utility, Network as a Service.

ACKNOWLEDGEMENT

My sincere gratitude goes Dr. M. Sumbwanyambe who was my supervisor for the great service he wholeheartedly rendered during the study. Special thanks to the entire academic staff of the School of Engineering for their tireless effort put in, for me to reach this far. I salute my classmates of the mighty 2014 MEng.Telecommunication Systems class for their encouragement.

And not forgetting my family for their support and prayers throughout this period.

DEDICATION

This thesis is dedicated to my Heavenly Father for seeing me through this far and to my wife Beenzu with our beloved children, Luyando, Lumuno, Lushomo and Lubomba for according me an opportunity to do this work by being away from them for a long time.

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LIST OF ABBREVIATIONS

BTS- Base Transceiver Station
CAPEX-Capital Expenditure

CGT- Cooperative game theory

DPC- Distributed Power Control

DSA- Dynamic Spectrum Allocation

EIR- Equipment Identity Register

GGSN-Gateway GPRS Support Node

GPRS-General Packet Radio Service

GSM- Global Mobile System

HLR- Home Location Register

ICT- Information and Communications Technology

InfraS- Infrastructure Sharing

InP- Infrastructure Providers

LTE- Long- Term Evolution

MAC- Media Access Control

MATLAB- MATrix LABoratory

MIMO- Multiple Input Multiple Output

MNO- Mobile Network Operator

MSC- Mobile Switch Centre

MVNO – Mobile Virtual Network Operator

NaaS- Network as a Service Provider

NE- Nash Equilibrium

NGT- Non-cooperative game theory

OPEX-Operation Expenditure

PLMN- Public Land Mobile Network

RAN- Radio Access Network

RNC- Radio Network Controller

SGSN- Serving GPRS Support Node

SP- Service Provider

TRX- Transmitter and Receiver

UMTS- Universal Mobile Telecommunications System

WLAN-Wireless Local Area Network

WTO- World Trade Organisation

ZAMTEL-Zambia Telecommunications Company Limited

ZESCO- Zambia Electricity Supply Corporation

ZICTA- Zambia Information and Communication Technology Authority

ZNBS- Zambia National Broadband Strategy

CHAPTER 1: INTRODUCTION

1.1 Mobile Service Operators in Zambia

Information and Communications Technology (ICTs) and telecommunication service provision in developing countries is experiencing rapid growth and motivating various deployments. It has been considered as a catalyst to hastening social and economic growth and shows the potential to provide the goal of "communication access for all" in both rural and urban areas [1].

There are presently three Mobile Network Operators (MNOs) in Zambia. The first mobile cellular licence in Zambia was given to Zamtel in 1994. This allowed Zamtel to provide mobile cellular services to the public. In 1995, MTN Zambia, then Telecel, entered the market after being duly licensed as a mobile cellular services provider. Zamcell, now Airtel Zambia, finally came on board into the Zambian market in 1997 as a third mobile cellular service provider [2]. The provided licence permitted the licensee to constructs, own and make available an electronic communications network or to provide a network service [3]. According to the licence requirement each operators had to construct its own telecommunication infrastructures.

Since the liberalization of telecommunication services in Zambia from monopoly, there has been significant growth in communication service. The introduction of Mobile Network Operators resulted in widespread telecommunication infrastructure development in many parts of the country. The competition brought a number of benefits such as improved choice, lower tariffs and better quality of mobile services to the end user.

According to Zambia Information and Communication Technology Authority (ZICTA), the telecommunications regulatory authority of Zambia, mobile phone subscribers stood at about 10.9 million by the end of September 2015 [4]. This represented a mobile penetration rate of about 70 percent. MTN Zambia had the largest subscriber base with a market share of 46 percent, followed by Airtel with 40 percent and Zamtel the state owned operator with the least market share of 14 percent [5].

Figure 1.1 shows the mobile market shares from 2007 to 2015.

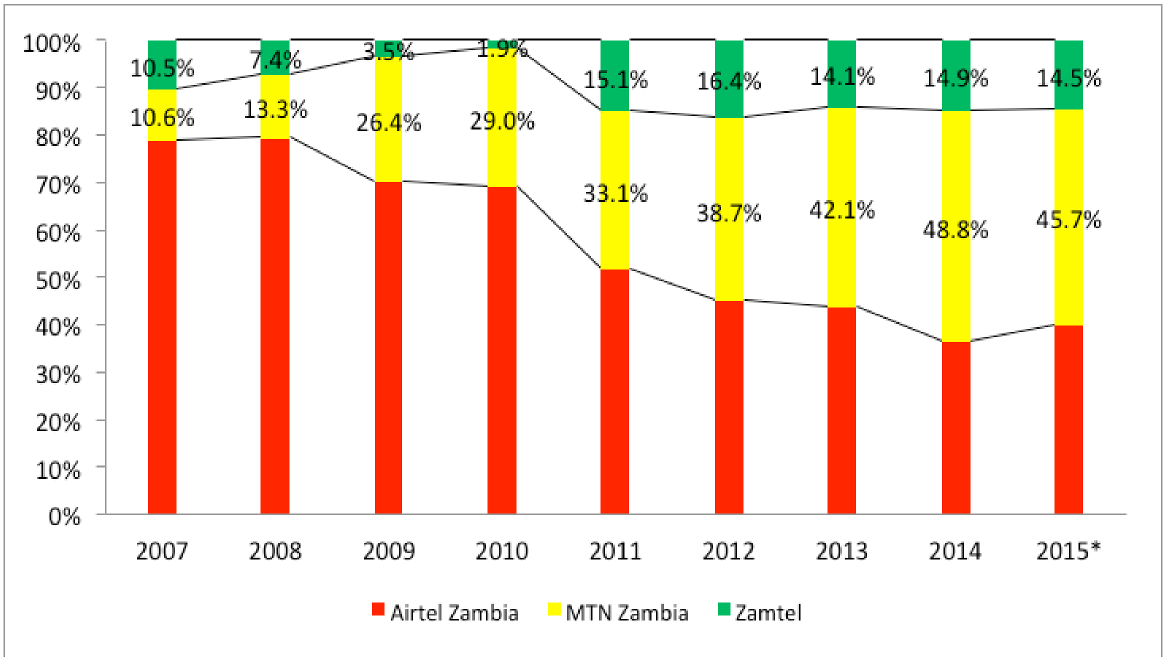


Figure 1.1: Mobile Markets Shares from 2007-2015 [4]

There has been deceleration in the annual growth of global mobile subscribers resulting into revenue stagnation in telecommunications industry as observed by ZICTA [5]. This is due to the shift in market demand from conventional mobile communication to wider portfolio such as internet, entertainment and other value added services.

The Zambian mobile industry trend in mobile subscriber numbers has not been positive enough since 2012. This calls for the Regulator to come in and re-position the market in order to have accelerated innovation by the incumbent and potentially new entrants to improve the trend positively. The mobile penetration level at the end of 2014 stood at 65 percent while there is still room for growth in the mobile sector as many people are still not being serviced effectively by the existing Mobile Network operators in Zambia [5]. Some MNOs have since been sued by ZICTA for failing to providing quality services as stipulated in the licence [6].

According to the WTO agreement and telecommunication reform policy [7] that required every Regulator to promote universal access for all, ZICTA was mandated by the ICT ACT of 2009 to take up the responsibility of designing, implementation and financing of the universal service programme [2][8]. It is for this regard that ZICTA commissioned a Universal Access Programme (UAP) to ensure the deployment of ICT to rural and un-served areas of the country by providing infrastructure that would facilitate service provision using public funds [2]. Mobile services operators in Zambia are rapidly covering the densely populated urban areas with communication and data services leaving out the sparsely populated areas in the rural which are deemed unprofitable.

The Zambia ICT regulator has a major role to play in ensuring that the Mobile industry continues to be effectively competitive [8].

Infrastructure sharing in Zambia is still at its infancy as most of the sharing that is done is at the passive level such as site sharing, tower sharing, shelter sharing and power. The agreement to share is done among the MNOs themselves. Active sharing such BTS, BSC, Core networks, RAN and spectrum sharing are not allowed by the regulator.

The challenges that are being faced by the MNOs in Zambia of providing poor quality of services [6] and been unable to provide service to the underserviced and unserved rural areas can be enhanced through infrastructure sharing or outsourcing infrastructure from the third party whose only role is to provide mobile network infrastructure as a service. Through InfraS or NaaS, the MNOs will focus on their core business of providing better and quality services to their customers. Instead of worrying about network coverage their focus will be on betterment of the services offered.

1.2 Game Theory

Game theory is a fascinating and recognized way of studying conflicts and cooperation [9] [10]. It is concerned with discovering the best actions for individual decision makers in these circumstances and make out stable results. It is a branch of applied mathematics which deals with numerous persons' decision prototypes of conflict and cooperation amongst cogent decision-makers [11] [12]. Game theoretic models are used every time the actions of numerous agents are inter-reliant [13] [14]. These agents could be individuals, groups, organizations or any amalgamation of the agents [9] [14]. Game theory endeavours to arithmetically capture rational behaviour in circumstances, or playoffs, in which an individual's success in making choices relies on the choices made by others. The plain norm is that the decision makers follow some well-defined goals or actions while considering the facts or prospects of the other decision makers' conduct [12]. The notions of game theory offer a language to articulate structure, evaluate, and comprehend strategic situations [9].

In economics, game theory finds its applications in the achievement of equilibrium of prices in competitive markets which leads to optimal levels of resource utility. Players furnished with facts about the intentions of other players can easily predict the moves thus facilitating potential maximization of proceeds [12]. It has been used extensively in rivalry modelling between firms and other segments of the economic market. Other examples of games in actions are competition among firms, the conflict between management and labour, the fight to pass bills through congress, the power of the judiciary, and war and peace negotiations between countries [9].

Games are branded by several players or decision makers, who interrelate, possibly threaten each other and form alliances, take actions under undefined situations, and lastly receive some benefit or incentive or possibly some penalty or financial loss [9] [15] [16].

Games are characterized by several users who should be rational [15] [16]. The user of the game has the rights to the following:

(i). Payoffs assessment;

(ii). Calculate strategies that will yield the best preferred payoff;

(iii). Given the strategies or movements of the opponent, the user can select actions that will result into the most desired payoff.

1.3 Background and Rationale

The business model of mobile communication was traditionally based on full ownership of network infrastructure [17] [18]. With the tremendous record of growth and demand for wireless communication services globally [19] , there is need to move from the traditional way of sole network infrastructure to network infrastructure sharing through the provision of Network as a Service (NaaS).

Rolling out mobile services in Zambia has been a daunting mission to some service providers, especially to the new entrants. The major cause underlies in the fact that each service provider, within the framework of policy and regulation [3], was required to carry out the deployment of its own infrastructure; starting from site survey, site acquisitions, space negotiations with land owners, constructions of towers, equipment room installations up to the final commissioning of the site. Normally, this cost money and time when other service providers' infrastructure that can be used or shared is already in place. The cost of deployment, management and maintaining network infrastructure is driving the need for innovative model of infrastructure deployment and management [20].

1.4 Problem statement

Infrastructure provision is a daunting task to service providers who want to provide Mobile Network as a Service (NaaS). Generally provision of network resources requires a strategic and well-coordinated business manoeuvres .Primarily, NaaS providers are faced with a myriad of factors to consider when hoping to provide NaaS. Some of the factors in question are [12] regulatory environment factor, willingness to pay, infrastructure investment and the price. All these factors have an effect on whether the NaaS should continue investing in network building and provide NaaS to users.

Usually the NaaS provider would pose and ask” What is my utility or payoff given the parameters or factors that may constrain or hinder network development.”

1.5 Research questions

The following are the research questions to be addressed:

(i). What factors are necessary for infrastructure sharing?
(ii). What are the effects of such factors on infrastructure sharing?
(iii). What model would be used to promote infrastructure sharing among operators?
(iv). What are the possible benefits of InfraS/ NaaS provision to the MNOs and End user?
(v). How can we apply cooperative game theory model and information symmetry and asymmetry in order to investigate the best response under which to optimize utility in infrastructure investment?

1.6 Objectives of the research

This research seeks to address the issue of infrastructure or network sharing among MNO as a service in Zambia. It identifies the modes of sharing, motivating factors and limitations to infrastructure sharing and also ascertain the benefits to the users and the providers. Furthermore, the research will consider scenarios where provider of Mobile Network as a Service (NaaS) will try to find out the best response in which to optimize utility by ways of investing in infrastructure under information symmetry and information asymmetry given governing parameters like willingness to pay, regulatory factors, investment in infrastructure and the price.

A utility based model will be given using cooperative game theory under, information symmetry and asymmetry environment.

In summary the objectives are as follows:

(i). Identify factors which are necessary for infrastructure sharing in Zambia.
(ii). Analyse the effect of such parameters on infrastructure sharing.
(iii). Come up with the model that will promote infrastructure sharing among operators.
(iv). Determine possible benefits to NaaS and the mobile service providers.
(v). To apply cooperative game theoretical model under information symmetry and asymmetry in order to investigate the best response under which to optimize utility in infrastructure investment.

1.7 Relevance of the study

It is evident that communication for all in developing countries like Zambia is far-fetched with the available infrastructure for both internet and mobile services unless the government of Zambia come with a deliberate policy of infrastructure sharing among providers or coming up with government driven Network as a Service entity (NaaS) through Public Private Partnership (PPP) . Having NaaS entity in place it will enable broadband infrastructure in not serviced areas [22] which are unprofitable to venture into by individual MNOs. It will also enhance quick deployment of not only broadband service but also mobile services to not serviced spacey populated rural areas which in turn will enhance the number of subscribers which can be translated into revenue growth. Quality of service from MNOs will greatly improve as the operators will focus on their core business of bringing satisfaction to the customer. It will furthermore help to optimize the usage of available infrastructure through sharing by mobile operators in Zambia.

1.8 Conclusion and Thesis structure

In this current chapter, an introduction on Mobile operators in Zambia, Mobile network as service and game theory are briefly given**.** The background and the rationale behind infrastructure sharing, the problem statements, the research questions, objectives and the significance of the study are also highlighted as well as looking at the outline for the rest of the thesis.

Chapter 2 gives a literature review on Infrastructure sharing implementation in developed and developing countries, the benefits, drivers and challenges. It further looks at cloud computing, models of cloud computing with its pros and cons. Game theory and its application in telecommunication engineering.

Chapter 3 looks at the methodology that was used to address the objectives and the materials that were used to execute the simulation in Matlab.

Chapter 4 provides results, discussion and analysis.

Chapter 5 finally gives a conclusion of the study with recommendations for the future research work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The main aim of this chapter is to look at the literature review of mobile infrastructure sharing globally with examples in developed and developing countries where it has been successfully implemented. It will further look at the drivers of venturing into infrastructure sharing, modes of sharing, the benefits and the constraints. The chapter will then look at the components of Cloud computing which include Infrastructure as a Service (IaaS), Network as a Service (NaaS), Platform as a Service (PaaS), Communication as a Service (CaaS) and Software as a Service (SaaS).

Finally it will look at game theory with more emphasis on the categories of game theory i.e. cooperative and non-cooperative. Furthermore we will look at the definitions in game theory like best response, Nash equilibrium, strategy, payoff or utility, rationality, dominance, mixed strategies, extensive games with perfect information and imperfect information and zero - sum game.

2.2 Overview of Mobile Infrastructure Sharing Globally

Before we dive into the mobile infrastructure sharing, it would be prudent to comprehend and define infrastructure sharing. Infrastructure sharing is defined as having two or more operators coming together with a view of sharing part or parts of their network infrastructure for the purpose of their service provisioning [23][24][25][26]. The core objective of infrastructure sharing is to maximize the rare resources, optimize on economic paybacks on investments and the development of business models that concentrates on affordable and accessible ICT services 23] [27] [28].

The levels of Mobile communication infrastructure sharing vary universally with high levels more apparent in Europe, USA and India. Austria had about 50 percent of its sites been shared by the close of 2009 while Sweden had 70 percent of the sites been shared by close of 2011. In India alone with an estimated total of 300, 000 sites, had 60 percent been shared with an average tenancy of 1.5. The major players in India such as Bharti Infratel had a tenancy ratio of 1.62, Indus at 1.71, while WTTIL Quippo was at 1.84. USA had an average tenancy ratio of 2.5 [29]. Among the mobile operators in Pakistan, Waridi had the highest tenancy ratio of 1.44 followed by Ufone at 1.3 [30]. Mobile virtual network operators (MVNOs) are on the increase in Europe, Australia and North America, with more than 760 MVNOs operation worldwide. The growth for the MVNO model in the Middle East and

Africa (MEA) region was still low and at infancy stage with the two regions having 8 and 4 active MVNO respectively in 2013 as compared to Europe which had 496 MVNOs [31].

Africa was estimated to have 165,000 sites in 2014 with major players being IHS Africa with 20,000 sites, Helios TA with over 7800, American towers with 5136, Eaton with over 5070 and Swap technologies with 1459 sites managed and owned. Ghana had the highest concentration of independent tower firms [32]. Information and communication technologies are vital and essential infrastructure for poverty reduction, high productivity, economic progression, enhanced accountability and governance [33]. The lack of infrastructure in Africa especially in the sub-Sahara region is widely recognized as, one of the continent's greatest barriers to feasible development [34].

Mobile telecommunication services have an impressive uptake in the past decade. Mobile telephony has played a major part in making cellular services accessible to part of the population that did not have access to such services before especially in developing countries. However, considerable advances are required to increase the penetration of mobile services and to improve competition in the cellular market, in particular in rural areas in developing countries. The roll-out of mobile networks requires high sunk investments and the need to recover those by charging the user heavily for accessing mobile services [35]. This often makes mobile services less affordable and may discourage operators to innovate and migrate to new technologies in emerging markets. It may also cause licensed mobile network operators (MNO) to obstruct the entry of new operators in the market and additionally, it may be too costly for new entrant operators to rollout mobile networks in rural and less populated areas, resulting in exclusion of a part of the population or certain regions from access to mobile telecommunication services [36].

Traditional mobile network operation strategy is characterized by a high degree of vertical integration where the MNO acquires and develops the sites needed for rolling out the network, plans the network architecture and topology, operates and maintains the network and customer relationships, creates, markets and provides services to its end users. However, technology migration, such as the introduction of third generation (3G) and 3.5G wireless technologies on top of 2G networks, and the introduction of 4G technologies including LTE, is becoming increasingly rapid and complex [28]. Regulatory requirements also mandate coverage of areas that is not attractive from a business perspective. With growing competitive intensity and rapid price declines, mobile operators are facing increased margin pressure and the need to systematically improve their cost position.

In current market environment, focusing merely on the provisioning of coverage and capacity has a relatively low success factor, and to address this reality, operators are adopting multiple strategies, with network sharing emerging as a more radical mechanism to substantially and sustainably improve network costs [37]. Mobile infrastructure sharing in telecom is an important measure to reduce costs. It is useful in the initial phase to build coverage quickly and in the longer term scenario to build more cost effective coverage, especially in rural and less populated or marginalized areas [37]. In the emerging market context, both in urban and rural areas infrastructure sharing should be adopted as an imperative for sustained telecom growth.

Mobile infrastructure sharing may also stimulate the migration to new technologies and the deployment of mobile broadband, which is increasingly seen as a viable means of making broadband services accessible for a larger part of the world population [38]. Mobile sharing may also enhance competition between mobile operators and service providers, at least where certain safeguards are used, without which concerns of anticompetitive behaviour could arise. Ultimately, mobile network sharing can play an important role in increasing access to information and communication technologies (ICTs), generating economic growth, improving quality of life and helping developing and developed countries to meet the objectives established by the World Summit on the Information Society (WSIS) and the Millennium Development Goals established by the United Nations [39].

2.2.1 Types of Infrastructure Sharing

Infrastructure sharing in telecommunications refers to the joint utilization of assets and/or services in order to provide telecommunication service with a view of cost reduction in construction, operation and maintenance of the network infrastructure [40]. There are three different types of sharing strategies. These strategies are infrastructure assets sharing, infrastructure mutualisation, and infrastructure cooperation with each strategy having different shared assets and bargaining power of involved agents.

- Infrastructure assets sharing strategy occurs when two or more telecom operators in the same market share an asset that is necessary for the provision of final service. Examples of network assets suitable for sharing are masts, ducts, antennas, transmitters or rights of use. This can arise through negotiations among interested parties, which results in a leasing or a cost sharing agreement, or through a regulatory provision. Regulations to mandate sharing can introduce competition in retail markets, lessen the rural-urban digital divide, and reduce the environmental footprint of network deployment.

- Infrastructure mutualisation strategy is adopted when a common infrastructure is erected, ran, and sustained by an infrastructure provider, and mutually used by telecommunication service providers, with each renting a portion of the mutualised infrastructure and paying for it at a wholesale price. This strategy can be driven by markets or promoted by governments when the private sector does not have the incentives or resources.

  Public Private Partnership (PPP) approaches with diverse degrees of ownership and risk sharing may be used to build the infrastructure under open access, non-discrimination and low-cost pricing principles. The four possible examples of PPP model that can be used are Cooperative Model which is a jointly built and operated infrastructure by service providers with government subsidy; the equity model where the government obtain equity in exchange for contribution; the concession model which is done through public tender issued by government to select a private operator to build and operate the infrastructure; and the management contact model where the government issues a public tender to choose a private operator to build, operate and commercialise the infrastructure.

  In this model, the infrastructure provider is normally not allowed to participate in the retail market. In certain occasions, governments offer the exclusive exploitation of the infrastructure as an incentive to invest in the deployment of the network infrastructure.

- The Infrastructure cooperation strategy refers to housing or jointly constructing linear Infrastructures [41] for proficiency gains in capital expenditures and operating expenses. Infrastructure cooperation occurs when utility operators (railways, waterways, pipelines or electricity distribution) share rights of way with broadband operators, or when telecommunication operators that provide different services share the same physical infrastructure. The presence and utilization of synergies in the coordinated erection, operation, and maintenance of linear networks [41] strengthen the cooperation strategy. Cooperation differs from mutualisation because agents are not competing in the same market and, as a result, are more willing to share.

2.2.2 Analysis of infrastructure sharing Models

Infrastructure sharing is a vital component in the organization of the telecommunications industry, but sharing also is essential for market agents trying to curtail costs and regulators targeting to capitalize on social welfare. Regulatory involvements can help overcome market failures in services provision and attain the socially anticipated redeployment of ICT resources, such as universal service obligations. Regulations can also overcome limitations derived from market agent's rationality and limited information.

Existing literature has analysed the share of different assets in the diverse networks that make up the Internet with game-theoretic models. Lee et al [42] and Bublin et al [43] analysed the share of spectrum and active infrastructure assets in the mobile access network, while Zhang et al [41] looked at the housing of telecommunication infrastructure assets with other linear infrastructures, such as energy and transportation.

Infrastructure sharing contains three interrelated dimensions, namely commercial, regulatory and technical. Each of these dimensions can be analysed from a static and dynamic perspective because of markets growth and technology variations.

The commercial dimension of infrastructure sharing refers to the strategic behaviour of an operator in reaction to competitive market structures, market conditions, regulatory obligations and existing technology. From the perspective of the operator's strategic behaviour, infrastructure sharing is worthwhile if it supports the operator's competitive advantage. According to Porter [44], a company has the competitive advantage if it produces at a lower cost than its rivals or if it offers differentiated products and commands a premium price that exceeds the extra cost of differentiation. Telecommunication operators can achieve this advantage by reducing capital and operation expenses through infrastructure sharing. However, if increased coverage allows an operator to charge a premium price, not sharing infrastructure may be the more attractive strategy.

The design of an infrastructure sharing strategy depends on four core factors such as the market's competitive structure, market conditions, network symmetry, and regulator behaviour [40]. The four core factors are as explained below:

(i). Market's competitive structure: In highly competitive markets, the focus of the diversity strategy changes from competition in network coverage to competition in service provision, which makes infrastructure sharing more attractive. In high technology markets, shorter technology life cycles, the commoditization of network equipment, and less capital expenditure needed to adopt new technologies shifts the incentives of operators toward sharing passive and active infrastructure. By contrast, in emerging markets where telecommunications is not yet liberalized, operators are more interested in differentiating products by expanding coverage, and infrastructure sharing will be limited to passive network components, such as towers, ducts and rights of way.

(ii).Market conditions: Network infrastructure deployment is a low return investment in areas with a low population density or income level. Under these circumstances, there is greater incentive to reduce capital and operating expenses through infrastructure sharing. In fact, sharing may be the only feasible way to deploy infrastructure under such budgetary constraints.

(iii). Network symmetry: Operators with analogous rollout cycles, known as symmetric network, have incentive to share and merge networks and deconstruct redundant sites to compete in service provision. In this environment, sharing can reduce capital expenditures and operating expenses, which allows providers to add network capacity in congested areas with limited space and free up capital for other strategic investments. However, if networks are asymmetric, the largest network operator will be reluctant to share in order to keep the competitive advantage.

(iv).Regulator behaviour: An operator’s incentive to share infrastructure is influenced by expectations about future regulator behaviour. If an entrant operator has the initial benefit of access to the incumbent infrastructure from mandated sharing and expects such regulation to continue, the operator may delay investments in new technologies. The analysis that was done by Friederiszick et al [45] and Grajek et al [46] on the relationship between the intensity of regulation and investment in infrastructure, they discovered that entrant’s into investment of new infrastructure were discouraged by the higher intensity of regulation.

Infrastructure sharing is also influenced by a regulatory dimension when regulators mandate infrastructure sharing to provide competitive access to infrastructures, reduce market failures and increase social welfare. To illustrate, mandatory sharing and price regulation is common when the high sunk costs of network infrastructure deployment of essential facilities threatens retail competition by encouraging monopolization. Regulators can also enable infrastructure sharing agreements by making regulatory changes that obstruct potential sharing contracts. Furthermore, state aid can sometimes be used to promote the development of shared telecommunication infrastructures under PPP models.

. According to Hasbani et al [39], the regulator´s role evolves as market and technology structure progresses. In early stages of liberalization, infrastructure sharing needs explicit participation of the regulatory authorities, while in established markets, infrastructure sharing can be reached through cooperation among market players.

Finally, there is a technical dimension to infrastructure sharing, such as the technically available options to implement a regulatory or market strategy. Technological progress has modified incentives for sharing and changed which assets are suitable to share.

2.2.3 Drivers of Infrastructure Sharing

There are various drivers that may lead to infrastructure sharing by telecommunications operators. According to the study done by Feng et al, [47] on the APEC region, cost saving on network construction and maintenance was found to be the leading driving force into infrastructure sharing. The other drivers being to protect environment and avoid the waste of resources" and "To enhance broadband access level and reduce the digital divide". It is thus clear that infrastructure sharing was considered an important means to improve broadband access level and narrow digital divide in each economy Moreover, some economies consider that infrastructure sharing was an important means to "relieve infrastructure bottleneck for new entrants' access". Malungu and Moturi [48] in the study of ict infrastructure sharing in developing countries discovered that the main drivers to infraS were that sharing resources lowers cost and generates revenue, enables new entrants firms to launch and market their services quicker, efficient utilization of scarce resources, enables operators to focus on core business/innovations, preserves environment due to reduced electronic waste, increase coverage and access to services, improves network reliability by use of redundancy routes, promotes cooperation among competitors, enables policy and regulatory compliance requirements and hurdles in obtaining clearance from multiple government agencies.

2.2.4 Barriers/Challenges of Infrastructure Sharing

Despite having drivers for InfraS, there are always challenges to be met through sharing. Some of the challenges that emerged from the studies done by other authors were as follows: Malungu and Moturi [48] in their case study on Kenya the following emerged as the main barriers:

- Complexity involved in sharing process,
- Unwillingness to share due to lack of capacity or limited space on existing infrastructure,
- Lack of regulatory and policy framework on infrastructure sharing,
- Incompatibility of different technologies,
- High contractual exit costs arising from breach of contract,
- High charges by infrastructure owners,
- High contractual exit costs arising from breach of contract,
- Dominant operators fear of market share loss and
- Competition due to reduced control and interdependence.

Feng et al [47] in their study on infrastructure sharing in the APEC region, security emerged as the main concern brought up by sharing. Security concerns raised vary according to the type of infrastructure being shared namely tower, base stations and transmission lines. The concerns were summarized as follows:

- Security problem relating to tower sharing include the structure safety, in line with load bearing and wind load of the iron tower, lightening protection, electromagnetic compatibility, radiation and interference among various systems to be shared.
- Base stations security concern- on the equipment room which include capacity safety, load-bearing safety, environment safety and power load safety.
- For transmission line sharing (ducts and optical cables) the main concern is on capacity and maintenance safety.

2.3 Modes of Networks Sharing

Network sharing is a very complex process. It has a variety of options that may be considered when evaluating the practicality of infrastructure sharing .The considerations range from tower sharing and other infrastructure facilities to sharing an entire mobile network. There are basically three categories of sharing namely [49] passive sharing, active sharing and roaming based sharing.

2.3.1 Passive infrastructure sharing

Passive infrastructure sharing [50] is identified as the options available for mobile service operators intending to share passive elements in the radio access network. The sharing of radio sites termed ‘site sharing’ or co-location has become common since the year 2000 [51]. Usually, the operators go into an agreement to share sites directly, but of late there are third parties involved in such agreements, which provides towers to mobile service operators. The tower companies usually have already established footprint in mature markets where as they are coming up in the emerging markets as well, like India and the MENA region [39]. In general, site sharing involves sharing of costs related to trading, leasing, acquisition of property items, contracts and technical facilities and the sharing of passive RAN infrastructure such as:

(i). Mast and pylons ,electrical or fiber optic cables,
(ii). Physical space on ground ,towers, roof tops and other premises,
(iii). Power supply, air conditioning, alarm installations and other passive equipment.

Site sharing enables operators to have reduction on both capital (CAPEX) and operating (OPEX) expenditure in the investments of passive network infrastructure and in network operating expenses. From the initial investment of fixed assets costs, site acquisition and civil works gobbles up to 40% while site-related recurring costs typically make up 5-20% of network OPEX, with the lager amount applying for sites that are leased, not owned. The sharing of electrical equipment, such as air conditioning, further makes power consumption an addressable cost item, which represents roughly 3% of the network OPEX [52].

2.3.1.1 Site sharing

Site sharing, comprises co-location of sites. It is feasibly the easiest and most utilized form of sharing [39] [53]. Operators share the same physical complex but install separate site masts, antennas, cabinets and backhaul [54].

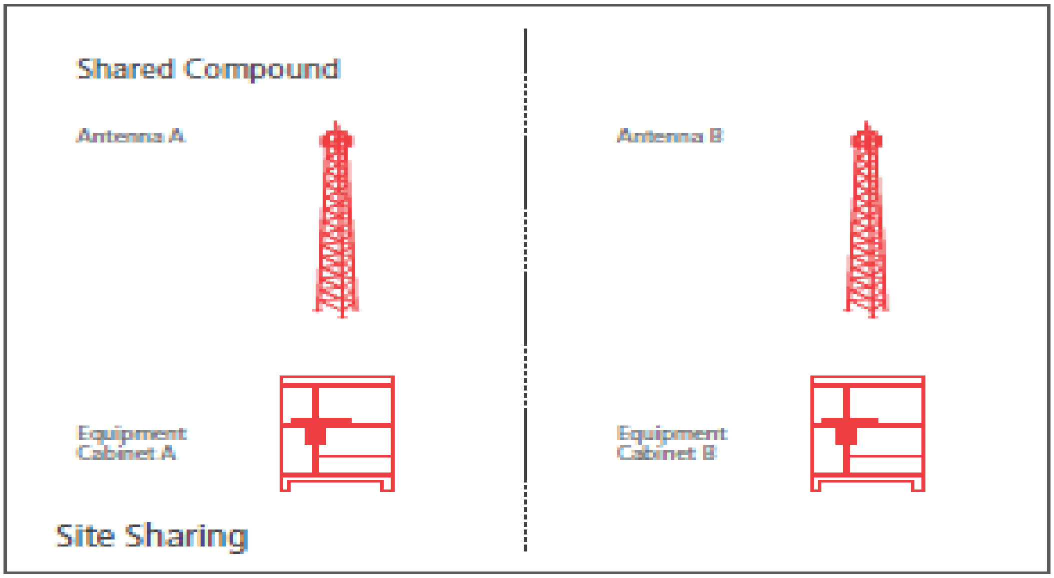


Figure 2.1: Site sharing [55]

As illustrated in Figure 2.1, the firm line around the equipment and masts represents the fenced-off complex that the operators will either own or lease. Within this complex each operator usually installs their own substructure separately from that of other operators. However, they may decide to share support equipment, including shelters, power supply and air conditioning. This form of sharing is often common in urban and suburban areas where there is a shortage of available sites or complex.

Site sharing has the following positive attributes [55] [56]:

(i). Reduction in site acquisitions costs and builds -out efforts.
(ii). Reductions in total number of sites.
(iii). Site rental costs decrease.
(iv). Enhanced utilization of scarce resources i.e. sites, mast and shelters.
(v). Better utilization of scarce resources.

Despite having numerous advantages, site sharing has also some disadvantages such as limitation of space for expansion in certain sites; power loss in shared antenna system which requires additional amplification of output and need for coordination among sharing partners on site-related operational aspects [55] [56].

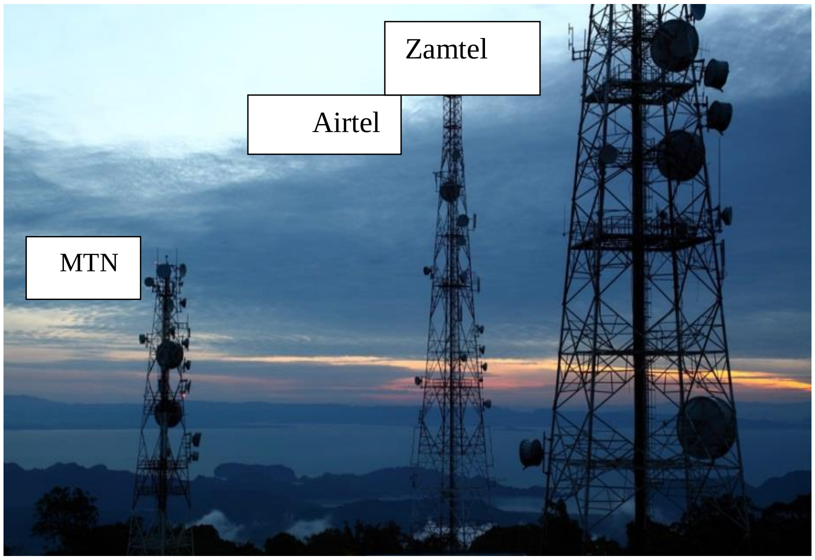


Figure 2.2: A typical shared site in Zambia [57]

2.3.1.2 Tower Sharing

Apart from just co-locating, the operators may decide to take a step further by sharing of the same mast, antenna frame or rooftop. The illustration of tower sharing is as shown in Figure 2.3. The access infrastructure could range from antennas to base transceiver station (BTS) cabinets. However, each operator will install their own antennas onto a shared physical mast or other structure. There may be necessity to strengthen or lengthen the mast or the tower in order to support several sets of antenna. Operators may share support equipment on site sharing while the coverage for each operator remains separate completely. The other alternative options available are that of third party structures such as Steel power pylons and chimneys and rooftops in built up areas.

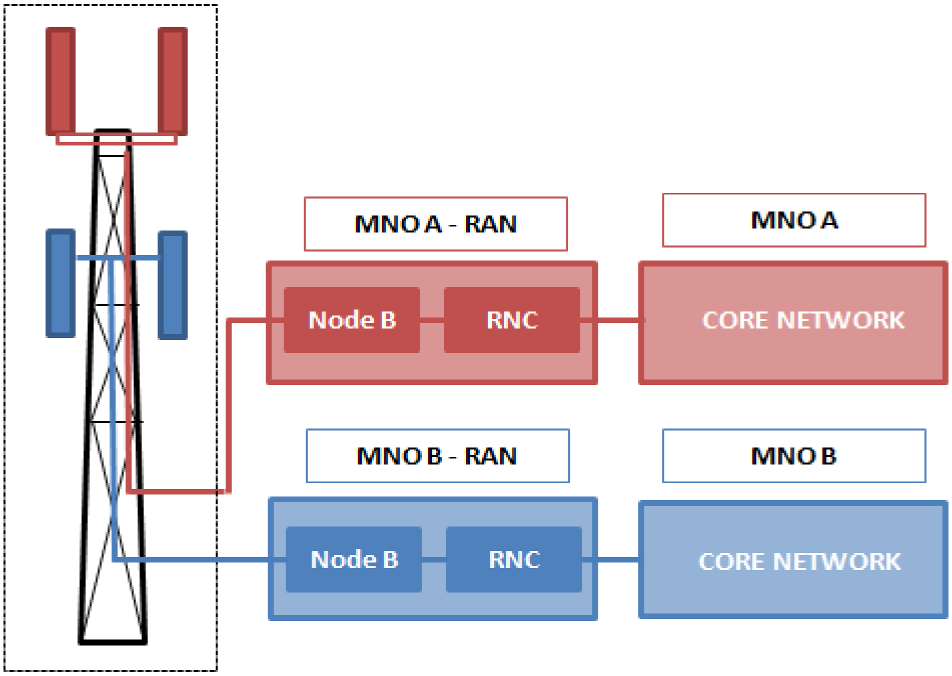


Figure 2.3: Tower sharing [54]

2.3.2 Active infrastructure sharing

The active sharing of infrastructure facilities is an advanced technical model that comprises a common sharing of not only passive but also active elements of the network that can be managed by the operators [51] [58]. These active elements involve the base stations, mobile network equipment, access node switches and the management systems of fiber optic networks. Savings on CAPEX and OPEX can be realized by sharing the active radio access networks infrastructure such as BTS and BSC in 2G networks or NodeB in 3G networks. The sharing of active infrastructure is more complex as it covers the essential elements of the value creation in the chain of economic activity. Active sharing is regulated in many countries for fear of promoting anticompetitive behaviour on price agreements or service offerings. Conversely, other regulatory authorities take a more lenient approach to active sharing as it encourages operators to increasingly compete based on quality of the service rather than the features on their networks.

2.3.2.1 RAN sharing

RAN sharing is the most all-inclusive form of access network sharing. It involves the sharing of all access network equipment, including the antenna, mast and backhaul equipment [53]. Each of the RAN access networks is amalgamated into a sole network, which is then split into distinct networks at the point of connection to the core. MNOs continue to keep discrete logical networks and spectrum and the degree of operational coordination is less than for other types of active sharing.

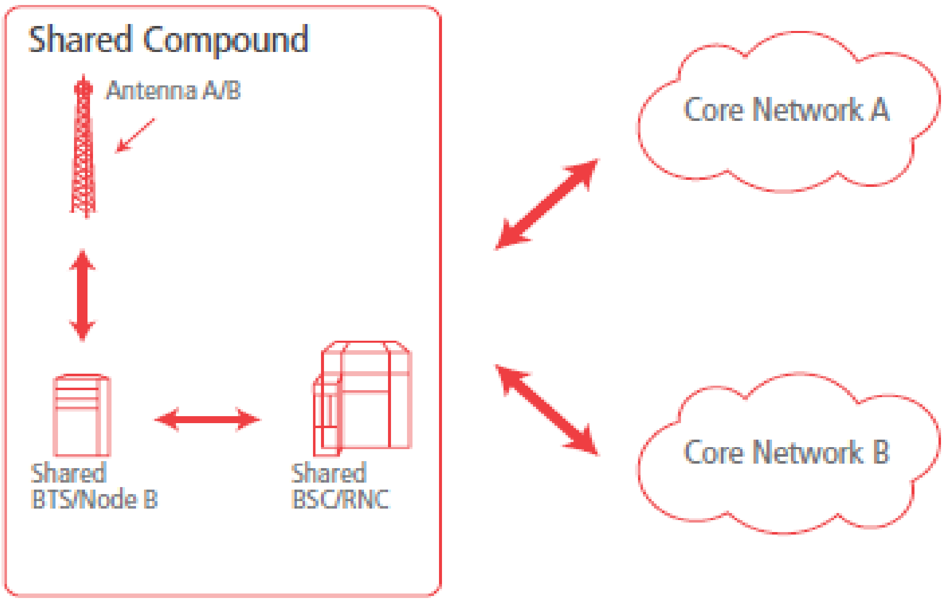


Figure 2.4: Full RAN sharing [55].

Figure 2.4 illustrates how Radio Access Network sharing might work between two partner networks. In this scenario both operators share all the access network components up to the point of linking with the core network. At this interconnect point; the traffic for each operator is then splits to its respective customers on its own core network ring for processing by its core network elements and infrastructure. The exact enactment may vary between different operators depending on the local implementation. The access network may include the following the radio equipment, towers, site complex or backhaul equipment.

Operators may face challenges in implementing a shared RAN network formed from existing networks, as they may have independently developed architectures to date. For example, there may be technical challenges around inter-working of equipment purchased from different vendors and operational techniques and control mechanisms [55].

2.3.2.2 Antenna sharing

In principle, antenna sharing can be considered as an extension of site sharing [51]. Under antenna sharing arrangement, operators may consider sharing of the TRX (transmitter and receiver), whereby demanding the sharing of the spectrum too. Even though, spectrum sharing is technically possible, it is usually met with several licensing and regulatory challenges due to spectrum regulations [51].
Compared to site sharing, antenna sharing has the potential of increasing CAPEX and OPEX savings for the operators. Although it is technically possible for MNOs using different sets of frequencies to share antennas, it may be a challenge when the radio optimization strategies are not aligned between MNOs [51]. Currently, equipment manufacturers are able to supply antennas which are adequate for antenna sharing.

2.3.2.3 Base Station sharing (NodeB)

The base station (NodeB) is the device that is placed in proximity to the antenna in the setting of 3G networks. It contains a number of devices that are responsible for controlling the transmission and reception of signals. Base station sharing is made possible under the following conditions:

(i). Each MNO should retain control of NodeB "logic" in order to operate independently of the competitor's allocated frequencies.
(ii). Each MNO should retain control of equipment assets of the base station such as TRX devices that controls the transmission/reception on the radio channel [51].

2.3.2.4 Base Station Controller (RNC) sharing

RNC sharing is made possible by maintaining logical control over the RNC of each operator separately [51]. As illustrated in Figure 2.5, the RNC is actually distributed into logical RNCs belonging to individual operators sharing the RNC. Each RNC has its own PLMN code logic and carrier frequency. The RNC is logically shared but physically divided. Such retention of the logical control over traffic by each operator guarantees them control over the equipment. The operator therefore maintains full control over crucial RNC control and operation functions such as radio resource allocation and optimization (access control, cell load control, spreading code assignment, power control, and service quality management) and mobility management and control of handover parameters.

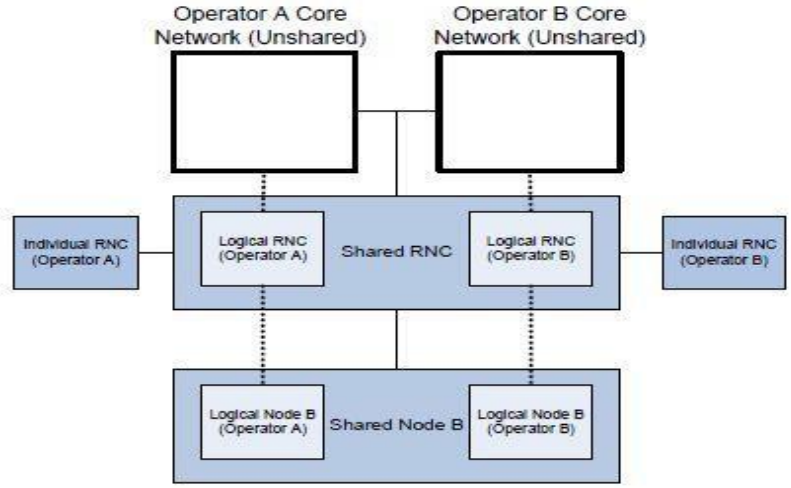


Figure 2.5: Schematic diagrams for a shared RNC [51]

2.3.2.5 Core network sharing

Core network sharing involves the sharing of servers and the core network functionalities in addition to radio equipment. It can basically be at core transmission ring or core network logical entities level. Conversely, the core network carries out numerous functionalities that are necessary for the performance of an operator’s service and encompasses a large amount of intimate information regarding the operator’s business. Thus, it may be difficult for contending operators to share a core network. Nevertheless, there are other varieties of sharing according to which operators may use the same core network to deliver their services, such as national roaming, or through a MVNO construction. In addition, with the advent of the so-called next-generation core networks in which the switching and the control and service functionality is physically separated, network sharing may move into the domain of core network switching while facilitating service distinction and discretion. The networks' "home" remain separate in core network sharing, which allows the differentiation of services. This is to pool the switches (MSC) and routers (SGSN) of the fixed network operator. Figure 2.6 shows a general schematic presentation of core network sharing [55].

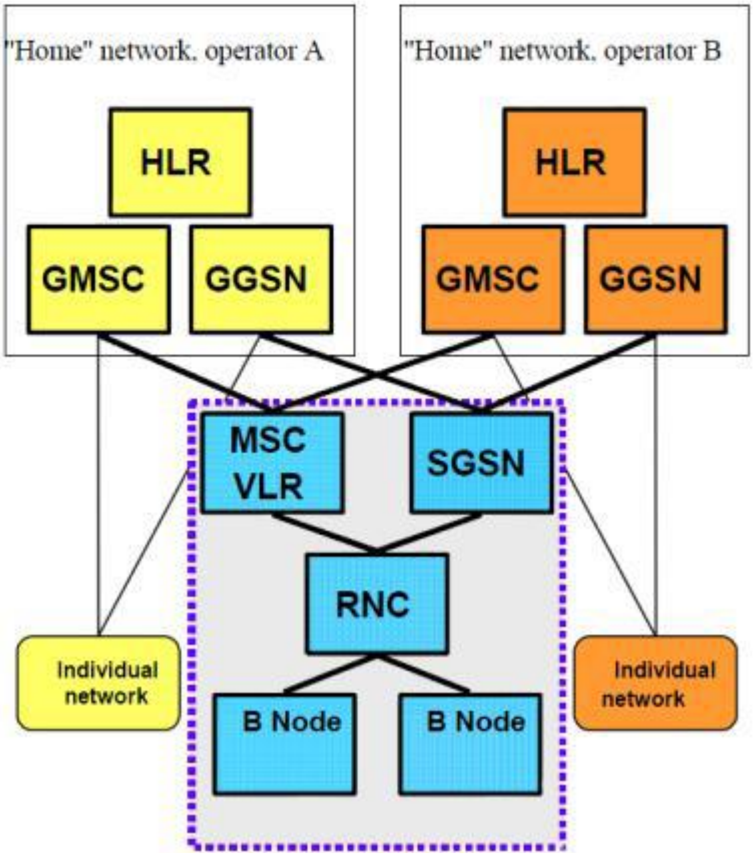


Figure 2.6: Schematic presentation of core network sharing [51]

2.3.2.6 Transmission ring sharing

If an operator has spare capacity on its core ring network, it may be realistic to share this with another operator. The situation may be principally attractive to new entrants who are lacking in time or resources to build their own ring. They may therefore purchase capacity, often in the form of rented lines, from established operators [55]. Nevertheless, if both companies use the same joint transmission and switching core then their services will become more affiliated as they will have the same infrastructure proficiencies. Any service, function or process that one operator implements can be simulated by the other as they have the same substructure capability. In Zambia transmission sharing services are been offered and promoted by CEC Liquid Telecoms and the Fiber backbone been offered by Fibercom of Zambia Electricity Supply Corporation (ZESCO).

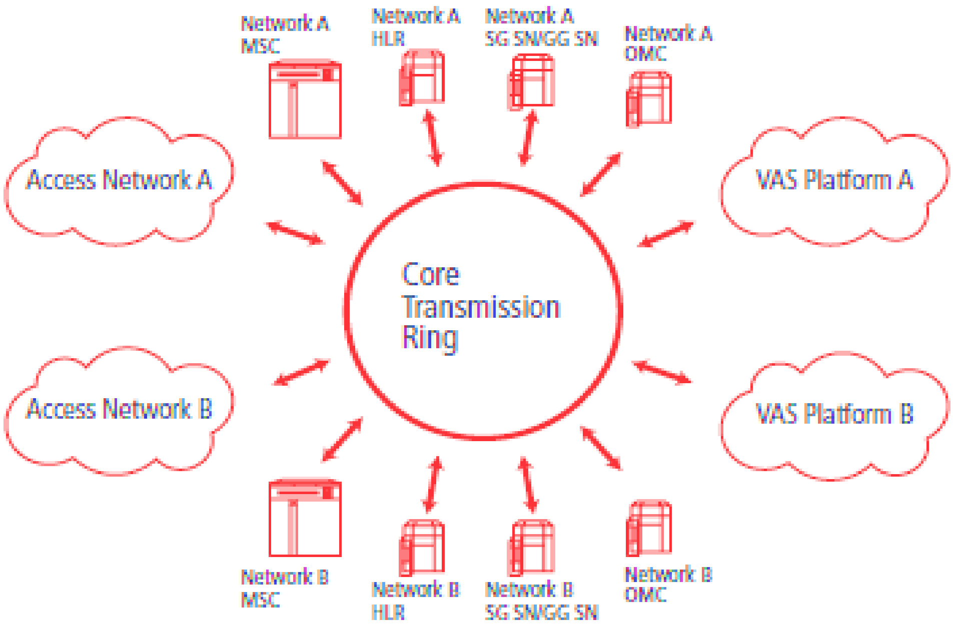


Figure 2.7: Core transmission ring sharing [55]

2.3.2.7 Roaming

Roaming is a form of sharing permitting customers of a mobile network operator to use mobile services of another operator in areas where they are not covered [58]. There are two types of roaming namely national and international [52]. From the genesis of 2G networks, roaming has every time been employed as a means of fundamentally extending the geographic coverage of an operator by letting its subscribers to use another operator's network [51] [52]. International roaming is used to serve one's customers abroad, where the operator has no license and no business. Roaming is also used domestically at national level, typically to allow a new entrant to extend coverage to its customers into areas where it has no network [52]. Roaming-based options in terms of network sharing, means that one operator depends on another operator's coverage for a certain, defined footprint on a perpetual basis. Such reliance can be either unilateral or bilateral, regionally split or for the network as a whole [51].

A geographically separated network does not contain shared nodes. Each operator owns an independent carrier, MNC, access networks, core network and covers different areas of the country [51]. National coverage can be provided in three ways. The first option has been a national roaming agreement where the load is shared. The second option done by connecting the two RAN with separate core networks and lastly through a shared core network as illustrated in Figure 2.8 a, b and c respectively.

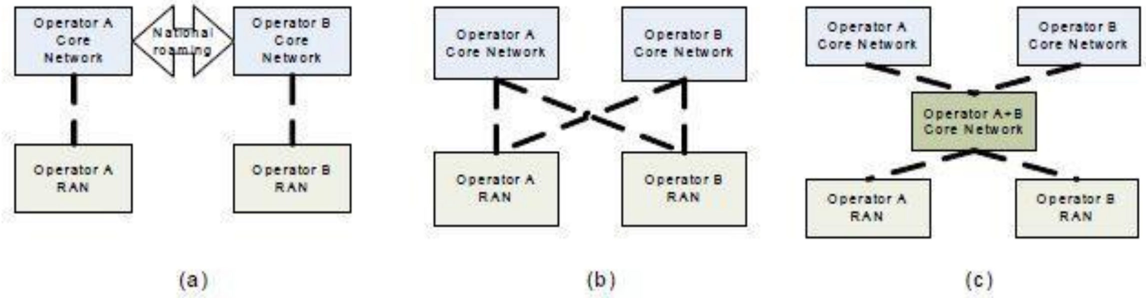


Figure 2.8 :Three ways to connect networks that are geographically divided [51]

2.4 Infrastructure sharing technical constraints

Infrastructure sharing may appear to be the positive way of rolling out mobile services to un-serviced, remote and sparsely populated areas but it comes with its own challenges or constraints for it to be fully achieved. Before the actual implementation, there are some technical constraints that need to be considered or addressed depending on the mode of sharing, be it passive or active.

It requires coordination and cooperation between or among operators who are involved in infrastructure sharing as the level of sharing increases [51].

2.4.1 Technical drawbacks in passive sharing

Passive sharing faces different constraints according to the mode of sharing. However when sharing sites, operators must take into consideration the following:

(i). The electromagnet compatibility, model blankets and optimization of 2G and 3G on the qualifying sites to be shared.

(ii). Installation of the equipment on sites, accessibility and safety must be taken into account.

(iii). The operation and maintenance of the shared sites.

2.4.2 Technical drawbacks in active sharing

Active sharing is more complicated as compared to passive sharing [59]. The following are the technical drawbacks depending on the mode of sharing:

(i). Antennas Sharing
  - The need for common choices affecting the quality of service i.e. technical diversity reception and transmission, radio planning and architecture of the antenna,
  - In radio planning, consideration of 3 dB loss induced by the coupling of the common antenna, for the separation of equipment connected to it must be taken into account,
  - Influence on the planning of the radio antenna amplifier linearity over several frequency bands.

(ii). NodeB Sharing
  - Limitation in the number of operators (normally 3or 4),
  - The operation and maintenance of shared assets,
  - Potential conflicts on the quality levels depending on the available services,
  - A danger of lead sole manufacturer solutions (in particular due to the interoperability links between NodeB and RNC,
  - The user of NodeB with at least two carriers (a substantial variance in frequency bands of operators offers other technical complexity).

(iii). The RNC Sharing
  - Separation of the RNC management functions like performance, radio access configuration and quality of radio services,
  - Interoperability of hardware and software configurations from different vendors,
  - Interoperability between RNC and shared RNC.

(iv). Core Network Sharing
  - Package design from core network management and service quality,
  - A selection of design of equipment common(NodeB, RNC,MSC,SGSN) to handle the traffic related to the providing of services of each operator,
  - Consistency in the intelligent network protocols in order to guarantee continuity of service to roaming customers from different operators on the shared network [51].

2.5 Merits of the infrastructure sharing to the mobile service provider

The concept of sharing network infrastructure has been gaining impressive traction in the past five years globally with an increase of 200 percent in sharing agreements occurring [59]. Regardless of this momentum, it still remains a challenge to measure the overall remunerations of infrastructure sharing due to various factors affecting the performance of an operator internally and externally. The generally acceptable benefit of the players who goes into infrastructure sharing is an increase in profit and reduction in cost which empowers them to re-invest in their industry [59]. Some of the renowned benefits in infrastructure sharing would be in the following area:

(i). Great saving in terms of Capital expenditure (Capex) and Operation expenditure (Opex).The principal benefit been cost saving in terms of planning, rolling out, maintenance and upgrading of their networks,

(ii). Service Centric networks-sharing of network infrastructure will encourage a shift from competition on the basis of network coverage to compete on the basis of feature and services, hence promoting innovation and growth which will finally benefit the whole mobile industry,

(iii). Spectral-efficiency- when operators share backhaul microwave frequencies or pool their spectrum, this result into optimal use of their spectral resources,

(iv). High uptime- Sharing infrastructure ensures speedy and easy commencement of operations,

(v). Reduced Time to Market-by leveraging existing infrastructure deployed in telecom circles, a new operator can immensely cut down the time taken to begin operations,

(vi). Coverage expansion-infrastructure sharing can facilitate the expansion of coverage to previously under-served areas via national roaming, or reduces operating costs by sharing sites, masts or the radio access network [59].

2.6 Merits of the infrastructure sharing to the end user

The sharing of infrastructure by mobile service players has ultimate positive results for the consumer as well**.** Sharing tend to have an impact on the coverage, quality of service and pricing of services to the consumer in a positive ways as explicated below:

(i). Decrease in replication of investment- tend to reduce costs to the operators and service prices to the consumer,
(ii). Optimization of rare national resources- land or spectrum may be used more efficiently and this may have a positive impact on the wider economy,
(iii). Improved quality of service- in congested areas, there may be black spots with poor quality and coverage which can be boosted by sharing hence servicing the consumer with quality service,
(iv). Increased consumer’s choice-as entry and expansion is made easier through sharing, the consumer has a wider choice of the providers,
(v). Positive incentives to provide service in underserved areas- consumers in un serviced area tend to benefit as this will encourage players to reach such areas,
(vi). Product and technological innovation- permitting operators to compete on service innovation and technology rather than solely on coverage will give a consumer product based choices rather than coverage.

2.7 Regulatory Policy on infrastructure sharing

Sharing of infrastructure varies from one country to the other depending on the levels of sharing and the governing regulatory**.** For this to be implemented successfully, the regulator must emphasize on promoting an enabling environment for sharing by enacting an appropriate regulatory framework and establishing competition and investment incentives. The guidelines that would be considered are as follows [49]:

(i). Reasonable terms and conditions- infrastructure sharing terms should not impose price or non-price discriminatory,
(ii). Pricing for shared facilities or network elements should provide the right economic signal to aid market players make the right decisions of either building or buying,

(iii). Efficient use of resources- non –replicable facilities such as towers, ducts, and rights-of –ways can be shared for optimal use,

(iv). The scarce resources such as radio spectrum which is limited in some regions must be considered for sharing as long as harmful interferences are addressed or managed,

(v). Having proper incentives, infrastructure sharing can be used to support regulator's universal access goals particularly in rural or underserved areas,

(vi). Dispute resolution mechanisms- regulators need to explore alternative dispute-resolution mechanisms and introduce necessary enforcement tools,

(vii). Establishing an infrastructure-sharing one-stop-shop – This would facilitate coordination of access and sharing among all telecommunication service providers, and among operators and other utilities,

(viii). Conditions for sharing should be accessible and transparent-need for well-established interconnections rules, terms and conditions,

(ix). Sharing of regulatory practices – regional organizations have a role to play in exchanging information and harmonizing regulatory practices related to sharing.

2.8 Infrastructure Sharing in Developed Nations

2.8.1 Implementation of Infrastructure Sharing in Sweden

According to the Swedish National Post and Telecom Agency (PTS), network sharing or infrastructure sharing is allowed in Sweden among MNOs provided the operator was able to provide the 30% of the population with its own network. There are a number of network sharing agreements which have successfully been implemented in Sweden. In December 2000, the PTS awarded four 3G licenses to Tele2 and Europolitan with GSM service and networks and the new entrants such as Orange and Hi3G (Hutchison) [60]. However, Orange did not deploy any network and its 3G license was returned to PTS and the spectrum were later allocated to the other licensees.

A 3G infrastructure (3GIS) network company was formed as a joint venture between Europolitan and the 3G Green field operator Hi3G. A new Act on Electronic Communications was enacted in Sweden on 24th July 2003 which required operator to co-location or share resources in return for commercial reward. In case of failure to voluntary agree the National regulation agency would impose an obligation. This was arrived at in order to protect the environment, public health or public security.

With the coming in of the Long Term Evolution (LTE), Telenor and Tele2 entered an agreement to form a joint venture known as Net4Mobility for the deployment of 4G in April 2009. TeliaSonera build its own 4G network as it was not interested into joint cooperation and was able to launch the first commercial LTE network in the world in July 2010.

The tenacity of the Swedish joint schemes is the deployment, management and operation of the entire mobile networks, where maintenance and installation of base station sites is an integrated part of the business. The cooperation is done within the mutually owned networks sharing company, where the owners have to agree on investments and then share the costs and split the work to be done. Other operators or joint ventures are allowed to rent space on commercial terms.
According to Village et al [61], Beckman and Smith [62], networks can be shared both technically and commercially in various ways. Telenor and Hi3G operated their individual 3G networks in addition to the 3GIS shared network. This is as illustrated in figure 2.10 below where there are three separate networks.

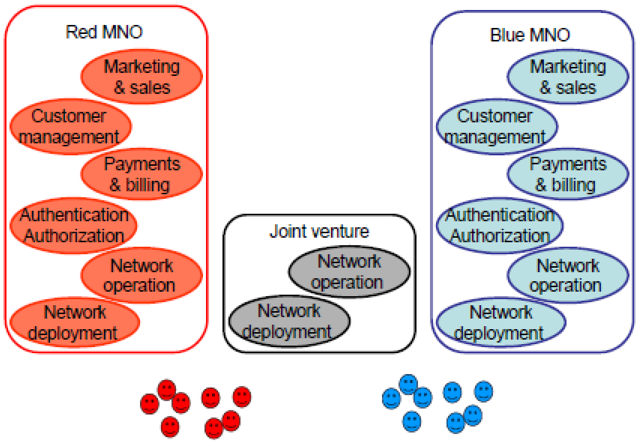


Figure 2.9: Examples of distribution of roles among operators, the case 3G networks provided by Hi3G and Telenor [63]

The cooperation between TeliaSonera and Tele2 is slightly different to the case of Telenor and Hi3G. There is only one 3G license, the one awarded to Tele2, and one 3G network. Tele2 and TeliaSonera are both owners and customers of SUNAB, but they are also suppliers. SUNAB does not have their own network planning group, but rather uses resources of Tele2 and TeliaSonera. In each of four geographical areas one of the operators is responsible for the network planning and deployment.

For all network sharing cases the operators compete for end-users. All resources for marketing, customer relation management, and billing are controlled by the separate mobile operators. It is only activities related to planning, deployment and operation of the mobile networks that are done jointly. Traffic data and user statistics of each operator is not available to the sharing partner. The "control of own customers" used for network sharing is the same as for other types of cooperation where operators share network resources, e.g. national roaming and Mobile Virtual Network Operators (MVNO).

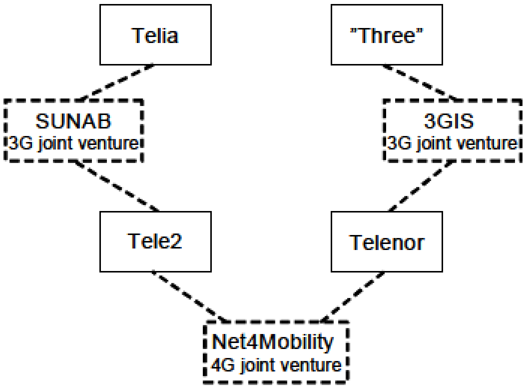


Figure 2.10: Mobile operators and network sharing joint ventures in Sweden [63]

2.8.1.1 Benefits of Infrastructure sharing in Sweden

From the study carried out by [63] Network sharing in Sweden resulted into the following attributes:

(i). User demand, increase in demand for mobile broadband access by customers,

(ii). Density of base station sites, network sharing has contributed to large deployment of sites in order to meet the license requirements and this has resulted into extensive coverage of 3G networks. This means that future deployment of "4G networks" (LTE) to a very large extent can be based on re-use of existing base station sites.

(iii). Reduction in cost of radio equipment and transmission, the intense competition among vendors of equipment pushed down the prices enabling operators to replace existing equipment with new LTE equipment [64].

(iv). Spectrum Availability, The access and control of radio spectrum is extremely important for mobile operators. More spectrums means more capacity and vital for high data transmission.

2.8.1.2 Challenges of InfraS in Sweden

From the study done, there were no negative consequences as a result of network sharing in Sweden**.**

2.8.1.3 Types of Sharing in Sweden

In Sweden operators are allowed to share sites, non-telecom and radio equipment and also radio spectrum. This has been used by the network sharing companies leading to a high degree of cost efficiency for the 3G networks; and the radio capacity has been build out when needed. The Swedish network sharing joint ventures are examples of very strong cooperation where infrastructure, base stations and spectrum are shared. The degree of trust and the strength of the tie are high, the operators share investments and risks. This may lead to high tensions as mentioned in Bengtsson et al [65].

For indoor networks in Sweden the cooperation between operators is quite strong but not as strong as for the network sharing joint ventures. Usually the operators use their own spectrum and radio base stations.

2.8.2 Infrastructure sharing in Singapore

The Information and Communication Development Authority of Singapore (IDA) [66] requested an input from the public on the proposed Code of Practice for Competition in the Telecommunication Services provision (TCC) in April 2000. With the input from the public, IDA came up with specific requirements on infrastructure sharing according to Chapter 7 of the TCC. The chapter contains the definition of sharing, standards for determining whether any infrastructure must be shared, sharing request procedure, methods of sharing and the mandatory shared facility as designated by IDA. According to IDA, [66] a Facilities-Based Licensee with control right over network infrastructure used to support the provision of telecommunication services permits other licensees to jointly utilise the network infrastructure on non- discriminatory terms and at cost-based prices. Sharing of infrastructure in Singapore is determined by the government based on whether the facility is deemed to be Critical Support Infrastructure (CSI) or based on public interest grounds.

The benchmarks for CSI are:

(i). the infrastructure is required to provide telecommunication services;

(ii). efficient new entrant would neither be able to replicate the infrastructure within the foreseeable future, nor obtain it from a third-party through a commercial transaction, at a cost that would allow market entry;

(iii). the Licensee that controls the infrastructure has sufficient current capacity to share with other Licensees and has no legitimate justification for refusing to share the infrastructure with other Licensees; and

(iv). Failure to share the infrastructure would unreasonably restrict competition in any telecommunication market in Singapore.

The specified kinds of facilities that must be shared according the TCC are the radio distribution systems for mobile coverage in train or road tunnels, in-building cabling and lead-in ducts and associated manholes.

The shared facilities or infrastructure are governed by the following four principles:

(i). The party responsible for infrastructure sharing shall be a telecom operator engaged in basic telecom services provisioning,

(ii). The shared facilities shall be telecom network infrastructure that support telecom services,

(iii). InfraS expenses must be a cost-based price,

(iv). InfraS must be non- discriminatory, meaning the telecom network infrastructure provider should treat all the telecom operators requesting sharing equally.

Infrastructure sharing in Singapore is implemented in accordance with the following procedure:

1. Voluntary negotiation, where the operator applies for InfraS and begins negotiation with the infrastructure owner.

2. Dispute resolution, when the infrastructure owner and the applicant fail to reach an agreement on InfraS with 60 days of application, IDA may be requested to resolve the dispute according to the dispute resolution procedure.
3. Sharing compensation mechanism, if the owner considers it impossible to conclude an infrastructure sharing agreement which can compensate for costs, IDA have the right to fix a cost-based, non- discriminative rate.

The major players in infrastructure sharing in Singapore are the new entrants such as OpenNet and Nucleus Connect, SingTel and StarHub Cable Vision among traditional operators and SingTel (traditional) and StarHub (new entrant) between traditional operators and new entrants.

The shared network infrastructure occurred between 2G network and 3G network an indication that a huge investment was required for establishment of new mobile networks; this made the telecom operators to share the existing 2G network infrastructure during the deployment of 3G so as to relieve the capital pressure. The shared infrastructures include both passive and active sharing. As for maintenance of the shared network infrastructure is done jointly by the sharing operators.

2.8.2.1 Benefits of InfraS in Singapore

The following are some of the benefits yielded from InfraS [47]:

(i). The infrastructure sharing have a positive impact on the quick enhancement of the service capacity of telecom operators;

(ii). The infrastructure sharing have a positive impact on improvement of the network coverage ability and universal service level; where coverage of mobile services in underground train and road tunnels was achieved through sharing of leaky coaxial cable radio distribution systems;

(iii). The infrastructure sharing have a positive pact on environmental protection and reduction of resource waste;

(iv). Economic benefit yielded due to saving and reductions on CAPEX and OPEX of telecom operators.

2.8.2.2 Challenges of InfraS in Singapore

According to the findings done by [47], security of the shared infrastructure emerged as the major concern. Tower sharing resulted into a series of technical problems regarding the tower structure, load bearing and feeder arrangement. Furthermore the newly added electromagnetic transmission equipment, electromagnetic radiations had an impact on environment and interference among different systems. However technical problems are no longer main obstacles for InfraS. They are been addressed during the manufacturing of new equipment.

2.8.3 Infrastructure Sharing in United State of America

In the US, state governments, regional governments and other auxiliary institutions according to the Code of Federal Regulations [67] cannot as a general rule, impose restrictions on wireless operators with regards to the installation, construction or maintenance of infrastructure. The Federal Communications Commission (FCC) has indicated that it will not be imposing any restrictions on Infrastructure Sharing (InfraS), generally speaking, because market principles are operating sufficiently in the US mobile communication industry [68]. Joint use of infrastructure (leasing) is actively promoted by the policies of FCC. There is policy that requires the owners of infrastructure to give feedback within 90 days of InfraS request on the possibility of the infrastructure to be shared [69].

Independent tower operators are more common examples of tower sharing providers Mobile Network Operators (MNO) in the US. These operators lease towers to MNO. The major players in the provisioning of towers are the American Tower with 26600, Crown Castle International with 24000 and SBA communications with 8,324 towers. American Tower and Crown Castle International have a huge presence in the US market, with a comprehensive market price in surplus of $ 10 billion.

According to the survey done by CTIA Semi- Annual Wireless Industry [70], there were a total of 247081 towers and total industry sales estimated at $ 14 Billion in the US by the end of December 2009.

2.8.4 Infrastructure Sharing in the United Kingdom (UK)

InfraS in the UK is recommended by the regulatory authority though with some restrictions. In May 2001, the UK'S Oftel [71] (the agency in charge of telecommunications at that time) issued its first note for information [72] regarding 3rd Generation (3G) infrastructure sharing. The fundamental guidelines regarding InfraS and the types of InfraS were spelled out in the Note issue by the Oftel. The sharing of towers was recommended but any infringements of the Wireless Telegraphy Act which banned the transfer of licences or spectrum were forbidden. It went further to forbid any anti-competitive practices between MNO using InfraS. The approval of 3G InfraS was given the UK by the European Union (EU) in April 2003.

In the UK, there are examples of comprehensive tie-in that include other European nations. The successfully implemented forms of InfraS in the UK are as explained as follows;

(i). The tie- up between Vodafone UK and Orange UK which was made in February 2007 was more concerned with the sharing of the domestic towers and Radio Access Network (RAN) [73] within the UK. RAN was defined as towers, BTS and BSC/RNC. Core Networks sharing was not part of sharing by the agreement.

(ii). T-Mobile and Hutchinson 3G made a tie-up in the sharing of 3G networks within the internal UK market. This agreement was made in December 2007. Like the tie-up between Vodafone UK and Orange UK, this arrangement was more concerned with the sharing of towers and access networks only but excluded core network sharing. With that sharing the expected number of tower reduction was put at 5000 which would result into a saving of £ 200, 000,000 over a period of 10 years.

(iii). In March 2009, Vodafone group and Telefonica entered into an agreement of working together to share mobile infrastructure in several European countries. The InfraS was expected to cut the cost by several hundreds of millions of pounds over a period of 10 years. The major mode of sharing was only limited to passive infrastructure sharing (such as BTS Site) but varied according to countries.

From the research that was done by[74] in March 2009 on the targeted countries, in Germany the sharing was on pre-existed 2G/3G sites, in Spain the sharing included power supply equipment, cabinets and masts. While in Ireland all sites were shared mutually and new construction were to be jointly done. In the UK, it was joint construction of new sites and the consolidation of pre-existing 2G/3G site.

2.9 Infrastructure Sharing in Developing Countries

2.9.1 Infrastructure Sharing in India

India's swift growth and development in telecommunication and mobile devices [75] has made telecom industry to expand their infrastructure. The industry has tried to keep up with the quality of services supplied with the required infrastructure development. The telecom companies in India generally had their own arrangements to fulfil their infrastructure needs until they realized huge investment in this sector. This resulted into the emergence of new business model of infrastructure sharing in the Indian telecom industry known as the infrastructure sharing. Although there are various forms of infrastructure sharing globally like passive, active and backhaul, India telecommunication industry operators primarily use the passive infrastructure sharing as encouraged by the Telecommunication Regulatory Authority of India (TRAI). In April 2007, TRAI went further to recommend the sharing of active infrastructure or backhauls between BTS and BSC in some nodes but not permitting the sharing of frequency [76].

The various models of passive infrastructure sharing deployed in the telecommunication industry of India are as follows:

(i). Telcos owned Tower Companies: This type consists of companies created by hiving off the tower portfolios of telcos into subsidiaries. Among operator-owned companies, while most are owned by a single Telco.

(ii). Independent Telecom Tower Companies jointly owned: This is jointly owned by Bharti Airtel Limited, Vodafone group and the Idea Cellular group to form a joint venture called Indus Towers Limited whose aim is to build, own and lease the telecommunications tower to telcos.

(iii). Inter-operator tower sharing: This one is based on bilateral arrangement between operators to execute Inter-operator sharing of passive infrastructure. Typically, bilateral agreements are on an 'in-kind' basis, with no payments made between the parties. The two parties agree to install BTSs on each other's towers.

The major tower company players in passive infrastructure sharing in India are:

(i). Viom Networks, a joint venture between Tata Teleservices and Srei groups where Tata Teleservices owns 54 %. It has over 40,000 mobile tower sites with a tower tenancy ratio of 2.4.

(ii). GTL Infrastructure, with 32,650 towers and 41,700 tenants as of March 31, 2011.

(iii). Indus Towers, a joint venture among Bharti Airtel, Vodafone Essar and Idea Cellular, is the market leader with about 110,000 towers.

(iv). American Tower Corp. (ATC): ATC India operates over 10,000 tower sites throughout the country, with an average of 1.8 tenants per tower.

2.9.1.1 Benefits of Infrastructure sharing in India

The introduction of passive infrastructure sharing in the telecommunications industry in India resulted into the following remunerations:

- Reduction in Capex which was heavily utilized in setting up and management of the Telecom infrastructure. Through sharing the Capex was optimised into new and innovative services to subscribers.
- By outsourcing the day to day management of own Telecom infrastructure to Infratel resulted into reduction in Opex cost.
- By leveraging existing Infrastructure that was already deployed in active Telecom circles enhanced access to markets where operators had no existence.
- The use of efficient processes and superior monitoring resulted into minimization of downtime for the operators.
- Increased connectivity to deployed tower infrastructure in rural and remote locations which are characterized by erratic power supply, poor access, difficult terrain and lack of adequate backup saved the hassle of operating in such conditions, and enables increase in penetration.
- Reduction in the number of towers through sharing resulted into a decrease in emissions and diesel consumption, hence cost and energy efficiencies.

2.9.1.2 Challenges Infrastructure sharing in India

While tower sharing and outsourcing offer significant advantages to operators, the initiative is not without its disadvantages. In order to have the full benefits of tower sharing Operators are met with strategic and operational challenges. Some of the challenges faced through InfraS in India were as follows [77]:

- Erosion of Competitive Differentiation- The biggest challenge for operators in striking sharing and outsourcing deals is to find the right balance between competition and cooperation.
- Risk of Information Sharing- For new entrants, entering into agreements with incumbent-owned tower companies is fraught with the risk of possible leakage of critical business information to the parent company.
- Regulatory Challenges in the prevention of cartel and anti- competitive behaviour where the incumbent operators may enter into agreements which in effect could create duopoly environments that keeps out new entrants.
- Loss of Strategic & Operational Flexibility-Alignment on a mechanism for identification of potential cell sites, cost-sharing mechanisms and the creation of a governance model will prove challenging in a joint venture between multiple operators.
- Long lock-in tenures- Such long lock in periods may heighten tenant risks in terms of restricting the ability to adapt to changing market and regulatory conditions [78].

2.9.2 Infrastructure Sharing in South Africa

The Independent Communication Authority of South Africa (ICASA), as the regulatory board of Information and Communication Technology (ICT) of South Africa, made a publication in the Government Gazette number 39208 on the Regulatory Framework [79] on Infrastructure Sharing on the 15th of September 2015.The purpose of the publication was to provide regulatory framework on electronic communications. The publication was made after consultation with all the stake holders who are major players in communication. These included the Competition Commission, MWEB; The Internet Service Providers' Association (ISPA);Transnet; ATC South Africa (ATCSA); Broadband Infraco;Cell C;The FTTH Council; Global Communications; Internet Solutions; Mobile Telephone Networks (MTN); The National Association of Broadcasters (NAB);Neotel; The South African Communications Forum (SACF);Telkom; Vodacom; and The Wireless Providers' Association of South Africa (WAPA).

The deployment of electronic communications infrastructure is capital intensive and has associated risks with regard to return on investment. The high costs of deploying electronic communications networks have been the main deterrent for operators deploying networks into rural and sparsely populated areas, thus perpetuating the problem of underservice in these areas.

In order to ensure that electronic communications infrastructure is deployed across the country and that the cost to communicate is significantly reduced, the costs associated with infrastructure deployment would need to be reduced. One way of significantly reducing the costs is through the sharing of existing infrastructure and future infrastructure deployments by the private and public sector stakeholders. The sharing of infrastructure is expected to drive down the capital expenditure (CAPEX) and operational expenditure (OPEX) of the sharing parties".

The sharing of infrastructure in South Africa is mainly realised through commercial agreements, in particular, electronic communications facilities leasing agreements. The main forms of infrastructure sharing in South Africa are:

(i). Colocation on real estate and masts or towers, and in equipment rooms;
(ii). Roaming or MVNO;
(iii). Open access in areas where it is difficult or expensive to deploy infrastructure;
(iv). Leasing space from tower companies;
(v). Sharing civil and electrical works;
(vi). Sharing multiplexers, contribution links and combiner systems
(vii). Lease of optic fibre cables and the 'swopping' of fibre pairs;
(viii). Lease of transmission circuits; and
(ix). Sharing of electrical power.

2.9.2.1 **Benefits of Infrastructure Sharing in South Africa**

The outcome of the stake holders and ICASA alluded to the following as the benefits of sharing the infrastructure [80]:

(i). Reduction in the duplication of infrastructure;
(ii). Increased saving in terms of Capex and Opex cost;
(iii). Passive infrastructure sharing encourages the deployment of services without the inhibiting cost of infrastructure; expedites the deployment of services of networks to rural and sparsely populated areas and enhances expansion coverage;

(iv). Reduces the involvement of operators in non-core businesses such as building and maintenance of sites thereby helping them to concentrate on their core businesses;

(v). Decreases fixed and operating costs and allows licensees to earn some revenue from their existing infrastructure, thereby lessening the burden of site upkeep; and

(vi). Passive infrastructure sharing may be beneficial for the efficient use of resources, environmental and health reasons;

2.9.2.2 Challenges of Infrastructure Sharing in South Africa

The following emerged as the main challenges [80] to passive and active infrastructure sharing:

(i). Sharing active infrastructure constitute the technical difficulties of segregating shared infrastructure; the introduction of technical complexities in the management of shared infrastructure; the challenges of sharing frequency spectrum licensed to one entity; and the creation of opportunity for bigger players to bully smaller ones with price control over bandwidth and spectrum;

(ii). sharing of active infrastructure can lead to complex engineering works; increased possibility of radio frequency interference and cross talk; conflicts among operators over areas of responsibility, jurisdiction, maintenance, equipment reliability; and the impact on quality of service;

(iii). The risk of market share loss by established players;

(iv). Sharing of commercially sensitive information which can result in coordinated outcomes would have a negative effect of chilling competition;

(v). passive infrastructure sharing will be cumbersome on incumbent networks as those networks were designed without taking consideration of additional load requirements and the needs of future operators;

(vi). Logical and physical security together with the potential for spectrum signal interference.

2.9.3 Infrastructure Sharing in Kenya

The deficiency of infrastructure in Africa particularly in sub- Sahara region is broadly acknowledged as one of the continent’s greatest impediments to viable development [34]. Even with this challenge, ICT operators in Kenya still prefer to invest in their own infrastructure in spite of the availability of underutilized ICT resources from other operators and other players such as utility companies.

2.9.3.1 Benefits of Infrastructure sharing in Kenya

The major drivers of infrastructure sharing among mobile operators in Kenya were capital expenditure (capex) and operational expenditure (opex) savings, the rise in demand for mobile broadband services offered on 3G/4G -LTE technologies and their licensing constraints, the need for new market players to rapidly increase coverage and to lower the cost of deploying ICT so as to achieve widespread affordable access to broadband services [81]. Infrastructure sharing generated extra revenue estimated at 10% of the total annual revenue, reduced infrastructure costs by 40-60%, offered better use of scarce spectrum resource, enabled easy market entry by new players hence increasing competition in the industry, improved innovation and better customer service hence addressing a decline in ARPU, achieved universal service goals by expanding network to underserved or rural areas to meet policy and regulator targets, minimized environmental degradation due to reduced network build up, resulted in higher uptime due to diversity routes, led to cost and energy efficiencies due to reduced emissions and diesel consumption hence improved green concept [23] [37] [82] [83]. Infrastructure sharing can also be used to bridge the digital divide, meet regulatory requirements and help governments to achieve ICT services universal access goals [24]. Infrastructure deployment came with multiple risks and by sharing infrastructure the risks were reduced among cooperating operators. Sharing encourages scarce national resources optimization such as rights of way and spectrum hence availing the freed resources for strategic use [25]. The rationale for infrastructure sharing differed between markets. For mature markets, sharing provided an additional source of revenue, minimized operating costs, added capacity in congested areas with limited space and towers. For developing markets, infrastructure sharing expanded network coverage and fast tracked on marketing strategies. ICT operators sharing infrastructure from the start of network rollout especially 3G/4G had an opportunity to reduce capital and operational expenditure [84]. Capital and operational expenditure capex and opex analysis show a difference between developed and emerging markets. In some emerging markets, fuel was a key cost component since sites were either not connected to a power grid or the power grid was unreliable hence requiring diesel generators. The valuation of tower build up capex varied significantly across markets with costs ranging from 150,000 USD to 173,000 USD per tower. This could explain why the developed countries shared sites to reduce opex [37]. Financial management consultants, KPGM and BOOZ & CO estimated revenue generated at 15% of total revenue, savings of 30 to 40%. The total amount of capex savings achieved from tower sharing in the Middle East and Africa regions was estimated to be USD 8 billion [39] [85].

2.9.3.2 Challenges of Infrastructure sharing in Kenya

The levels of the challenges experienced in Kenya varied according to the development of the communication segment. Among infrastructure challenges identified by mobile service operators in Kenya were asset valuation and management, shareholder and cost pressure, cultural alignment and stakeholder management [39].

The five main challenges that emerged out of infrastructure sharing in Kenya were as follows:

(i). Lack of regulatory framework to govern, guide and ensure fair competition on infrastructure sharing was a hindrance. According to the Kenya Information and Communications law of 2009 CAP. 411A section 85A, which recognize infrastructure sharing but is not specific on the implementation guidelines.

(ii). Complexity involved in the process of sharing which is accompanied by hurdles of obtaining clearance from multitude of governmental bodies [85].

(iii). Exorbitant charges been demanded by the owners of infrastructure.

(iv). The operators' unwillingness to share with their competitors in order to protect their investment and maintain monopoly in certain area, lack of network capacity, variation in technology used by different vendors and compromised quality of service. [86].

(v). Network sharing had some risks such as projects implementation, third-party interests, and confidentiality risks which required to be managed to achieve success [23] [28].

2.9.3.3 Types of Sharing in Kenya

Passive sharing is the most utilized mode of sharing. Active sharing required close commercial cooperation between operators which could impede competition. Mobile virtual network operator concept (MVNO) was still at infancy stage in Africa due to regulatory issues, low ARPU and high interconnection charges by incumbent operators [28] [86].

2.9.4 Infrastructure sharing in Viet Nam

The regulation of telecommunication infrastructures in Vietnam is controlled by the Ministry of Information and Communications**.** According to the survey done by [87] the main drive behind infrastructure sharing in Viet Nam has been cost saving in terms of network construction and maintenance. The other motivations having been to enhance broadband access level and reduce the digital divide, environmental protection and avoiding resources wastage. InfraS plays an important role in relieving infrastructure bottleneck to new entrants' access.

The regulatory policies on InfraS by the Viet Nam regulatory institute are formulated on cost-based prices and non-discriminatory principles. In Viet Nam, passive infrastructure sharing is mandatory while active sharing is not. InfraS has been promoted and implemented in both rural and urban areas. Shared network management is mainly on operation mode, where maintenance and operation is done independently by respective players on the shared infrastructure. The major participants in the sharing are Viet Nam's FBO and SBO (new entrant) where sharing is done among traditional operators and between traditional operators and new entrants.

2.9.4.1 Benefits of InfraS in Viet Nam

There were various economic and social benefits that resulted from InfraS. Some of the benefits were as follows:

(i). Positive impact on the quick enhancement of the service capacity of telecom operators; namely new services, quality of service improvement and broadband service affordability,

(ii). Positive impact on universal service, environmental protection, reduction of network construction costs and enabling quick entry into the market and preparation time to new entrants,

(iii). Brings telecoms market competition,

(iv). Improvement of network coverage ability and universal service for instance in Viet Nam it resulted into quick rolling out and wide spread of 3G coverage,

(v). Positive impact on environmental protection and reduction in wastage of resources,

(vi). Saving and reduction in terms of CAPEX and OPEX for the operators,

(vii). Service level improvement by the operators.

2.9.4.2 Challenges of Infrastructure sharing

The following emerged as challenges in InfraS [47]:

(i). Handling of the relations between the infrastructure sharing and market competitions was a challenge when formulating policies on InfraS, (ii). Security concerns in terms structure safety, lightening protections, electromagnetic compatibility, electromagnetic radiation and interference on shared towers,

(iii). Capacity and maintenance safety on shared transmissions lines,

(iv). Capacity safety, load-bearing safety, equipment room environment safety, power load safety, lightening protection on shared base stations.

2.9.5 Infrastructure Sharing in Zambia

Information and Communications Technology (ICTs) and telecommunication service provision in developing countries is experiencing rapid growth and motivating various deployments. It has been considered as a substitute to hastening social and economic growth and shows the potential to provide the goal of "communication access for all" in both rural and urban areas [1]. Mobile services operators in Zambia are rapidly covering the densely populated urban area with communication and data services leaving out the sparsely populated areas in the rural which are deemed unprofitable.

The business model of mobile communication was traditionally based on full ownership of network infrastructure [17] [18]. With the tremendous record of growth and demand for wireless communication services globally [19] [20], there is need to move from the traditional way of sole network infrastructure ownership to network infrastructure sharing through the provision of Mobile Network as a Service (NaaS) due to the huge investment that goes with infrastructure development required to sustain or meet the demand which is costly to done by individual MNOs'. The cost of deployment, management and maintaining network infrastructure is driving the need for innovative model of infrastructure deployment and management through network sharing [21]

In line with universal commitment on globalizing broadband for all, the Zambian government through its Zambia National Broadband Strategy (ZNBS) needs to create an enabling environment for investment in broadband infrastructure [22] especially in under serviced rural areas.

Through the establishment of a national information and communication technology infrastructure agency [22], the ZNBS should consider Mobile Network as a Service (NaaS) for mobile service and internet service providers in order to realize communication for all in Zambia.

Infrastructure sharing can play an increasingly important role in speeding up the rolling out of mobile services to the sparsely serviced rural areas and a lot of saving to the MNO in terms of operation expenditure and capital expenditure.

There are three major mobile service players in Zambia, namely Airtel, MTN and ZAMTEL [2]. Each operator has its own mobile infrastructure network. They generally use the same cellular network infrastructure and network architecture and basic operations. The map below in Figure 2.11 shows the mobile network coverage comparison among the three MNO in Zambia i.e. Zamtel, MTN and Airtel. As of December 2015, the distribution of mobile sites among Zambian MNOs, Zamtel had 880; MTN Zambia had 1089 while Airtel stood at 1350.

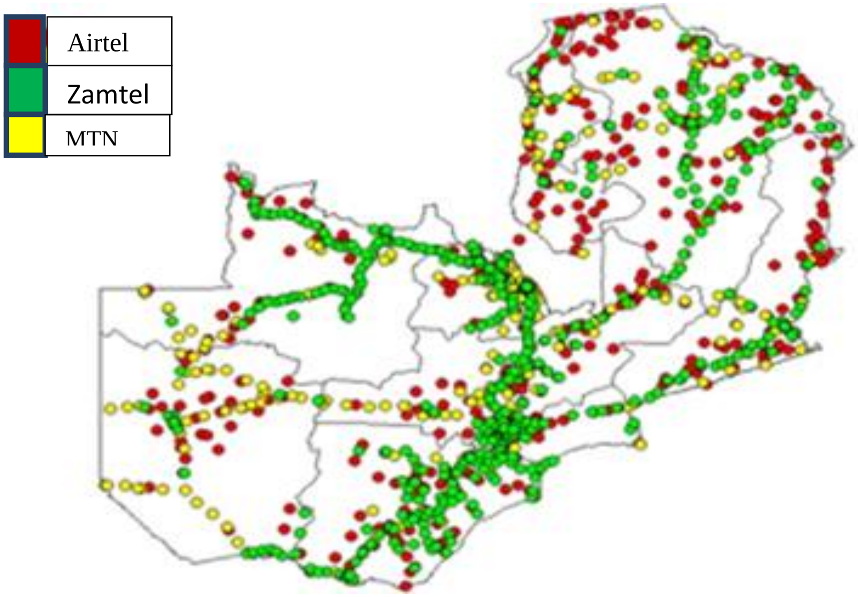


Figure 2.11: Mobile network coverage: Zamtel (green), MTN (yellow) and Airtel (red) [2]

2.9.5.1 Mobile Market Shares in Zambia

The market structure of Mobile telecommunication industry in Zambia is categorised as an oligopoly. According to Webster J.T [88] an oligopoly "is an industry comprising very few firms producing homogenous or differentiated products; it is difficult to enter or leave the industry." It is put in this category because it is dominated by very few firms/ producers who compete for customer base. These firms operating in the market seem to deter any entry by other firms from entering industry on the pretext that the market is very small hence can't accommodate numerous firms. This market is dominated by three players, namely Airtel Zambia, MTN Zambia and Zamtel. They compete for market, hence they show varying position.

According ZICTA’s Mobile market shares [89] in 2012 Airtel Zambia was leading at 46.2 percent followed by MTN Zambia at 38.7 percent while the Zamtel stood at 15.1 percent. By the third quarter of 2015 MTN Zambia took the lead with 45.7percent, Airtel Zambia at 39.8 percent while Zamtel the state owned operator dropped to 14.5 percent. With this market share, it can clearly be seen that it is Airtel and MTN who are controlling the market while Zamtel follows. Zambia has a highly competitive market in this industry as each MNO is trying to win as many subscribers as possible.

As the market is comprised of only three players, they are usually very much aware of each other’s actions. Their existence is interdependence as for one firm to effect the price changes is always aware of the reaction of the other firm. Webster [88] shows that “oligopolistic industries are characterized by interdependence of managerial decisions between and among the firms in the industry.” Firms are keenly aware that pricing and output decisions of any firm will provoke a reaction by competing firms. So the pricing system of one firm like MTN is dependent on how Airtel or Zamtel will react to that system. Price competition in an oligopostic market goes on in terms of internet service, dongles and network locked phone just to maintain the customers. War on non- price competition is currently going on in terms quality of service, after sales service, customer relations and quantity of product. Furthermore to win and maintain market shares each player has instituted several strategies to overcome the other like point accumulation plans, mobile banking services, threshold plan, network coverage increase and corporation social responsibility.

2.9.5.2 Government’s Regulation on Mobile Service in Zambia

The momentum for universal service provision in Zambia was done in accordance with the ITU and World Trade Organisation (WTO) principles and world leaders agreement on the need to work towards bridging the digital divide and build “ a people –centred inclusive and development-oriented information society, where everyone can create, access, utilise and share information and knowledge enabling individuals, communities and people to achieve their full potential in social- economic development and quality of life premised on purposes and principles of the charter of the United Nations and respecting fully and upholding the universal Declaration of Human Right” [90]. Working within such a framework, the fundamental objective of government of Zambia through the Ministry of Communications and Transport (MCT) and ZICTA the regulatory authority in Zambia [91] [92] has the mandate to provide universal service and access by provisioning of communication services throughout the country including those in rural and underserviced areas. It is clearly articulated in the Information and Communication Technologies act of 2009, part 8 and section (70) (2) states [92] “The authority shall determine a system to promote the wide spread availability and usage of Electronic Communication services in un-served or under-served area and communities” for that reason that [92] ZICTA under universal access project has embarked upon construction of mobile tower in various rural areas of Zambia.

The ICT Act of 2009 provides for the economic and technical regulation of information and communication technology. It specifically provides for the facilitation of access to ICTs, the protection of rights and interest of service providers and consumers and the management of radio spectrum. It is through the same act that ZICTA was established as the regulator of ICTs in Zambia.

The mobile operators were licensed under the revoked Communications Act of 1996 which was later substituted by the Information and Technologies Act of 2009. The Act of 1996 provided for a competitive process as a means of licensing a mobile operator and the licenses issued were that of service with appropriate frequency spectrum assignment.

The new licensing framework under the ICT Act of 2009 provided for licensing of mobile operators under the Guidelines of June 2010. According to the ICT act of 2009, for the MNO to start operating a license must be obtained from ZICTA which can be either a network or service license. The license is issued under competitive environment.

The mobile license for either Network or Service has duration of 15 years and subjected to the following scope;

(i). Construction and installation of the mobile cellular network.
(ii). The Licensee shall interconnect the mobile cellular network with Public Switched Telephone Network (PSTN) for origination or termination of calls from or to a cellular subscriber.
(iii). The Licensee shall interconnect with the PSTN so as to make available to the consumers the long distance and international services of the PSTN operators.
(iv). Provision of cellular services by the Licensee to subscribers over the mobile cellular network.

(v). In addition, the Licensee shall provide such other or further services, which shall include but not be limited to mobile cellular voice, mobile cellular data, and mobile cellular internet, voice messaging and facsimile.

(vi). The Licensee shall be permitted to sell Mobile Subscriber Radio Units (MSRU) to general public, provided that all MSRU's sold must be the type approved by the authority

(vii). In addition, the Licensee shall provide such other or further services, which shall include but not be limited to mobile cellular voice, mobile cellular data, and mobile cellular internet, voice messaging and facsimile.

(viii). The Licensee shall be permitted to sell Mobile Subscriber Radio Units (MSRU) to the general public, provided that all MSRU's sold must be type approved by the Authority.

2.9.5.3 Challenges of Mobile Operators in Zambia

Mobile subscribers as of September 2015 according to ZICTA stood at 10,830,000 out of the total population of 15,545,000 with a penetration rate of 70% [4]. Mobile internet users stood at 4,961,000 with a penetration of 32 percent [2] When compared to the mobile subscriber base of 10,830,000 mainly voice, there is still a lot required to enhance the usage of mobile internet.

With the sunk investment that goes with infrastructure deployment, there is need to promote InfraS/NaaS provision by the regulatory authority ZICTA and the government in order to achieve 'communication for all' according to the WTO regulatory paper of 1997 [7]. Currently the regulatory framework of telecommunications in Zambia does not allow the sharing of radio spectrum [3] which becomes a deterrent to the advancement of promoting InfraS through the provision of MVNO. The Licensee (MNO/NaaS) is prohibited to share/lease its radio spectrum. The norm under sharing has just been done at the MNOs level where they would agree on what to share without the involvement of the regulatory authority.

The issue of resource sharing has been debated for some time but has not yet been publicized into law. Issue under debate include resource sharing, spectrum management and service standardization. For the regulator the issue of universal access is an important challenge in terms of how broadband services can be made available to underserved communities [93].

Power supply challenges in rural areas which are not on grid. It is very expensive for individual MNO to run a site on diesel generator. But through InfraS cost are minimized as alluded by Tong in their study of network sharing and energy efficiency benefit.

With high demand and growth in the use of broadband by mobile internet users there is need for high and fast medium of accessing broadband through fibre cable links to the submarine cable which requires sunk deployment cost and technology acquisition especially in the development of backbone infrastructure. There are no incentives given for the private sector partaking into the management, development and operation of ICT and other project [94].

2.9.5.4 Mobile Network

A Cellular network is divided into two major parts of Radio Access Network (RAN) and Core Network (CN) as illustrated in Figure 2.12. In this thesis we will look at the mostly used systems in Zambia ranging from 2G-4G. 2G- Global Mobile System(GSM), 3G-Universal Mobile Telecommunications System (UMTS) and 4G- Long- Term Evolution (LTE). GSM is the most widely deployed 2 G cellular network technology that offers mostly voice and data service on edge. UMTS is the 3G cellular network technology that offers both voice and data services while LTE is the only mainstream 4G standard [95].

The overall architecture in all the three generations cellular networks is similar. 3G UMTS/4G LTE is used as the context to introduce network equipment and their functions; the idea of the work is applicable to other cellular without loss of generality [95].

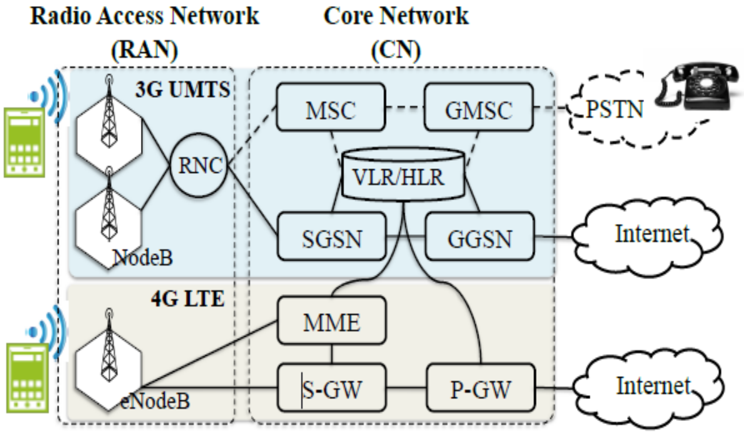


Figure 2.12: 3G UMTS/4G LTE cellular network architecture [95]

Figure 2.13 shows an illustration of infrastructure sharing by a number of service providers through Network as a Service provision.

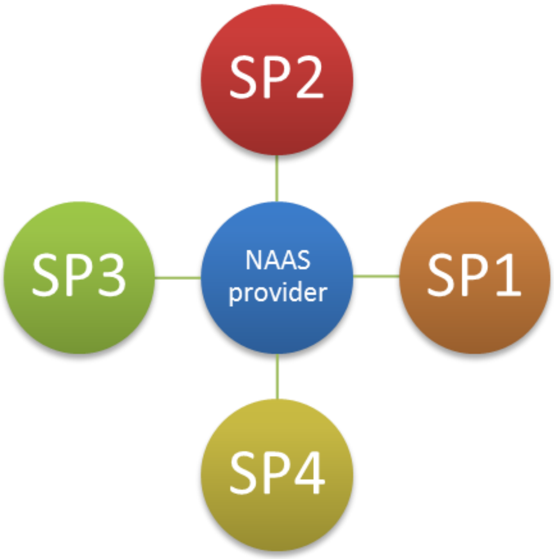


Figure 2.13: Network as a Service provider illustration

2.10 Introduction of Game Theory

Game theory is a fascinating and recognized way of studying conflicts and cooperation [9] [10]. It is concerned with discovering the best actions for individual decision makers in these circumstances and make out stable results. It is a branch of applied mathematics which deals with numerous persons' decision prototypes of conflict and cooperation amongst cogent decision-makers [11] [12]. Game theoretic models are used every time the actions of numerous agents are inter-reliant [13] [14]. These agents could be individuals, groups, organizations or any amalgamation of the agents [9] [14]. Game theory endeavours to arithmetically capture rational behaviour in circumstances, or playoffs, in which an individual's success in making choices relies on the choices made by others. The plain norm is that the decision makers follow some well-defined goals or actions while considering the facts or prospects of the other decision makers' conduct [12]. The notions of game theory offer a language to articulate, structure, evaluate, and comprehend strategic situations [9].

In economics, game theory finds its applications in the achievement of equilibrium of prices in competitive markets which leads to optimal levels of resource utility. Players furnished with facts about the intentions of other players can easily predict the moves thus facilitating potential maximization of proceeds [12]. It has been used extensively in rivalry modelling between firms and other segments of the economic market. Other examples of games in actions are competition among firms, the conflict between management and labour, the fight to pass bills through congress, the power of the judiciary, war and peace negotiations between countries [9].

Games are branded by several players or decision makers, who interrelate, possibly threaten each other and form alliances, take actions under undefined situations, and lastly receive some benefit or incentive or possibly some penalty or financial loss [9] [15] [16].

A game is recognized while at least a player or user endeavours to capitalize on his utility through expecting the reactions to his movements by other users or players knowledgeably or discreetly. Games are characterized by several users who should be rational [15] [16]. The user of the game has the right to the following:

(i). Payoffs assessment;
(ii). Calculate strategies that will yield the best preferred payoff;
(iii). Given the strategies or movements of the opponent, the user can select actions that will result into the most desired payoff.

2.11 Definitions of Games

The object of study in game theory is the game, which is a formal model of an interactive circumstances [9]. The users or players participating in a game are arranged according to their inclinations, their information, the availed strategic actions and how these impact the end result. At high level, a game specifies only what each individual or a group will benefits by assistance of its members. The two main branches of game theory are cooperative and non-cooperative [16]. All the branches of game theory [96] depend on whether communications exist among players.

2.11.1 Cooperative Game Theory

Cooperative game theory (CGT) provides analytical tools for studying the behaviour of rational when they cooperate. CGT’s main focus describes the formation of cooperating groups of players that can reinforce the positions of the players in a game. In a cooperative game, it is very beneficial for the players or users to work as team in order to receive the greatest total payoff or utility [12][96]. Lim described CGT concepts as combinations of payoff that brings gratifications to both individual and group prudence. Rasmussen [15] explicates that CGT is clear and often appeals to pareto- optimality, impartiality and parity. It is mostly used or applied in situations which have a strong incentive or payoff resulting from cooperation [12]. Cooperative game theory is coalitional [97].

2.11.2 Non-cooperative Game Theory

Non-cooperative game theory (NGT) is apprehensive with the exploration of strategic choices made by players in order to maximize their own interest subject to stated constraints in a game [12] [98]. The pattern of NGT is that the details of the collation and scheduling of players' choices are fundamental in determining the effect of a game [99]. In contrast to Nash's cooperative model, a non-cooperative model of brokering would position a particular process in which it is pre-specified who gets to make a bargain at a particular time [12] [99]. NGT models the movements of agents, capitalize on their utility in a distinct way, banking on a comprehensive explanation of the moves and information presented to each agent. NGT focuses on competitive scenarios. The word "non-cooperative" entails that this division of game theory plainly replicas the procedure of players making choices out of their own interest and independently [12]. NGT is procedural.

2.12 Definitions in Games Theory

2.12.1 Best Response

The notion of best response [100] in game theory is usually applied in circumstances where a player has to take the best strategy or strategies which produces the most favourable result for a player while taking into consideration the strategies of other players [9] [12]. Each individual player, working under an assumption and knowing the payoff structure of the game and what pertains to his or her own payoff, can choose a set of strategies or changes that will lead to maximization of his or her present utility or payoff. The notion of a best response or best strategy is essential to the Nash Equilibrium [101], the point where each player in a game picks the best strategy in comparison to the other players' responses.

2.12.2 Nash Equilibrium

A Nash Equilibrium (NE) is defined as a profile of strategies such that each player's strategy is an optimal response to the other players' strategies [102]. The concept of a NE is derived from imposing an additional constraint that beliefs must be consistently aligned across players [101] [103]. Alternatively, a NE, also called strategic equilibrium, is a list of strategies, one for each player, which has the property that no player can individually change his strategy and get a better payoff [99] [104].

In forecasting the effect of the game, the player focuses on the best possible outcome of the game from the diverse strategies that are available in a game. To elude confusion, a perfect distinction between strategy combination and outcomes must be well-known. Often times predicting the conclusion of the game is typically the hardest and usually involves the selection of best strategy or payoff among a collection of possible strategies so as to maximize payoff or utility. The most probable prediction of what will happen is called the Nash Equilibrium [12].

2.12.3 Strategy

In a game in strategic form, a strategy is one of the given potential movements of a player. In an extensive game, a strategy is a complete plan of choices, one for each decision point of the player [99]. In optimizing the best payoff or utility in game theory, players or users usually strive to take the best possible moves or sequence of actions known as strategies. A player's strategy will determine the move to be taken by the player at any stage of the game and for every possible history of play to that stage. Taking up a strategy for a player may mean taking a single global decision before playing, which in some cases may include all the fundamental decision she or he could have considered during the course of the game [12].

2.12.4 Free riding

Free riding is a situation where users consume more than their fair ration of resource, or shoulder less than a fair portion of the costs of production. Economically, free riding is usually considered to be a problem only when it results into over-usage or misuse of public good by users or consumers. Pasour [105] describes free riding as a problem that arises in situation where an individual may be able to obtain the benefits of a good without contributing to the cost. Furthermore, he defines free riding as a league in which “a group of competitive producers may be able to gain super profits through collusion by restricting output and increasing price. The ability to collude, however, is undercut by the incentive each member has to free ride”.

2.12.5 Payoffs or Utilities

These are numbers that reflects the desirability of an outcome to a player, for any kind of reason. When the outcome is random, payoffs or utilities are typically weighted with their probabilities. The expected payoff includes the player’s attitude towards risk [9].

Expected payoffs:

Let $x = (x_1, \ldots, x_n) \in X$ (2.1)

be a profile of mixed strategies,

For $s = (s_1, \ldots, s_n) \in S$ a combination of pure strategies.

Let $x(s) := \prod_{j=1}^{n} x_j(s_j)$ (2.2)

be the probability of combinations under mixed profile *x*. (Assuming players make their random choices independently.)

Definition2.1: The expected payoff of player *i* under a mixed strategy profile

$$U_i(x) := \sum_{s \in S} x(s) * u_i(s) \tag{2.3}$$

i.e., it is the “weighted average” of what player *i* win under each pure combinations, weighted by the probability of that combination [106].

Key Assumption: The goal of every player is to optimize its own expected payoff.

2.12.6 Rationality

Rationality is the most common term used in game theory [12]. A player is said to be rational if he seeks to play in a way which exploits his own payoff [107]. It is often assumed that the rationality of all players is common knowledge [9]. In everyday language, rational is a synonym of “sensible” but in game theory a player is rational when his or her inclinations are complete and transitive [106]. Rationality is based on the principles that the observer or user, who is aware of his expectations and makes decisions about the expectations of any unknowns, has clear inclinations and selects his actions after some process of optimization [108]. It stands in contrast to hastiness, in which players or users reply to selections or circumstances which may, in some cases, depend on their existing variable emotional state at the time when such a resolution is made.

The two categories of rationality are perfect rationality and bounded rationality. Perfect rationality adopts that users are beings who can store and process huge quantities of information and execute complex computational and make steady decisions based on those computations. Bounded rationality on the other hand recognizes the fact that users or players are problem solvers with limited information processing capabilities [12].

2.13 Dominance

In some games, a player's strategy is superior to all other strategies regardless of what the other players do. This strategy then strictly dominates the other strategies [100]. Since all players are presumed to be normal, they make selections which end in the outcome they desire most, when given actions of their opponents. In the extreme instance, a player may have two strategies *X* and *Y* so that, given any combination of strategies of the other players, the outcome resulting from *X* is better than one resulting from *Y*. Then strategy *X* is said to dominate strategy *Y*. A rational player will never choose to play a dominated strategy. In some games, examination of which strategies are dominated results in the conclusion that rational players could only ever choose one of their strategies [99]. This scenario can be illustrated as shown in Figure 2.14. Consider the Prisoner's Dilemma game. The choice of *D* strictly dominates the choice of *C* because it produces a better payoff irrespective of the choice made by the other player [107]. If one player is going to play *D*, then the other is better off by playing *D* as well. Also, if one player is going to play *C*, then the other is better off by playing *D* again. For each prisoner, choosing *D* is always better than *C* regardless of what the other prisoner does. We say that *D* strictly dominates *C*.

		Player 2	
		C	D
	C	2,2	0,2
Player 1	D	3,0	1,1

Figure 2.14: Prisoner’s Dilemma [100]

2.14 Extensive games with perfect information

An extensive game is a detailed description of the sequential structure of the decision problems encountered by the players in a strategic situation. There is perfect information in such a game if each player, when making any decision, is perfectly informed of all the events that have previously occurred. For simplicity we initially restrict attention to games in which no two players make decisions at the same time and all relevant moves are made by the players (no randomness ever intervenes) [98].

Extensive games with perfect information, which is also called a game tree with perfect information, can be presented on a tree diagram as illustrated in figure 2.15. Osborne outlined an example of extensive games with perfect information as follows:

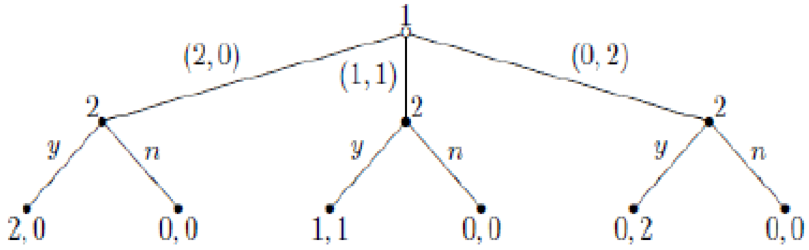


Figure 2.15: Extensive games with perfect information [98].

Figure 2.15 represents extensive games with perfect information on a tree diagram. The starting point of the game is represented by a small circle at the top of the diagram. The 1 above the small circle indicates that player 1 has to make the first move. The possible actions of player 1 are represented by three branching points from the circle at the starting point of the game. Beside the branching points are the labels for the names of the actions to be taken. Each branching points leads to a small dot beside which is the label 2, indicating that player 2 takes an action after any history of length one. The labels beside the branching points that originate from these small dots are the names of player 2's actions, ‘y’ for *accepting* and ‘n’ for *rejecting *. The numbers at the end of the branches are payoffs for player’s preferences, the first and second number in each pair represents the payoffs for player 1 and for player 2 respectively.

2.15 Extensive games with imperfect information

This is the type of game in which every player taking part may have only partial information of the previous action taken [98] [108]. In situations using more than one player, every player’s payoff is usually affected by the actions taken by the other players. Hence, the ultimate strategy of each player can be influenced by other players. Extensive games with imperfect information are one of the ways to deal with such strategies. Extensive games with imperfect information are defined as the games that are not wholly noticeable. Osborne argued that when the player’s information is imperfect in extensive games, a player does not need to know the actions taken by his opponents before him. This simply mean when it is the turn for a player to move, he does so without accessing all the data about the other player’s choices. Gilpin and Sandholm contended that such games, the choice of what to do at a point in time cannot usually be optimally decided without taking into considerations choices at every points in time [97]. This is because those other decisions affect the probabilities of being at different states at the current point in time. Extensive games with imperfect information were further illustrated on a tree diagram by Osborne and Rubinstein on Figure 2.16.

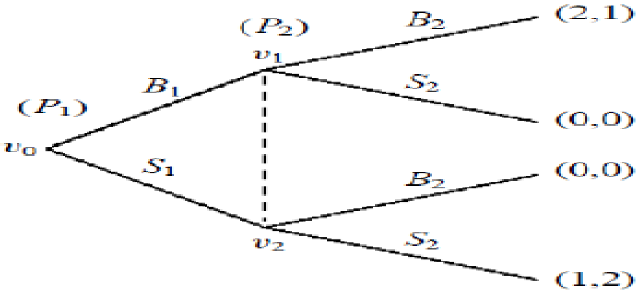


Figure 2.16: Extensive games with imperfect information [97]

In Figure 2.16, the game starts at v_0, and P_2 must make a choice at branches v_1 and v_2 without knowing the choice of player P_1. They are then connected with a dotted line and label the edges coming out with common labels, B_2 and S_2. Player P_2 must make the choice of the edges with the same labels at both ends of these branches. These pair of branches (v_1 and v_2) is called the information sets.

2.16 Zero-Sum Games and Computation

According to Sihlobo [13] zero-sum game is a mathematical representation of a situation in which a participant's gain or loss of utility is exactly balanced by the losses or gains of the utility of the other participant. If the total gains of the participants are added up, and the total losses are subtracted, they will sum to zero, thus it's called a zero-sum game. Turocy and von Stengel [9] outlined that the extreme case of players with fully opposed interests is demonstrated in the class of two player zero-sum games. The theory of von Neumann and Morgenstern is mostly applied in games such as two-person zero-sum games, that is games with only two players in which one player wins what the other player loses. Mathematical description of the zero-sum games is when a two-person zero-sum game, the payoff function of Player II is the negative of the payoff of Player I [9].

In game theory, a game with only a few strategies can be easily represented by a matrix showing the payoff for each player along with the strategy they use [13]. This can be represented in the form of zero-sum games where there are two players and every set of payoffs adds to zero. Zero sum games can also be viewed as a closed system, meaning everything that someone wins must be lost by someone else. Brook emphasized that zero-sum games are those in which the payoffs for each player sum to zero, and went on to outlined an example that shows the differences in representation of zero-sum and non-zero-sum games [109].

	Stag	Hare
Stag	3,3	0,2
Hare	2,0	2,2

	Stag	Hare
Stag	3	0
Hare	2	2

Figure 2.17: Prisoner's Dilemma [109]

2.17 Related Literature Review

Game theoretical approach has been used in the study of telecommunications by other authors before. Nel et al [12] in their study of the optimal spectrum assignment and pricing used game theory to arrive at the optimal spectrum assignment. The utility model used to arrive at the optimal level was subjected to parameters such as willingness to pay, the price, the bandwidth, the quality of service.

In their study, they modelled the spectrum assignment game as a non –cooperative game among a spectrum regulator, multiple service providers and users, and developed an economic framework which analysed the spectrum assignment and pricing problem from both revenue maximization and a social welfare maximization perspective.

Sumbwanyambe et al [110] did a study on a dynamic spectrum allocation with Price Policy in order to address the issue of spectrum allocation and usage in developed and developing countries.

In their study they presented game theoretical scheme to control spectrum usage when given a pricing policy from the central controller or policy engine. With the right pricing mechanism to control the demand of spectrum by a mobile SP a NE was achieved. They also proved that in a competitive environment where users tend to monopolize resources, a correct pricing policy, under information symmetry could control spectrum resource usage in way that promotes efficiency and encourage competition. By adjusting the levels of spectral efficiency through a correct policy mechanism the NE can be reached.

Marsan et al [111] ,in their study of network infrastructure sharing among European Mobile Operators, they investigated the potential energy saving inherent in the network sharing approach, where by all or significant parts of the network infrastructure existing in a country can be shared by different network operators. The simple analytical models that were used indicated a reduction in the amount of energy required to run mobile networks in most European countries by 35% to 60%.

In their study they quantified the energy savings which could be achieved by MNOs offering service in the largest European countries due to widespread adoption of the network sharing approach. Their results also indicated that about half of the energy cost presently incurred by operators could be avoided by cleverly exploiting the fact that most European countries were covered by several overlapping cellular network infrastructures.

Tong and Lin Bai [112] did an analysis on the benefit-cost of wireless telecommunications network infrastructure sharing in China. From their analysis done on InfraS model (i.e. Site sharing, RAN sharing, RAN sharing with gateway, MVNO and Geographical network sharing) they discovered that Network InfraS leads to significant reduction in cost of network infrastructure deployment and capacity expansions for telecommunications operators. Network sharing also led to an improvement in the usage efficiency of telecoms infrastructure and resulted into significant savings in the operational expenditure (OPEX) dissipated by telecoms operators. When properly managed InfraS does not affect quality of service adversely. Network sharing can also help MNOs in China achieve better competitive advantage through new product development and service innovations in order to create value for customers.

2.18 Cloud Computing

Cloud Computing is a broad term that describes a wide range of services. As with other important developments in technology, several vendors have seized the term “Cloud” and are using it for products that sit outside of the common definition [113]. In order to really comprehend how the Cloud can be of value to an organization, it is first imperative to comprehend what the Cloud really is and its different components. Since the Cloud is a broad collection of services, organizations can choose where, when, and how they use Cloud Computing.

Cloud computing is defined as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources such as networks, servers, storage, applications, and services that can be quickly provisioned and released with nominal management effort or service provider interaction. Buyya et al. (2009) [114] have defined it as follows: “Cloud is a parallel and distributed computing system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreements (SLA) established through negotiation between the service provider and consumers.”

Figure2.18: Cloud computing concept [115]

For service to be considered as cloud, according to the National Institute of Standards and Technology (NIST) [116] it must possess the following characteristics:

- On-demand self-service- Quick access of the services by the end user without long delayed characterised by the traditional information technology.
- Broad network access- Ability to access the service via standard platforms such as desktop, laptop and mobile apparatus.
- Resource pooling- Ability for resources to be pooled across multiple clients.
- Rapid elasticity- Capability can scale to cope with demand peaks.
- Measured Service- Billing is metered and delivered as a utility service.

2.18.1 Benefits of Cloud Computing (CC)

The following are the benefits of cloud computing:

(i). Cloud computing’s shared resources enables the provision of services to multiple users. The resources are easily scaled up and down according to demand.

(ii). Better hardware management; it is easy for cloud service providers to manage hardware as all the computers use the same hardware [117].

(iii). Cloud computing cuts the operational and capital costs for the users. With cloud computing, users will not be required to purchase the physical infrastructure and spend money on maintenance as they will be using the availed technology by the providers.

(iv). Pay-As-You-Go: Users only need to pay for the resources been used and are free to release or demand for more resources as per their requirements.

2.18.2 Disadvantages of Cloud Computing

Despite having positive attributes, cloud computing has also the negative parts of it. The following are some of the major negative attributes contributed by cloud computing [118]:

(i). High speed internet availability is required all the time for the user to be able to access the data or use services of cloud computing.

(ii). Non interoperability between cloud based systems, Users can not move his/her data stored in one cloud provider to another cloud service provider.

(iii). Less Reliability: Cloud Computing is less reliable as its resources are shared among multiple users. Data from one organisation may mix with data of another organisation, like what happened in 2007 where Microsoft and Yahoo! released some search data to the US Department of Justice as part of a child pornography case.

2.18.3 Types of Cloud Computing

Cloud computing is mainly comprised of five different types of service [119]. These are briefly explained as follows:

(i). Infrastructure as a Service (IaaS): virtualized on-demand server, virtualized data centre, flexible on-demand storage space, flexible local networks (LANs), firewalls, security services, etc.

(ii). Platform as a Service (PaaS): platform for cloud computing service provision (customer service management, billing, etc.)

(iii). Software as a Service (SaaS): business applications, customer relations and support (CRM), HR, finance (ERP), online payments, electronic marketplace (for very small and small and medium sized enterprises), etc.

(iv). Communication as a Service (CaaS): audio/video communication services, collaborative services, unified communications, e-mail, instant messaging, data sharing (web conference).

(v). Network as a Service (NaaS): managed Internet (guaranteed speed, availability, etc.), virtualized networks (VPNs) coupled with cloud computing services, flexible and on-demand bandwidth.

2.18.3.1 Infrastructure as a Service (IaaS)

IaaS is a way of delivering Cloud Computing infrastructure [119] [120] such as servers, storage, network and operating systems as an on-demand service. Clients usually purchase fully outsourced service on demand instead of buying servers, software, and data centre or network equipment [121]. There are some sub-categories of IaaS worth noting as classified by i.e. public or private of Hybrid cloud. “Public cloud” is considered infrastructure that consists of shared resources, deployed on a self-service basis over the Internet, while private cloud is infrastructure that emulates some of Cloud Computing features such as virtualization but done on a private network. The combination of the traditional dedicated hosting alongside public and/or private cloud networks is known as “Hybrid Cloud”.

Under IaaS, Clients do control and manage the systems in terms of the operating systems, applications, storage and network connectivity but do not control the cloud infrastructure. As with all cloud computing services it provides access to computing resources in a virtualised environment, “the Cloud”, across a public connection usually the internet.

Physically, the pool of hardware resource is drawn from a multitude of servers and networks usually dispersed across various data centres, all of which are maintained by the cloud provider. The client, on the other hand, is given access to the virtualised components in order to build their own IT platforms.

The salient examples where IaaS can be used by enterprise are Enterprise infrastructure; by internal business networks such as private clouds and virtual local area networks which use pooled server and networking resources. It could also be used in Cloud hosting where websites are hosted on virtual servers which are found on pooled resources from underlying physical servers. IaaS can also find its application in Virtual Data Centre (VDC) where a virtualised network of interconnected virtual servers can be utilised to offer enhanced cloud.

2.18.3.1.1 Benefits and Features of IaaS

The following are the typical features and benefits of typical IaaS [120]:

(i). Scalability: resources are readily available as on demand from the client which results into speedy capacity expansion and no wastage on unutilized capacity.
(ii). No investment in hardware by the clients as the underlying physical hardware that support IaaS service is set up and wholly maintained by the cloud provider, hence saving on the part of the client in terms of time and cost.
(iii). Not location dependant; service can usually be accessed from any locality with internet connectivity and allowed by the security protocol that govern the cloud.
(iv). Utility based costing; clients pay only for the actual utilized resources.
(v). No single point of failure; failure on one part of IaaS would not affect the broader service as it will be supported by the other various resources and redundancy configurations.
(vi). Physical security of data centre locations; services available through a public cloud, or private clouds hosted externally with the cloud provider, benefit from the physical security accorded to the servers been hosted within the data centre.

IaaS is a rapidly evolving field of cloud computing. The major players in IaaS provision are the Amazon Web Services and Rackspare.

2.18.3.2 Software as a Service (SaaS)

Software as a Service (SaaS) is defined as [120] [122] software that is deployed over the internet. With SaaS, a provider licenses an application to customers either as a service on demand, through a subscription, in a “pay-as-you-go” model, or (increasingly) at no charge when there is opportunity to generate revenue from streams other than the user, such as from advertisement or user list sales. Under SaaS, Clients purchase the ability to access and use an application or service that is hosted in the cloud. A benchmark example of this is Salesforce.com, where necessary information for the collaboration between the consumer and the service is hosted as part of the service in the cloud. Microsoft is also expanding its involvement in this area, and as part of the cloud computing option for Microsoft® Office 2010, its Office Web Apps are available to Office volume licensing customers and Office Web App subscriptions through its cloud-based Online Services.

SaaS is a rapidly growing market as indicated in recent reports that predict on-going double digit growth [122]. This rapid growth indicates that SaaS will soon become common place within every organization and hence it is imperative that buyers and users of technology understand what SaaS is and where it is suitable.

2.18.3.2.1 Characteristics of SaaS

Like other forms of Cloud Computing, it is important to ensure that solutions sold as SaaS in fact comply with generally accepted definitions of Cloud Computing. Some of the essential characteristics of Software as a Service (SaaS) include the following;

(i). Web access to commercial software ,
(ii). Software is managed from a central location,
(iii). Software delivered in a “single to multiple” model,
(iv). Clients are not required to handle software upgrades and patches, Application Programming Interfaces (APIs) allow for integration between different pieces of software.

Cloud Computing and SaaS in particular, is a fast growing mode of delivering technology. Organization would consider moving to SaaS in cloud computing under the following conditions that are appropriate for SaaS;

(i). Applications where there is substantial interaction between the organization and the outside world. For example, email newsletter campaign software
(ii). Applications that have a significant need for web or mobile access such as mobile sales management software,
(iii). Software for short term use, such as collaboration software for a specific project.
(iv). Software where demand spikes significantly, such as monthly tax or billing software.

SaaS is widely accepted to have been introduced to the business world by the Salesforce Customer Relationship Management (CRM) product. As one of the earliest entrants it is not surprising that CRM is the most popular SaaS application area, however e-mail, financial management, customer service and expense management have also gotten good uptake via SaaS.

2.18.3.3 Platform as a Service (PaaS)

PaaS can be defined [119] [123] as a computing platform that permits quick and easy creation of web applications without the complexity of purchasing and maintaining the software and infrastructure underneath it. Consumers under PaaS purchase access to the platforms, which enables them deployment of their own software and applications in the cloud. The operating systems and network access are not managed by the consumer, and there might be constraints on the applications that can be deployed.

PaaS is analogous to SaaS except that it is a platform for the creation of software, delivered over the web rather than being software delivered over the web as it is the case with SaaS. Platform as a Service (PaaS) brings the benefits that SaaS bought for applications, but over to the software development world.

2.18.3.3.1 Characteristics of PaaS

There are a number of different takes on what constitutes PaaS but some basic characteristics include [123];

(i). Services to develop, test, deploy, host and maintain applications in the same integrated development environment. All the varying services needed to fulfil the application development process.
(ii). Web based user interface creation tools assist to create, modify, test and deploy different UI scenarios,
(iii). Multi-tenant architecture where multiple concurrent users utilize the same development application,
(iv). Built in scalability of deployed software including load balancing and failover,
(v). Integration with web services and databases via common standards,

(vi). Tools to handle billing and subscription management,

(vii). Support for development team collaboration-some PaaS solutions includes project planning and communication tools.

PaaS, which is similar in many ways to Infrastructure as a Service that was discussed above, is differentiated from IaaS by the addition of value added services and comes in two distinct flavours;

- A collaborative platform for software development, focused on workflow management regardless of the data source being used for the application. An example of this approach would be Heroku, a PaaS that utilizes the Ruby on Rails development language.
- A platform that allows for the creation of software utilizing proprietary data from an application. This sort of PaaS can be seen as a method to create applications with a common data type. An example of this sort of platform would be the Force.com PaaS from Salesforce.com which is used almost exclusively to develop applications that work with the Salesforce.com CRM. Some examples of PaaS include Google App Engine Microsoft Azure Services and the Force.com platform.

2.18.3.4 Communication as a Service (CaaS)

Communications as a Service (CaaS) [124] is one such subset model used to describe hosted IP telephony services. Along with the move to CaaS is a shift to more Internet Protocol (IP) centric communications and more SIP trunking deployments. With IP and SIP in place, it can be as easy to have the PBX in the cloud as it is to have it on the premise. In this context, CaaS could be seen as a subset of SaaS. The types of services being offered under CaaS are audio and video communication services, collaborative services, unified communications, e-mail, instant messaging, and data sharing through web conferencing. Users can communicate with each other using the cloud.

2.18.3.5 Network as a Service (NaaS)

NaaS is [125] in principle the ‘cloudification’ of traditional networking. While Virtual Machines (VMs) have unshackled applications from being tied to particular physical servers, traditional network virtualization techniques such as virtual LANs (VLANs), virtual private networks (VPNs) do not offer an analogous Virtual Network (VN) abstraction that decouples the network from the physical infrastructure (refer to figure 2.19). NaaS is the vision of providing the VN abstraction as a service such that this VN abstraction can be instantiated, operated, emulated, moved, and repurposed as desired by the user in cloud computing style.

In this dissertation NaaS is defined as the business practice among MNO's of interconnecting/ accessing each other's infrastructure; i.e. 'access means the making available of facilities or services to another operator under defined conditions, or either an exclusive or non- exclusive basis, for the purpose of electronic communication services provisioning.[126]

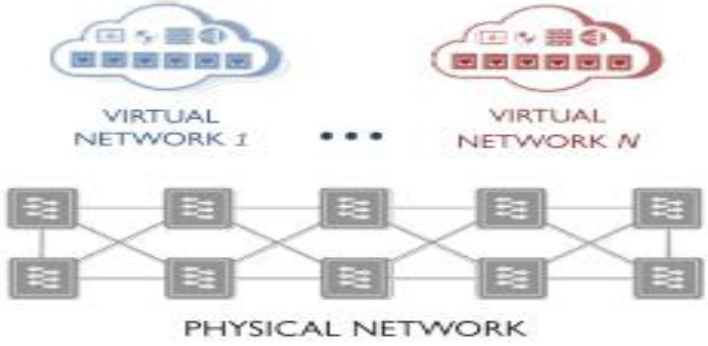


Figure 2.19: In NaaS, virtual networks are logically decoupled from underlying physical infrastructure substrate

Network as a Service (NaaS) is sometimes listed as a separate Cloud provider along with Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). This factors out networking, firewalls, related security, etc. from IaaS as is shown in the figure below.

NaaS can include flexible and extended Virtual Private Network (VPN), bandwidth on demand, custom routing, multicast protocols, security firewall, intrusions detection and prevention, Wide Area Network (WAN), content monitoring and filtering, and antivirus. There is no standard specification as to what is included in NaaS. Implementations vary.

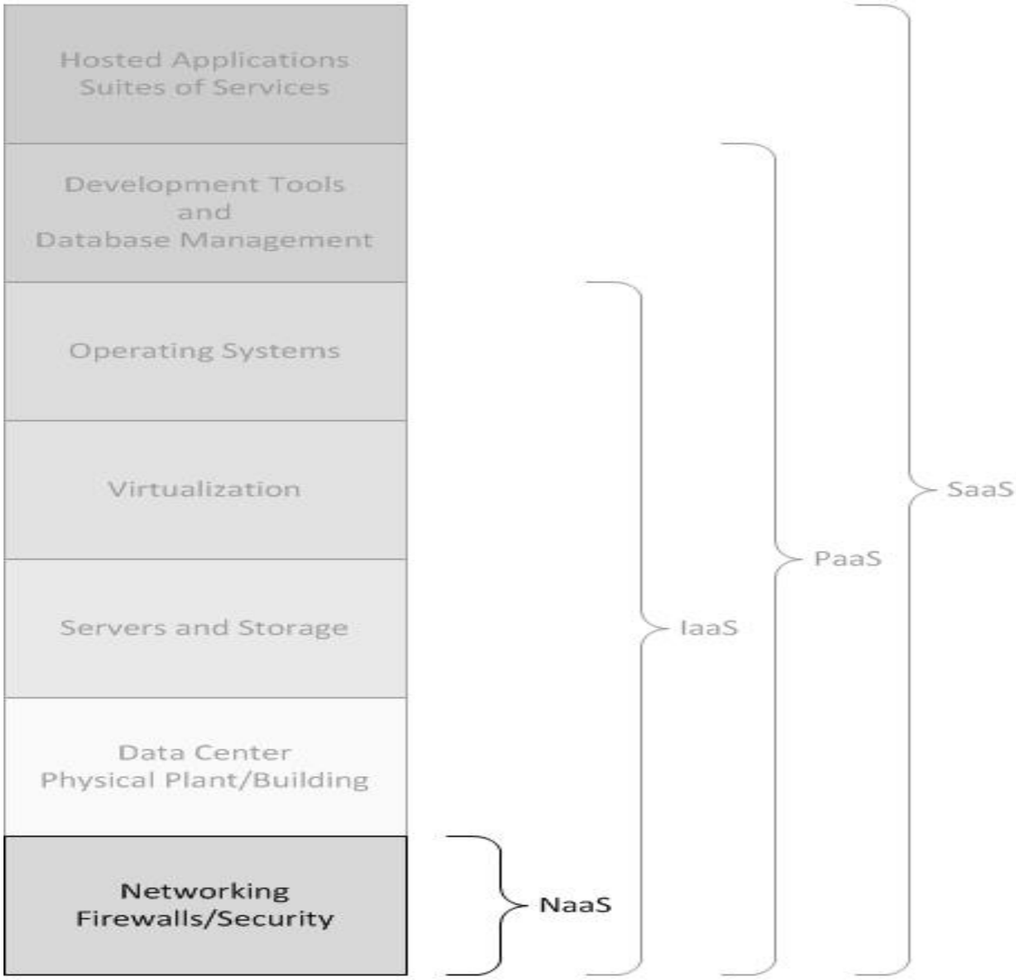


Figure 2.20: Types of Cloud Computing [125]

Why NaaS

The key drive of NaaS is the craving to address the inefficiencies of traditional cloud networking. Traditional networking in recent times is widely believed to be a bottleneck or hindrance in cloud innovations because of its dependence on manual configurations due to its tight link of services and infrastructure. The manual configuration required under traditional Data Centre (DC) networking solutions results into networks commission delays. With NaaS, cloud network can overcome bottleneck of traditional technologies like 4K VLAN. In line with cloud computing resolution, it is required to have prompt self-service provisioning. The other drive for NaaS is the necessity to avoid the costly process of application rewriting which can result with limitations of traditional networking.

(Like lack of broadcast domain abstraction, or lack of support for custom assigned IPs to the virtual servers). The innovations of virtualization technology, the frugality of functioning at cloud scale, the rise of high-level APIs for mechanized provisioning and service orchestration makes NaaS a very attractive scheme for both the Cloud service providers and the service users. NaaS is also motivated by the Clients' ability to customise their own virtual private cloud network (VPCN) such as VPN connection, network services and network topology. With Public cloud, network abilities can be vended as a service to data centre clients, such as IP address, VLAN, Bandwidth, Load Balancing, Firewall.

2.18.3.5.1 Characteristics of NaaS

NaaS is characterized by the following attributes [127]:

(i). Network virtualization: NaaS must support Multi-tenancy requirement. And it should hide the execution details of the network infrastructure

(ii). Close integration with virtual IT resources (compute, storage): NaaS must have the proficiencies of VM auto-discovery, integrated operation/provision together with IT resources;

(iii). Elasticity/High Availability: NaaS must have the abilities of on-demand bandwidth allocation, dynamic link/network creation, dynamic and geographically distributed pools of shared ICT resources, etc.;

(iv). Flexible service chain: Flexible interposition of various middle boxes in the NaaS network becomes a vital and treasured necessity for it and an IETF WG (SFC: Service Function Chaining) has been created to study and resolve the series of requirements;

(v). SDN paradigm: SDN is optional paradigm, but provides great flexibility and efficiency in network resource management, optimized path selection for DC interconnection.

2.18.3.5.2 Benefits of NaaS

The prime benefits of NaaS [127] are as follows:

(i). Agility in deployment with which networks provisioning can be done in a matter of minutes,

(ii). Scalability and elasticity of service, networks are upgraded at will with the suitable pricing model of pay-as-you-use, (iii). The users of NaaS have the benefit of full automation using where the consumer can program, manage, and orchestrate the network with programmatic control at convenient granular utility pricing leading to savings and productivity.

(iv). The consumer can support custom policies in its own virtual network which leads to enterprise network innovation. This can mean orchestration of numerous networking functions as preferred by the user such as custom routing, load balancing, network isolation, firewalling, and custom addressing, etc.

(v). In addition, the consumers can work with any hardware, or even mixed vendor hardware, without worrying about the burden of configuration and management and thereby avoid vendor lock-in.

(vi). The CSPs also gain a lot from offering NaaS: e.g., by utilizing the features of VM mobility, the DC resources can be effectively utilized by moving the VMs from loaded servers to idle servers without disrupting the VNs.

(vii). The NaaS model has full support for multi-tenancy with isolation which leads to better economics for CSPs while satisfying the isolation and security requirements of customers.

(viii). Lastly, another benefit of the NaaS approach is fault-localization with which a fault in one VN (due to policy configuration or otherwise) does not cascade to affect the whole network infrastructure.

2.18.3.5.3 Challenges of NaaS

Despite having significant benefits, NaaS has also some disadvantages as eluded below [128]:

(i). Constraints of physical DC: The location dependence of the traditional network technologies such as vlan, broadcast domain, firewall setting, etc., is a constraint.

(ii). Distributed subnet: One L3 subnet can span across the whole DC by virtualization technology. Hosts in a L3 subnet are no longer limited in one location. This kind of distributed subnet scenario brings new challenges of hosts' unified identification and access control;

(iii). Programmable network: SDN paradigm needs to define information model and data model used by the related interfaces, and the information mapping between overlay and underlay network;

(iv). On-demand and flexible service chain: It means dynamic service awareness and automatic service provision;

(v). End to end connection provision**:** End to end VPN service provision to users on separate WAN/ MAN network and DC network; integration of enterprise's current infrastructure and NaaS in cloud seamlessly and securely are challenge;

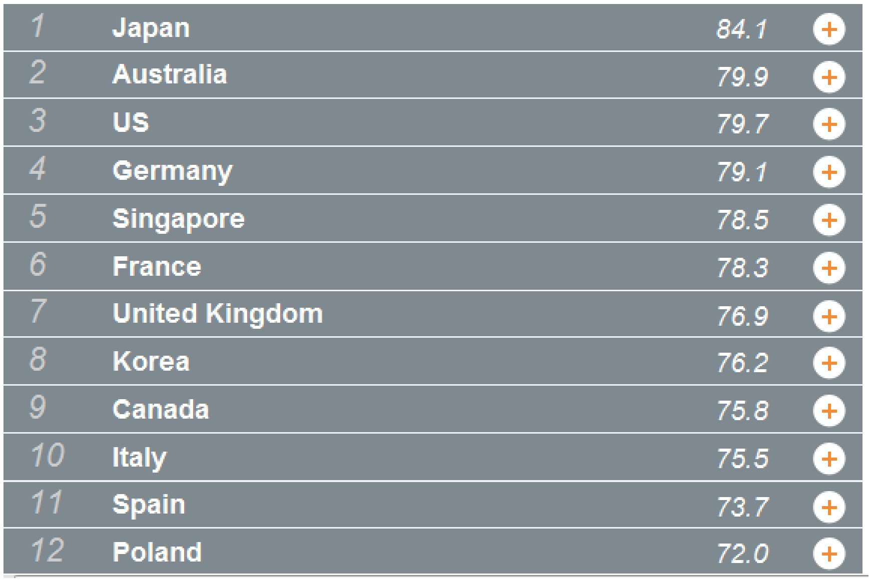
(vi). Backwards compatibility and smooth migration;

(vii). Security related issue.

2.18.3.6 Cloud Computing Implementation

Cloud computing has successfully being implemented at various levels globally. The study carried out by 2013 BSA Global Cloud Computing [129] found mark improvements in policy environment for cloud computing in several countries around the world. The finding were based on the seven policy categories that measured the countries' readiness to support the growth of cloud computing. Japan was rated the first in the world while South Africa was rated 20th. The 24 countries together account for 80 percent of the global information and communication technologies (ICT) market. The table 2.1 below shows the top ranking of the 24 countries in the world;

Table 2.1: Top ranking Countries in Cloud Computing implementation



1	Japan	84.1	+
2	Australia	79.9	+
3	US	79.7	+
4	Germany	79.1	+
5	Singapore	78.5	+
6	France	78.3	+
7	United Kingdom	76.9	+
8	Korea	76.2	+
9	Canada	75.8	+
10	Italy	75.5	+
11	Spain	73.7	+
12	Poland	72.0	+

13	Malaysia	69.5	⊕
14	Russia	59.1	⊕
15	Mexico	56.9	⊕
16	Argentina	56.5	⊕
17	India	53.1	⊕
18	Turkey	52.4	⊕
19	China	51.5	⊕
20	South Africa	51.3	⊕
21	Indonesia	48.4	⊕
22	Brazil	44.1	⊕
23	Thailand	44.0	⊕
24	Vietnam	40.1	⊕

In Africa, [130] the following countries have implemented Cloud computing in various models with different providers as illustrated in Table 2.2 below:

Table 2.2: Services offered by National Entities

Type	Description of service	Service Provider
IaaS	Security services Data centre service	ACCESS LINK COMTEL technologies Huawei
	Virtualized and on-demand server, flexible and on-demand storage space	RINGO
	E-mail services	Access Kenya MTN Business Safaricom
	Reseller of Computing Solutions	Agumba Computers
	Shared data centres	
PaaS	Provision of storage services	SOFNET
	Customer management, billing services	Bandwidth & Cloud Services Group
		Safaricom
SaaS	Business applications for customer relations and support (CRM), HR, finance (ERP)	HRM and IT engineering company
	Business applications	MyISP Safaricom
	Software as a service in partnership with international companies (CRM)	
	Provision of accounting packages in cloud computing	CATS Tanzania
	E-mail / web hosting	
CaaS	Audio communication services, collaborative services, unified communications, e-mail, instant messaging, data sharing (web conference)	H2COM
	E-mail	CAMTEL-CAMNET
	Unified communications, e-mail	MTN Business Safaricom
	Unified communication, collaborative services, email and instant messaging	Information Technologies and Communication Agency; telecommunication operators; a number of companies for their internal requirements.
	E-services and virtual resources for small enterprise	Net Innovations Ltd.
NaaS	Propagation of Internet flows	Huawei
	Managed Internet, flexible and on-demand bandwidth	CAMTEL, ORANGE Cameroun, MTN Cameroun, RINGO, YooMee
	Managed Internet Bandwidth & Cloud Services Group	Kenya Data Networks (KDN) MTN Business Safaricom

2.19 Cluster

Cluster computing is a type of computing in which several nodes are made to run as a single entity [131]. A computer cluster consists of a set of loosely or tightly connected computers that work together so that, in many aspects, they can be viewed as a single system. Each node of a computer cluster is set to perform the same tasks, which are controlled and scheduled by software. The various nodes involved in cluster are normally connected to each other using some fast local area networks [117]. There are primarily two reasons of deploying a cluster instead of a single computer, these are performance and fault tolerance. An application desires high computation in terms of response time, memory and throughput especially when we talk about real time applications. Cluster computing provides high computation by using parallel programming, where various processors are engaged simultaneously for a number of or a single problem.

Another reason is fault tolerance which is actually the ability of a system to operate elegantly even in the existence of any fault. Since clusters are the replicas of similar components, the fault in one component only affects the cluster's power but not its availability. So, consumers always have some components to use even in the presence of fault.

There are several methods offered when dealing with clustering computers are clustering for redundancy and load balancing/sharing, clustering for high performance computing and storage cluster.

2.19.1 Advantages of Cluster Computing

Cluster computing has the following positive attributes [132]:

(i). High Availability: As all the components are replicas of each other, so if one component goes down because of a technical reason, then some other component can takes its place, and user can continue to work with the system .

(ii). Manageability: It takes a lot of effort, cost and money to manage a large number of components. But, with cluster, large numbers of components are combined to work as a single entity. So, management becomes easy.

(iii). Single System Image: Again, with cluster, user just gets the feel that he is working with a single system, but actually he is working with a large number of components. He need not worry about that components, he only needs to manage a single system image.

2.19.2 Disadvantages of Cluster Computing

The following are the negative attributes of Cluster Computing [132]:

(i). Programmability Matters: Programming becomes a challenge where components to be amalgamated into a single entity vary in terms of software.
(ii). Difficult in Fault Location: Since a cluster is dealt as a single entity challenges may arise when troubleshooting and locating of fault components.
(iii). Difficult to handle by a Layman: As cluster computing involves amalgamation of different or same components together with diverse programmability, so a non-professional person may find it difficult to manage.

2.20 Virtualization

Virtualization is defined as the creation of virtual rather than actual version of something, such as an operating system, a server, a storage device or network resources. [133] In computing virtualization simply means to create a virtual version of a device or resource such as server, storage device, network or even an operating system where the framework divides the resources into one or more execution environments. According to [134], virtualization is defined as the ability to run multiple operating systems on a single physical system and share the underlying hardware resources. It is a process by which a single computer hosts the appearance of several computers. Virtualization is utilized to improve IT throughput and costs by using physical resources as a pool from which virtual resources can be assigned.

The virtual machine architecture is composed of a virtual machine (VM) with an isolated runtime environment (i.e. guest operation system and applications) and a multiple virtual systems (VMs) which run on a single physical system. The program that enables multiple operating systems to share one hardware host is known as a hypervisor. Every guest operating system appears to have all to itself the host's resources such as processor, memory and other. The Hypervisor's major roles are resources isolation and emulation, CPU scheduling of virtual machines, memory management, and emulation of input-output devices, networking and management of virtual machines. All this is done to ensure that there is no disruption among guest operating systems (VMs).

2.20.1 Benefits of Virtualisation

Virtualization offers various benefits. Some of the benefits are as follows [135];

(i). Greater efficiency in CPU utilization,
(ii). Greener Information Technology (IT) with less power consumption,
(iii). Provides better management through central environment control,

(iv). Provides more availability as a result of fault tolerance of key infrastructure components,

(v). Reduction in project timelines through the elimination of hardware procurement, making deployment easier,

(vi). Offers enhanced disaster recovery capability and improved outsourcing services. Availability.

2.20.2 Challenges of Virtualization

Although virtualization offers a number of benefits, there are emerging concerns in term of management. It is imperative to keep in mind that quicker creation of virtual servers than the specific installation of hardware may have the tendency of creating virtual environments which could quickly be uncontrollable. Furthermore, increase in virtual server instances results into workload upsurge for patching, maintaining and securing.

There are also security concerns on the trusted computing base (TCB) of a virtual machine which is too large [136].The security concerns in terms of network interface and secondary storage can be addressed using Transport layer security (TLS) and Network file system (NFS) respectively. The other challenge is vulnerability of hypervisor where malicious software can run in the VM and attack the hypervisor and also obstruct access to other VMs.

2.20.3 Major Player of Virtualization

The leading player in Virtualization is VMware. VMware, being the most prevalent virtual operating system, with its offer of long history and robust virtual services, make it the highest in market penetration. Microsoft is the main challenger to VMware. Other operating systems include Hyper-V, XenSource, Oracle VM, Solaris 10 Zones, Sun xVM, etc.

2.21 Research Methods

The technique used to systematically solve the research problem is known as research methodology. It may also be comprehended as a discipline of studying how research is done logically. Research methods refer to all the methods/techniques which are applied during the research conduction. In other words, all those methods which are applied by the researcher in the course of carrying out his research problem are termed as research methods.

The two main classes of research approach are qualitative and quantitative. Qualitative approach of research is more concerned with subjective assessment of attitudes, behaviour and opinions [137]. This type of research applies in-depth interviews in order to find out the motives and the desires of the subject matter. It examines, describes and test individual relationship [138] applying a deductive way of knowledge achievement.

On the other hand, quantitative research provide an in-depth comprehension of the variations in information gathered, analysed and the extent to which such analysis is able to provide on the subjects at study [139]. Its application is found in phenomenon that is expressed in terms of quantity. When compared to qualitative research, the collected statistics from quantitative investigations is easy to understand and gives enhanced understanding.

Quantitative research can further be subdivided into inferential, experimental and simulation approaches. Under inferential approach to research, a survey is usually done on a sample of population to determine its characteristics. The surveyed data collected is then used to infer characteristics of population.

Experimental approach is characterized by much greater control over the research environment, where some parameters are manipulated in order to monitor the effect it would have on other variables. Whereas simulations approach involve the setting up of an artificial environment in which pertinent information and data can be generated. This allows monitoring of the dynamic behaviour of a system under regulated conditions. This approach is very useful in building models for understanding future conditions. In business and social sciences applications, simulation refers to “the operation of a numerical model that represents the structure of dynamic process. Given the values of primary circumstances, parameters and exogenous variables, a simulation is run to represent the behaviour of the process over time [137]”.

2.22 Matrix Laboratory

MATLAB is a software package for doing numerical computation. It was originally designed for solving linear algebra type problems using matrices. It derives its name from MATrix LABoratory. MATLAB has since been expanded and now has built-in functions for solving problems requiring data analysis, signal processing, optimization, and several other types of scientific computations. It also contains functions for 2-D and 3-D graphics and animation [140].

2.23 **Summary**

With the global evolution of mobile telephony, MNOs also come under pressure to provide services such as mobile broadband, mobile TV and several other value-added services. It is imperative that operators find solutions to manage costs and ensure profitability. Infrastructure sharing emerged as the solution to the evolution. Infrastructure sharing is defined as having two or more operators coming together with a view of sharing part or parts of their network infrastructure for the purpose of their service provisioning [23][24][25][26] and cost reduction in construction, operation and maintenance of the network infrastructure . Where the core objective is to maximize the rare resources, optimize on economic paybacks on investments and the development of business models that concentrates on affordable and accessible ICT services [23] [27] [28].

The levels of Mobile communication infrastructure sharing vary universally with high levels more apparent in Europe, USA and India. Comparison of InfraS was done on developed nations such as Sweden, USA, UK and Singapore and developing nations like India, South Africa, Kenya and Viet Nam and Zambia.

The three strategies of InfraS are infrastructure assets sharing, infrastructure mutualisation, and infrastructure cooperation with each strategy having different shared assets and bargaining power of involved agents. The design of an infrastructure sharing strategy depends on four core factors such as the market's competitive structure, market conditions, network symmetry, and regulator behaviour.

Infrastructure sharing contains three interrelated dimensions: commercial, regulatory and technical. There are basically three categories of sharing namely passive sharing, active sharing and roaming based sharing.

Some of the renowned benefits in infrastructure sharing would be in the following areas of Capex and Opex great saving, Spectral –efficiency, service centric networks, high uptime, reduced time to market and coverage expansion [90].

Game theory is a powerful tool to study situations of conflict and cooperation, which is mostly concerned with discovering the best actions for individual decision makers in these circumstances and recognizing stable results. Game theory should not simply be viewed as a matter of mathematics but concerns the real world, in the sense that it involves decision-making by various players that have an effect on the interest of other players.

Players or participants are arranged in their preferences, their information, strategic actions available to them, and how these influence their payoffs (utilities). In instances where there are more than two players, a decision made by the first player will also have an effect on the interest of the other players.

Game theory is also viewed as a broad subject but basically divided into two categories of non-cooperative games and cooperative games, where non cooperative game theory is concerned with the analysis of strategic choices and explicitly models the decision making process of a player out of his/her own interests. In cooperative game theory, the players can make binding agreement.

Some of the definitions in game theory are:

(i). Nash equilibrium has been viewed as a basic concept of the subject, but situations of strategic games players base their random selection of strategies using certain probabilities, where a strategy is viewed as the given possible actions of a player.

(ii). Rationality occurs when a player is seeking to play in a manner which exploits his own payoff.

(iii). Payoff (utility) is a number that reveals the desirability of the outcome to a player for whatever reason.

(iv). Mixed strategy is viewed as an active randomization, with given possibilities, which regulate the player’s decision.

(v). Zero sum game is when the outcome, the sum of the payoff to all players is zero.

Cloud computing is defined as [113] a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources such as networks, servers, storage, applications, and services that can be quickly provisioned and released with nominal management effort or service provider interaction. Cloud computing is mainly comprised of five different types of service such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), Communication as a Service (CaaS) and Network as a Service (NaaS [119].

Cluster computing is a type of computing in which several nodes are made to run as a single entity [131] for the purpose of performance improvement and fault tolerance.

Virtualization is defined as the creation of virtual rather than actual version of something, such as an operating system, a server, a storage device or network resources. Virtualization is utilized to improve IT throughput and costs by using physical resources as a pool from which virtual resources can be assigned.

The technique used to systematically solve the research problem is known as research methodology. It may also be comprehended as a discipline of studying how research is done logically. Research methods refer to all the methods/techniques which are applied during the research conduction.

MATLAB is a software package for doing numerical computation. It was originally designed for solving linear algebra type problems using matrices. It can be used to produce 2 and 3D graphs.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Game theory is a mathematical concept that is used for the analysis and resolution of conflict situations in which parties have opposing interests. The concepts of game theory provide a tool for formulating, analysing and understanding different strategies. It endeavours to address the functional relationship between the selected strategies of discrete players and their market outcome, which may be either profit or loss [141].

A game is any situation in which players, i.e. participants in the game, make strategic decisions, taking into account actions and reactions of others. A strategy is a rule or plan of action for playing the game. For example, for an oligopoly company which needs to determine the price of its products, a possible strategy is “to maintain a high price as long as that is how my competitors act, but when some of the competitors lower their price, to lower my price even further“ [142].

The main objective of game theory is to determine the optimal strategy for each player. The strategy that maximizes the expected return of the player is known as an optimal strategy. The mechanisms of game theory allow a study of a large number of possible strategies, from a total agreement to a conflict of interest. Also, the economic game in which companies participate can be cooperative, when participants in the game may enter into binding contracts that allow them to plan mutual strategies and achieve greater profit, and non-cooperative in which there can be no negotiations or implementation of mandatory agreements between players.

Oligopoly is a prevalent form of market structure. This is one of the intermediate forms between pure competition and pure monopoly. The characteristics of oligopoly markets are to harbour a few businesses and that the entry of new companies is limited.

The scope of the monopoly power of companies partially depends on the interaction that exists between them. In some oligopolistic industries, companies cooperate, and in others they implement aggressive competition, and consequently achieve lower profits. In decision making in an oligopolistic market, one must take into account possible reactions of the competitors. In addition, we assume that companies, as subjects, act rationally, that is, think about the consequences of their actions. Game theory is widely applied in oligopolistic market situations research. In fact, many of the central problems of oligopoly depend on strategic reciprocal relations that exist between the market participants. The issue of the strength of the above mentioned reciprocal connections is especially important, and game theory models provide answers to this question.

In an oligopolistic market, a company determines the price and quantity taking into account the behaviour of its competitors, whereas the competitors' decisions depend on the decisions of the company. Nash equilibrium does exist in the oligopolistic market, which is based on the fact that every company operates as best as it can, considering the competitors' performances. When companies are in Nash equilibrium, neither of the companies has incentive to disturb it, because each operates as best as it can, that is, achieves the highest profits (as well as its competitor) with the strategy chosen.

In the context of this dissertation, game theory comprises simultaneous strategic pricing actions employed by the Zambian Market MNOs in pricing decisions on their access/ interconnection infrastructures; information asymmetry are situations in which MNOs hold information for self-interests on pricing of access infrastructure from competitors and even from ZICTA the regulator. The result is that due to having incomplete market information about other MNOs, market players make strategic pricing decisions.

In an oligopoly, firms are interdependent; they are affected not only by their own decisions regarding how much to produce, but by the decisions of other firms in the market as well. Game theory offers a useful framework for thinking about how firms may act in the context of this interdependence. More specifically, game theory can be used to model situations in which each actor, when deciding on a course of action, must also consider how others might respond to that action [143].

The Nash equilibrium is a significant concept in game theory. Nash equilibrium, named after Nobel winning economist, John Nash [144] is a solution to a game comprising of two or more players who want the best result for themselves and must take the actions of others into account. When Nash equilibrium is reached, players cannot improve their payoff by independently changing their strategy. This means that it is the best strategy assuming the other has chosen a strategy and will not alter it [145].

It is the set of strategies such that no player can do better by individually altering his or her strategy. If a player knew the strategies of the other players (and those strategies could not change), and could not benefit by changing his or her strategy, then that set of strategies represents a Nash equilibrium. If any player would benefit by changing his or her strategy, then that set of strategies is not Nash equilibrium. This concept is used for making optimal pricing decision.

In the context of this dissertation work Nash Equilibrium may be defined as the collective pricing response by MNOs players in Zambia (MTN, Airtel and Zamtel) who despite being rational competitors capable of pursuing self-pricing interests so as maximise their individual utility instead all opt to adhere to common pricing strategy called the best response since this common pricing response yields the best utility for all MNOs or the NaaS provider even if such a utility is not optimal for them all.

3.2 Prisoner's Dilemma

The prisoner's dilemma [146] is a type of game that illuminates why cooperation is difficult to maintain for oligopolistic even when it is mutually beneficial. Prisoner's dilemma arise in a situation where two suspected- criminals held in separate cells in order not share information are given an opportunity to either confess or deny committing a crime. In this game, the dominant strategy of each actor is to defect. However, acting in self-interest leads to a sub-optimal collective outcome. The prisoners are separated and left to contemplate their options. If both prisoners confess, each will serve a Three-year prison term. If one confesses, but the other denies the crime, the one that confessed will serve one year, while the one that denied the crime would get a ten-year sentence. If both deny the crime, they will both serve only two -year sentence. Betraying the partner by confessing is the dominant strategy; it is the better strategy for each player regardless of how the other plays. This is known as Nash equilibrium. The result of the game is that both prisoners pursue individual logic and betray when they would have collectively gotten a better outcome if they had both cooperated.

Prisoner's dilemma can be explained as illustrated in the 2x2 matrix below:

		Prisoner A	
		Confess	Deny
Prisoner B	Confess	3 ,3	1 ,10
	Deny	10 ,1	2 ,2

Prisoner A and Prisoner B are held in a separate room and cannot communicate, they are both suspected of a crime of which they can either confess or deny. Payoffs shown in the matrix are years in prison from their chosen course of action.

- Equilibrium happens when each player takes decisions which maximize the outcome for them given the actions of the other player in the game.
- In our example of the Prisoners' Dilemma, the dominant strategy for each player is to confess since this is a course of action likely to minimize the average number of years they might expect to remain in prison.
- But if both prisoners choose to confess, their "pay-off" i.e. 3 years each in prison is higher than if they both choose to deny any involvement in the crime.
- In following narrowly defined self-interest, both prisoners make themselves worse off.
- That said, even if both prisoners chose to deny the crime (and indeed could communicate to agree this course of action), then each prisoner has an incentive to cheat on any agreement and confess, thereby reducing their own spell in custody.
- The equilibrium in the prisoner’s Dilemma occurs when each player takes the best possible action for themselves given the action of other player.

- The dominant strategy is each prisoner’s unique best strategy regardless of the other players’ action is to confess.
- A bad outcome- Both prisoners could do better by both denying, but once collusion sets in, each prisoner has an incentive to lie! [146]

When applied to MNO’s the prisoner’s Dilemma results in all MNOs in an oligopoly market being trapped in pricing matching strategies ending in all of them failing to realize gainful utility and thus collapsing their operations and the market; such a situation is mainly avoided through regulatory intervention to ensure that pricing strategies among MNOs are sustainably cost-based.

In this dissertation Prisoner Dilemma is a special Nash Equilibrium condition in which independent (or non- cooperative decisions) by each MNO lead to a collective non-profitable utility for all MNOs.

In order to avoid the Prisoner’s Dilemma among MNOs in Zambia, the regulatory authority ZICTA, need to intervene and assist in developing access/interconnection pricing agreements which promotes healthy competition. According to the World Telecommunications Organization (WTO) agreement on Basic Telecommunications Reference Paper of 1997 [7], every member of the WTO was mandated to come up with Regulatory body that will govern Telecommunications service in each country. The Regulatory body must be independent from the service providers of telecommunications. ZICTA being the regulatory board in Zambia is required to regulate the telecommunications service according to the WTO Reference Paper which is summarized as follows [7]:

(i). It requires the governments and the regulators to regulate Telecommunications service major suppliers as they control essential facilities for public network that can't reasonably be duplicated for economic reasons, technical reasons, or both.

(ii). Government and regulators must put measures to ensure that major players/suppliers do not engage in anti-competitive practices such as cross-subsidies, use information obtained from competitors or withhold needed technical information from competitors.

(iii). Interconnection with a major player for competitors must be assured at any technically feasible point in the network. The terms, conditions and quality must be non-discriminatory (level playing field for both competitor and the major supplier). Interconnections must be timely, and rates must be reasonable and transparent while considering the economic feasibility. Service must be unbundled so that suppliers do not pay for network components or facilities they do not need. The interconnection must be publicly available and enforceable on a timely basis.

(iv). It allows governments to maintain policy measures that are designed to achieve universal service which must be administered transparently, non-discriminatory, and competitively neutral way. They should not be more burdensome than is necessary to achieve universal service.

(v). It requires governments to use procedures for the allocation and use of scare resources such as frequencies that are timely, objective, transparent and non-discriminatory.

(vi). It stipulates that the regulatory body be separate from the actual suppliers and that it employ procedures to ensure impartiality for all market players.

3.3 Materials used in the Simulations

In this simulation, one personal computer equipped with the following characteristics was used:

(i). Windows 7 home premium
(ii). System Rating: 2.0 Windows Experience index
(iii). Processor: Intel® Celeron ® CPU 540@ 1.86 GHz
(iv). RAM: 2.00 GB
(v). System type: 32-bit operating system

MATLAB 2013 software was used to carry out the experiments. It was used mainly because it was easily available and much easier to use than other software.

3.4 Simulations Process

In our research, experimental and simulation approaches were applied as alluded in the explanation that follows. In this section we discuss on the method that was used in analysing and evaluating the effect of governing parameters such as the willingness to pay, the regulatory factor, the investment in infrastructure and the price on utility. Matlab was used to simulate utility. The model for infrastructure sharing adapted from Sumbwanyambe and Nel [12] was used in the simulations scenarios as discussed below. The model is as illustrated in equation (3.1)

$$u_i = \alpha_i \log\left(1 + \frac{\omega_i}{g_i}\right) - p_i \omega_i \tag{3.1}$$

Where u, is the utility (payoff) to the provider, α_i is user's willingness to pay, ω_i is investment in infrastructure, g_i is regulatory factor and p_i is the price.

Using Matlab, simulations were done on infrastructure sharing model of equation 3.1. In this dissertation the data that was used to simulate represented all the MNOs in Zambia, the Regulator (ZICTA) and the NaaS Provider. The data reflected on assumptions made in order to find out its effect on utility once varied in such a manner. Simulations were done under the following scenarios:

3.4.1 First scenario effect of infrastructure investment on utility

(i). Simulation was done on utility versus infrastructure investment while keeping other parameters like willingness to pay, regulatory factor and the price constant.

- Utility versus Investment in Infrastructure at g_i =6, p_i =0.4 and α_i =40

(ii). Simulation was done on utility versus infrastructure investment while varying other parameters one at time.

- Utility versus Investment in Infrastructure and willingness to pay at g_i =5 and p_i =0.3
- Utility versus Investment in Infrastructure and Regulatory Factor at α_i =60 and p_i =0.3
- Utility versus Investment in Infrastructure and Regulatory Factor at α_i =120 and p_i =0.3

3.4.2 Second scenario effect of regulatory factor on utility

(i). Simulation was done on utility versus the regulatory factor while keeping other parameters constant.

- Utility versus Regulatory Factor at ω_i =120, p_i = 0.4 and α_i =50
- Utility versus Regulatory Factor and investment in infrastructure when p_i =0.3 and α_i =60

(ii). Simulation was done on utility versus the regulatory factor while varying other parameters one at time.

3.4.3 Third scenario effect of willingness to pay on utility

(i). Simulation was done on utility versus the willingness to pay while keeping other parameters constant.

- Utility versus Willingness to Pay and Investment in Infrastructure at g_i =5 and p_i =0.3

(ii). Simulation was done on utility versus the willingness to pay while varying other parameters.

- Utility versus Willingness to Pay and Investment in Infrastructure at g_i =5 and p_i =2
- Utility versus Willingness to Pay and Investment in Infrastructure at g_i =24 and p_i =2
- Utility versus Willingness to Pay and Regulatory Factor at ω_i =150 and p_i =2
- Utility versus Willingness to Pay and Regulatory Factor at ω_i =300 and p_i =4

3.4.4 Fourth scenario effect of price on utility

(iii). Simulation was also done on the effect of pricing on utility while maintaining other parameters constant on the other hand varying parameters.

- Utility versus Price and Investment in Infrastructure at $g_i = 5, \alpha_i = 40$
- Utility versus Price and Regulatory Factor at $\omega_i = 120, \alpha_i = 40$

3.5 Summary

Using the simulated results from the four scenarios, analysis was done to determine the effects of such factors on investment in infrastructure and recommendations were made on the best factors to consider when venturing into infrastructure investment for mobile service providers as NaaS. The simulation results /data were collected and analysed as illustrated under findings and discussions.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the findings from the reviewed literature on the factors that will promote InfraS, the effect of such factors on InfraS, the benefits of infrastructure sharing using mobile Network as service globally. Furthermore the results and discussions from the four scenarios that were simulated from the previous chapter are done.

4.2 Factors Promoting Infrastructure Sharing

To address the first research question and the objective which was looking at the factors that would promote infrastructure sharing, from the literature reviewed by other authors [12] [111] [112], pointed out that the parameters/factors of Willingness to pay, regulatory factors, the price and investment in infrastructure plays a bigger role in order to enhance infrastructure sharing through NaaS provision. These factors would help the NaaS on what to consider when venturing into service provisioning.

Willingness to Pay (WTP) was the response given by MNO to pay for the service rendered by the NaaS provider. Knowledge of the customer's (MNO) response to different prices is a basis of market strategies predominantly in the areas of invention development and competitive strategy [147] .WTP is essential for developing an optimal pricing strategy [148] [149] [150].

The Regulatory factors are taken as the policies that govern and regulate telecommunications industry by the regulatory body e.g. price caps, incentives, access/ interconnections rates and licensing requirements.

The price is the amount charged to the MNO for accessing / using the network of the NaaS provider. Pricing plays an important role as it can either draw or drive away the users of the network. According to the studies done by Marn, et al [151] prices in correspondence to customers (MNOs) 'behaviour (WTP) can have notable effect on revenues and profits as is the case for NaaS provider, in this study.

4.3 Infrastructure Sharing Model

The second objective was looking at coming up with the model that can be used for infrastructure sharing by mobile operators. The Model was adapted from Sumbwanyambe and Nel model which was applied to determine the optimal spectrum assignment and pricing. The model as applied by [12] used factors such as the willingness to pay, the price, the quality of service and the spectrum bandwidth to determine the optimal utility or payoff. In our study the adapted model was used to determine the payoff for NaaS provider when subjected to factors such as willingness to pay, price, regulatory factor and the investment in infrastructure.

4.4 Effects of the Factors on the NaaS' Payoff

The third objective of determining the effect that the factors raised under the first objective have on infrastructure sharing was achieved as explained below:

The results collected from the simulations were analysed and discussed in details with the main focus been on the effect of parameters such as the investment in infrastructure, the willingness to pay, the price and the regulatory factors have on utility. The following terms were mainly used in the simulation.

(i). Utility (payoff) is the numerical value that reflects the desirability of an outcome to a player for whatever reason. The expected utility incorporates the player's attitude towards risks. In this case, utility determines whether it is wealthy to venture into NaaS by the provider.

(ii). For the sake of universality, Investment in infrastructure and the price in monetary terms are rated in units.

(iii). The response given by the MNO to pay for the service is referred to as Willingness to pay. Where the response was seen by the magnitude of WTP value. The bigger the value the higher the response to pay for the service.

(iv). Regulatory factors are taken as the policies that govern and regulate telecommunications industry by the regulatory body e.g. price caps, incentives, access/ interconnections rates and licensing requirements. The higher the value the tougher the regulatory factors that impede investments.

(v). Nash Equilibrium, also called strategic equilibrium, is a list of strategies, one for every player, which has the property that no player can unilaterally alter his strategy in order to get a better payoff or utility.

(vi). Best Response in game theory, is the strategy or strategies which produces the most favourable outcome for a player in comparison to other players' strategies. In the case of the simulated results at study the following are two conditions of best response:

    (i). Best response to invest been when $u>0$

    (ii). Best response not to invest is when $u< 0$

4.4.1 Mathematical Notations

In game theory, the decision makers are called players. The way they choose their action is referred to as their strategy. The meticulousness of game theory is the presence of interactions: the benefit (i.e. utility) that a player gets does not only depends on his or her actions but also on the actions other players. The basic assumption made in game theory is that players are rational, i.e. when given the available information; they look for strategies that optimize their payoff. As a result of interactions, the choices that a player makes to optimize his or her utility depends on the selections of the others. A game is constituted by the set of players, their set of strategies and the definition of utility function [152].

A strategic game Γ consists of:

(i). A set N of players;

(ii). A set A_i of actions available to each player $i \in N$

(iii). For each player $i \in N$ a utility function $u_i : A \rightarrow R$ (with $A := \prod_{i \in N} A_i$), characterizing the preferences of the player among possible action configurations we then note that

$$\Gamma = \left(N, (\mathrm{A}_i)_{i \in N}, (U_i)_{i \in N} \right) \tag{4.1}$$

Game theoretical notation of the game played between the NaaS provider and the MNOs providers in this study are defined as follows; we define the NaaS provider I and the MNOs as

$$I \in \{ i_1, i_2 \ldots \ldots i_n \}$$

We provide the following assumptions for this game;

(i). The NaaS provider will only invest in infrastructure if the willingness to pay by the Service providers is good. This is in line with the fact that the willingness to pay may sometimes increase revenue for the NaaS to invest in infrastructure.

(ii). The regulatory factor can either constrain or promote investment in infrastructure. Note that in this game there are no units for the regulatory factor. As a matter of fact the assumption is based on the fact that a higher regulatory factor number will provide for tough regulation that does not allow investment.

(iii). Furthermore, we assumed that the investment pattern in terms of money is same across the country. We know that network investment patterns are sometimes driven by geographical terrain, cultural and social norms. In this study the investment pattern is same but only separated between urban and rural setting.

Using the adapted model of infrastructure sharing from Sumbwanyambe and Nel [12] (equation 3.1 as shown from the previous chapter).

$$u_i = \alpha_i \log\left(1 + \frac{\omega_i}{g_i}\right) - p_i \omega_i \tag{3.1}$$

The following Lemma was introduced;

LEMMA 1

The provider of NaaS will invest in infrastructure under information symmetry if and only if $u_i \geq 0$

Proof: From equation (3.1)

Assume α_i (willingness to pay) is 0, when substituted in the equation it will result into the following:

$$u_\text{i} = 0 - p_i \, \omega_i \tag{4.2}$$

$$u_i = - p_i \, \omega_i$$

Depending on the value of willingness to pay the utility will either be positive or negative.

The proof of LEMMA1 leads us to the definition of the best response of NaaS provider given the revelation of information by the mobile provider.

Definition 1: The Best Response of NaaS provider given the information on the willingness to pay is to invest in infrastructure.

The best response equation is as expressed in equation 4.3

$$br_i\left(s_j\right) = \arg\max_{s_i \in S} u_i\left(s_i, s_j\right) \tag{4.3}$$

Lemma 2

The provider of NaaS will not invest in infrastructure under information asymmetry due to lack of information on the strategies.

Proof: Without clear information the NaaS will not invest in infrastructure due to the fact that the NaaS won't have an idea of whether the mobile operators will use the network or not. As a matter of fact there is no guarantee of Return on Investment (ROI) given the conditions of information asymmetry the utility can be negative as shown in equation 4.2.

Having put up the two LEMMAs above it will be prudent for us to provide the three probable states as follows:

$$u_i = \alpha_i \log\left(1+\frac{\omega_i}{g_i}\right) - p_i\omega_i \geq 0 \qquad \text{Invest} \qquad (4.4)$$

$$u_i = \alpha_i \log\left(1+\frac{\omega_i}{g_i}\right) - p_i\omega_i \leq 0 \qquad \text{Do not invest} \qquad (4.5)$$

$$u_i = \alpha_i \log\left(1+\frac{\omega_i}{g_i}\right) - p_i\omega_i = 0 \qquad \text{The NaaS is indifference} \qquad (4.6)$$

From the three states above, it is clear that equation 4.4 will present a state where the NaaS provider has information about the willingness to pay of service providers.

Equation 4.5 presents a scenario where the willingness to pay may not be known to the NaaS provider. This situation can yield a negative utility for the NaaS.

Equation 4.6 gives rise to situation where the NaaS provider is indifference between investing and not investing. When such a situation happens equilibrium may be reached. The situation of equation 4.6 leads us to the following definition:

Definition 2: Nash equilibrium is a term used in game theory to describe a situation where each player's strategy is optimal given the strategies of all other players. NE exists when there is no unilateral profitable deviation from any of the players [153].

A Nash equilibrium of a strategic game Γ= is a profile $a^* \in A$ such that for every player *i*,

$$u_i\left(a_i^*, a_{-i}^*\right) \geq u_i\left(a_i, a_{-i}^*\right) \forall_{ai} \in A_i \qquad (4.7)$$

Where a_i^* and a_{-i}^* are the Nash equilibrium strategies of players.

4.4.2 Effect of investment in infrastructure on utility

Figure 4.1 show the effect of investment in infrastructure on utility while maintaining the regulatory factor, willingness to pay and the price. The figure shows that continuous investment across a developing country, like Zambia may result in a negative utility for the NaaS provider. This is in line with the fact that most mobile service providers may only be willing to pay for service to access and interconnect with Naas within urban environment where it is profitable due to the economic status of the end users which is more superior in urban that rural set up. As a matter of fact figure 4.1 shows that investment in urban area may be profitable for the NaaS but continuous investment (in billions of units) across the non- profitable areas may reach a negative utility as shown.

When other factors are maintained especially willingness to pay as seen from the graph utility reaches it maximum point or concave. i.e. a point when utility starts dropping negatively despite the increase in infrastructure investment. This is due to the fact that investment alone cannot increase utility unless there is a positive response in willingness to pay by users (mobile providers) as shown in Figures 4.2, 4.3 and 4.4. Utility was doubled with an adjustment of willingness to pay from 60 to 120 as illustrated in Figures 4.3 and 4.4 respectively.

The response of investment in infrastructure versus the utility can also be proofed mathematically by finding the second derivative of the expression for utility (*u*) in terms of investment in infrastructure (*w*) as follows:

$$u_i = \alpha_i \log\left(1+\frac{\omega_i}{g_i}\right) - p_i\omega_i \qquad (3.1)$$

Taking the partial derivative of 3.1, we obtain an expression of *u* as follows:

$$\frac{\partial u}{\partial \omega} = \alpha\left(\frac{1}{g+\omega}\right) - p \qquad (4.8)$$

Differentiating further, of equation (4.8) yield us with the following:

$$\frac{\partial 2_u}{\partial \omega^2} = -\alpha\left(\frac{1}{1+g}\right) \qquad (4.9)$$

A close analysis of equation (3.1), (4.8) and (4.9) shows that there is an optimal solution (investment in infrastructure) to equation (3.1) which gives the provider of NaaS with optimum payoff (utility).

Proof: From equation (3.1),(4.8) and (4.9) we see that $\frac{\partial u}{\partial \omega} = 0$ has a maximum point since $\frac{\partial 2_{u}}{\partial \omega^{2}} < 0,$ It can be inferred from equation (3.1) that if $\frac{\partial 2_{u}}{\partial \omega^{2}} < 0$, utility contains at least one maximization point or fixed point (Kakutani fixed point theorem) [154] , at which $\frac{\partial u}{\partial \omega} = 0$, thus the optimal investment in infrastructure can be found by equating the first derivative to zero and solving for ω. However such an optimal utility is determined by the user's willingness to pay and the regulatory factors.

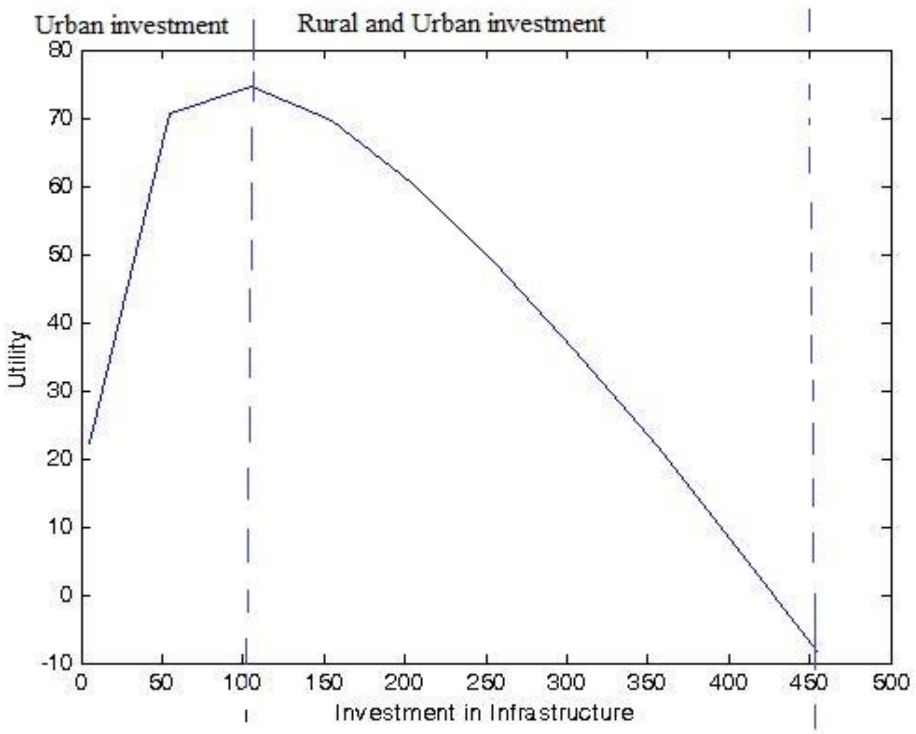


Figure 4.1: Utility versus investment in infrastructure when g_i =6, p_i =0.4 and α_i =40

Table 4.1: Utility versus investment in infrastructure when g_i =6, p_i =0.4 and α_i =40

u	22.24543	70.76458	74.71083	69.5858	60.40395	48.91044	35.92134	21.88474	7.07335	-8.33446
w	5	55	105	155	205	255	305	355	405	455
g	6	6	6	6	6	6	6	6	6	6
p	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
α	40	40	40	40	40	40	40	40	40	40

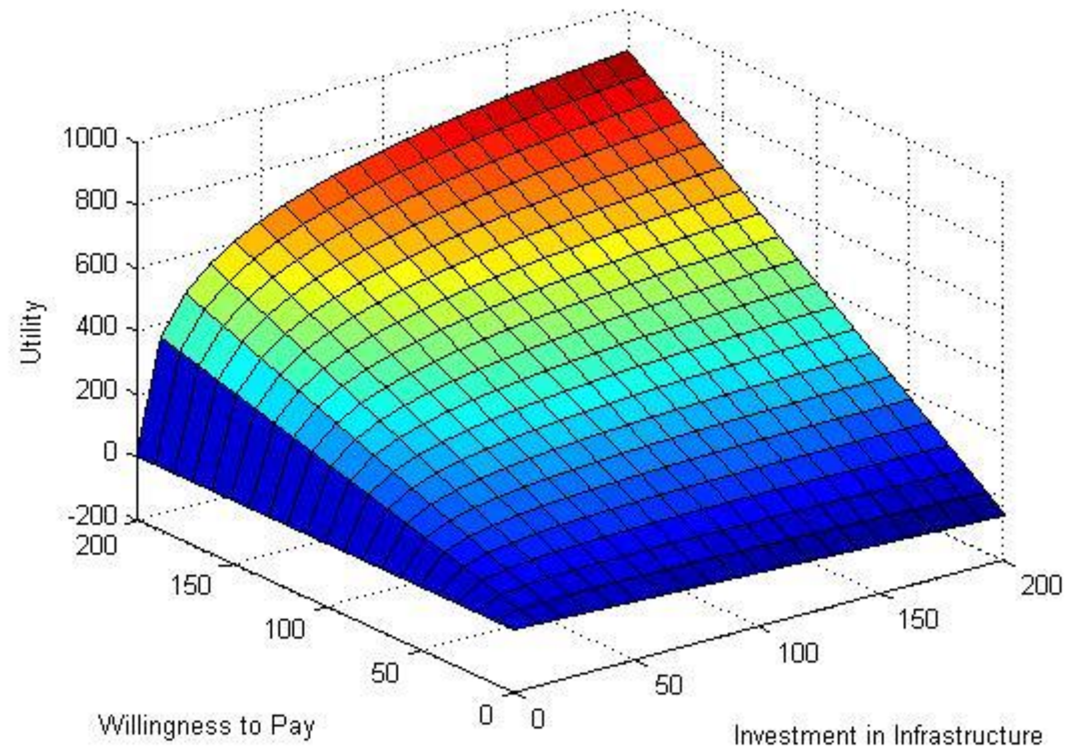


Figure 4.2: Utility versus investment in infrastructure and willingness to pay when g_i =2 and p_i =0.3

Table 4.2: Utility versus investment in infrastructure and willingness to pay when g_i =2 and p_i =0.3

Name	**Value**	**Min**	**Max**	**Range**
w	21*21 Double	0	200	200
g	21*21 Double	0	200	200
u	21*21 Double	-60	863.02	923.02
p	0.3	0.3	0.3	0
α	60	60	60	0

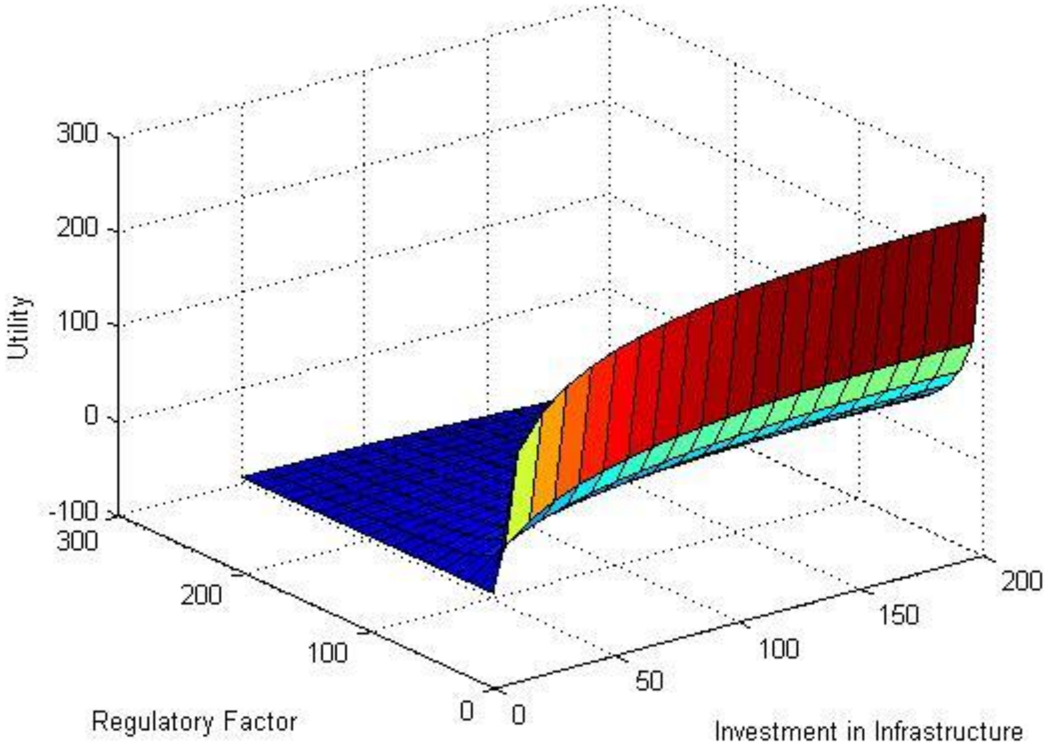


Figure 4.3: Utility versus investment in infrastructure and regulatory factor when $\alpha_i = 60$, $p_i = 0.3$

Table 4.3: Utility versus investment in infrastructure and regulatory factor when $\alpha_i = 60$, $p_i = 0.3$

Name	**Value**	**Min**	**Max**	**Range**
w	21*21 Double	0	200	200
g	21*21 Double	1	201	200
u	21*21 Double	-18.56	258.19	276.75
p	0.3	0.3	0.3	0
α	60	60	60	0

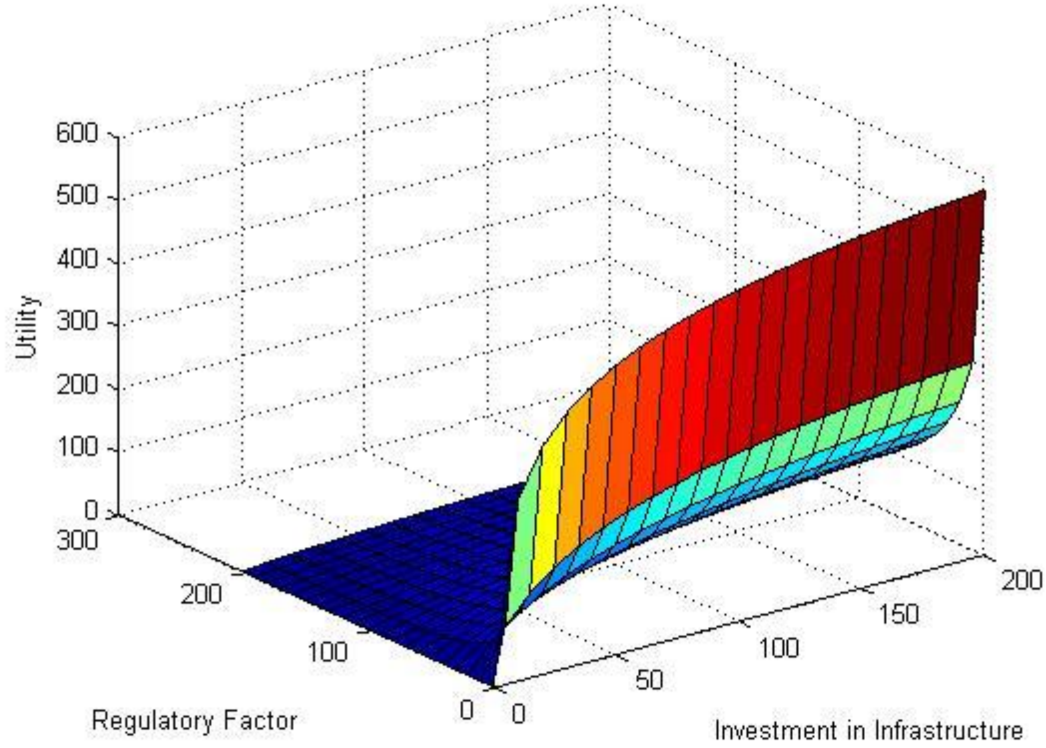


Figure 4.4: Utility versus investment in infrastructure and regulatory factor at $\alpha_i = 120$, $p_i = 0.3$

Table 4.4: Utility versus investment in infrastructure and regulatory factor at $\alpha_i = 120$, $p_i = 0.3$

Name	**Value**	**Min**	**Max**	**Range**
w	<201*201 Double>	0	200	200
g	<201*201 Double>	1	201	200
u	<201*201 Double>	0	576.39	576.39
p	0.3	0.3	0.3	0
α	120	120	120	0

4.4.3 Effect of Regulatory factor on Utility

Figure 4.5 and Figure 4.6 show the results of regulatory factor on utility .When the regulatory factors are adjusted upwards, this result into a decrease in utility which will have a negative effect on the NaaS in terms of payoff. The upward adjustment of regulatory factor constrains the NaaS provider into infrastructure investment due to tough regulations that goes with the adjustment which is not favourable for investment. This is in line with the finding that was done by done by Friederiszick et al [45] and Grajek et al [46] on the relationship between the intensity of regulation and investment in infrastructure, they discovered that entrant's into investment of new infrastructure were discouraged by the higher intensity of regulation. Utility reduces drastically with any slight adjustment in regulatory factor.

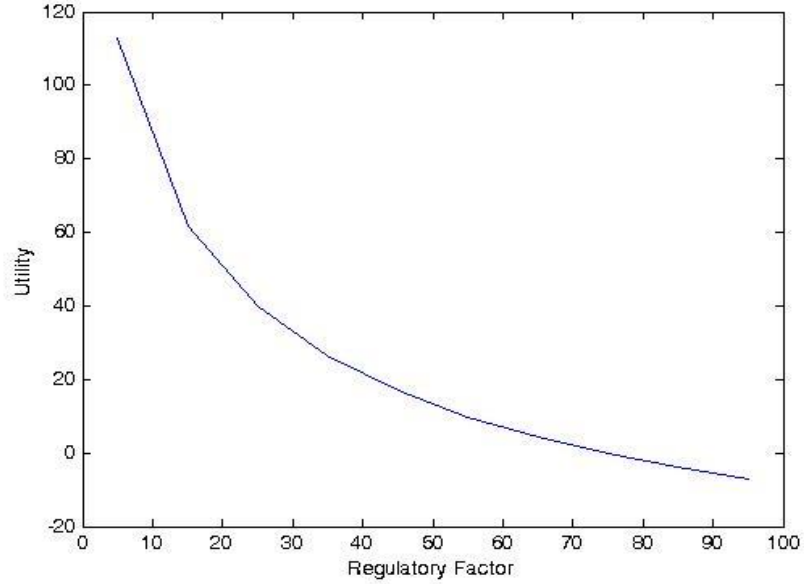


Figure 4.5: Utility versus regulatory factor when ω_i =120, p_i =0.4 and α_i =50

Table 4.5: Utility versus regulatory factor when ω_i =120, p_i =0.4 and α_i =50

u	112.9438	61.86123	39.8929	26.40385	16.96415	9.872639	4.298428	-0.22443	-3.98206	-7.16194
g	5	15	25	35	45	55	65	75	85	95
w	120	120	120	120	120	120	120	120	120	120
p	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
α	50	50	50	50	50	50	50	50	50	50

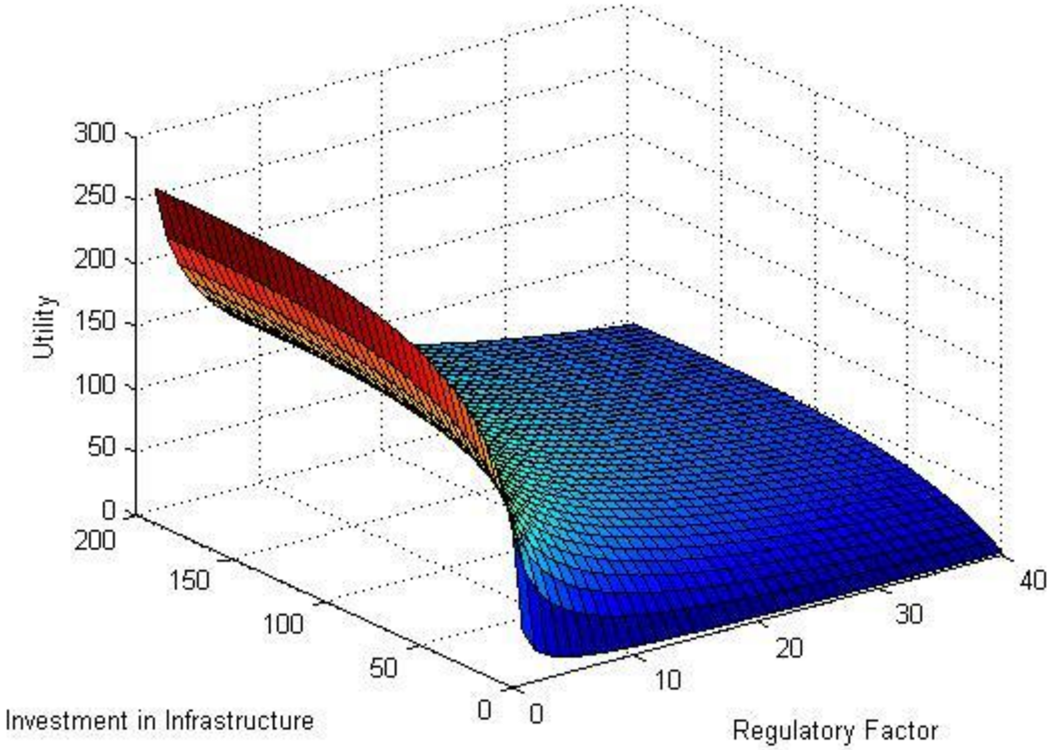


Figure 4.6: Utility versus regulatory factor and investment in infrastructure when α_i =60 and p_i =0.3

Table 4.6: Utility versus regulatory factor and investment in infrastructure when α_i =60 and p_i =0.3

Name	**Value**	**Min**	**Max**	**Range**
w	<40*40> Double	1	196	195
g	<40*40> Double	1	40	39
u	<40*40> Double	1.18	258.19	257.01
p	0.3	0.3	0.3	0
α	60	60	60	0

4.4.4 Effect of willingness to pay on utility

The payoffs in Figures 4.7 and 4.8 indicate that it increases with a positive response in willingness to pay for the service by the mobile service provider.ie increasing with an increase in willingness to pay. The higher the utility the profitable or the favourable it is for the NaaS provider to invest. As illustrated in Figures 4.10 and 4.11, there was drastic reduction in utility when the infrastructure investments and prices were increased from 150 to 300 and 2 to 4 respectively. WTP is associated with a number of factors such as type of access/interconnections been provided by the NaaS provider and the price of the service.

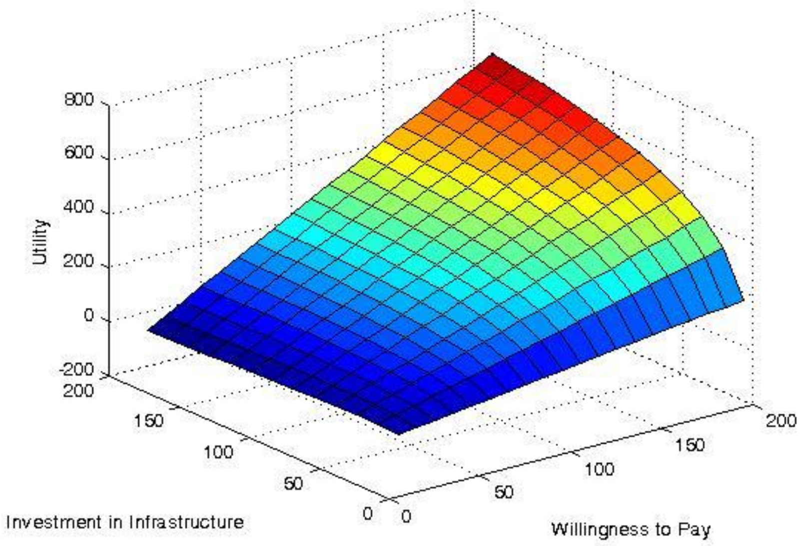


Figure 4.7:Utility versus willingness to pay and investment in infrastructure when $g_i = 5$, $p_i = 0.2$

Table 4.7: Utility versus willingness to pay and investment in infrastructure when $g_i = 5$, $p_i = 0.2$

Name	Value	Min	Max	Range
w	<21*21> Double	0	200	200
g	5	5	5	0
u	<21*21> Double	-40	702.71	742.71
p	0.2	0.2	0.2	0
α	<21*21> Double	0	200	200

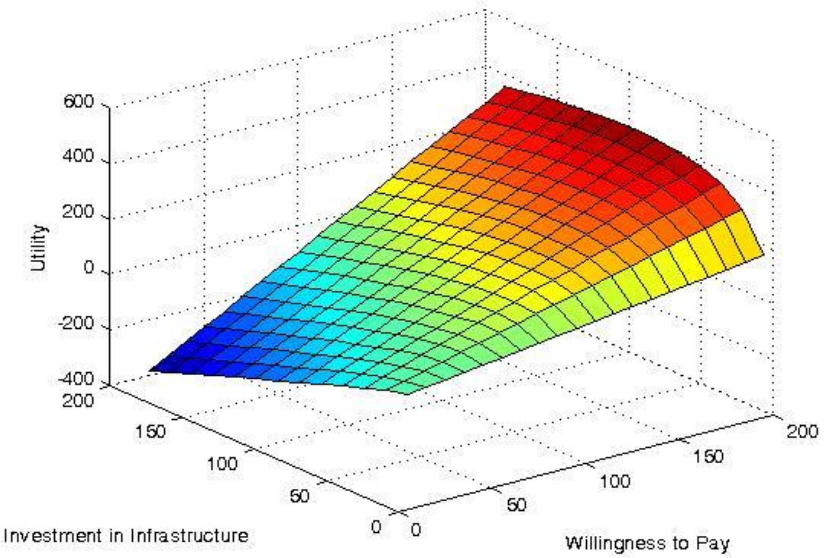


Figure 4.8: Utility versus willingness to pay and investment in infrastructure when $g_i = 5$ & $p_i = 2$

Table 4.8: Utility versus willingness to pay and investment in infrastructure when $g_i = 5$ and $p_i = 2$

Name	**Value**	**Min**	**Max**	**Range**
w	<21*21> Double	0	200	200
g	5	5	5	0
u	<21*21> Double	-400	408.9	808.9
p	2	2	2	0
α	<21*21> Double	0	200	200

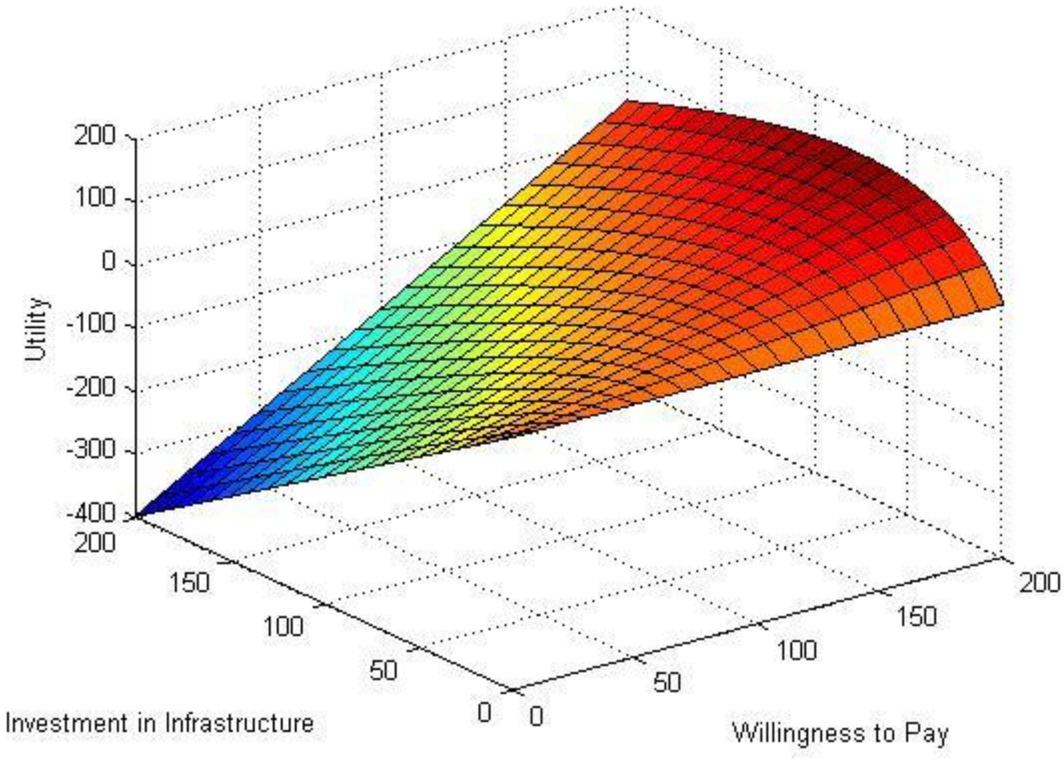


Figure 4.9: Utility versus willingness to pay and investment in infrastructure when g_i =24, p_i =2

Table 4.9: Utility versus willingness to pay and investment in infrastructure when g_i =24, p_i =2

Name	**Value**	**Min**	**Max**	**Range**
w	<21*21> Double	0	200	200
g	24	24	24	0
u	<21*21> Double	-400	133.26	533.26
p	2	2	2	0
α	<21*21> Double	0	200	200

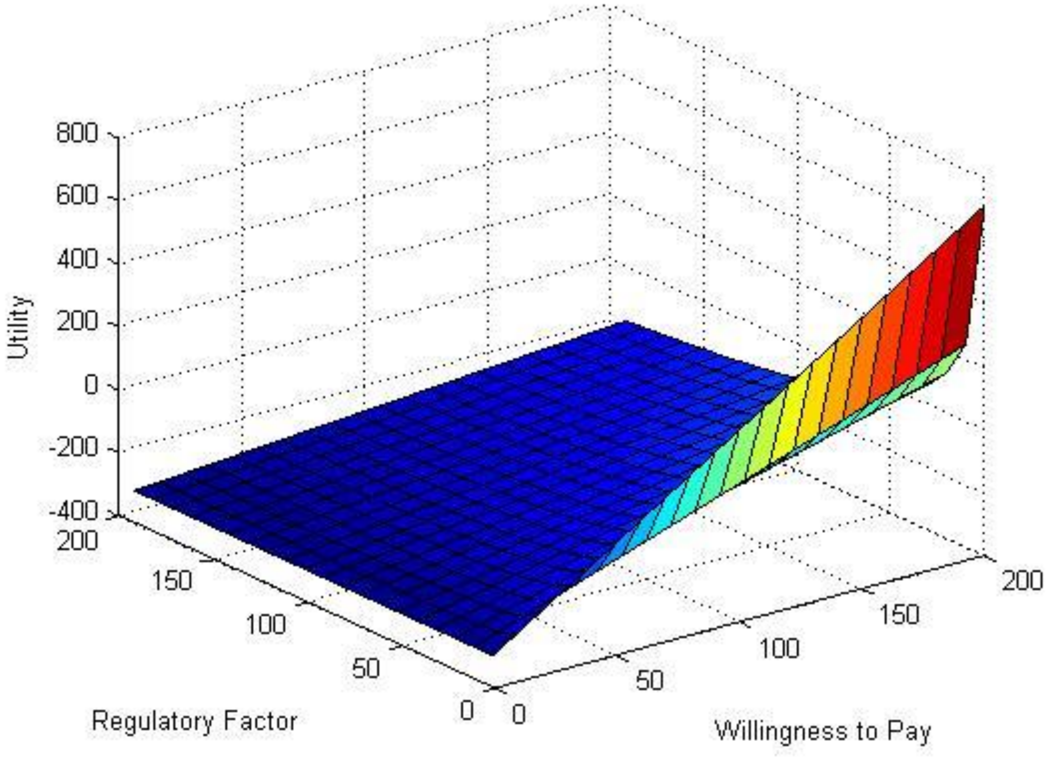


Figure 4.10: Utility versus willingness to pay and regulatory factor at ω_i =150, p_i =2

Table 4.10: Utility versus willingness to pay and regulatory factor at ω_i =150, p_i =2

Name	**Value**	**Min**	**Max**	**Range**
w	150	150	150	0
g	<20*21> Double	1	191	190
u	<20*21> Double	-300	703.45	1003.5
p	2	2	2	0
α	<20*21> Double	0	200	200

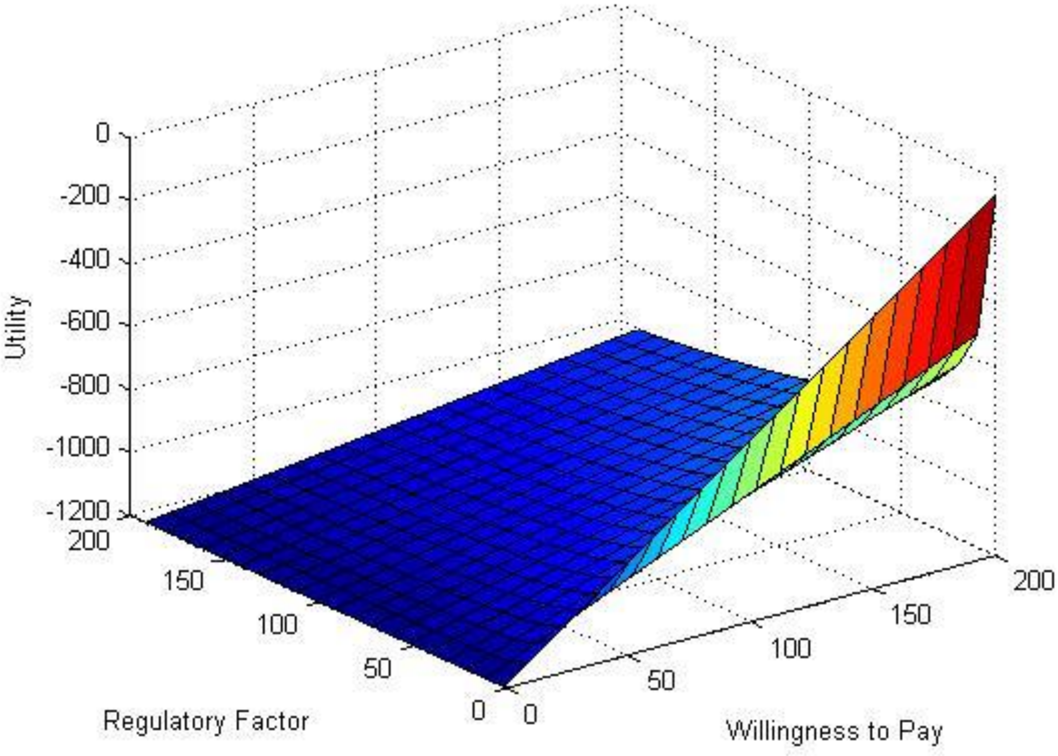


Figure 4.11: Utility versus willingness to pay and regulatory factor at ω_i =300, p_i =4

Table 4.11: Utility versus willingness to pay and regulatory factor at ω_i =300, p_i =4

Name	**Value**	**Min**	**Max**	**Range**
w	300	300	300	0
g	<20*21> Double	1	191	190
u	<20*21> Double	-1200	-58.57	1141.4
p	4	4	4	0
α	<20*21> Double	0	200	200

4.4.5 Effect of price on utility

From Figures 4.12 and 4.13, it can further be deduced that utility is higher at lower price compared to high prices an indication that users are motivated to utilize the service by the price. Pricing plays a vital role for NaaS provider to venture into investment. The higher the price the less conducive and unprofitable for the Mobile service provider to ride on the network been provided by the NaaS provider. But lower prices are a boast to the service user as it is favourable for their business i.e. the Mobile Network Operators (MNO).

Considering a Zambian scenario where the three mobile operators i.e. MTN, Airtel and Zamtel will be attracted to increase their traffic on the NaaS provider's network by lower prices. The increase in the usage of the NaaS infrastructure by mobile players means more benefit in terms of revenue for NaaS provider. Higher prices deter or limits the mobile players usage of the network hence the reduction in utility which is translated in revenue for the provider.

In developing country like Zambia, however, it is obvious that most MNOs tend to behave in an economical and rational way which makes price discrimination and provider differentiation strategies valuable tool in setting business models that will promote social and economic development. From the MNO's point of view price affects operation behaviour in terms of network usage which is correlated to their willingness to pay for such service.

From the NaaS provider's perspective, choosing the right price which is close to the player/MNOs maximum willingness to pay level or reservation price is of great significance in optimizing NaaS provider's payoff.

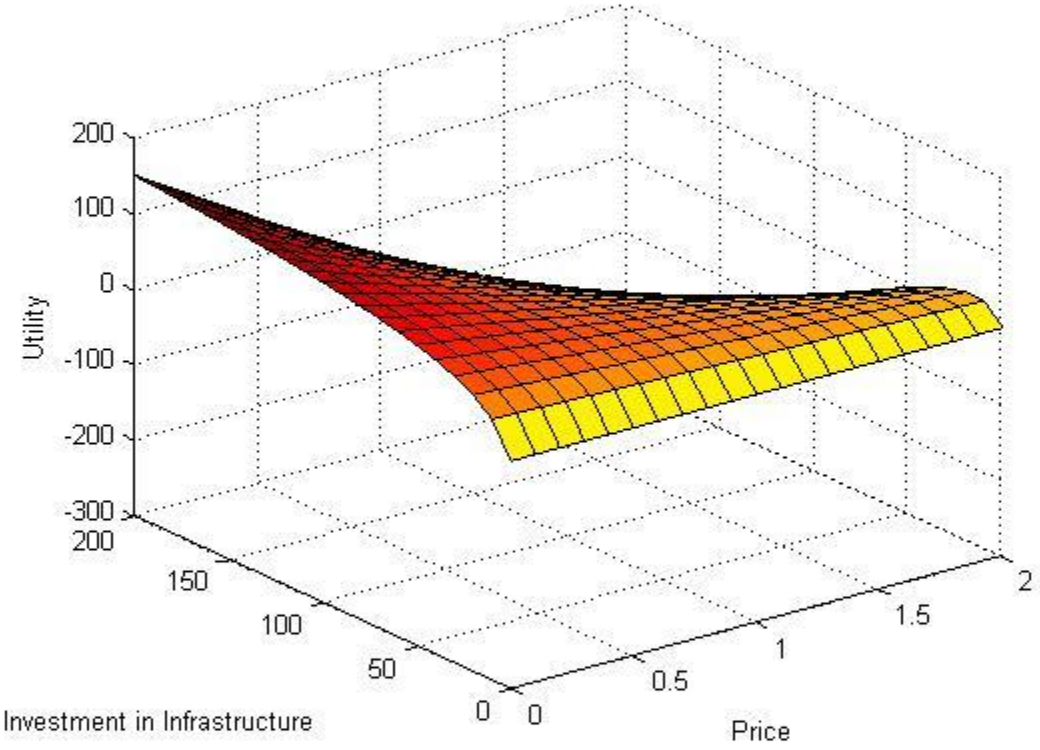


Figure 4.12: Utility versus price and investment in infrastructure when g_i =5 and α_i =40

Table 4:12: Utility versus price and investment in infrastructure when g_i =5 and α_i =40

Name	**Value**	**Min**	**Max**	**Range**
w	<21*21> Double	0	200	200
g	5	5	5	0
u	<21*21> Double	-251.4	148.54	400
p	<21*21> Double	0	2	2
α	40	40	40	0

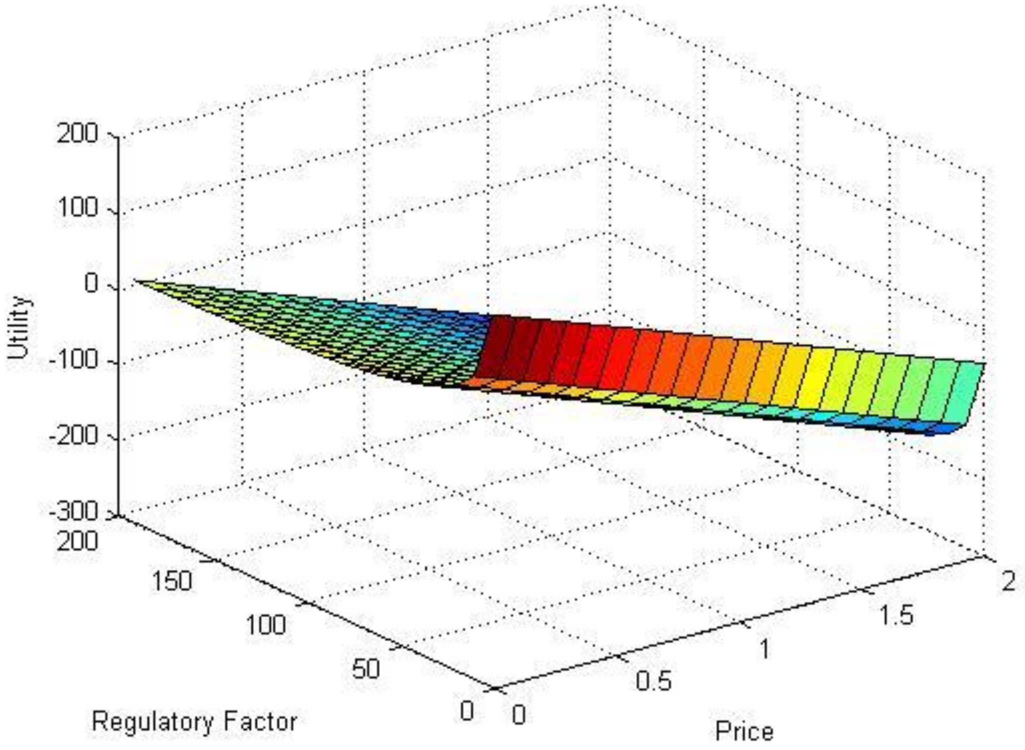


Figure 4.13: Utility versus price and regulatory factor when $\alpha_i = 40$ and $\omega_i = 120$

Table 4.13: Utility versus price and regulatory factor when $\alpha_i = 40$ and $\omega_i = 120$

Name	**Value**	**Min**	**Max**	**Range**
w	120	120	120	0
g	<20*21> Double	1	199	190
u	<20*21> Double	-220.4	191.83	412.33
p	<20*21> Double	0	2	2
α	40	40	40	0

4.5 Benefits of InfraS through Mobile NaaS to MNO and End User

The fourth objective is addressing the benefits of InfraS through Mobile NaaS to the service provider and the end user. From the literature reviewed from developed and developing countries globally, the following emerged as the benefits of InfraS through Mobile NaaS to the MNOs:

(i). NaaS enables mobile network operators (MNO) to participate in more profitable distribution models that meet the needs of their customers while minimizing the cost of adding subscribers.
(ii). Through NaaS, the mobile operator can move away from the current default of "sell through" to the more profitable "sell-as" and "sell-with" models.
(iii). The infrastructure sharing have a positive impact on the quick enhancement of the service capacity of telecom operators;
(iv). Economic benefit yielded due to saving and reductions on CAPEX and OPEX of telecom operators;
(v). The infrastructure sharing have a positive pact on environmental protection and reduction of resource waste;
(vi). Reduction in cost of radio equipment and transmission, the intense competition among vendors of equipment pushed down the prices enabling operators to replace existing equipment with new LTE equipment;
(vii). Reduces the involvement of operators in non-core businesses such as building and maintenance of sites thereby helping them to concentrate on their core businesses;
(viii). Increased connectivity to deployed tower infrastructure in rural and remote locations which are characterized by erratic power supply, poor access, difficult terrain and lack of adequate backup saved the hassle of operating in such conditions, and enables increase in penetration.

NaaS/ InfraS offer the following benefits to the end user;

(i). The infrastructure sharing have a positive impact on improvement of the network coverage ability and universal service level; where coverage of mobile services in underground train and road tunnels was achieved through sharing of leaky coaxial cable radio distribution systems as was the case with Singapore.

(ii). Increased connectivity to deployed tower infrastructure in rural and remote locations which are characterized by erratic power supply, poor access, difficult terrain and lack of adequate backup saved the hassle of operating in such conditions, and enables increase in penetration allowing service extension to un-serviced user.

(iii). Gives wider variety of choices based on quality to the end user in terms service provision by various MNOs.

(vii). Decrease in replication of investment- tend to reduce costs to the operators and service prices to the consumer,

(viii). Optimization of rare national resources- land or spectrum may be used more efficiently and this may have a positive impact on the wider economy,

(ix). Improved quality of service- in congested areas, there may be black spots with poor quality and coverage which can be boosted by sharing hence servicing the consumer with quality service,

(x). Positive incentives to provide service in underserved areas- consumers in un serviced area tend to benefit as this will encourage players to reach such areas,

(xi). Product and technological innovation- permitting operators to compete on service innovation and technology rather than solely on coverage will give a consumer product based choices rather than coverage.

4.6 Summary

From the reviewed literature by other authors, Willingness to pay, regulatory factors, the price and investment in infrastructure plays a bigger role in order to enhance infrastructure sharing through NaaS provision.

The results obtained from the simulations above, we have analysed the effect of willingness to pay (α_k), regulatory factor (g_i), investment in infrastructure (ω_i) and the price (*p*) on the utility (*u*). We have shown that willingness to pay has positive contributions to the provider of Network as a Service (NaaS).

An increased investment in infrastructure coupled with positive response in willingness to pay also increases utility to the NaaS provider. It was further deduced that investment in infrastructure alone when the other factors are constant it reaches a concave point or maximum point from which it starts reducing negatively.

The regulatory factor (g_i) and the price (*p*) have negative contributions on utility. When the regulatory factor is adjusted upwards by the regulator it reduces utility. Similarly, an upward adjustment in price also has a negative effect on the utility.

Therefore it can finally be concluded that for the NaaS provider to be enhanced in taking up the challenge of providing network infrastructure as a Service, willingness to pay response plays a significant role coupled with well-regulated regulating factors and pricing. Utility or payoff which is a number that reflects the desirability of an outcome to a player, for any kind of reason must be high for NaaS to venture into service provisioning otherwise it won’t be conducive to invest.

From the literature reviewed from developed and developing countries globally, the following emerged as the benefits of InfraS through Mobile NaaS to the MNOs: enable the MNO to participate in more profitable distribution model that meet the need of their customers and MNO can move away from the current default of sell through to the more profitable sell as and sell with models. It has also a positive impact on quick enhancement of service capacity of telecoms operators. Apart from the economic benefit yielded through Capex and Opex saving by MNO, InfraS have a positive impact on environmental protection and reduction in resources wastage.

Reduction in the involvement of operators in non-core businesses such as building and maintenance of sites thereby helping them to concentrate on their core businesses;

NaaS/ InfraS offer the following benefits to the end user results into network coverage improvement, quality of service and wider variety of choices for user. The reductions in replication of investment tend to reduce costs to the operators which are translated into service charges reduction to the consumer.

The optimization of the rare national resources such land or spectrum when used efficiently may have a positive impact on the wider economy.

CHAPTER 5: CONCLUSION, RECOMMENDATION and FUTURE WORK

5.1 Introduction

Rolling out mobile services in Zambia has been a daunting mission to some service providers, especially to the new entrants. The major cause underlies in the fact that each service provider, within the framework of policy and regulation, was required to carry out the deployment of its own infrastructure; starting from site survey, site acquisitions, space negotiations with land owners, constructions of towers, equipment room installations up to the final commissioning of the site. Normally, this cost money and time when other service providers' infrastructure that can be used or shared is already in place. Infrastructure sharing by mobile network operators can play a significant role in addressing such vices. The service provision is just concentrated in the urban areas while the rural areas deemed unprofitable are underserviced.

To address these challenges a study was taken to see how infrastructure sharing can be enhanced in Zambia in order to achieve communication for all according to the Zambia National Broadband Strategy of 2014 [22] , where the following objectives of the study were addressed:

(i). Identify factors which are necessary for infrastructure sharing in Zambia.
(ii). Analyse the effect of such parameters on infrastructure sharing.
(iii). Come up with the model that will promote infrastructure sharing among operators.
(iv). Determine possible benefits of InfraS/ NaaS to the MNOs and the end users.
(v). To apply cooperative game theoretical model under information symmetry and asymmetry in order to investigate the best response under which to optimize utility in infrastructure investment.

5.2 Summary of the Study

From the literature of game theory in chapter 2, it has been reviewed that Game theory is a branch of applied mathematics which deals with numerous persons' decision prototypes of conflict and cooperation amongst cogent decision-makers [11] [12]. The definitions of the terms used are as listed below:

(i). Nash Equilibrium, also called strategic equilibrium, is a list of strategies, one for every player, which has the property that no player can unilaterally alter his strategy in order to get a better payoff or utility.
(ii). Rationality occurs when a player is seeking to play in a manner which exploits his own payoff.
(iii). Payoff (utility) is a number that reveals the desirability of the outcome to a player for whatever reason.
(iv). Mixed strategy is viewed as an active randomization, with given possibilities, which regulate the player's decision.
(v). Best Response in game theory, is the strategy or strategies which produces the most favourable outcome for a player in comparison to other players' strategies.

From chapter 2 it was review that the business model of mobile communication was traditionally based on full ownership of network infrastructure [11] [12]. With the tremendous record of growth and demand for wireless communication services globally, there is need to move from the traditional way of sole network infrastructure to network infrastructure sharing through the provision of Network as a Service (NaaS).The cost of deployment, management and maintaining network infrastructure is driving the need for innovative model of infrastructure deployment and management.

Some of the renowned benefits of infrastructure sharing have being:

(i). Great saving in terms of Capital expenditure (Capex) and Operation expenditure (Opex).The principal benefit been cost saving in terms of planning, rolling out, maintenance and upgrading of their networks,
(ii). Sharing of network infrastructure will encourage a shift from competition on the basis of network coverage to compete on the basis of feature and services, hence promoting innovation and growth which will finally benefit the whole mobile industry,
(iii). Spectral-efficiency- when operators share backhaul microwave frequencies or pool their spectrum, this result into optimal use of their spectral resources,
(iv). Sharing infrastructure ensures speedy and easy commencement of operations,
(v). Reduced Time to Market,
(vi). Coverage expansion.

As highlighted in Chapter 3, using the adapted model on infrastructure sharing from Sumbwanyambe and Nel [12], simulation was done using Matlab in order to determine the effect of parameters such as the investment in infrastructure, the willingness to pay, the regulatory factor and price have on utility. It was done to determine the best response for the NaaS provider to venture into infrastructure investment.

It was done under information symmetry and information asymmetry with the following conditions respectively:

1. The provider of NaaS will invest in infrastructure under information symmetry if and only if $u_i \geq 0$
2. The provider of NaaS will not invest in infrastructure under information asymmetry if and only if $u_i \leq 0$

From the simulations results obtained from chapter 3, analysis on the effect of willingness to pay (α_i), regulatory factor (g_i), investment in infrastructure (ω_i) and the price (*p*) on the utility (*u*) was done as evidenced from the simulated results in chapter 4. We have shown that willingness to pay has positive contributions to the provider of Network as a Service (NaaS).

An increased investment in infrastructure coupled with positive response in willingness to pay also increases utility to the NaaS provider. It was further deduced that investment in infrastructure alone when the other factors are kept constant it reaches a concave point or maximum point from which it starts reducing negatively.

The regulatory factor (g_i) and the price (*p*) have negative contributions on utility. When the regulatory factor is adjusted upwards by the regulator it reduces utility. Similarly, an upward adjustment in price also has a negative effect on the utility.

Therefore it can finally be concluded that for the NaaS provider to be enhanced in taking up the challenge of providing network infrastructure as a Service, willingness to pay response plays a significant role coupled with well-regulated regulating factors and pricing. Utility or payoff which is a number that reflects the desirability of an outcome to a player, for any kind of reason must be high for NaaS to venture into service provisioning otherwise it won’t be conducive to invest.

5.3 Recommendations and Future work

With the Zambia Nation Broadband Strategy (ZNBS) proposal of 2014 in place whose aim is to provide ‘communication for all’ with broadband in the country [22] , we can recommend Network as a Service (NaaS) provision to be the answer to the strategy. For the strategy to be a reality, according to the analysis from the simulated results, the Zambia government and the regulatory body ZICTA should avail enabling environment for venturing into the provisioning of network as a service. This can be dangling attractive incentives that would woe third part investors into NaaS in terms of price caps and other regulatory factors. This strategy can be driven by markets or promoted by governments when the private sector does not have the incentives or resources.

We also recommend that the government and ZICTA should consider taking the Public Private Partnership (PPP) approaches to enhance InfraS through the building of infrastructure under open access, non- discriminatory and low-cost pricing principles. The recommended PPP model that can be used are Cooperative Model which is a jointly built and operated infrastructure by service providers with government subsidy; the equity model where the government obtain equity in exchange for contribution; the concession model which is done through public tender issued by government to select a private operator to build and operate the infrastructure; and the management contact model where the government issues a public tender to choose a private operator to build, operate and commercialise the infrastructure.

Having the infrastructure model in place with the controlling parameters, future works should concentrate on taking a step further on how Network as a Service can be implemented fully and effectively in Zambia under the theme “Spread the Infrastructure, they will follow”.

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APPENDIX A: MATLAB SIMULATION CODES

2D GRAPH PLOTING

```
>> a=>0; b=>0; c=>0; s=>0;   (Parameters defining)

>> u= s*log (1+a/.b)-a.*c;

>> Plot(x, y); (2D graph plot)
```

3D GRAPH SURFACING

```
>> a=>0; b=>0; c=>0; s=>0;   (Parameters defining)

>>[x, y] = Meshgrid (xgv, ygv);   (Scalar/ vector conversion into matrix)

>> u= s*log (1+a/.b)-a.*c;

>> Surf(x, y, z); (3D graph surfacing)
```

APPENDIX B: CONFIMATION LETTER OF PAPER SUBMISSION TO UNIVERSITY OF ZAMBIA JOURNAL