Sustainable off-grid electricity supply using a LTE communication model for rural towns in South Africa.

by

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DECLARATION

I, Barend Bernhardus Johannes Groenewald, declare that the contents of this dissertation/thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

As far back as 2008 the demand for electricity in South Africa (SA) has exceeded the supply of electricity (Joffe, 2012). Electricity generation in SA is a monopolistic industry driven by Eskom with most of its electricity generated by large coal-fired plants and one nuclear plant. This is in line with most countries where electricity is generated by these large power-generating plants and then transmitted via high voltage transmission systems. This situation in SA however came to a head during 2008 with a power crisis which the majority of South Africans will not easily forget. This crisis shook the South African nation and at the same time made the consumers realise that they can no longer rely on Eskom as a sole supplier of electricity and that they, the consumer will have to invest in ways to alleviate this crisis. The months of blackouts reminded every consumer how important it is to have access to electricity. Since 2008, the electricity provision in SA has seen some changes but in spite of these changes SA's power system remains under huge strain and will continue to be under strain until Eskom manage to complete and add their latest two large power stations, Medupi and Kusile to their network to deliver the capacity needed to relieve the shortage of supply. Recovering from the effect that the 2008 crisis had on the South African industries and the public as a whole is without doubt the most pressing and immediate challenge for South Africans. As this is to the long term prospects for the economy a secure supply of electricity is essential. This will have to be done at a cost which South Africans can afford if the economy is to sustain better and faster rates of investment and economic growth whilst providing access to electricity for all.

It is therefore absolutely critical that the dependence on Eskom as a sole supplier of electricity should diminish. The South African government and policymakers will, therefore, need to consider measures on how to transform Eskom to allow its current grid to integrate alternate power generation sources such as renewable energy to open up opportunities for independent power producers (IPPs) to compete and stabilise the country's electricity supply market. In addition to the inputs from the South African government and the policymakers South African industries and potential power generators will have to expand the energy supply mix in SA. This is important if the industry is committed to addressing the challenges of climate change. New players in the energy generation fields will have to be brought in together with new investors, technology and skills.

One of the biggest challenges is to convince the South African government that an energy generation monopoly is no longer sustainable and that an energy generation mix can be perhaps more sustainable, reliable and "cleaner" if the right balance between IPPs and SA's monopoly energy generator is carefully orchestrated and properly governed. Affordable cost structures will attract investments from IPP's and have already started doing so. Fin24

(Lameez Omarjee (Fin24), 2019) reported that South Africa’s Energy Minister Jeff Radebe explained; “The National Energy Regulator of SA (Nersa) issues a licence to all IPPs, based on a full disclosure of information required, tariff and tariff escalation. A public participation process also takes pace to scrutinise the tariff before a licence is granted, before Eskom signs purchase power agreements (PPAs), Nersa will issue an approval for Eskom to enter into PPAs and confirm in writing that Eskom will be allowed the full associated cost under the cost recovery mechanism. Radebe further stated that the cost of buying energy from IPPs through purchase power agreements (PPAs) was included as expenditure, before the calculation of Eskom's operating profit” (Appendix A provides more insight).

With the many renewable energy resources being developed, distributed power generation is an alternative way of diversifying the energy mix to satisfy most of the above requirements. The challenge here is how South Africans ensure that distributed power generation as an integrated energy mix between existing generation and new renewable energy generating resources are optimally utilised. In light of the growing global population which is driving an even greater increase in the demand for electricity and governments around the world focusing on reducing carbon dioxide (CO_2) emissions by increasing the utilization of renewable energy sources in the power, chain seems to be the ultimate answer. In addition, these complex challenges are indeed driving the evolution of smart grid (SG) technologies which come with a whole host of new challenges and questions that needs to be answered.

One of the most important challenges and questions to be answered is how effective communication systems will be deployed within smart grids (SGs) that will have highly efficient, fast very reliable and very secure characteristics to transmit and respond to any type of fault conditions which may occur within SG’s. There are many wireless technologies available such as Cognitive Radio Networks (CRNs), 3rd Generation Partnership Project (3GPP) release, Universal Mobile Telecommunications System (UMTS) and Long-Term Evolution (LTE) etc. Cognitive radios are intelligent software-defined radios (SDRs) that efficiently utilize the unused regions of the frequency spectrum, to achieve higher data rates. The CRNs however is an unlicensed technology which suffers from lower Quality of Service (QoS) (Ekström, 2009) and high latency problems. LTE and 3GPP releases is a promising licensed technology which addresses issues of QoS and latency, one of the technologies which can address all these issues (Patel et al., 2016). The potential of utilising existing LTE networks could reduce the cost of operation and expansion during the introduction phase of SG deployment in SA. Some work is available in literature to ascertain the viability of LTE as a communication technology for SG applications (Peng Cheng et al., 2011). For the purpose of this thesis, different communication networks will be studied, compared and modelled to determine their suitability for deployment within SG’s for rural areas in South Africa. In this thesis, the work is done mostly on communication technologies that can automate and manage the increased degree of

complexity when the present grid system will be replaced by a smart grid. The digital technology that will allow a swift communication between the user and the utility, along with sensing along the transmission lines. The research considered smart metering, different interruptions, power outage and disturbances as a type of call that might originate in smart grids. These calls are handled using cognitive radio networks first and which are replaced by LTE networks due to the problem of license in cognitive radio networks,

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GLOSSARY

Abbreviations	Definition
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partner Project
BBU	Baseband Unit
CA	Carrier Aggregation
CC	Component carrier
CDMA	Code Division Multiple Access
CQI	Channel Quality Indicator
CR	Cognitive Radio
CSFB	Circuit Switched Fall Back
EB	Exabyte
EPC	Evolved Packet Core
EPS	Evolved Packet System
ERAA	Energy-efficient RB Allocation Algorithm
EUTRA	Evolved Universal Terrestrial Radio Access
EUTRAN	Enhance Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GA	Greedy Algorithm
GBR	Guaranteed bit rate
GSM	Global System for Mobile communication
IMT	International Mobile Telecommunication
IMT 2000	International Mobile Telecommunications 2000
IMT ADVANCED	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control
MBR	Maximum bit rate
MCS	Modulation and Coding Scheme
MHz	MegaHertz

MIMO	Multiple In Multiple Out
MME	Mobility Management Entity
MRFU	Multi-mode Radio Frequency Unit
OVSF	Orthogonal Variable Spreading Factor
PCELL	Primary Cell
PDCP	Packet Data Convergence Protocol
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RLC	Radio Link Control Link
RRC	Radio Resource Control
RRM	Radio Resource Management
RRU	Remote Radio Unit
SAE	System Architecture Evolution
SCELL	Secondary Cell
SF	Spreading Factor
TBS	Transport Block Size
TDD	Time Division Duplex
UE	User Equipment
UMTS	Universal Mobile Terrestrial Systems
WP5D	Working Party 5D

CHAPTER ONE
INTRODUCTION

1.1 Introduction

South Africa's (SA's) current major sole national supplier of electricity is currently reported to be in a state of chaos due to alleged misappropriation of revenue, corruption and state capture by the previous government. This puts the current government under enormous pressure to rectify this situation as this has a huge negative impact on the economy of South Africa (SA)[1]. Independent Power Producers are also no longer willing to wait and tolerate the slow progress in this regard. In addition to this, the very steep increases in electricity price have also woken up the public to start putting pressure on the government to expedite decisions on the economically viable implementation of IPP's and governance of off-grid micro and nano-grid systems. This situation is forcing the SA government to consider different ways of providing electricity to the SA public. Initial investments by licensed IPP's, the vastness of the country and the multitudes of people in rural areas of the country are driving the electricity industry towards a system of distributed power generation. The positive spin-off from this is that the SA government is in the fortunate position that its power- producing and power distribution industry can leapfrog much of the initial technologies other countries tried and found inadequate. The opportunity to learn from a wide range of developments from across the globe is at its disposal in this regard. The need for the sustainable development of electricity, energy efficiency improvement, and environment pollution reduction is favoring the development and deployment of distributed generation (DG) (Wang, 2009).

1.1.1 Distributed Generation

Distributed power generation, also termed distributed generation (DG) is electricity generating plants that is connected to a distribution network rather than the transmission network. In contrast with large generating plants, they produce power on the customer's site or at a local distribution utility and supply power directly to the local distribution network (Sweta & Samir, 2013). DG technologies include wind farms hydroelectric power, bio-gas power, small turbines, fuel cells, and photovoltaic systems. Smaller versions of DG can result in microgrids and nano grids (Infield & Li, 2008) (Mohn & Piasecki, 2011). Much has been written about the penetration of distributed generation into power generation networks and their future impact. India, as reported by (Sweta & Samir, 2013) and (Singh & Jain, 2009) is a prime example of

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[1] *"South Africa economy: Quick View - Eskom backs down over IPP connections." Economist Intelligence Unit: Country ViewsWire, 15 Feb. 2017. Academic OneFile, http://link.galegroup.com/apps/doc/A481291190/AONE?u=capetech&sid=AONE&xid=3ab5f963. Accessed 10 Sept. 2018.*

this. This kind of generation has the potential to fundamentally alter the structure and organisation of the SA electric power system in lessons learned from (Singh & Jain, 2009).

With today's technology, the power grid can become a smart grid (SG), capable of recording, analysing and reacting to transmission data, allowing for more efficient management of resources, and more cost-effective appliances for consumers (Rekola, 2012) (Gertmar et al., 2005). This raises the need for government organizations and power producers to develop an understanding of how most effectively to introduce SG capability into the current and future power distribution strategies of the country. For this to happen, inoperability of components within current and future DG's linked to a reliable and fast responding communication system must be key and an understanding of the various techniques in smart condition monitoring, smart sensing technologies, and fault condition monitoring in SGs is essential.

1.1.2 Interoperability

Incorporating smart condition monitoring systems, which monitors real-time condition and diagnoses faults automatically in existing or potential future SGs requires that all data actuators deployed in a SG system provide accurate data for fast corrective action. This implies that all the components within the power networks and the distributed networks required to generate data must technologically match each other. The process of "matching" components technically and operationally is usually referred to as interoperable. Inoperability in simple terms means that all components of a network must be able to interface and "talk" to one another without causing any additional or unrelated fault conditions in a particular network. The major challenge is to integrate and match interchangeable parts from different vendors globally (Commission, n.d.). This raises the need for interoperability standards that will allow network planners to incorporate network components from any supplier with the understanding that these components faultlessly integrate and with existing equipment at all levels within a particular network regardless of its size and coverage. Eskom provides some guidelines in this regard which is a combination of international best practices. (Chatterton, n.d.), (Craib et al., 2013). Helpful in this regard is the standards that the IEEE (Standards et al., 2011) introduced. This set of interoperability standards known as "The IEEE 2030 Smart Grid Interoperability Reference Model (SGIRM)" provides a reference model with its intended methodology to provide interoperable design and implementation alternatives for systems that facilitate data exchange between SG elements, loads, and end-use applications. This platform provides a theoretical representation of the SG architecture from three perspectives: 1) power systems; 2) communications; and 3) information technology. Its intensions are to create a common dialogue and cataloging for the SG community to communicate effectively. The SGIRM contains both entities and relationships within the environment of the SG and defines interfaces in a technology-agnostic manner. Similarly, the European Standards Organisation (ESO) in collaboration with the European Committee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI) produced a report (Joint et al., 2011) as a guide to identify existing standards and the gaps still in place as well as to the work ahead to meet suggested European standards for SGs. The studies conducted in this thesis are compatible with the IEEE 2030 as it mostly follows the three SG architecture perspectives mentioned above and the tier classifications as prescribed in (IEEE Std 2030-2011, 2011).

This provides SA network planners with a platform from which they will have to define standards in future networks so that components not only “speak” the same language but also understand each other’s "thought" processes.

On the different networks, it should, therefore, be clear that all the different elements of the system “speak” the same language without the need for translators to achieve optimal speed for information exchange. On the systems management level, there should be clarity on how information should be routed and whilst doing so determine what information is fundamental for the communication of the equipment and on the physical level it needs to be determined which way the information needs to be transported either via wires, cables, Internet, WiFi etc.

In the recent past years, the power distribution grid in SA has been under discussion and the consensus is that deep transformation is required and that government, Eskom and independent power producers will soon have to agree on the widespread diffusion of Distributed Energy Resources (DER), the management of Distributed Energy Storage (DES), and the potential of hosting the future presence of electric vehicles, which will pose serious control issues to the traditional management system of the distribution grid.

1.1.3 Smart grids

To alleviate problems experienced by providing electricity to remote areas the current electrical distribution system will need to undergo significant adjustments. To satisfy both the increasing demand for power and the need to “keep the lights on” in SA whilst at the same time provide electricity to remote areas power grids that can handle these challenges in a sustainable, reliable and economical way is needed.

One alternative way is the deployment of SGs which will help provide more electricity to meet rising demand, increase reliability and quality of power supplies. SGs can be designed to respond to the demand and to help balance electrical consumption with supply, as well as the potential to integrate new technologies to enable energy storage devices in these remote areas. Deployment of SGs will provide greater control over energy costs and more reliable energy supply for consumers.

1.1.4 Potential of deploying smart grids within South African power grids

Current research and the fast developments in the renewable energy environments coupled to the latest developments in the power electronics and electronic communication environments demonstrate that the current electricity grid structures are no longer adequate for the demand imposed on traditional electricity grids. Traditional electricity grids can and must become smarter. This is driven by the improvements in substation automation, better power flow/demand response and the constantly growing demand and the advent of more and more DGs.

To fully implement "smart technology" into the current SA electricity grid, the state and structure of the current power grid are inadequate. SA has a relatively good communications infrastructure supplied and supported by four different communication networks within the country and its international communication network partners. These networks using the latest 3G, 4G and the prospects of 5G technologies have the potential to expand and support the penetration of DG's into rural parts of the country. The main requirements of an SG are that it needs to be highly efficient, fast, very reliable and very secure communication network to interconnect their intelligent devices that could be distributed over a wide area, (Yan et al., 2013). The current grid can be enhanced with the deployment of DG's. The deployment of DG's and the potential dissemination of data across the current SA communication network providers will enhance the opportunities for future SGs. This will enable interconnections among various components and systems, public networks, and devices, as well as operations and planning functions. The introduction of SGs will further enhance the opportunity to increase information about network performance metrics to help to better understand, manage, and control performance, flexibility, and a host of other elements while data management and analytics can be increased to effectively collect, store, and interpret the massive amounts of data that can potentially be collected.

The data collection, analysis of data and the management of SG data have sparked questions around what communication network topologies and combinations of communication technologies will be required to successfully, effectively and efficiently implement SGs, especially in the rural parts of the country. To find answers to these questions the different existing communication networks and the latest combinations of communication technologies best suited to the SA needs and requirements will be investigated, tested and recommendations proposed can be implemented in

Careful consideration will be given to unlicensed technologies such as Cognitive Radio Networks (CRNs) which will be tested, simulated and recommendations made against its latent qualities that allow systems to adapt themselves according to the surrounding conditions, traffic load, congestions in network topology and wireless channel propagation. In spite of its low QoS this still makes CR based networks ability to handle heterogeneity and robustness in the next-generation wireless communications systems data address spectrum requirements. (Li-Chun Wang et al. 2011). (Wang et al., 2007). The utilization of the bandwidth spectrum is always a precious commodity in any communication system and network. As previously indicated LTE and 3GPP releases are promising licensed technologies which address issues of QoS and latency, one of the technologies which can address all these issues (Patel et al., 2016).

Long Term Evolution (LTE), 4th generation (4G) communication has been around for a while in SA but with its recent rapid spread in deployment as a public network LTE and the performance of LTE as a public network has not been tested a viable option to be used as a backbone for a SG system in the South African environment with its many rural areas that is desperately in need of electricity. Due to its widespread deployment, LTE could be considered as a viable opportunity for communication in SGs (Madueno et al., 2016).

1.2 Statement of the research problem

Over the past few decades, electricity consumption has experienced phenomenal growth across the world (al., 2013). This saw the introduction of new technology on the distributed generation platform, namely the smart grid.

At this stage, a level of maturity in smart grid generation and applications has been reached which allows us to see areas that can benefit from applications based research. At distribution voltage level in SGs, one of the major challenges is the variability and uncertainty of short circuit current from distributed generation (DG) sources.

Renewable generation operating conditions are often highly unpredictable. In many cases, low voltage ride-through capability mitigates that the protection settings of distributed generation systems are of crucial importance. These should be able to not only isolate the faulted part of the system in a short time to prevent large scale tripping of smart grid supply systems but also be capable to adapt in a very short time to new scenarios. This will allow the achievement of high reliability and selectivity.

Power plant items usually have a higher failure rate during their early life (0-5 years) due to manufacturing and installation problems and when they age, failures of power plants threaten the reliability of network in both developing and developed countries.

It is thus anticipated that smart monitoring would play an increasing and crucial role in improving the reliability of power networks as a whole, but more importantly in SGs.

To address these problems, it is necessary to transmit fault condition data experienced in SGs ultra-fast, highly securely via communication networks to accurately analyze and transmit the fault condition data to manage and implement measures to minimize and control the impact on the electricity grid. For this the current South African communication infrastructure and communication network topologies will be studied, analyzed and simulated to propose the best possible answers to these questions.

1.3 Rational and motivation for the research

The economy of SA faces the challenge of rapid increases in energy demand. According to SA info reporter (2012), the energy demand is projected to double by 2030. Due to a lack of adequate investment in the country's energy infrastructure in the past years, the energy demand is increasing faster than it can be met by the power utility company (SAinfo reporter, 2012).

More than 3.4 million households are without electricity in SA (Carbon Trust Advisory, 2013), with approximately 1.3 million households located in rural communities (Carbon Trust Advisory, 2013). Despite the determined effort by the SA government to improve power capacity and transmission lines, large areas in some parts of the country will still be off-grid soon (Carbon Trust Advisory, 2013).

Recognizing this major problem and the inability of its sole energy supplier to cope with this demand the SA government has recently granted 29 licenses to IPP's to start developing an independent distributed generation of power. DG is an established practice throughout many parts of the world and this now opens the doors in SA for several power utility companies to take up the challenge (Candelaria, 2012).

Recently many distributed power systems have been researched and developed, especially to meet the need for high penetration of renewable energy resources such as wind turbines and photovoltaic systems. The distributed power systems have advantages such as the capacity relief of transmission and distribution, better operational and economical generation efficiency, improved reliability, eco-friendliness and power quality (R.C. Dugan and T.E. McDermott, 2002) (Ramakumar, 2004) . The current energy policy of many governments in the world, as is the case with the SA government is to competitively increase the requirement of the penetration of renewable energy sources and distributed generation.

Although DG appears to be the ultimate solution to alleviating the power demand in SA, DG comes with its challenges in terms of how it fits into the overall power infrastructure of SA, how distribution will take place, i.e. topologies used, size of distribution networks and the smart monitoring and management/protection of infrastructure of these networks.

1.4 The Research Objectives and Aims

1.4.1 The research objective

One important feature of an SG is the integration of high-speed, reliable and secure data communication networks to manage the complex power systems effectively and intelligently. These communication networks are responsible for delivering fault condition messages to a central control point to maintain a secure and stable power system. The secondary objective of this study is to comprehensively interrogate the South African mobile communication network architectures in terms of how to optimise and maximally utilise any available frequency channels in the mobile communication spectrum for the transmission of any fault message related to future SGs.

On completion of the above, the primary objective of this research is to provide spectrum sensing/utilization algorithms, simulations and recommendations on which current technology, i.e. Cognitive Radio, UMTS and LTE is best suited for transmission of SG data in terms of data priority.

1.4.2 The research aim

The aim of the research is intended to realise the objective and these are:

- Literature review of Cognitive Radio Networks (CRNs), Universal Mobile Telecommunications System (UMTS) and LTE communication topologies currently used for condition monitoring within existing SGs.
- Determine the most appropriate and most effective communication technology topology for potential SGs in SA by mathematical modeling and simulation of CRNs, UMTS' and LTE technologies.
- Based on the simulation results, investigate, analyse and recommend the most appropriate communication topology for potential SGs in SA.
- Recommend possible future work to ensure fast, secure and reliable transmission of fault condition data in SGs

1.5 Research design and methodology

To achieve the research, aim as set out, a brief overview of the different communications technologies and networks currently deployed within current electrical networks, Distributed Energy Resources (DER) and Distributed Energy Systems (DES) are studied and investigated, with the focus on the feasibility of LTE network topologies combined with other communication technologies as a backbone for application in SGs.

Unoccupied or underutilized spectrum within communication networks is uneconomical. The objective of cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability. Since most of the spectrum is already assigned, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users The MATLAB network simulator is used to model and simulate the complex behaviour of the data parameters and proposed scheme as applied to the CRN. The assignment of channels is modelled as continuous time Markov chain based on studies conducted by (Xing et al., 2006) which shows that continuous time Markov chain models are accurate in predicting the behaviour of open spectrum access under the assumption that the arrival traffic has Poisson distribution. The Poisson distribution is a statistical distribution showing the likely number of times that an event, in this case, SG fault condition calls will occur within a specified period. This will be used for the independent events of Secondary Users (SUs) opportunistically or randomly accessing the licensed mobile communication channel when it is not being used by any Primary Users (PUs) which occur at a constant rate within a given interval of time.

LTE provides low latency, high capacity, ubiquitous coverage and use of the existing public infrastructure. Its scalability, reliability, and security constitute also important factors that enhance the suitability of this particular technology. Although, LTE was not initially intended for Smart Grid applications as SG data traffic characteristics are not the same as those generated by commercial and enterprise communication networks in use, hence the LTE network needs to be optimized for data flows related to SG applications. The MATLAB network simulator is used to model and simulate the complex behaviour of the data parameters and proposed scheme as applied to the LTE-UMTS network.

Based on the data gathered from the resultant CRN, UMTS and LTE simulations recommendations are compiled.

1.6 Research significance

So many challenges and concerns that relates to power supply globally, these are the rapid increase in global energy demands, the high costs of connecting rural communities and remote locations to an existing power grid, the need to mitigate climate change by use of green energy sources and resource depletion (Omer, 2008).

The ongoing modernization of the electrical grid mainly relies on the evolution of the power distribution grid into a fully automated and interconnected electrical network in medium-voltage level. As smart grid capabilities expand dramatically, real-time monitoring, protection and control of distribution within SGs will require the reliable transmission of system-critical protection messages and/or massive amounts of monitoring information (Lewin et al., 2013).

LTE is a communication standard to meet the rapid increase of mobile data usage in the future, and because it is high speed, it offers solutions of a commercial nature, including business network expansion with the deployment of electrical energy in rural networks.

1.7 Thesis outline

The chapters in this thesis covers the current research on the latest communication topologies used within current electrical grids, DER's, DES' and SGs, the existing challenges and problems of the available communication topologies, and the modeling, design, control, and development of an experimental topology for application and deployment within SGs (Li, Fangxing, Qiao, 2010).

Chapter One: An introduction to the thesis. It defines the statement of the research problem, the background to the research, the objectives, the aims and the goals of the research.

Chapter Two: deals with the literature review: An investigation of the various communication topologies available, their advantages and disadvantages for deployment within SGs.

Chapter Three: discusses the suitability of integrating Cognitive Radio (CR) technology in Smart Grid applications. Cognitive Radio having to handle both primary users (PUs) and secondary users (SUs) in the same frequency spectrum provide opportunities for SUs to access the spectrum watchfully when PUs is not using it. SG data or information is considered as a SU in Cognitive Radio in terms of prioritize utilization of available frequency spectrum. An assignment Smart Grid Priority (SG-P) scheme is proposed for CRNs used as underlying communication for SGs. Simulation and performance analysis of SG-priority schemes of the relevant SG data or information transmitted is then concluded. A new dynamic access scheme is proposed which differentiates secondary users (SUs) based on their type, voice or data call.

Chapter Four: Discusses the advances in UTMS and LTE and the impact of each technology on the transfer of data or information. Both technologies are further discussed in terms of their available capacity threshold checks regarding speed, the direction of motion and type of requested call, voice or data before assigning the relevant calls. An appropriate scheme is then proposed.

Chapter Five: Based on the technology advances and scheme proposed in chapter four further investigations proposes a handoff *LTE-UMTS* (*HLU*) scheme for a base station (*BS*) having both UMTS and LTE interface for a 4G network handling mobile traffic (M-T) and smart grid traffic (SG-T). The proposed scheme uses spectrum available at the *BS* for mobile as well as smart grid traffic (SG-T).

Chapter Six: Linking to chapter five, chapter six proposes an optimum code assignment (OCA) scheme which meets the demand for quality of service (QoS) of a call with improved capacity utilization of the Downlink of Multi-Rate MC-DS-CDMA when used for SGs. The simulations and results indicate that the proposed scheme is ideal for both mobile network and SG network traffic originating together.

In summary, the work in chapters 5 and 6, is using LTE and 3G interface to handle SG traffic along with normal mobile traffic. The LTE interface provides faster communication but has limited bandwidth (BW) which requires careful access schemes. The work in literature researched uses only the LTE interface to handle SG and mobile traffic which leads to more waiting time for SG traffic. These two chapters propose the use of a 3G interface which is already available on Base Stations and is used by voice calls only. This BW or capacity is available most of the time. This interface has OVSF codes that are spread in time and frequency. They can be assigned in one dimension but we spread it in 2-dimension to improve quality of service (QoS). The use of a 3G interface provides better services to SG traffic in the absence of LTE traffic and also uses LTE interface during non-busy hours. These schemes together with LTE communication show optimum usage of BW or capacity as compare to other schemes in the literature.

Chapter Seven: The work in this chapter uses the same basic models and parameters as in chapter 5. Here the difference is the variation in mobile traffic and SG traffic, to test the performance of the communication technology in case one of these streams of traffic is higher and its overall impact.

The synergy of the work conducted firstly illustrates the possibilities of the use of cognitive radio and LTE communication technologies in dealing with a future increase in SG traffic. Secondly, the LTE work available is further improved by using a 3G interface for SG traffic. Future SGs require efficient communication technology for handling communication between two nodes. The grids are combined with LTE to provide this synergy. The LTE communication is used to handle the calls, data transfer requests, etc. emerging from grids.

Chapter Eight: Conclusion and future work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The literature reviewed covers both past and present research on communication topologies applied and integrated into SGs. In the review, a discussion of the topologies and various technicalities of communication networks are presented. The discussion highlights the importance of the utilization of the current SA cellular communications backbone, limitations of available bandwidth and frequency spectrum within existing communication networks. Maximizing and fully utilizing available frequency channels within the allocated frequency spectrum is cost-effective and allows for increased channel capacity. This, however, is rarely the case and hence a review of all current and past communication technologies and topologies was conducted to investigate vacant channel opportunities that can be utilized for the transmission of data as required by SGs.

2.2 Communication topologies, advantages, and disadvantages

The most appropriate communication topologies for SGs in SA is dependent on the current communication infrastructure and the state of existing and future planned power networks in the country. The current degrading state of the power networks was highlighted in the abstract and chapter 1. Although mention is made of the expansion of the current power network with the future addition of the Kusile and Medupi power stations the unavoidable introduction of renewable resources (GreenCape, 2017)(Bawaba, 2017) either as part of the current power network or as an addition to the existing power networks requires fair consideration of each communication topology's advantages and disadvantages to ensure the most efficient, stable and secure communication networks. For this purpose, an investigation into the evolution of SGs and the evolution of various communication topologies into SGs was conducted to set a platform from which recommendations and decisions can be made suited to South African circumstances and its communication infrastructure.

2.3 Evolution from "Conventional Power Grids towards Smarter Power Grids"

In the past 20 years electricity consumption has experienced exponential growth across the globe (Dong et al., 2013). This has seen the introduction of new technologies on the distributed generation platform, namely the smart grid. At this stage, a level of maturity in smart grid generation and applications has been reached which allows us to see areas that can benefit from applications based research. Historically the distribution of energy was mostly distributed through large interconnected networks in a unidirectional fashion (Khan et al., 2015). Due to the unidirectional flow of the electric power, from generation to the consumers within a city the monitoring of network information is managed and monitored only within the distribution networks. These large distribution networks and structures are very costly to build and as costly to maintain. As a result, many of these large structures are starting to age and as a result of the aging will be facing new challenges. This will be mainly due to increased energy demands, new developments in the renewable energy markets, protection and security of systems and reliability of systems demanded by the consumers. Confronted with these challenges various researchers such as (Wang et al., 2011)(Khan et al., 2015)(Communication et al., 2014) and others started proposing smart grid (SG) prototypes or SG paradigms. These SG paradigms are the introduction of state-of-the-art enabling information technologies such as embedded sensing, broadband wireless communication, universal computing, and adaptive control. In addition to these technologies, they recommended the automation and intelligent management of these enabling information technologies. The authors of (Khan et al., 2015) and (Wang et al., 2011) indicated that the inclusion of these SG technologies can lead to significant improvements in the efficiency, effectiveness, sustainability, reliability, security, and stability of the electrical grid. The most prominent features which distinguishes SGs from conventional power grids highlighted by (Peng Cheng et al., 2011), (Omer, 2008), (Lewin et al., 2013) and (Li, Fangxing, Qiao, 2010) are their supervisory control and data acquisition (SCADA), advanced metering infrastructure (AMI), i.e. smart meters, load balancing through real-time demand-side management to real-time energy pricing, fault-tolerance, remote meter reading, power quality, and detection of unauthorized usage. The potential self-healing properties of SGs described by (Amin & Wollenberg, 2005) are the benefits of detection, isolation, and recovery from faults.

The reviewed literature covers both past and current research on communication technologies and techniques used to develop “smarter” grids in terms of communicating the overall condition of a particular electrical network. As indicated, new technology on the distributed generation platform has opened up opportunities to consider high tech communications technologies which were not previously possible or considered.

2.4 Evolution from Conventional Smart Power Grids towards Smart Grids

As far back as 2005, (Amin & Wollenberg, 2005) set the platform for SGs of the 21st century for the United States of America. Although the development of SGs potentially brings many benefits to future grids in terms of network agility they pointed out that large power networks opens itself up to vulnerabilities in terms of how to maintain security within the network and the expected durability/survivability of these large scale power providing infrastructures and the possible new threats that networks may experience which was never experienced or anticipated in the past. Further reference by (Amin & Wollenberg, 2005) was made to grid computing and possible self-healing networks that would be deployed within SGs to cope with the mentioned vulnerabilities. During this time the European Commission (ETP SmartGrids, 2006) provided their “Vision and Strategy for Europe’s Electricity Networks of the Future”. In this vision and strategy, they illustrated their future technology platform for SGs to be implemented in Europe. The main elements of their vision included:

- Creation of a toolbox containing a set of technical solutions for rapid and cost-effective deployment which will enable existing grids to receive power injections from all energy-generating resources;
- Enhance European cross-border trading off grid and power services through the merging of regulatory and commercial frameworks;
- Provide open access to shared technical standards and protocols for the deployment of equipment from any chosen manufacturer;
- Enable businesses to use their innovative service delivery to improve their efficiency and quality of service to their customers through the development of information, computing, and telecommunication systems;
- Provide guidelines on how “old” and new” designs of grid equipment can be interface without compromising the interoperability of automation and control arrangements.

The period 2005 to 2008 was characterized for a period during which technology platforms, visions and strategies started emerging for SGs. From the research conducted during this period, it is clear that stakeholders were starting to realize that SGs can no longer be ignored. Hence in 2009, work of (Ipakchi & Albuyeh, 2009) posed the question of whether the industry is ready for the transition to SGs indicating that global consumer needs are driving and forcing electric power systems globally to change to meet their needs. Analyzing consumer needs allowed (Ipakchi & Albuyeh, 2009) to classify these consumer needs into two categories namely, need for “environmental compliance” and “energy conservation”. It was clear from the customer-driven needs that future grids will have to be extremely reliable whilst the existing infrastructure needs to be better maintained. This transition will require better operational efficiency and customer service. The electricity distribution grid will in future experience more significant changes and the old ways of manually handling operations which mostly contained electromechanical components will have to be more “smartly” dealt with. The transformation to a “smarter grid” will have to take cognizance of the consumer-driven environmental targets to accommodate a greater emphasis on demand response (DR) providing support to future plug-in hybrid electric vehicles (PHEVs) inclusive of new technologies that will drive distributed generation and the associated storage capabilities. These needs and changes will have a profound effect on the power industry with challenges which will require the future smart grid to be evolutionary while keeping current operations going and at the same time ensuring that the changes required in the smart grid philosophies are significant enough to demand the major changes the future power systems will require.

During 2011 the focus of researchers started shifting towards the investigation of possible communication architectures that would carry power networks into the future. End-to-end communication architecture for SG's was proposed by (Sauter & Lobashov, 2011), suggesting that a two-level system focusing specifically on metering, monitoring and the management of data collection applications. During this investigation, it was found that future communication architecture for SG's need to provide specific qualities and services which will satisfy application requirements whilst being able to distinguish them from other networks. At this stage research recommendation indicated that the considered communication architecture would be beneficial for low-bandwidth and high-latency field-level networks using point-to-multipoint communication.

Several communication infrastructure industrial trials were conducted during 2012 by (Sharif, 2013) who recorded the basic requirements of these communication infrastructures as part of the global view of what future communication structures should strive for. Enabling smart grid communication infrastructures is critical to maintaining efficiency and reliability in interconnected devices and systems together with the security of these devices and systems. While enabling smart grid communication technologies are critical to future power networks it is further critical that interconnectivity is maintained to avoid situations where wholesale changes are required to existing power network communication systems. For this, a balance in technical standards is required to ensure that the overall innovation of future communication structures continues to evolve as technology evolves. In conclusion, it was acknowledged that communication infrastructures are essential to the success of the evolving SGs. Flexible and universal communication infrastructure is imperative in both the construction and operation of future SGs. Based on their survey, it was suggested that developments within the smart grid environment should constantly consider both system design and operations to ensure the most efficient and secure communication infrastructures.

With the power generation and power distribution fraternity realizing that smart power grid communications infrastructure is inevitable, (Yan et al., 2013) supported this notion with a survey on smart grid communication structures. This was followed in 2013 by (Sharif, 2013), a survey on smart grid communication infrastructures which highlighted the requirements and challenges of communication within a smart grid. An integrated and multifaceted smart grid will allow for improved efficiency of legacy power generation within its transmission and distribution systems allowing the penetration of modern communication systems to enable the usage of clean renewable energy resources. It was highlighted by (Sharif, 2013) that there is a global consensus that SGs need to be endorsed and encouraged. At this early stage, many researchers agreed that the deployment of SGs will merge traditional electrical grids and communications infrastructures to form “smart” electrical networks. The “smart” convergence of traditional electrical grids and communication infrastructures will safeguard the interconnection of all electrical grid and communication infrastructures to provide sustainable electricity supplies. Apart from the strong consensus amongst many researchers globally that SGs need to be promoted they have identified numerous innovative communication technologies suitable for SG applications (Gungor et al., 2013) which will significantly increase the overall efficiency of power grids. Parallel to this, their studies highlight that one of the significant challenges and applications of communication technologies in SG will require a complex two-way communication infrastructure. The work of (Sharif, 2013) and (Gungor et al., 2013) has provided a SG roadmap for the further evolution of SGs.

Complex two-way communication infrastructure will speed up the evolution of SGs supporting power flow between intelligent components, sophisticated computing, information technologies, as well as business applications. Future SGs will possibly be considered as data communication networks that will with the aid of specific power management hardware devices provide a flexible and seamless interface between the different complex components of the system for efficient utilization of the energy. The suggested two-way communication infrastructure should contain 1) *an application layer*, 2) *a power layer*, and 3) *a communication layer*, the core of the system responsible for the interfacing of all the systems and devices. These SG communication infrastructures could be either public or private infrastructures. The core of this thesis is to investigate, model and propose how best the public or private communication network infrastructures in SA can be utilized to provide SA with sustainable SGs.

2.5 Future impact of communication technologies on smart grids

Smart grids are the next-generation electric power grid for electricity generation, transmission, distribution and control with energy savings, reduced cost and increased reliability, security, safety, quality of service and transparency. This is reflected in a report compiled by the United States Department of Energy’s National Energy Technology Laboratory. (NETL, 2010) and supported by many researchers.

To achieve this goal, along with smart management, protection, and energy sub-systems, SG requires smart information and communication sub-systems (Fang et al., 2012). Smart information and communication sub-systems are responsible for smart metering, monitoring and management and reliable transfer of information among the communicating components of SG. Smart meters (SMs) are considered to be used in SGs for metering which is advanced metering infrastructure (AMI) and enabled of two-way communications with the central system (Modern et al., 2008) (Homes et al., 2012). SMs record electricity consumptions in a small interval of time, collect data from different sensors and voltage, current, phasors measuring units, and send the data to the central system for monitoring grid status and billing the customers. SMs also perform two-way communication of the data traffic generated for real-time pricing, DR, and protection and control.

The key to achieving the potential benefits of SG is the effective design and implementation of reliable, secure, energy-aware and cost-effective communication infrastructure (Gungor et al., 2010). Wired solutions for backbone networks and wireless solutions for the rest of the smart grid networks (SGNs) are promising for SG since wireless technologies provide significant benefits over wired technologies such as low installation cost, rapid deployment, mobility etc. (Gungor et al., 2010). SMs are usually connected to the power outlets at residential homes and there transmit power levels are not very high for wireless communication to the gateways (GWs) of the backbone network. GWs of the backbone network can be the base stations (BSs) of cellular networks or GWs/access points (APs) of wireless local area networks (WLANs). Thus, there is no constraint of energy for network lifetime in wireless SGNs unlike the battery-powered wireless sensor networks (WSNs). However, greenhouse gas emission can be significantly high due to the exponential growth in the number of SMs (Saghezchi et al., 2013). SMs are expected to communicate with the GWs of the backbone network within a small time interval and hence, the duration of electromagnetic radiation per day from an SM is significantly high compared to that of a mobile phone. As a result, the effect of electromagnetic radiation on public health is also a major issue in SG wireless communication (Smart Grid Interoperability Panel, 2012). Therefore, it is essential to perform green wireless communication in SGNs considering the ongoing concerns about climate change, environment protection and public health (Bera et al., 2014) (Erol-Kantarci & Mouftah, 2015). Considering the priority of green SG communication, IEEE has a special interest group (SIG) on green SG communications.

Smart grid data traffic at the SMs is to be quite different from the commercial and enterprise communication network data traffic (Luan et al., 2013). The data volume at an SM at a particular time is considered to be significantly low for SG (Kuzlu et al., 2014) (Ramírez et al., 2015) (Khan & Khan, 2013).

Further, data traffic at the SMs can be classified as periodic and aperiodic. Energy consumption, voltage, current, and phasors information provides periodic data traffic whereas real time pricing, DR and protection and control information are likely to provide aperiodic data traffic. The periodic data traffic is usually delay-insensitive. However, the aperiodic data traffic can be both delay-sensitive and insensitive. One of the big challenges in SG is to handle the massive amount of data to the data center from a large number of SMs (Aiello, 2016). Since the packet sizes at an SM are small and comparable with a packet headers, protocol overhead due to packet headers will increase SG data volume significantly. For SG, one of the ways to reduce data volume is to concatenate multiple small packets to a single larger packet. Since, the packet generation rate in an SM is low, packet concatenation at the SMs is not effective. A better approach is to aggregate small packets from many SMs to an intermediate point called data aggregator (AG), concatenate the small packets to larger packets, and then send the larger packets to the GWs of the backbone network (Bartoli & Hern, 2010), (Karimi et al., 2015).

For an SG communication system, reducing energy consumption to transfer the massive amount of data traffic from a large number of SMs to the GWs of the backbone network is a big challenge. Generally, energy consumption increases if data traffic is transferred to the GWs via AGs due to the increment of the number of transmission hops and physical distance (Mark, Jon W., 2003). Conversely, data volume as well as energy consumption, can be reduced by aggregation if data traffic is sent to the GWs via AGs and the small packets are concatenated at the AGs. Thus, it is very difficult to decide whether aggregation is better or not for transferring data traffic of an SM. Path loss, fading, and shadowing are the main characteristics of the wireless channel (Mark, Jon W., 2003). A packet transmission from a transmitter to a receiver may be unsuccessful due to the unreliability of the wireless channel. Usually, a packet is retransmitted until it becomes successful. The average number of required transmissions for the successful transmission of a data packet depends on the signal to noise ratio (SNR) of transmission and the packet length. Generally, it increases with decreasing SNR and increasing packet length. A low transmit power results in low SNR at the receiver and hence, the energy consumption is expected to be high at a low transmit power due to the high average number of retransmissions per packet. Further, if transmit power is very high, the average number of retransmissions becomes low but the energy consumption remains high due to the high transmit power. Thus, for a data packet of an SM, there is an optimal transmit power between low and high transmit power levels. On the other hand, if the size of a concatenated packet is large, it requires a higher number of retransmissions and higher energy for successful transmission. A concatenated packet of small size is not energy efficient due to protocol overhead. Thus, data concatenation should be performed with the optimal concatenated packet size.

The related work can be divided into three categories: communication architecture, data aggregation, and energy-efficient SG communications. *Communication Architecture:* Several researches have been conducted on finding suitable SG communication architecture. Heterogeneous architectures are proposed in (Zaballos et al., 2011) and (Wang et al., 2011) with both power-line and wireless communications. Ho *et al.* propose a wired solution for backbone network and wireless solution with heterogeneous networks, i.e., home area network (HANs), neighbourhood area networks (NANs) and wide area networks (WANs) for the rest of the SGNs. Bu and Yu (Bu & Yu, 2012) propose an energy-efficient scheme for heterogeneous networks, cognitive radios, and smart grid using an interference pricing policy for avoiding the interference caused by different entities in the network. Sun *et al.* (Hongjian Sun, Arumugam Nallanathan, Bo Tan, John S. Thompson, 2012) analyze the impact of different relaying strategies used in the conventional wireless networks in the context of SG applications.

Data Aggregation: Data packet concatenation and data aggregation are addressed in many research works. Karimi *et al.* (Karimi et al., 2015) address the packet concatenation for data aggregation by formulating an integer linear program (ILP) optimization problem for minimizing the total data bits by optimally configuring the sizes of the concatenated packets for a given number of aggregated small packets. They demonstrate that the optimal concatenation method is very effective in reducing data volume and capacity requirements. A significant number of researches have been carried out on data aggregation in WSNs for reducing data volume by redundancy elimination and information analysis (Maraiya et al., 2011), (Dhasian & Balasubramanian, 2013), (Khedo et al., 2010), (Raventós, 2015). Energy-aware data aggregation problem in WSNs is also studied in many studies (Intanagonwiwat, n.d.), (Heinzelman et al., 2000), (Lmdsey & Raghavendra, 2001), (Sivaranjani et al., 2013). However, these studies focus on routing, tree or cluster formation for energy-efficient data aggregation.

Moreover, SG data is quite different from WSN data. There are very limited studies on data aggregation in SGNs. The studies in (Yan et al., 2011), (Tavasoli et al., 2016) (Kursawe et al., 2020) (Jin et al., 2014) and (Uludag et al., 2016) focus on secure aggregation of data traffic in SGNs where most of the studies do not address the issue of reduction of SG data volume in aggregation process. Tavasoli *et al.* (Tavasoli et al., 2016) study the optimal placement of data aggregators in a hybrid wireless and wired network that helps the customers and the micro-grid to communicate within themselves with less delay and overhead in getting energy services. Bartoli *et al.* (Bartoli & Hern, 2010) consider secure lossless data aggregation and packet concatenation for SG machine to machine (M2M) networks and show that data aggregation and packet concatenation reduces energy consumption and traffic volume. However, this study has not addressed the optimal data aggregation, data concatenation, and power control to optimally minimize the energy consumption.

Energy Efficient Communication: In recent years, only a very few researches focus on energy-efficient SG wireless communication (Bera et al., 2014), (Bu et al., 2012). Bera *et al.* proposes an energy efficient smart metering scheme for green SG communication by forming a coalition game among SMs and plug-in hybrid vehicles. Bu *et al.* (Bu et al., 2012) consider energy-efficient communications and the dynamics of the SG in operating green wireless cellular networks and show that SG has a significant impact on green wireless cellular networks, operational expenditure and CO_2 emissions. A literature review on the energy-efficient information and communication infrastructure in SG is presented in (Erol-Kantarci & Mouftah, 2015).

2.6 Transmission of Smart Grid Data via Cellular Communication Networks

Linking to the above research findings a survey conducted by (Kalalas, Thrybom, et al., 2016) points out that cellular communications within neighbourhood area networks (NANs) creates a favourable communication paradigm for cellular communications as a supporting technology for fundamental operations of SG NANs, such as the transmission of SM data within networks.

Germán Fernández, (Germán Fernández, 2019) confirms that not only has bidirectional communications has become a need but a necessity for SGs. The drive for continued efficiency and resiliency has led to further SG application demands such as grid visualization, real-time load monitoring, asset monitoring, smart metering, and consumer load control. Establishing two-way communications over a vast grid is a formidable challenge. Integrating public cellular networks within SGs does provide a cost-effective solution. A mix of public cellular networks with the right network design and routing equipment can be combined to deliver reliable, high data rate solutions. This study is not aimed at designing cellular or SG networks but focusses on how to optimally utilise the current communication technologies within the existing SA communications backbone. More specific it focusses on techniques to fully exhaust the available bandwidth and frequency spectrum. Full utilisation of the frequency spectrum within existing communication networks is not only cost-effective but allows for increased channel capacity and hence transmission of SG data. For this reason, the following cellular technologies in SA cellular networks were investigated.

2.6.1 Cellular Communication Technologies

There are several existing technologies for cellular communication such as GSM, GPRS, 2G, 3G, 4G and WiMAX. Cellular networks operate on different frequency bands including the 450 MHz band, 700 MHz band, 800 MHz band, 900 MHz band, 1800 MHz band, 2100 MHz band, and 2600 MHz band. Administrations typically issue "frequency band management rights" rather than individual licenses per base station. Mobile operators can thus manage and monitor the awarded spectrum themselves. A growing number of Administrations allow carriers to decide which wireless standard to deploy (e.g. GSM, CDMA, UMTS, LTE or a combination of cellular technologies). This modern spectrum management concept poses new challenges to spectrum monitoring. How to measure frequency occupancy, spectrum efficiency, license compliance or spectrum interference?

The majority of these technologies currently exist in the SA cellular communications backbone. The advantages of the cellular networks are that it is an already existing infrastructure with a wide area of deployment, high rates of data transfer, available security algorithms that are already implemented in cellular communication. The major disadvantage is that cellular networks are shared with other users and are not fully dedicated to smart grid communications. This can be a serious problem in the case of an emergency state of the grid (Baimel & Tapuchi, 2016). A very basic overview of each technology, GSM, CDMA, UMTS, LTE is provided in the next sections.

2.6.1.1 Global System for Mobile communications

Global System for Mobile communications (GSM) is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices such as mobile phones and tablets. It was first deployed in Finland in December 1991. As of 2014, it has become the global standard for mobile communications – with over 90% market share, operating in over 193 countries and territories including SA.

2.6.1.2 Code-Division Multiple Access

Code-division multiple access (CDMA) is a channel access method used by various radio communication technologies. CDMA is an example of multiple access, where several transmitters can send information simultaneously over a single communication channel. This allows several users to share a band of frequencies (see bandwidth). To permit this without undue interference between the users, CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code).

2.6.1.3 Cognitive radio Networks

Cognitive radio technology is a stand-alone radio based on IEEE 802.22; it is a key technology for optimizing the underutilization of spectrum (Ghassemi et al., 2010) and (Ejaz et al., 2013) due to spectrum increasing demands caused by the advancement of wireless technologies. CR networks enable secondary users (SUs) to efficiently and without interference access the spectrum when it is not used by the primary licensed user. This spectrum sensing technique provides opportunities to be widely deployed in SG WAN, backhaul and distribution networks over large geographic areas. The CR technique consists of opportunistic access to unused spectrum, we believe that this technique will have a great future for SG since it delivers high performance, high-speed data transmission, scalability and, fault-tolerant broadband access.

According to FCC rules, cognitive devices operate within the very high frequency (VHF) channels and the ultra-high frequency (UHF) channels. The bandwidth of these channels is 6 MHz and they range from 54 MHz to 72 MHz, 76-88 MHz, 174-216 MHz, and 470-806 MHz.

2.6.1.4 Universal Mobile Telecommunications System

The Universal Mobile Telecommunications System (UMTS) is a third-generation mobile cellular system for networks based on the GSM standard. Developed and maintained by the 3GPP (3rd Generation Partnership Project), UMTS is a component of the International Telecommunications Union IMT-2000 standard set and compares with the CDMA2000 standard set for networks based on the competing CDMA One technology.

2.6.1.5 Long Term Evolution

Long Term Evolution (LTE) is a successor of UMTS. LTE is a 4G standard that represents the high-speed wireless communications technology that many modern cell phones and cellular devices use for high-speed mobile communication. LTE downlink speed is around 325 Mbps compared to UMTS has a peak downlink throughput of 85 Mbps. LTE uses OFDMA in its downlink and SC-FDMA in uplink while UMTS supports WCDMA.

CHAPTER THREE

COGNITIVE RADIO: SMART GRID COMMUNICATION TECHNOLOGY

3.1 Introduction

Like most other countries SA is no different when it comes to the increasing demand for new wireless services. The increasing number of wireless users and their need for applications places a huge strain on the available frequency spectrum which is becoming increasingly scarce. With SA on the brink of opening up opportunities to convert its monopolist power-producing regime to that of a possible world-leading renewable energy resource market demands careful planning of how the IPP's will feed their power into existing power networks or link them as lone standing power units. As new grids from renewable resources will come online in SA the country need to ready itself to capitalise on existing communication technologies and maximise the usage of current available communications infrastructures in the country. Prior research has pointed out that there are many proposed communication architecture platforms from which information can be drawn to meet the needs of SA for the development of a smart grid power information communication network with comprehensive high-speed, broadband, strong self-healing abilities(IEEE Std 2030-2011, 2011), (Dehalwar et al., 2014), (Kazičková & Buhnova, 2016), (Tuballa & Abundo, 2016) and (Anon, n.d.).

Based on the research background, the state of the current SA power grid and the investments made by IPP's and the realisation by the SA government that the integration of power grids can no longer be avoided. This thesis set out to highlight how the SA communications backbone can be utilised to fully exhaust the available bandwidth and frequency spectrum. Full utilisation of the frequency spectrum within existing communication networks is not only cost effective but allows for increased channel capacity. Various communication technologies were investigated and evaluated to make this possible. The first innovative technology that was investigated to exploit unused or under-utilised spectrum to accommodate the additional data requirements that a fully integrated smart grid requires is the cognitive radio (CR) technology.

The key purpose is to allow unlicensed *(secondary)* users to use licensed frequencies on condition that the primary licensed users can be given the guarantee of minimum interference during their communication applications. Allowing opportunistic use of the wireless spectrum generates new problems such as peaceful coexistence with other wireless technologies as well as understanding the influence of interference that each of these networks can create. In this chapter two schemes for smart grids are proposed and are implemented on the Cognitive Radio network environment.

3.2 Prioritize Utilization of available Spectrum in Smart Grid Communications[2].

In todays' era, the smart grid (SG) requires communication between energy generation, its transmission, end to end distribution and utilization at user premises. This needs integration of an excellent communication technology to intelligently control and transfer a large amount of information from one node to another without effecting underlying the electricity distribution system. Cognitive radio networks (CRNs) is a promising technology which can address issues of controlling, collecting and transferring data in large amount and with improved utilization of available spectrum. The implementation and deployment of cognitive radio networks within SGs are thus an effective solution to alleviate the increasing demand for radio spectrum (Ma et al., 2011)(Wang et al., 2011). In CRNs, the transmission channel is licensed to the primary users (PUs) while secondary users (SUs) opportunistically or randomly access the licensed channel when it is not being used by any PU. Sus, therefore, needs to detect vacant channels for transmission and must vacate these channels when a PU starts to use the channel. The CRN must have the ability to provide priority of use to the PUs and avoid causing interference to PUs acting as receivers. SU transmissions must thus be interrupted whenever a PU starts transmitting. A CRN based communication scheme for SGs is proposed in this section, which prioritizes the communication traffic. The traffic is classified as prioritize and non-prioritize, the preference to access the spectrum is given to prioritized traffic and non-prioritize may be placed in a queue/buffer or end up being blocked. Simulation and results demonstrate a considerable reduction in blocking of prioritizing traffic and utilization of spectrum.

The SG is a rational system for power transmission, for which the communication technologies are utilized for the transfer of information and to enhance capability. These information technologies include wireless communication, sensing using embedded systems, adaptive, automated and management control to achieve reliability and bring sustainability in the interconnected power networks (Wang et al., 2011), (Ma et al., 2011), (Yu et al., 2011). Using communication technologies in SGs introduces many new services and functions like meter reading from a remote location, unauthorized utilization detection, control of SGs remotely. SGs can detect and control appliances remotely. It can also diagnoses faults in housing complexes or business complexes which bring down the energy cost and safety for consumer (Anon, n.d.), which includes traditional generator with or without emerging renewable distributed generator (DGs), industrial consumer and home consumers controlling thermostats, vehicles run by electricity and smart appliances (Erol-Kantarci & Mouftah, 2011).

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Many communication technologies can be implemented for SGs like wired communication, power line which uses the current wiring infrastructure for electrical power (Sebaali & Evans, 2015), (Güzelgöz et al., 2011). Wireless communication is the heart of all the communication in today's era and its developing too, which makes it an obvious candidate for SGs communication. Wireless technology was initially restricted to small distances and associated with low data rates (Wang et al., 2011). However, wireless sensor networks (WSNs) can be utilized for several SGs applications by the adequate implementation of its sensor nodes (Gungor et al., 2010), (Eris et al., 2014), (Yiğit et al., 2014). Traditionally, wireless networks are typically regulated and provided access to licensed users only which resulted in inefficient utilization of spectrum. The spectrum utilization can be improved by dynamically providing access of this spectrum to unlicensed users, CRNs is operating on this principle (Cacciapuoti et al., 2014). It not only addresses the requirements for communication but also addresses issues related to the standardization and security for SG communications (Yu et al., 2011), (Ghassemi et al., 2010), (Qiu et al., 2011). The utilization of the spectrum is limited to 15% normally and up to 85% in peak hours by licensed users. The CRNs also support different traffic types like multimedia, real-time while maintaining their quality of service (QoS) requirements which will become more stringent in future SGs.

3.2.1 Background to employ Cognitive Radio Networks in Smart Grids

CRNs can flexibly support many applications and needs of SGs employing it. Recently, some surveys on SGs and CRNs paved the path for SGs communication using CRNs. The survey in (Yigit et al., 2014), (Dehalwar et al., 2012), (Ma et al., 2013) briefly mentions the use of CRNs in SGs and its applications without mentioning the method of utilization.

SGs using CRNs are quite efficient in the collection and transporting the bulk of data with improved utilization of the mobile communication spectrum. The SG communications of today include all housing complexes and business entities. CRNs with reconfiguration capability can manage and control varied service types. CRNs use the unused spectrum within the mobile communication spectrum as a secondary user (unlicensed) (SU) in the absence of a primary user (licensed) (PU) which provides less delay in communication to time sensitive or real time data in SGs. CRNs also lead to a reduction in power consumption which influences the cost of the network, reduced congestion, better indoor propagation of signals etc. In this section, an assignment Smart Grid- Priority (SG-P) scheme is proposed for CRNs used as underlying communication medium for SGs. This scheme differentiates SGs data transfer based on their importance and amount. Within the SG network, certain fault conditions will trigger an emergency alarm which requires immediate attention and immediate response. Transmission of these data calls indicating emergency fault condition alarms will require priority within the CRN communication network. This type of data is given priority and is termed as priority calls and remaining as non-priority calls.

3.2.2 Cognitive Radio Network Parameters and Smart Grid Data

For the proposed Smart Grid- Priority (SG-P) scheme it will be assumed that the communication network has *N* channels and that the capacity of each channel is the same. Further assumptions are that the network is also equipped with a buffer (queue) with a capacity of n_B. The data or information CRNs transfers for SGs vary.

a) Alarm messages: This includes fault, error messages which need immediate attention. Also, neglecting them might lead to complete failure of the grid partially or fully. These messages are given the highest priority and are considered as real time calls (which cannot tolerate delay) and are denoted by SU_1.

b) Monitoring of Sensors: The sensors referred here are sensors distributed throughout the power network to monitor the general condition or “health” of the power network in its totality. These sensors are continuously monitored for security from any type of disruption due to any external disturbances. These messages are considered are at level 2 in priority and considered as multimedia calls (they can tolerate small delays). These are usually large volumes of data and are denoted by SU_2.

c) Meter Readings: The meter readings referred to in this context are end-user billing details acquired from advanced smart meters deployed through the power network collecting data that provides detailed and accurate power consumption information. As these meter readings mostly do not contain “urgent” details these meter readings are given the lowest priority and can withstand delay. These are denoted by SU_3.

For CRNs all these calls are secondary user calls. The SUs can only get access to a channel when a PU is not using it. If a channel is in use by a SU and a PU arrives, SU is kept on hold or maybe blocked if the buffer is full. A PU can only be blocked if and only if $n_{pu} = N$, where n_{pu} are the number of PUs. The remaining characteristic of CRNs also exists in the network. For example:

a) A channel is used by one call at a time.
b) A SU call is assigned randomly.
c) A PU call can use free or a channel assigned to a SU on arrival.

3.2.3 Smart Grid Priority Scheme in Cognitive Radio Networks

For the proposed SG-P scheme, the arrival of data requests of PU calls and SU calls (SU_1, SU_2 and SU_3) at sensor nodes is assumed to be Poisson’s distributed denoted by λ_p and λ_s respectively. While μ_p and μ_s are their service time respectively and they are considered as exponentially distributed. In the mobile communication environment, arrival and departure of calls is a random process. In a similar way information which SG nodes need to transfer is also a random process. Each node has its queue and each corresponding base station also maintains a queue with a capacity of n_B calls. Let the capacity of the buffer at any instant be denoted by n_{Bt}.

An illustration of different types of calls and their resultant algorithms is demonstrated below:

Primary User Arrival and Departure

Arrival Process

Case 1: If $n_{pu} = N$, and a new PU request arrives, the call will be blocked.

Case 2: $n_{pu} \neq N$,

a. One or more channel is free, assign PU call to any of them randomly.

b. All channels are occupied by PUs and SUs. Arrange the SUs in order of their priority and place the SU with the lowest priority in the buffer for buffer current capacity $n_{Bt} < n_B$. If buffer capacity at a node is full block the call. For two or more SU calls of the same priority, shift or block the call with minimum elapsed time in the network.

Departure Process

When a PU call ends. Check the status of the queue at the base station (BS), if $n_{Bt} \neq 0$ assign this free channel to the SU with the highest priority. If two or more SUs of the same priority exist in the buffer, assign a channel to SU with maximum elapsed time in the buffer.

Primary User Arrival and Departure

Arrival Process

When a SU arrives, the algorithm works as follows.

a. Check the priority level of arrived SU.

b. *If* (SU_1)

List all the channels assigned to $SU_2 and\ SU_3$.

If (no SU with priority 2 and 3 available)

If ($n_{Bt} < n_B$)

Place the new SU call with elapsed time

$t^E_{SU_1} = 0$ units in buffer and update $n_{Bt} = n_{Bt} + 1$.

Else

Block the SU_1call.

```
      End
    Else
    Select the SU with the lowest priority and minimum elapsed time in network i.e ($SU_2|SU_3$ && $(\min(t^{E_n}_{SU_2|SU_3}))$.
    If ($n_{Bt} < n_B$)
    Place the SU call with elapsed time $t^{E}_{SU_2|SU_3} = t^{E_n}_{SU_2|SU_3}$ units in buffer and update $n_{Bt} = n_{Bt} + 1$.
    Else
    Block the SU call.
    End.
    End
c.  Else if ($SU_2$)
    List all the channels assigned to $SU_3$.
    If (no SU with priority 3 available)
      If ($n_{Bt} < n_B$)
      Place the new SU call with elapsed time $t^{E}_{SU_2} = 0$ units in buffer and update $n_{Bt} = n_{Bt} + 1$.
      Else
      Block the $SU_2$ call.
      End
    Else
    Select the SU with the lowest priority and minimum elapsed time in network i.e ($SU_3$ && $(\min(t^{E_n}_{SU_3})))$.
    If ($n_{Bt} < n_B$))
    Place the SU call with elapsed time $t^{E}_{SU_3} = t^{E_n}_{SU_3}$ units in buffer and update $n_{Bt} = n_{Bt} + 1$.
    Else
```

```
        Block the SU call.
        End
    End
d.  Else
    If ($n_{Bt} < n_B$)
        Place the new SU call of lowest priority with elapsed time $t_{SU_3}^{E} = 0$ units in buffer and update $n_{Bt} = n_{Bt} + 1$.
    End
e.  End
```

In this algorithm, SU calls are originating from different sensor nodes placed on SGs. The calls are again a random process like simple mobile communication.

Consider a SGs network with 10 nodes with a centralized monitoring center that decide based on the information it receives from different nodes. Let the CRN network be equipped with *N* = 5, channels. The current status of the network is $n_p = 2, n_s = 2$ and $n_{Bt} = 0$ *i.e.* all the channels are currently occupied.

Let one SU is of priority 2 with $t_{SU_3}^{En} = 5$ units of time and two SUs (SU_{31} with $t_{SU_{31}}^{En} = 6$ units of time and SU_{32} with $t_{SU_{32}}^{En} = 5$ units of time) are of priority 3.

Scenario 1: If a PU or SU_1or SU_2 arrives the SU_{32} is placed in buffer with $t_{SU_{32}}^{E} = 5$ and channel assigned to the arriving call.

Scenario 2: If a SU_3, arrives it will be placed in buffer with $t_{SU_3}^{E} = 3$.

3.2.4 Simulation and Results

For performance analysis using simulations and results, the following assumptions are made:

- Number of channels of CRNs for SGs are L=10.
- The service times of primary users is $\mu_s = 0.5$ and service time of secondary users are $\mu_{s1} = 0.10$, $\mu_{s2} = 0.60$ and $\mu_{s3} = 0.20$ for SU_1, SU_2 and SU_3 respectively.
- Arrival rate of primary users is only 20% of the SUs, times more than primary users *i.e* $\lambda_p = 0.2\lambda_s$.
- Maximum buffer size is $n_B = 4$, buffer size is also varied 0, 2 and 4 for performance evaluation.

1) Blocking Probability: The blocking probability for a call is the ratio of blocking rate and arrival rate.

a) PUs: A PU call will only be blocked if $n_p \geq N$ and PU call arrive. The blocking probability for PU users is given by

$$P_p = \sum_{n_{p \geq N}} \frac{\lambda_p \, \pi}{\lambda_p} \tag{3.1}$$

where π is a function of n_p and n_{Bt}.

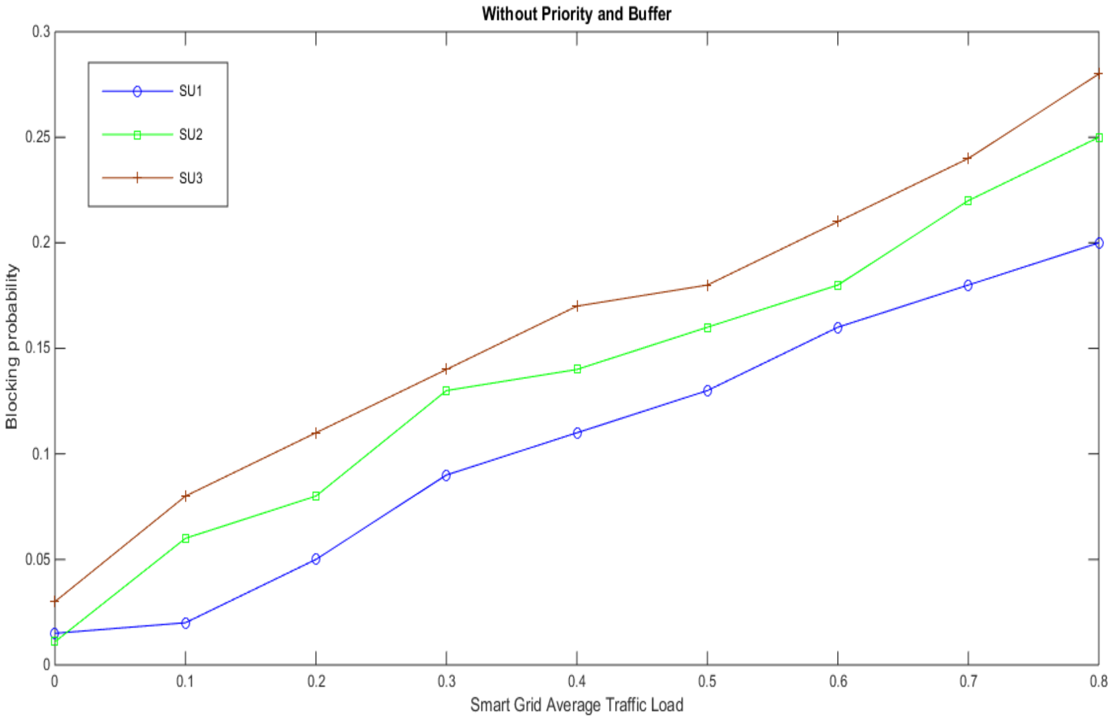

Figure 3.1. Performance of smart grid traffic in presence of PU without priority and buffer.

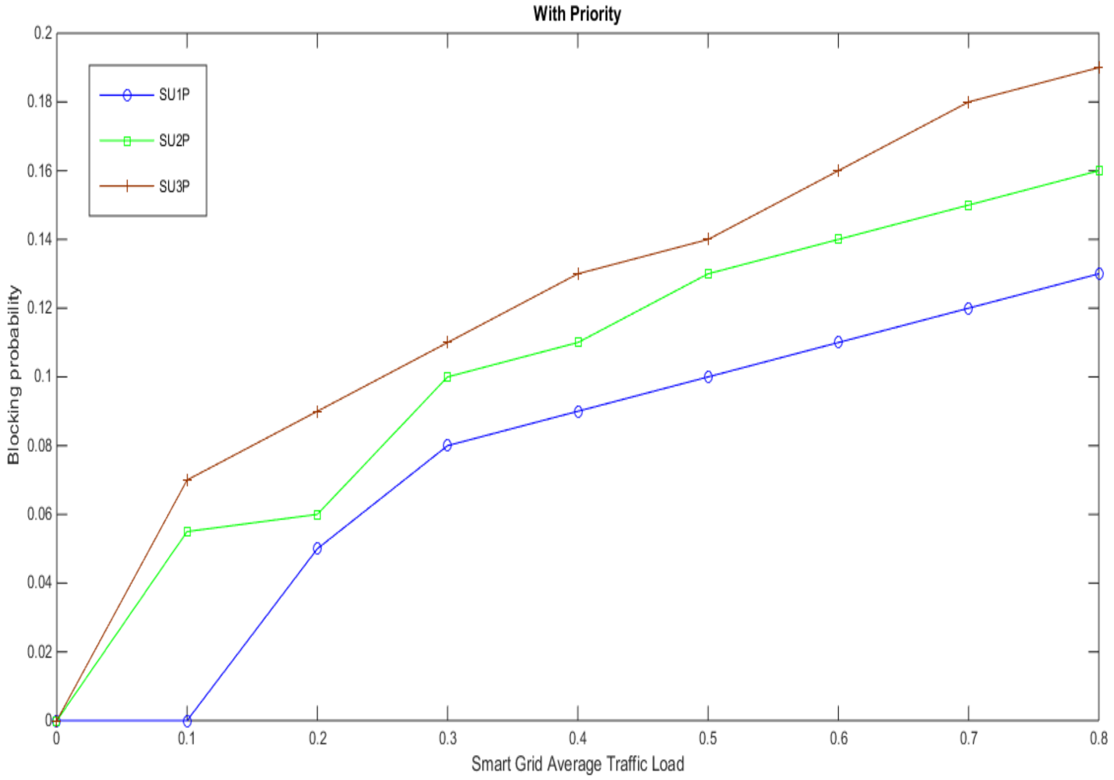

Figure 3.2: Performance of smart grid traffic in the presence of a PU without priority

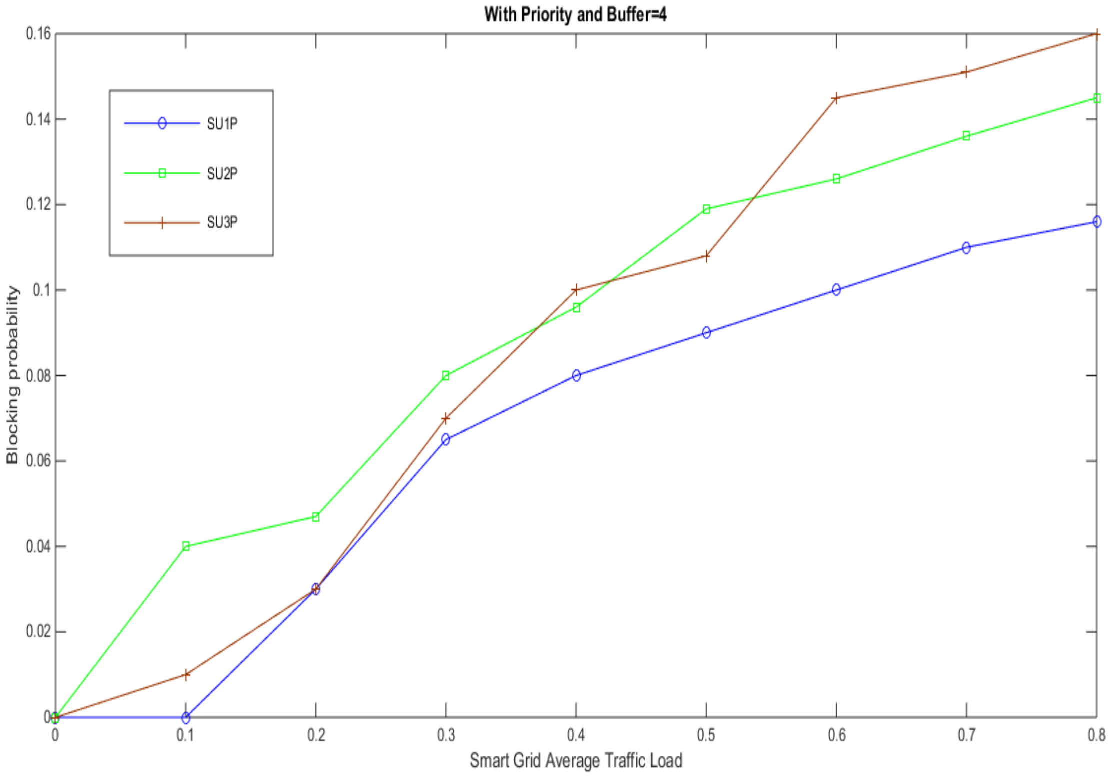

Figure 3.3: Comparison of blocking probability for distribution with priority and Buffer=2

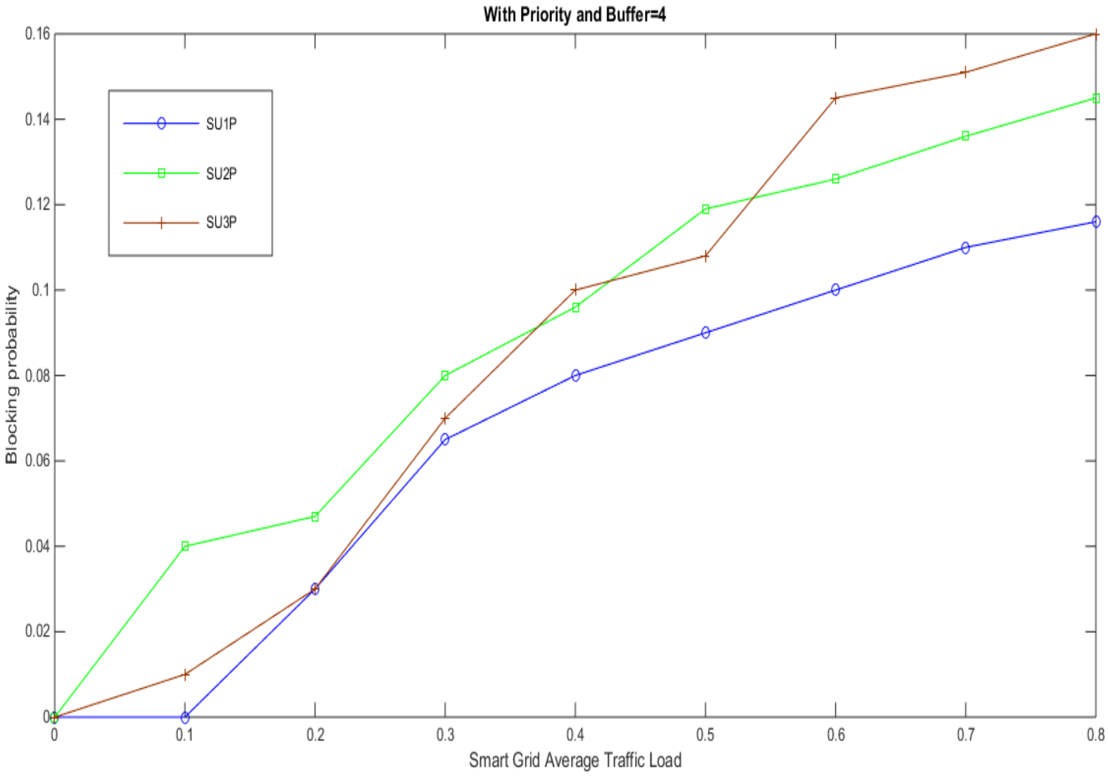

Figure 3.4: Comparison of blocking probability for distribution with priority and Buffer=4

SUs: For secondary users, it is defined as the ratio of the total blocked calls to total arrived calls

$$P_s = \frac{[\sum_{n_{Bt=}n_B} \lambda_s \pi + \sum_{n_{Bt} \leq n_B} n_{Bt} \mu_s \pi]}{\lambda_s} \tag{3.2}$$

where, π is function of n_p, n_s and n_{Bt}.

A CRN is deployed using above defined parameters and faults, alarms, voltage outage, metering etc. which appears in the SG network are generated and are considered calls for CRNs. Results are an average of ten simulations. The results in Figure 3.1, Figure 3.2, Figure 3.3 and Figure 3.4 are obtained with and without priority and value of buffer as 0, 2 and 4. The results justify that by giving priority to alarm messages blocking probability for them reduces significantly. However, it Increases for lowest priority calls. In Figure 3.3 and Figure 3.4, the blocking probability of su_2 and su_3 are overlapping each other, the su_2 calls are multimedia calls which takes more time to complete and even though their priority is higher than su_3 there blocking probability is higher. It's due to the calls which left buffer after a threshold time in the buffer.

3.3 Voice Secondary User Call Prioritize Cognitive Radio Networks with Buffering.[3]

In this work, a new dynamic access scheme is proposed which differentiates secondary users (SUs) on the basis of their type: voice or data call. The smart grid requests are data calls originated and voice calls are normal mobile communication calls. The voice calls are preferred over a data call in this section. If a primary user (PU) wants to access the spectrum, then a SU with a data call will be placed in the buffer. If no SU with data call is accessing the spectrum, then one of the SU with voice calls will give way for PU. The work also uses the elapsed time of SU calls in the buffer to allow access to the spectrum. Comparative results show that buffering the SU data call (SG calls) significantly reduces the SU blocking probability of voice calls and non-completion probability with very minor increased forced termination probability. However, it leads to a delay in data call SU completion.

Cognitive radio (CR) is a communication paradigm to effectively addresses the spectrum requirements (Akyildiz et al., 2006), (Zhang et al., 2014). The spectrum is always a precious resource in any communication systems and networks. Cognitive radio has those latent qualities that systems are able to adapt themselves according to the surrounding conditions, traffic load, congestions in network topology and wireless channel propagation etc. This makes

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CR based networks ability to handle heterogeneity and robustness in the next-generation wireless communications systems. CR has to handle both primary users (PUs) and secondary users (SUs) in the same frequency spectrum. PUs refers to the licensed users who paid for and have a regulatory allocated spectrum. They have the exclusive privilege to access the allocated spectrum to them. SUs refer to the unlicensed CR users and can only access the spectrum watchfully when PUs is not using it. This spectrum sharing approach allows the unlicensed SUs to dynamically access the spectrum without any changes in their devices, services, architectures, and networks etc. in the PUs presence (Ondral & Arlsruhe, 2004). For PUs, the presence of SUs is transparent. If a PU wants to access the spectrum or a particular spectrum range SU has to leave the spectrum range for PU. The SU can transfer to another vacant spectrum, if available it can use it otherwise it has to leave the system. A Markov Chain is presented in (Capar et al., 2002) to study controlled/ uncontrolled channel assignment schemes in a spectrum sharing environment. A model is developed in (Xing et al., 2006) to predict the behaviour in unlicensed bands of open spectrum access. To keep analysis simple, the required spectrum for PUs and SUs is respectively fixed as one and three. A channel reservation is proposed in (Zhu et al., 2007) for a spectrum sharing system. The forced termination probability and the non-completion probability during SU connection lifetime are not dealt with in the above papers. Further, there is no queuing policy for a SU request if there is no vacant spectrum which is not desirable. Dynamic spectrum access (DSA) schemes are proposed in (Wong et al., 2009)(Zhang et al., 2014)(Zhu et al., 2007). In the IEEE 802.22 network (Cordeiro et al., 2006), which is expected to provide DSA for SUs in the TV spectrum, the MAC protocol is divided into uplink (i.e., SUs to the central controller) and downlink (central controller to SUs) subframes. In each frame, the central controller broadcasts the uplink and downlink schedules. The central controller assigns exclusive bandwidth (portions of an idle TV channel) to the SUs based on their bandwidth requests for the uplink transmission. In (Zhang, 2008), the central controller uses a scheduling algorithm to assign SUs to the licensed channels at the beginning of each frame such that the aggregate throughput is maximized. In (Tumuluru et al., 2011), the channel status varies within the frame duration. In the call-level DSA schemes, the SU and PU transmissions are treated as calls, which are assigned, dedicated frequency bands. However, a SU should relinquish its frequency band when a PU call claims it because the PU call assignment is oblivious of any ongoing SU calls. The central controller admits a SU call if the requested bandwidth is available and performs spectrum handoff (i.e., reassigning a SU call to another vacant frequency band when it interferes with a new PU call). According to the DSA scheme (Wong et al., 2009), an incoming SU call was queued until a new transmission opportunity was found. In addition, the SUs that experienced handoff failure were dropped. In (Zhang, 2008), the effect of a buffer was used for SU call arrivals. The SUs that leads to handoff failure are dropped. The SUs are queued when handoff failure and reassigned to vacant channels when they are available (Arrivals et al., 2009). In this way, the forced terminations of SU transmissions are prevented due to a PU arrival in (Kannappa & Saquib, 2010). In (Zhu et al., 2007), a DSA scheme is proposed, which reserves channels for SU handoff. An incoming SU call in this paper was assigned a channel only when the numbers of idle channels in the licensed spectrum are more than the reserved channels for SU handoff. In the (Zhu et al., 2007) DSA scheme (Kannappa & Saquib, 2010), the central controller is assigned as much as a possible spectrum to the SUs in order to use spectrum efficiently. This spectrum assignment is done at the time of system state change. In all the above call level DSA schemes, the performance was analyzed using a continuous-time Markov chain (CTMC) (Zhang & Jiang, 2012). The performance was evaluated in terms of the blocking probability and probability of forced termination for the SU calls. The number of accessed channel for the intracluster transmission in a cluster and inter-cluster transmission is set as one in (Zhang & Jiang, 2012), In (Yang et al., 2014), femtocells are deployed over the conventional macrocell network to increase capacity. In (Noroozoliaee et al., 2014), the performance of CR networks is measured using realistic channel handoff agility, where SUs can only handoff to their neighbouring channels only. The CR network here is employed to handle SG requests which are considered as SUs, using network resources opportunistically.

3.3.1 Network Parameters

When the network is equipped with *L* channels, the capacity (bandwidth) of all *L* channels are assumed to be the same. The primary users can gain access to a channel and have rights to keep secondary users on hold or in blocking state whenever they require channel. A primary user can be blocked if $n_p = L$, where n_p denotes the number of primary users in network otherwise secondary users has to leave the spectrum they are using for primary users. The channels are not reserved for handoff secondary users and the secondary users are differentiated on the basis of their priority in this network.

The network employs all other characteristics of the cognitive radio network (CRN). A channel can be assigned to only one user. A new primary user can be serviced if $n_p < L$ *i.e.* at least one channel is free or occupied by the secondary user. When a new secondary user call arrives it is assigned randomly to any free channel while a primary user can gain access randomly to any free or secondary user occupied channel.

3.3.2 Proposed Scheme

As previously indicated this research uses the continuous Markov chain models as they are proven to be accurate in predicting the behaviour of open spectrum access under the assumption that the arrival traffic has Poisson distribution. The assignment of channels is thus modelled as a continuous time Markov chains. The threshold limit of new or handoff calls that can be placed in a queue or stored in a buffer is referenced as *B*. The traffic load of primary users and secondary users are $\rho_p = \lambda_p/\mu_p$ and $\rho_s = \lambda_s/\mu_s$, where λ_p and λ_s are arrival rates of primary and secondary users respectively which are assumed to be Poisson distributed, $\frac{1}{\mu_p}$ and $\frac{1}{\mu_s}$ are service times of primary and secondary users respectively which are exponentially distributed. As the arrival and departure of users (calls) in the network are random, a state is moved from current to another when a call arrives or departs. Depending upon the current status of n_p, n_s^v, n_s^d and b, where, n_s^v, n_s^d and b; denotes number of secondary voice calls, number of secondary data calls and number of calls in the buffer. The network changes it states from one level to another if any one of the changes. The threshold limit of these state parameters are $n_p \leq L$, $n_p = n_s^v + n_s^d \leq (L - n_p)$ and $b \leq B$. The numbers of free channels are denoted by n_f at any time instant. The state is defined as (n_p, n_s^v, n_s^d, b). Initially, the state is $(0,0,0,0)$.

Level I: If $n_f \gg n_p + n_s$. The number of free channels (n_f) are sufficiently greater than the number of primary and number users call currently handled by the network. Therefore, if a new call (primary or secondary) arrives it will be handled without affecting *b.* The state-space for level is

$$S = \{n_p, n_s^v, n_s^d, b \big| n_f \gg n_p + n_s, b = 0\} \tag{3.3}$$

The buffer is empty, delay in handling secondary user call is zero and no handoff secondary user calls. The state transition rates are on arrows

For a new primary user call arrival and departure respectively.

$$S_{n_p,n_s^v,n_s^d,0} \overset{\lambda_p}{\rightarrow} S_{n_p+1,n_s^v,n_s^d,0}, S_{n_p,n_s^v,n_s^d,0} \xrightarrow{n_p\mu_p} S_{n_p-1,n_s^v,n_s^d,0} \tag{3.4}$$

For a new secondary user, voice call arrival and departure respectively.

$$S_{n_p,n_s^v,n_s^d,0} \overset{\lambda_s}{\rightarrow} S_{n_p,n_s^v+1,n_s^d,0}, S_{n_p,n_s^v,n_s^d,0} \xrightarrow{n_s\mu_s} S_{n_p,n_s^v-1,n_s^d,0} \tag{3.5}$$

For a new secondary user data call arrival and departure respectively.

$$S_{n_p,n_s^v,n_s^d+1,0} \overset{\lambda_s}{\rightarrow} S_{n_p,n_s^v,n_s^d+1,0}, S_{n_p,n_s^v,n_s^d-1,0} \xrightarrow{n_s\mu_s} S_{n_p,n_s^v,n_s^d-1,0} \tag{3.6}$$

where, $n_s\mu_s = n_s^v\mu_s^v + n_s^d\mu_s^d$.

Level II: $n_p + n_s^v + n_s^d = L$ and $b \geq 0$.

Case 1: Primary user call arrives.

A new primary user call arrives, it will lead to forced state transition as $(n_p + 1) + n_s^v + n_s^d > L$. A channel is at once assigned to it, and a secondary user data call is buffered for future handling.

$$S_{n_p,n_s^v,n_s^d,0} \overset{\lambda_p}{\rightarrow} S_{n_p+1,n_s^v,n_s^d-1,b+1} \tag{3.7}$$

Case 2: Primary user call departs.

A primary user call ends, it will lead to a free channel which can be assigned to a secondary user call here $(n_p - 1) + n_s^v + n_s^d < L$. If $b \neq 0$. a free channel is at once assigned to a data call with $\max(t_i^B), 1 \leq i \leq b, b \leq B$ *i.e* with maximum elapsed time in the buffer, where t_i^B is elapsed time of *i*th call in the buffer.

$$S_{n_p,n_s^v,n_s^d,b} \xrightarrow{n_p\lambda_p} S_{n_p-1,n_s^v,n_s^d+1,b-1} \quad (3.8)$$

Case 3: Secondary user voice call arrives, $b < \boldsymbol{B}$

A new secondary user call arrives $n_p + (n_s^v + 1) + n_s^d > L$, as all *L* channels are occupied by primary users and secondary users, primary users cannot free channel or be placed in the buffer to handle a new voice call, secondary user call with minimum elapsed time channel assigned to it. The data call is placed in buffer with its elapsed time $t_i^B = 0$, the buffer size is increased by '1'

$$S_{n_p,n_s^v,n_s^d,b} \overset{\lambda_s}{\rightarrow} S_{n_p,n_s^v+1,n_s^d-1,b+1} \quad (3.9)$$

Case 4: Secondary user data call arrives, $b < \boldsymbol{B}$

A new secondary user call arrives $n_p + n_s^v + (n_s^d + 1) > L$, if $b < \boldsymbol{B}$, new secondary user call is placed in buffer with elapsed time $t_i^B = 0$, the buffer size is increased by '1',

$$S_{n_p,n_s^v,n_s^d,b} \overset{\lambda_s}{\rightarrow} S_{n_p,n_s^v,n_s^d,b+1} \quad (3.10)$$

Case 5: Secondary user voice/ data call departs.

The departure of secondary user call voice/data is similar, if a secondary user call departs call and if $b \neq 0$ free channel is at once assigned to a data call with $\max(t_i^B)$,$1 \leq i \leq b, b \leq B$ *i.e* with maximum elapsed time in the buffer, where t_i^B is elapsed time of *i*th call in the buffer.

$$S_{n_p,n_s^v,n_s^d,0} \xrightarrow{n_s\mu_s + b\mu_b} S_{n_p,n_s^v,n_s^d+1,b-1}, S_{n_p,n_s^v,n_s^d,b} \xrightarrow{n_s\mu_s + b\mu_b} S_{n_p,n_s^v,n_s^d,b-1} (3.11)$$

3.2.3 Simulation and Results

For comparison of blocking probability and dropping probability following simulation, parameters are assumed.

- Number of channels are *L*=10.
- Service times of Smart Grid (or SU)and primary users are $\mu_s = 0.90$ and $\mu_p = 0.067$..
- Arrival rate of secondary users is five times more than primary users *i.e.* $\lambda_s = 5\lambda_p$.

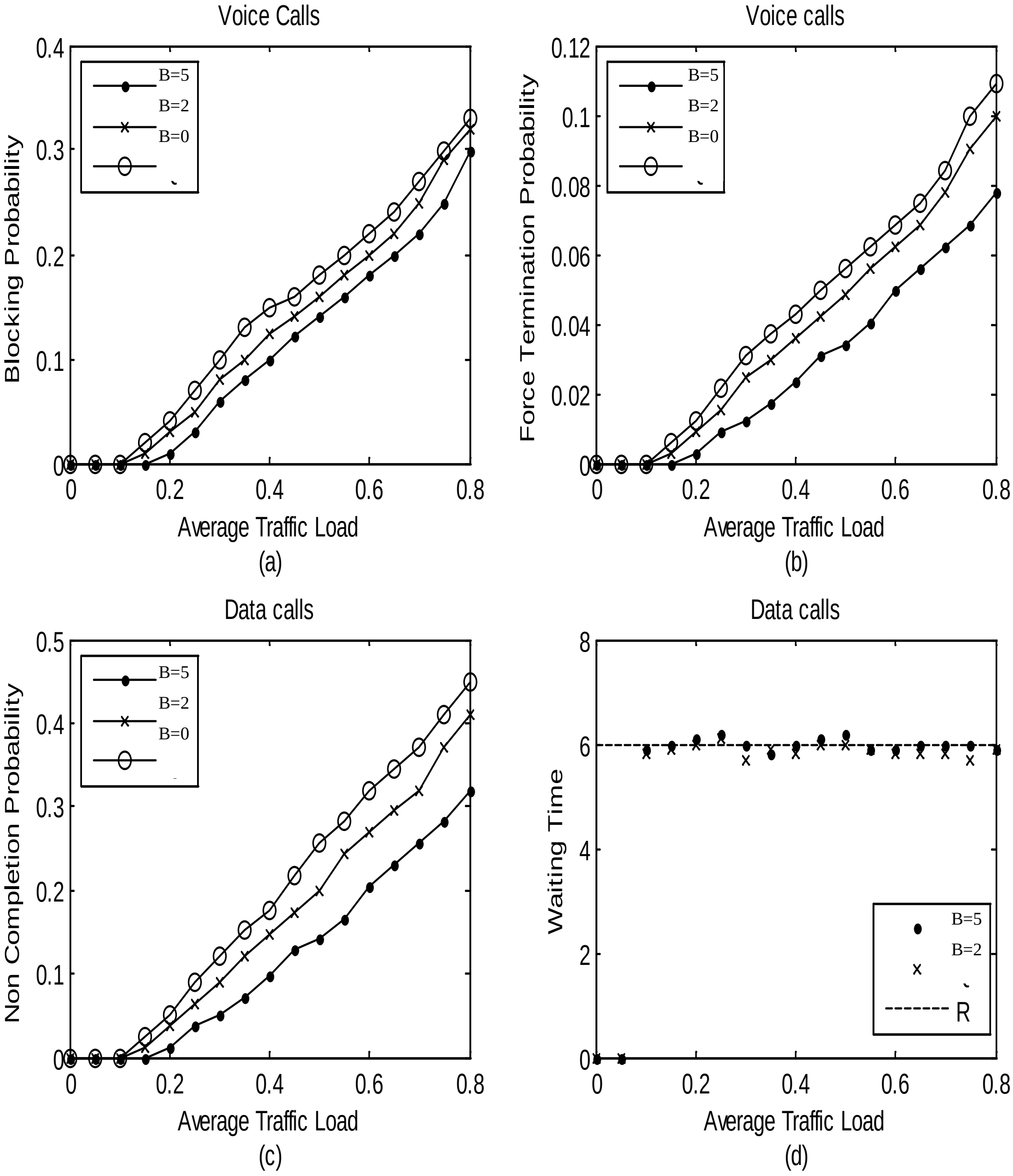

Figure 3.5. Performance analysis of voice calls (*a,b*) and data calls(*c,d*) for different parameters. *--R indicates reference value 6

- Maximum buffer size is *b*=5.
- The leaving rates of impatient secondary users in the buffer is $\mu_b = 0.01$.

1) Blocking Probability: The blocking probability is the ratio of the total blocking rate and the total arrival rate.
    a. Primary users: A primary user call is blocked if $n_p \geq L$and new call arrives.

$$P_b^p = \sum_{n_p \geq L} \lambda_p \, . \, \pi(n_p, 0{,}0, b)/\lambda_p \tag{3.12}$$

    b. Secondary users: For secondary users, it is defined as the ratio of the total blocked calls to total arrived calls:

$$P_b^s = \left[\sum_{b=B} \lambda_s \, . \, \pi\left(n_p, n_s^v, n_s^d, b\right) + \sum_{b \leq B} b\mu_b \, . \, \pi\left(n_p, n_s^v, n_s^d, b\right)\right]/\lambda_s \tag{3.13}$$

the 1st term on the right is the number of blocked calls when the buffer is full and 2nd term are those calls which are dropped due to impatience. Also, $n_s\mu_s = n_s^v\mu_s^v + n_s^d\mu_s^d$ and $\lambda_s = \lambda_v + \lambda_d$, blocking probability of secondary user data and voice calls can be calculated separately

Voice calls blocking probability

$$P_b^s = \left[\sum_{b=B} \lambda_v \, . \, \pi(L, 0{,}0, b) + \sum_{b \leq B} \lambda_v \, . \, \pi\left(n_p, n_s^v, 0, b\right)\right]/\lambda_v \tag{3.14}$$

here, 1st term on the right is the number of secondary voice calls blocked

Data calls

$$P_b^d = \left[\sum_{b=B} \lambda_d \, . \, \pi\left(n_p, n_s^v, 0, b\right) + \sum_{b \leq B} b\mu_b \, . \, \pi\left(n_p, n_s^v, n_s^d, b\right)\right]/\lambda_d \tag{3.15}$$

The above equations are used to verify the proposed scheme on sets of values defined earlier on MATLAB. The simulations are an average of 10 runs.

The results of Figure 3.5 (a), Figure 3.5 (b), Figure 3.5 (c) and Figure 3.5 (d) are obtained with different threshold values of buffer B=0, 2 and 5 respectively. It is clear from the results that the blocking probability, forced termination of the voice calls decreased considerably for different values of buffer size and due to priority over data calls. The non-completion probability and waiting time of data calls increase with higher SU voice calls, which is intuitively understandable.

3.4 Conclusion

Smart grids are the backbone of the electrical distribution networks, due to sustainability and better control of resources at a centralized or distributed location. Research shows that wireless technology mixed with cellular networks and cellular technology such as cognitive radios is a very useful way of distributing SG information. The disadvantage is always the amount of available spectrum. Wireless and cellular technologies however always offer opportunities to utilise unused channels within the spectrum. Section 3.2 proposes a SG-P scheme which gives priority to SG fault alarm messages over other types of information, the blocking of them reduces considerably. In the future, work can be done to analyse the blocking probability at specific nodes of SG, serial transfer of metering information from one sensor node to another and added metering information at each node or sending metering information on CRNs at the time of the day when PU arrivals are minimum. It can also be extended to calculate waiting time in the buffer, by varying information size in each type of data SU_1, SU_2 and SU_3.

The initial research in section 3.2 is followed in section 3.3 to illustrate how the spectrum handoff for Smart Grid (SUs) users is prioritized on the basis of their type: voice or data call. The buffering of SU data calls is done to avoid blocking of voice calls. A Markov model is developed to analyse the proposed scheme. Performance metrics are analysed with respect to blocking probability, interrupted probability and forced termination probability of SU voice calls. While for data call SU, the performance metrics are analysed with respect to non-completion probability and waiting time. The results indicate that the priority of voice call significantly reduces the blocking probability and forced termination probability for voice calls. However, it increases the non-completion probability of data calls and waiting time.

Both the schemes provide good results in conditions when the incoming call rate is low or in other words when disturbances are limited. When the incoming call rate increases the licensing problem starts surfacing, due to this reason the LTE networks are used in the following chapters.

CHAPTER FOUR

UMTS AND LTE INTERFACE UTILIZATION IMPROVEMENT WITH QOS IN MOBILE COMMUNICATION SYSTEMS[4]

4.1 Introduction

Long Term Evolution is a fourth-generation (4G) communication technology standardized by the 3rd Generation Partnership Project (3GPP). It is capable of providing high data rates as well as the support of high-speed mobility. It has completely packet-switched core network architecture. Compared to UMTS, the LTE system uses new access schemes on the air interface: Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink, which brings flexibility in scheduling as well as power efficiency. LTE features low latency in both the control plane and user plane. The success and rapid roll-out of LTE in many countries have led to an increased interest to use this networking technology for, among others, smart metering, distribution automation, fault location, etc., within electricity distribution networks. Therefore, LTE is a promising choice as the Wide Area Network (WAN) communication technology to support the transmission of SG data or information.

To provide support for both data and voice calls is an essential requirement of present mobile networks both LTE and UMTS networks. Contrary to the schemes proposed in the CRN which was based on priority allocations per call the proposed scheme in this LTE and UMTS study differentiates assignment of requested calls on: *speed, the direction of motion* and *type of requested call*. It also checks the used capacity threshold of LTE and UMTS before the assignment. Different communication interfaces are used in hybrid mobile communication to address these issues. The UMTS uses VSF-OFCDM interface for the assignment of orthogonal codes from the orthogonal variable spreading factor (OVSF) code tree in two dimensions. The LTE interface assigns resource blocks. The UMTS is prone to the high probability of packet loss and less spectral efficiency too. LTE has a problem with a moderate reward with unbalanced loads. The proposed scheme minimises these problems considerably by differentiating requested calls related to interference and movement as compared to other schemes in the literature. Both the interfaces are used to handle SG requests, the 3G interface is mostly used for handling SG requests.

In order to meet the increased demand of traffic, the fourth generation (4G), mobile communication systems provides data rates support of up to 100 Mb/s for higher mobility user

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and up to 1 Gb/s for lesser mobility users (3GPP, 2013) (Kottkamp, 2010), (913, 2011), (Tu et al., 2013). 3GPPs' (3GPP, 2013), Variable Spreading Factor Orthogonal Frequency and Code Division Multiplexing (VSF-OFCDM) (Maeda et al., 2003), the LTE and LTE-Advanced (G. A. Daniel, 2010) etc., several communication technologies have been used. The proposed variable spreading factor OFCDM (VSF-OFCDM) in (Atarashi & Ahashi, 2002) combines OFCDM with a variable spreading factor and used for a downlink transmission scheme. The advantage of OVSF and OFCDM communication technology is taken by VSF-OFCDM and adopts a 2-D spreading in the time and frequency domains to control certain parameters like the channel load, delay spread, interference and increase the spectrum utilization. The voice and data calls arrive in the network randomly, 3G (UMTS) handles both voice and data calls while high mobility data calls are handled using LTE.

UMTS and LTE architecture is illustrated in Figure 4.1 (Tu et al., 2013). The UMTS provides support to both data and voice calls with mobility (less). The radio access network (RAN) of UMTS has a radio network system (RNS) in order to allow access. The central part of it contains (a) Gateway Mobile Switching Center (GMSC) which pilots and establishes the voice calls with mobile users; (b) home location register (HLR) which has user information and its visitor location register (VLR); the VLR knows HLR details of users; (c) the 3G gateways which route data packets between the RAN and the internet. The LTE network only offers service to

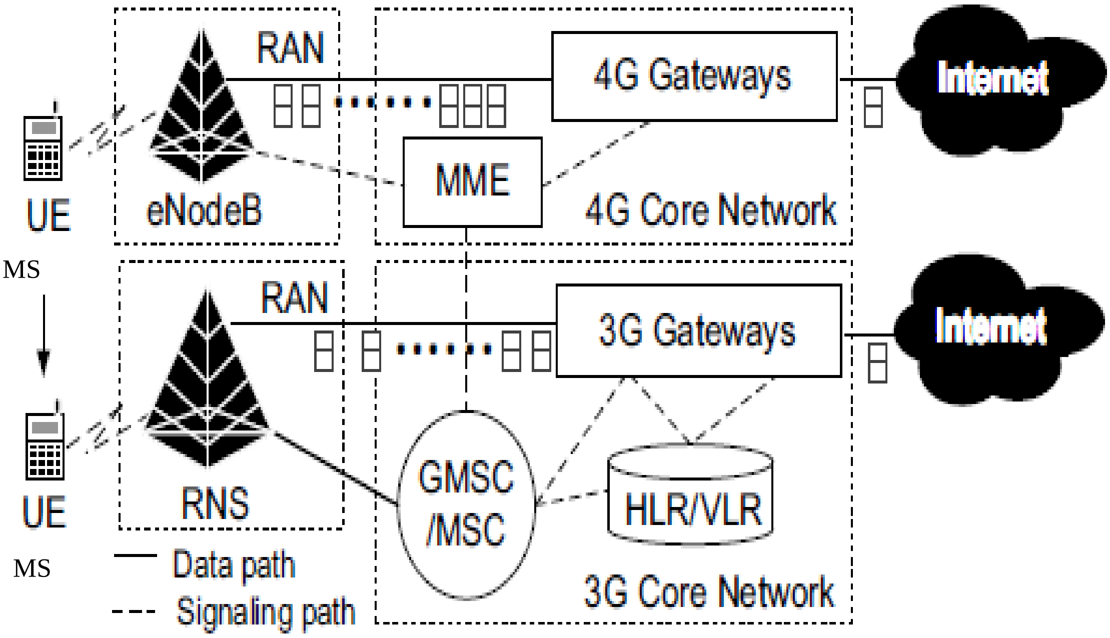

Figure 4.1 Architecture of 4G-3G networks.

high mobility data users. The central part of it consists of mobile stations (MSs) and RAN. The RAN of MS uses eNodeB (which is base station) for allowing access of radio spectrum to MSs. The network core of LTE is using internet protocol (IP), it consists of a Mobility Management

Entity (MME) which is used to handle mobility of users and 4G gateways which routes data traffic between 4G RAN and internet.

There are several schemes given in the literature to minimize code blocking probability of mobile networks using OVSF (Adachi et al., 2005). These schemes are single code (Tseng & Chao, 2002), (Balyan & Saini, 2014) and multi-code assignment schemes (Saini & Upadhyay, 2009), (Balyan et al., 2010), (Saini & Balyan, 2016). The most common single code assignment schemes are: leftmost code assignment (LCA) and crowded first assignment (CFA) both given in (Tseng & Chao, 2002) and (Adachi et al., 1997), the fixed set partitioning (FSP) (Atarashi & Ahashi, 2002) and recursive fewer codes blocked (RFCB) scheme proposed in (Rouskas et al., 2005). These schemes use only one-dimensional spreading of codes and which increases code blocking at the expense of radio resources wastage. The schemes proposed in (Saini & Upadhyay, 2009), (Balyan et al., 2010), (Saini & Balyan, 2016) use of multiple codes to handle a single call which reduces code blocking and with increased complexity. To address the aforementioned problems UMTS uses the VSF-OFCDM interface to allocate OVSF codes in two dimensions. In (Saini & Balyan, 2016), a new multi code scheme is proposed which leads to real time calls waiting time zero. The scheme assigns any incoming call without delay to an available free code of same rate and in the meantime divides the incoming rate into quantized rate fractions and searches for the free codes for all quantized fraction. When the free codes for all fractions located, reassign the call to these free codes using multiple rakes. The information of these codes utilized is updated to receiver like existing schemes. An interference avoidance (IA+CF) scheme is proposed in (Wang et al., 2007) which provide significant improvement of code blocking probability at better QoS. Adaptive reward based selection of UMTS and LTE considering the effect of interference and mobility environments are proposed in (Chang et al., 2013) which are further used for assignment using multicodes in order to maximize the bandwidth waste (Chang et al., 2015). The downlink of the Multi-Rate MC-DS-CDMA networks demands QoS together with efficient utilization of available capacity. The ADCL scheme in this section assigns calls to a code for which $Cl<Cl_{Threshold}$ and offers lesser capacity utilization. The top down scheme proposed in (Saini & Balyan, 2014), starts searching a vacant code from top code and significantly minimize the call establishment delay which depends upon the number of code searches before assignment.
The remainder of chapter 4 is arranged as follows. The speed type direction (TSD) assignment scheme is given in section 4.4. The results and simulations are given in section 4.5.

4.3 OVSF, VSF-OFCDM and LTE FUNDAMENTALS

The network model for a mobile system using LTE and UMTS is defined here:

For UMTS interface: An OVSF code is denoted as C_{k,n_k}, all the codes in all layers have quantized rates given by $2^{m-1}R, 1 \leq m \leq L$, *L* denotes the total number of layers in code tree and the spreading factor (*SF*) of a code in layer *m* is 2^{L-m}. The time-domain spreading factor is denoted by $TCd^{T}_{sf_t,i_t}$ where $sf_{m_t} = 2^{m_t-1}$ and i_t is the index level of time-domain code, also $1 \leq i_t \leq m_t$ and $1 \leq sf_{m_t} \leq (L - m_t)$. The frequency-domain spreading factor is denoted by $FCd^{F}_{sfm_f,i_f}$ where $sf_{k_f} = 2^{k_f-1}$ and i_f is the index level of frequency-domain code, also $1 \leq i_f \leq m_f$ and $1 \leq sf_{m_f} \leq (L - m_f)$. The total spreading factor

$$sf_m = sf_m \times sf_{m_t} \tag{4.1}$$

for a VSF-OFCDM network.

i : OVSF Code index and $i_f = i - (i_t - 1) \times 2^{m_f-1}$.

For LTE interface**:** A normal PHY frame structure for LTE is having subframes = 10 in the time domain with two slots in each, 14 OFDM symbols can be carried in each subframe as given in Figure 4.2. The frequency-domain subchannel has 12 carriers. The number of subchannels varied with bandwidth like each channel of capacity 1.4 MHz and has six subchannels. For a mobile station (MS) in LTE, the transmission unit is called a resource block (RB) within a subframe (in time) and a subchannel (in frequency).

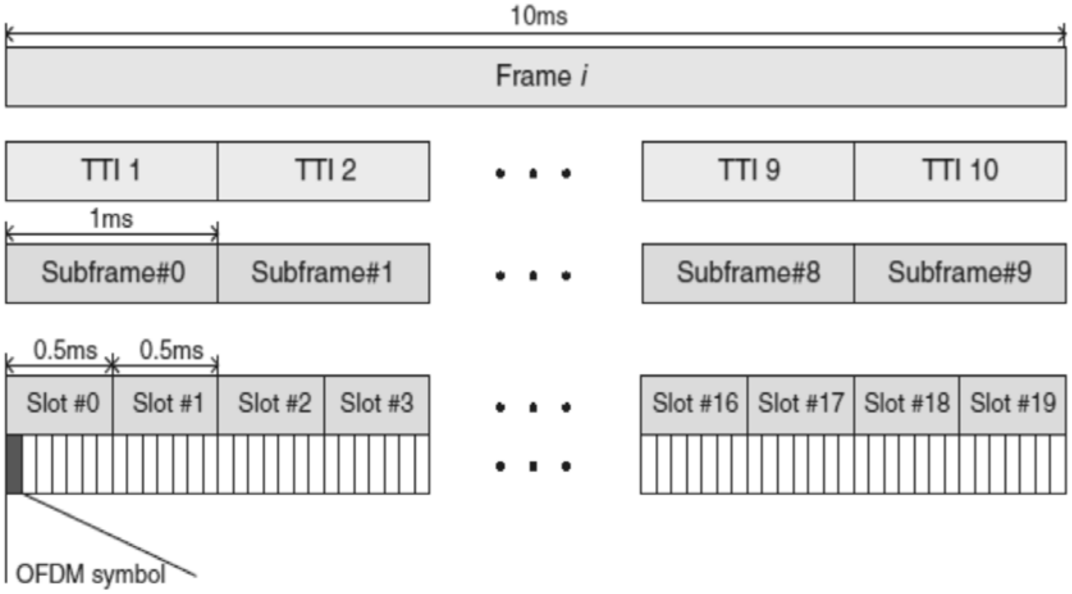

Figure 4.2 Frame structure of LTE

4.4 Proposed Scheme

The problem associated with OVSF codes is that they suffer from code blocking problems. UMTS uses VSF-OFCDM which assigns channelization code to a call from the OVSF code tree. For LTE numbers of RBs are assigned to a new call. Using both interfaces in 4G gives an advantage of additional spectrum, the mobility in users force careful use of them. The main disadvantage of unmanaged assignment of calls will lead to reduced spectral efficiency and will provide less profit to mobile operators. Thus, a TSD scheme is proposed which assigns calls to UMTS and LTE, considering factors related to users like speed, call type, and direction of motion. It also checks the used capacity of UMTS and LTE.

$$C_{Used}^{UMTS} = \sum_{m=1}^{L} n_m \times 2^{m-L} \tag{4.2}$$

$$C_{Used}^{LTE} = \frac{n_{Used}^{RB}}{n^{RB}} \tag{4.3}$$

Where n_m denotes the number of codes of layer *m* assigned in UMTS, n^{RB} and n_{Used}^{RB}denotes total and used RB in LTE interface respectively. The modulation schemes used in UMTS are BPSK used for the longest distance, QPSK moderate distance and 16-QAM or 64-QAM for a close area to the base station (BS) (Balyan & Saini, 2014). The TSD scheme is defined as any $max\ (n^{RB})$ which can be assigned according to location when a user is going away from BS. The proposed TSD scheme uses both interfaces to handle Smart Grid traffic also. The data calls originated during simulations are mostly SG calls. The TSD scheme assigns an interface to these calls depending upon their QoS, latency and data. The SG calls requiring better QoS and low latency are handled using the LTE interface and the calls which can tolerate delay are handled using 3G/UMTS interface.

Algorithm of TSD scheme

```
1. Generate a new call of rate $kR, 1 \leq k \leq 16$
2. Check the call type voice or data.
3. If (Voice)
      Find a suitable UMTS code using TD (Balyan & Saini, 2013), and update
      $C_{Used}^{UMTS} = C_{Used}^{UMTS} + kR$.
4. Else (Data)
(a) Find its speed, direction of motion and location from BS.
(b) Case 1: High Speed, moving towards the BS
      If $C_{Used}^{LTE} < C_{Th}^{LTE}$
      Assign calls to LTE interface and update $C_{Used}^{LTE} = C_{Used}^{LTE} + n_{Used\ for\ kR}^{RB}$.
      Else $C_{Used}^{LTE} > C_{Th}^{LTE}$ and $C_{Used}^{UMTS} < C_{Th}^{UMTS}$
      Assign new call to UMTS interface and assign codes using TD multi-code approach
      (Balyan & Saini, 2013), and update $C_{Used}^{UMTS} = C_{Used}^{UMTS} + kR$.
      Else if $C_{Used}^{LTE} > C_{Th}^{LTE}$ and $C_{Used}^{UMTS} > C_{Th}^{UMTS}$
      Block the call.
```

End.

(c) Case 2: Moderate Speed, moving away from the BS

If $C_{Used}^{LTE} < C_{Th}^{LTE}$

Assign calls to LTE interface and update $C_{Used}^{LTE} = C_{Used}^{LTE} + n_{Used\ for\ kR}^{RB}$.

Else $C_{Used}^{LTE} > C_{Th}^{LTE}$ and $C_{Used}^{UMTS} < C_{Th}^{UMTS}$

Calls can be handled using the UMTS interface, divide kR into no. of fractions<$max\ (n^{RB})$ and assign codes using TD multi-code approach (Balyan & Saini, 2013), and update $C_{Used}^{UMTS} = C_{Used}^{UMTS} + kR$.

Else if no. of fractions<$max\ (n^{RB})$ or $C_{Used}^{LTE} > C_{Th}^{LTE}$ with $C_{Used}^{UMTS} > C_{Th}^{UMTS}$

Block the call.

5. End.

4.5 Simulations and Results

In this section, the proposed TSD scheme performance is compared with 3GPP UMTS popular schemes LCA, CFA, FSP, RFCB and IA+CF in the single-cell environment. The user classes considered are kR and $[1 \leq k \leq 16]$. The calls generated are normal mobile network calls and SG calls. The network will generate equal calls of all rates and both types. The total capacity of the UMTS code tree is $2^{L-1}R, L = 9$. The arrival rate (λ) is Poisson distributed with the mean varying from 0 to 4 calls per minute. The call duration (1/μ) is exponentially distributed with mean value 1. The numbers of users are 10000 (50% SG) and results are an average of 10 simulations. Average traffic load

$$\rho = \sum_{i=1}^{16} \lambda_i / \mu_i = \sum_{i=1}^{16} \lambda_i \qquad (4.4)$$

The threshold value of UMTS and LTE interfaces are $C_{Th}^{UMTS} = 0.75$ and $C_{Th}^{LTE} = 0.75$.

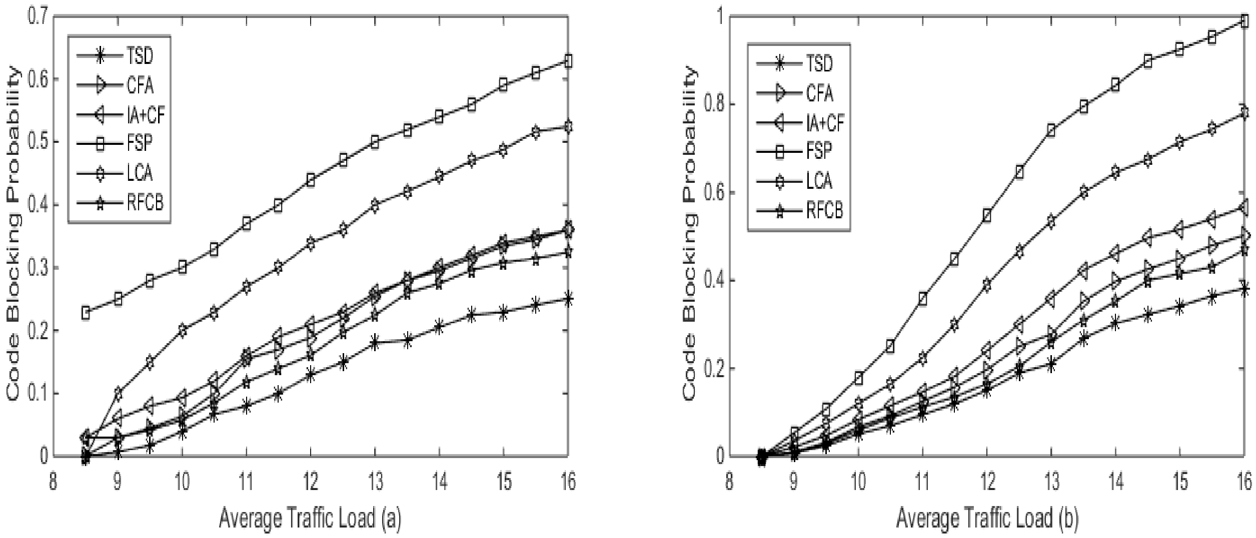

Figure 4.3. Code blocking probability comparison of (a) Quantized arrival rates and (b) Quantized rates and Non-quantized rates both [*R*-16*R*].

Figure 4.3, shows the comparison of a TSD scheme versus other schemes. In Figure 4.3(a) when arrived calls are quantized only *i.e* $2^{m-1}R$, in this case, the performance of all the schemes are better as compared to their performance when non-quantized calls arrive shown in Figure 4.3(b) due to the increased scattering due to internal fragmentation. The TSD code blocking probability is lowest due to the use of multi-code and LTE interfaces. The real-time calls are handled well as higher speed users are usually handled by LTE interface. The performance of all the schemes degrades with an increase in traffic.

Code blocking probability of a 16 class system can be calculated from

$$P_B = \sum_{i=1}^{16}(\lambda_i P_{B_i}/\lambda) \tag{4.5}$$

the *i*th class code blocking probability is P_{B_i} .

The average code blocking for quantized call scenario will be

$$P_B = P_{B_R} + P_{B_{2R}} + P_{B_{4R}} \ldots\ldots P_{B_{16R}} \tag{4.6}$$

The flowchart diagram in figure 4.4 illustrates these algorithms in order to provide the reader better with a better understanding.

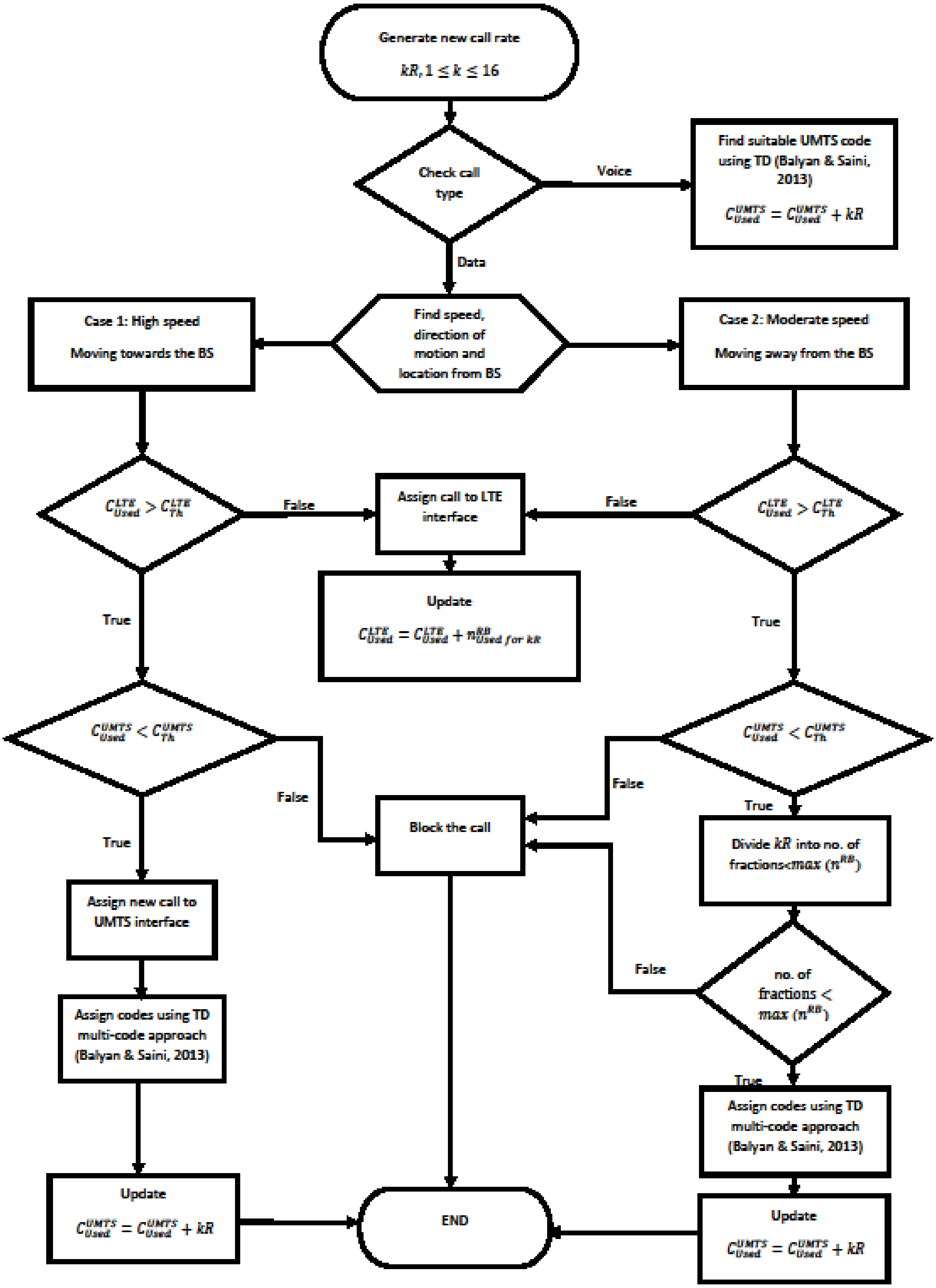

Figure 4.4 Illustrates the algorithms in described in paragraph 4.4.

4.4 Conclusion

The simulations and result shows that the TSD scheme is best suited for both quantized and non-quantized calls. It takes the benefit of LTE interface. The results can also be simulated for different SG and mobile traffic distributions depending upon busy hour, rural or urban traffic scenarios. There are problems with handover and complexity related to it. The interference between voice and data calls (SG calls) in the present mobile network is inevitable. However, the SG traffic is not affected as they are mostly stationary and transfer a fixed amount of data. The voice calls arriving at the time of on-going data calls may lead to degradation in throughput as their 4G connection will change to 3G, and which will lead to the application being aborted. The present 4G networks suffer from handover issues that arise not due to mobility but inter handover i.e. from 3G to 4G and 4G to 3G. Further, future work can be done to address and resolve these problems.

CHAPTER FIVE

SMART GRIDS AND MOBILE TRAFFIC COMMUNICATION FOR IMPROVED SPECTRAL EFFICIENCY OF LTE SYSTEMS.[5]

5.1 Introduction

The *LTE* network also provides voice support using *UMTS*. The voice calls are considered as real-time calls which cannot tolerate any type of delays. The 3GPP standards propose Circuit Switched Fall Back (*CSFB*) when voice services are rendered by the mobile station (MS), which means fall back to the heritage radio spectrum. This can result in one of the possible conditions *i.e* a) switching to a UMTS or GSM network, b) switching to a non-*LTE* network, c) opening two connections simultaneously for voice and data respectively. The CSFB to 2G/3G networks is the most common solution for voice call requests occurring in the *LTE* network for data calls. When a voice call arrives or originated in a deployed network, the eNodeB containing both *LTE* interface and *UMTS/GSM* interface will redirect calls to *LTE* or UMTS/GSM interface. This interface in this application is *UMTS*. Due to this, the CSFB architecture needs coordination between the evolved packet core (EPC) (*LTE*-interface) and the 2G/3G core (*UMTS*-interface) network. The need to reduce the number of interfaces of the main networks and also utilization of the air interface of the existing *UMTS* for the voice calls to speed up the CSFB deployment. Due to this reason, voice over *LTE* network (VoLTE) adopted it (Specification & Services, 2014) (3GPP, 2010) (Anon, n.d.). There are disadvantages associated with due to the increased coverage of the *LTE* and increased multimedia activities the users need to fall back to legacy *UMTS* frequently, which urges for the deployment of a framework that reduces or minimizes it. The CSFB might lead to the idle state of connection for some time using VoLTE and connection will be lost in the absence of VoLTE. This is a frequent process in any network. 3GPP standards use GSMA IR.92 IMS profile for voice and SMS services (GSMA IR.92 v8.0, 2014) and GSMA IR.94 IMS profile for conversational video (Standards Institutions, 2012) to provide better quality IMS-based telephony services using *LTE* radio access. All the industry stakeholders like service provider and user equipment manufacturers, 3GPP functionalities and optimal sets decider must participate to provide compatibility to *LTE* voice or video calls. The implementation of CSFB and VoLTE are essential to provide guaranteed better voice experience in *LTE* network (Specification & Services, 2011), (Bautista et al., 2013).

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In order to enhance, the *UMTS* interface quality of service (QoS), the orthogonal variable spreading factor (OVSF) codes using OFCDM spreads across two dimensions, time and frequency (Yiqing Zhou, Tung-Sang Ng, Jiangzhou Wang, 2008), (Kuo et al., 2008). This reduces the interference by using subcarriers which are orthogonal and introduces code blocking problem. This requires an efficient algorithm to manage or assign OVSF codes to incoming variable rate call requests which arrive randomly in the network. The allocations schemes in the literature can be classified into three however, the VSF-OFCDM managed by an OVSF code tree needs an efficient algorithm to allocate codes to different arrival connections. The code allocation algorithms of the VSF-OFCDM scheme can be classified into four categories: single code one-dimensional (Hwang et al., 2006) (Saini & Balyan, 2014), (Tsai & Lin, 2009), multi-code one-dimensional (Chang & Chang, 2006), (Saini & Upadhyay, 2009), (Yu et al., 2010),(Balyan et al., 2010), single code two- dimensional (Zhou et al., 2008), (Chang & Wu, 2009), and multi-code two-dimensional (Chang et al., 2015).

The one dimensional proposed single code schemes in (Hwang et al., 2006), (Balyan & Saini, 2013), (Tseng & Chao, 2002), (Saini & Balyan, 2014), (Tsai & Lin, 2009), most of them suffer wastage of spectrum. The one-dimensional multi-code schemes proposed in (Chang & Chang, 2006), (Saini & Upadhyay, 2009), (Yu et al., 2010), (Balyan et al., 2010), are mainly used to reduce spectrum wastage. The papers in (Saini & Upadhyay, 2009), (Yu et al., 2010),(Balyan et al., 2010) suffer from higher complexity with no focus on the residual spectrum when multi codes are used for assignment. The (Chang & Chang, 2006) does not consider interference also before assignment. In (Yu et al., 2010), the assignment scheme increases the computation time and overhead for determining the suitable code for an assignment.

In (Wang et al., 2007) a time-slicing scheme is proposed which does spreading in two dimensions in frequency and time code. In (Chang & Wu, 2009) and (Chang et al., 2015), a single code and multi codes assignment scheme are proposed for two-dimensional spreading of OVSF codes which considers the effect of load balancing and the current location of the user.

The *LTE* resources can also be used for handling SG-T. Random access for distribution automation (RADA) scheme is given in (Kalalas, Vazquez-Gallego, et al., 2016), which provide support to distribution automation (DA) services with minimum effect on M-T. Another resource assignment scheme named as Lotka-Volterra (*LV*) is defined in (Webster et al., 2016), which first of all do modelling of all classes of traffic, considering them as a species and then look for possible *LTE* resources. The scheme also provides fairness among different classes. The scheme in (Yaacoub & Kadri, 2015), investigated the use of *LTE* resources in regions of advance meter for transfer of meter readings automatically. The scheme is used for transmission from smart meters to base stations and from aggregators to the *BS*.

This chapter proposes a handoff *LTE-UMTS* (*HLU*) scheme for a base station (*BS*) having both UMTS and LTE interface for a 4G network handling mobile traffic (M-T) and smart grid traffic (SG-T). The *LTE* interface is used for high-speed data calls and assigns resource blocks (*RB*s). The 3GPP *UMTS* interface in this work uses the VSF-OFCDM which allocates OVSF codes which are orthogonal in nature and handle both types of calls data and voice. The codes are spread in both the frequency domain and time domain. The *HLU* scheme assigns *RB*s or the number of codes depending upon the current location and direction of the motion of a new call user. The assigned resources are increased or decreased when the distance of the user increases or decreases from the *BS* respectively. The handoff calls considered are from one adaptive modulation and coding (AMC) location to another, which leads to variation in radio resource calls are using. The load on the channel is also considered before assignment in *HLU* scheme for the *UMTS* interface *i.e.* the number of calls handled by a subtree which leads to less interference. The traffic arrival is of two types: Mobile Traffic (M-T) and smart grid traffic (SG-T). The SG-T improves the spectral efficiency of the network by using resources during non-busy hours. The simulations and results are shown for spectral utilization, call blocking probability and code blocking probability. The proposed *UMTS* scheme is also compared with existing schemes in the literature.

5.2 Motivation of the work

The *BS* nowadays supports multimedia calls of variable rate and with mobility. Most of the schemes in literature proposed for *LTE* systems focus on spectrum utilization, the spectrum is used for only mobile traffic (M-T). The proposed scheme in this chapter uses a spectrum available at *BS* for mobile as well as smart grid traffic (SG-T). The *UMTS* interface is used mostly for mobile voice traffic and SG-Ts while *LTE* interface is used for fast moving mobile data traffic and high data SG-Ts. The scheme in (Huang & Dou, 2004) uses various modulation techniques to provide codes and *RBs* to a requested call depending upon the current location of the call. The proposed *Handoff LTE-UMTS* (*HLU*) scheme in this chapter reduces or increases the assigned resources to a call when the distance of a user decreases or increases from the *BS*. The SG-T communication is usually stationary. The scheme also reserves a portion of code tree for possible handoff, which is likely due to the high mobility of the users.

The remaining organisation of the chapter is as follows. Section 3 defines the network architecture and parameters. Next, in section 4, *UMTS* and *LTE* loads (traffic) are described. Section 5 discusses the proposed *HLU* scheme. The results and simulations are given in section 6.

5.3 Network Architecture and Parameters

The eNodeB of 4G has two interfaces *UMTS* and *LTE*. The eNodeB allows access to different users with different traffic requirements and different mobility. 4G *LTE* network structure and its 3G network are explained in this section. The *LTE* network with its 3G interface is illustrated in Figure 4.1. The data (packet) service is offered by *LTE* network. It consists of a core network radio access network (*RAN*) and mobile stations (MSs). Its *RAN* uses eNodeB *i.e LTE* base station (BS) which allows access to MSs. The network core is IP-based and uses a mobile management entity (MME) in order to locate MSs movement *e.g.* location update and paging information. The 4G gateways are used to route packets between the 4G RAN and the Internet.

In contrast, the 3G network provides support to both data and voice calls or in other words packet-switched and circuit-switched calls. Its *RAN* uses radio network systems (RNS) to allow access to radio resources. Its network consists of *a*) Gateway mobile switching centre (GMSC/VLR) which stores/updates user location. *b*) A 3G gateway that provides data (packet) service and provides a route between the RAN and the internet.

The UMTS interface adopts VSF-OFCDM in order to allocate OVSF codes of a code tree spread in two dimensions: time and frequency. The OVSF code tree used is of layer *L*. The rate of code in the layer is $2^{l-1}R$, where1 $\leq l \leq L$. The OVSF channelization code in layer *l* is denoted by C_{l,n_l} where n_l denotes its position in layer *l*, also $1 \leq n_l \leq 2^{l-1}$. A layer *l* OVSF code $C_{sf_{l,m}}$ spreads in both frequency and time domains. The frequency-domain code for which is $C^F_{sf_{l_f,m_f}}$, where sf_{l_f} denotes its frequency domain spreading, also $sf_{l_f} = 2^{l_f} - 1$ and m_f is the position of the frequency domain code in a layer l_f, where $1 \leq m_f \leq sf_{l_f}$. The time-domain code for which is $C^T_{sf_{l_t,m_t}}$, where sf_{l_t} denotes its time-domain spreading, m_t is the time-domain code position in the layer l_t.

Also, the OVSF code tree spreading factor, frequency domain and time domain spreading factor are related to each other by

$$sf_{l,m} = sf_{l_f} \times sf_{l_t} \tag{5.1}$$

$$l = l_f + l_t - 1 \tag{5.2}$$

$$m = m_f + (m_t - 1) \times 2^{l_f - 1} \tag{5.3}$$

For the *LTE* interface, *LTE-PHY* structure as shown in Figure 4.2 has 10-time domain subframes, each of which has two slots. The subframe can carry 14 OFDM symbols and the frequency domain subchannel has 12 subcarriers.

The transmission unit for an MS is defined by resource block (*RB*) within a subframe (for time) and a subchannel (for frequency) for *LTE* interface. The *LTE* interface uses spatial multiplexing with four antennas and the eNodeB for every channel pilot symbol is used as the individual reference signal symbol.

For multiuser access in OFDMA, a subframe *RB*s can be allocated to different MSs. For single user access in OFDM, the *RM*s of the subframe can be allocated to one MS, they cannot be allocated to different MSs. For *LTE* using OFDMA, an MS will be allocated at least one *RB* and in the same subframe duration different MSs can use the number of *RB*s allocated to them by eNodeB.

For the *LTE* interface, *LTE-PHY* structure as shown in Figure 4.2 has 10-time domain subframes, each of which has two slots. The subframe can carry 14 OFDM symbols and the frequency domain subchannel has 12 subcarriers. The number of subchannels depends upon the channel bandwidth (BW) (Chang & Wu, 2009). The transmission unit for an MS is defined by resource block (*RB*) within a subframe (for time) and a subchannel (for frequency) for *LTE* interface. The *LTE* interface uses spatial multiplexing with four antennas and the eNodeB for every channel pilot symbol is used as the individual reference signal symbol.

For multiuser access in OFDMA, a subframe *RB*s can be allocated to different MSs. For single-user access in OFDM, the *RM*s of the subframe can be allocated to one MS, they cannot be allocated to different MSs. For *LTE* using OFDMA, an MS will be allocated at least one *RB* and in the same subframe duration different MSs can use the number of *RB*s allocated to them by eNodeB. Adaptive load balancing MDP

5.4 Calculation of utilization of LTE interface and UMTS interface

UMTS Interface: The *UMTS* interface in this chapter consists of *L* layers. The total capacity of the code tree is $2^{L-1}R$. If the numbers of codes assigned to layers 1, 2, 3 …*L* are n_1, n_2, n_3… n_L, then utilized capacity (*UC*) of the code tree

$$UMTS_{UC} = n_1 \cdot R + n_2 \cdot 2R + n_2 \cdot 4R \ldots n_{L-1} \cdot 2^{L-1}R \tag{5.4}$$

$$UMTS_{UC} = \sum_{l=1}^{L} n_l \cdot 2^{l-1}R \tag{5.5}$$

A new call of rate $2^{i-1}R$ will be handled by UMTS interface when

$$UMTS_{UC} + 2^{i-1}R \leq UMTS_{Th} \tag{5.6}$$

here $UMTS_{Th} = 2^{L-1}R$, the effect of the channel load is not considered.

$$UMTS_{UC} + 2^{i-1}R \leq UMTS_{Th} \tag{5.7}$$

here $UMTS_{Th} = 0.7 \times 2^{L-1}R$, channel load threshold is set to 70%.

LTE Interface: The *LTE* interface assigns *RB*s. If the interface has the total number of *RB*s equals to NRB_{total} and $NRB_{Utilized}$ are the number of assigned *RB*s. A new call of rate $2^{i-1}R$ requires $RB^{mp}_{Required}$ will be handled by *LTE* interface without any threshold, when

$$NRB_{total} - NRB_{Utilized} \geq RB^{mp}_{Required} \tag{5.8}$$

The number of *RB*s or *UMTS* codes required by the call of rate $2^{i-1}R$ depends upon its position in the cell. The number of *RBs* for a call is calculated

$$RB^{AMC}_{required} = \left\lceil \frac{2^{l-1}}{n_{AMC}} \right\rceil \tag{5.9}$$

Also, the time required for the completion of calls

$$T^{AMC}_{required} = \frac{t_1}{\left\lceil \frac{2^{l-1}}{n_{AMC}} \right\rceil \times n_{AMC}} \tag{5.10}$$

here ⌈ ⌉ denotes $ceiling\ function$, *l*=1,2,3,4,5 , $t_1 = \frac{d}{144Kbps} s$ is the time required for data *d* and n_{AMC} is bits/symbol value is given in Table 5.1.

Table 5.1 AMC schemes and antennas used.

Modulation Scheme Used due to location	Antennas Used at Transmitter and receiver	n_{AMC}
QPSK 1/2	Single	1
16QAM 1/2	Single	2
16QAM 3/4	Single	3
64QAM	Single	6
64QAM	2x2 MIMO	12
64QAM	4x4 MIMO	24

5.5 Proposed Handoff LTE-UMTS Scheme

The rapid increase in traffic and their velocities leads to several handover problems. The proposed *Handoff LTE- UMTS* (*HLU*) for *LTE* and *UMTS* assignment scheme provides access to high data rate calls together with voice calls in high mobility wireless communications forward link. Wireless communication resources are allocated dynamically to stationary and fast moving vehicles which lead to the problem of scattered resources. The 4G-3G network consists of both *LTE* architecture and legacy 3G networks. For improved spectral efficiency of *LTE* and *UMTS* interface, SGs traffic can be handled with mobile traffic. The SGs traffic is static and data transfer mostly, which reduces the complexity of handling two types of traffics.

The SG data calls are used for transferring meter information of a subscriber(s) in a particular area. The SG alarm messages are considered as voice calls, these are also static in terms of location. The handoff process considered in the chapter is a handoff from the location of one adaptive modulation and coding (AMC) (Huang & Dou, 2004) to another for e.g. *QPSK* to 16*QAM* and vice versa. The *HLU* scheme also reserves a portion of capacity in *UMTS* for *LTE* on-going calls for a possible handoff to 3G and checks the *RB* availability in *LTE* interface for a possible handoff from 3G-4G. This is due to the possible movement of a call away from BS. The *HLU* assignment scheme is divided into three levels as it differentiates incoming call on the basis of these parameters

Level 1: Incoming call type data or voice.

Level 2: Current location of the MS.

Level 3: Speed and direction of motion of the MS.

Level 1: Incoming call type data or voice

For an incoming call of rate $2^{i-1}R$, check the incoming call type: voice or data. For a voice call *UMTS* interface is used and if the sum of utilized capacity of the *UMTS* interface with incoming call rate is less than the *UMTS* threshold capacity call is handled using the *UMTS* interface otherwise block the call. For data calls, go to level 2.

Algorithm:

```
•  Check the incoming call type: voice or data.
•  If (voice)
     Find whether $UMTS_{UC} + 2^{i-1}R \leq UMTS_{Th}$.
     If (yes)
     The call will be handled by the UMTS interface using the UMTS assignment
     scheme defined in section 5.7.
     Else
     Block the call.
     End
•  Else (data)
     Go to level 2.
•  End
```

Level 2: Current location of the MS

The number of *RB*s or *UMTS* code required by the data call of rate $2^{i-1}R$ depends upon its position in the cell.

```
   Check whether $NRB_{total} = NRB_{Utilized}$
•  If (yes)
```

```
    Find whether $UMTS_{UC} + 2^{i-1}R \leq UMTS_{Th}$.
    If (yes)
    The call will be handled using the UMTS interface using the assignment scheme defined in section 5.7.
    Else
    Block the call.
    End
•   Else
    Find the current location of MS.  Determine the minimum number of RBs required at this location $RB_{Required}^{mp}$ using equation (5.9).
•   If ( $RB_{Required}^{mp} + NRB_{Utilized} \leq NRB_{Total}$)
    If ( $RB_{Required}^{mp} \leq RB_{Threshold}$)
    Assign $RB_{Required}^{mp}$to the call.
    Else
       Go to level 3.
    End
•   Else
    Block the call.
•   End
•   End
```

Level 3: Speed and direction of the MS

When the direction of motion of the M-T is taken into consideration. For example, let the requested call of rate 8*R* is at a 16QAM ½ location and is moving towards 16QAM3/4 location. The number of $RB_{Required}^{AMC} = 4$ at 16QAM ½ location, i.e $RB_{Required}^{AMC} \geq RB_{Threshold}$=3 and at 16QAM3/4, $RB_{Required}^{AMC} = 3$. For $NRB_{Total} - NRB_{Utilized} \geq 6$, the $RB_{Required}^{AMC}$ are assigned to the new call. When it will enter another *AMC* location, the network can reduce the number of assigned *RBs* when required. The different call arrivals, the resources required or assigned and the effect on call duration are shown in Table 5.2.

The performance of the algorithm can be improved by assigning more *RBs* to a call than required. This will also improve spectral efficiency. For example, when a data call requires 3*RBs* and due to availability of resources *BS* assigns 6 *RBs* for the complete duration of the call, the duration of call reduces to half. This assignment of resources is dynamic due to the dynamic nature of calls and also due to the mobility of the calls.

Table 5.2 Call Completion time with different assigned RBs for AMC scheme

Modulation Scheme Used due to location	Antennas Used at Transmitter and receiver	Offered Rate	Assigned RBs	Call Completion time for a data 'd'
Requested call rate - 2R				
QPSK 1/2	Single	144 Kbps	2	$\frac{t_1}{2}$
16QAM 1/2	Single	288 Kbps	1	$\frac{t_1}{2}$
16QAM 3/4	Single	432 Kbps	1	$\frac{t_1}{3}$
64QAM	Single	864 Kbps	1	$\frac{t_1}{6}$
64QAM	2x2 MIMO	1728 Kbps	1	$\frac{t_1}{12}$
64QAM	4x4 MIMO	3.456 Mbps	1	$\frac{t_1}{24}$
Requested call rate - 4R				
QPSK 1/2	Single	144 Kbps	4	$\frac{t_1}{4}$
16QAM 1/2	Single	288 Kbps	2	$\frac{t_1}{4}$
16QAM 3/4	Single	432 Kbps	2	$\frac{t_1}{6}$
64QAM	Single	864 Kbps	2	$\frac{t_1}{6}$
64QAM	2x2 MIMO	1728 Kbps	1	$\frac{t_1}{12}$
64QAM	4x4 MIMO	3.456 Mbps	1	$\frac{t_1}{24}$
Requested call rate - 8R				
QPSK 1/2	Single	144 Kbps	8	$\frac{t_1}{8}$
16QAM 1/2	Single	288 Kbps	4	$\frac{t_1}{8}$
16QAM 3/4	Single	432 Kbps	3	$\frac{t_1}{9}$
64QAM	Single	864 Kbps	2	$\frac{t_1}{12}$
64QAM	2x2 MIMO	1728 Kbps	1	$\frac{t_1}{12}$
64QAM	4x4 MIMO	3.456 Mbps	1	$\frac{t_1}{24}$
Requested call rate - 16R				
QPSK 1/2	Single	144 Kbps	16	$\frac{t_1}{16}$
16QAM 1/2	Single	288 Kbps	8	$\frac{t_1}{16}$
16QAM 3/4	Single	432 Kbps	6	$\frac{t_1}{18}$
64QAM	Single	864 Kbps	3	$\frac{t_1}{18}$
64QAM	2x2 MIMO	1728 Kbps	2	$\frac{t_1}{24}$
64QAM	4x4 MIMO	3.456 Mbps	1	$\frac{t_1}{24}$
$t_1 = \frac{d}{144\ Kbps}$				

5.6 Proposed UMTS ANC Scheme

The scheme for 4G and beyond communication networks available in literature assigns codes to a new call on the basis of its current location. Due to this reason more calls are blocked which leads to poor utilization of available UMTS resources. The proposed scheme uses the adaptive modulation and coding (AMC) process which is defined in (Huang & Dou, 2004) conditions when interference or distance varies between MS and eNodeB. The chapter also considers 64-QAM, 16-QAM, QPSK and BPSK adaptive modulation schemes for comparison with existing schemes. The data rate in which these schemes offer decreases from 64-QAM to BPSK. These schemes support the data rates of 8*R*, 4*R*, 2*R*, and *R* for a single code assignment respectively from 64-QAM to BPSK. The 64-QAM location provides a better *SNR* and offers an 8*R* data rate for one channelization code, therefore when a call request of 8*R* at 64-QAM location arrives it can be handled by using one code. The same call of rate 8*R* handled using 8 codes of rate *R* at BPSK location. The data rate supported by a single channelization code for different *AMC* schemes is given in Table 5.1.

A. Multi code assignment scheme

For an incoming call of rate $2^{i-1}R$, at the location of QPSK. The number of codes required are $\frac{2^{i-1}R}{2R} = 2^{i-2}$ *i.e* number of rakes required are 2^{i-2} . The multi-code assignment now checks the direction of motion. When the user is moving towards 16-QAM location, the algorithm will search for a vacant code of rate $2^{i-1}R$ with time-domain code channel load less than 0.70.

a. If (*a vacant code of rate* $2^{i-1}R$ *available*)

   Assign new call to the codes of rate 2^{i-2} using 2^{i-2} rakes.

b. Elseif (*search vacant codes of rate* $2^{i-2}R$ *in the code tree with time-domain code channel load less than 0.75*)

   Assign call to all codes using 2^{i-2} rakes and count number of vacant code of rate 2^{i-2} denoted by k_1.

c. Elseif (*search vacant codes of rate* $2^{i-3}R$ *in the code tree with time-domain code channel load less than 0.75*)

   Count number of vacant code of rate 2^{i-3} denoted by k_2. Assign call to k_1 codes of rate $2^{i-2}R$ and k_2 codes of rate 2^{i-3}using $k_1 + k_2$ rakes.

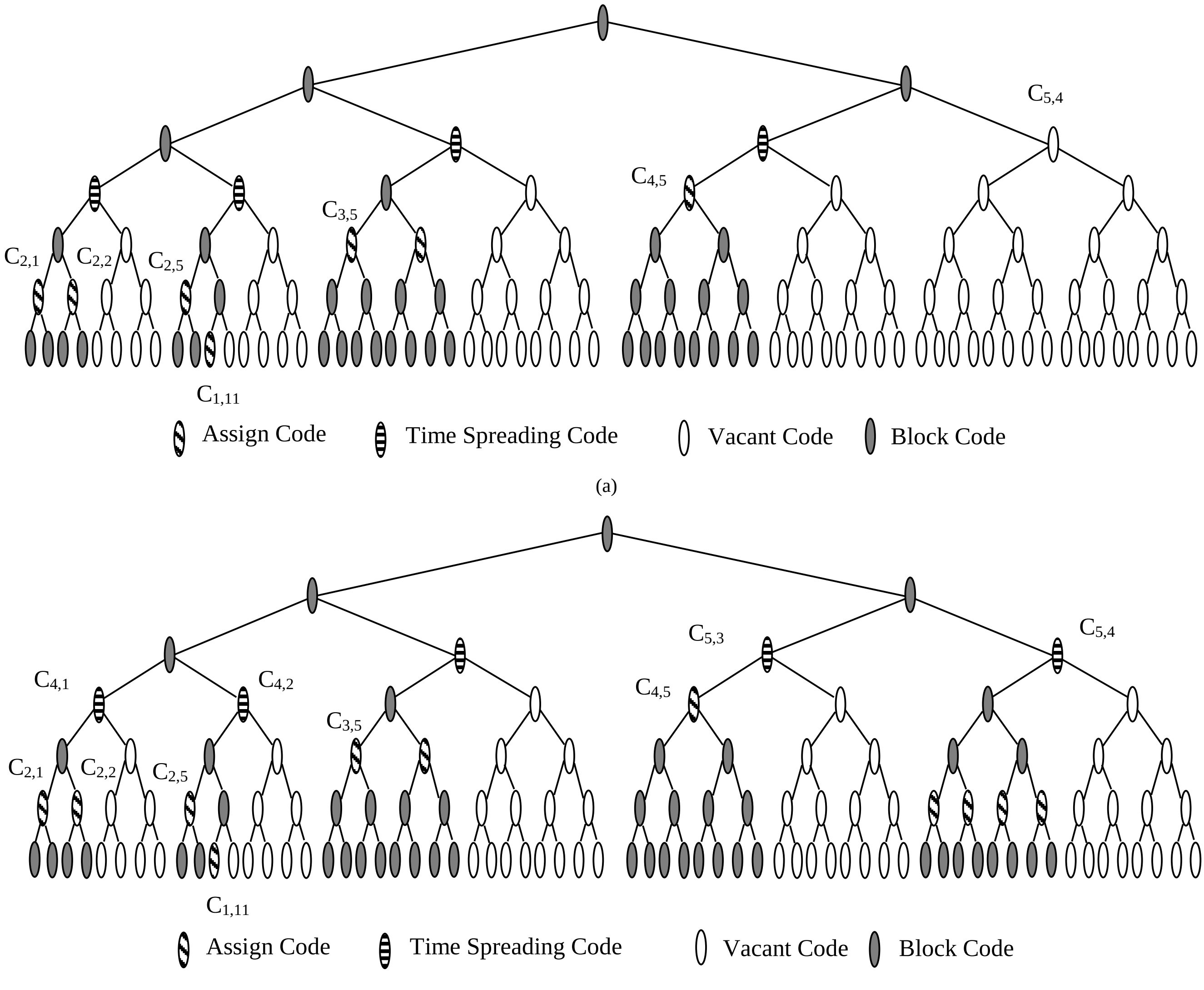
d. Else

   Block the call.

e. End.

When the user enters 16-QAM location merge codes of lower rates and handles call using a lesser number of rakes. These rakes can be used for other calls.

For an illustration of *ANC* multi-code assignment scheme, consider the arrival of a call of rate $8R$ at a location of QPSK moving towards 16-QAM. The QPSK supports $2R$ for a single code assignment, therefore it requires 4 codes of rate $2R$ which is under channelization code $C_{5,4}$ as shown in Figure 5.1 (a) and assigned in Figure 5.1 (b) using 4 rakes with codes $C_{2,25}$ to $C_{2,28}$. When it will enter, the 16-QAM location, the call be handled by codes $C_{3,13}$ and $C_{3,14}$ using 2 rakes, the remaining two rakes can be used for future calls. If the same user is moving towards the BPSK location then will require 8 codes of rate R, the system has enough rakes to support the call, the call will be handled using those rakes otherwise call will be either



(a)

(b)

Figure 5.1 Illustration of ANC multi code assign (a) $8R$ arrives (b) $8R$ arrives again

blocked or handled at lower QoS. Consider the status of the OVSF code tree in Figure 5.1 (b), when the second call of $8R$ arrives with the location of BPSK, it will require 8 codes of rate R. It will use 2 codes, 3 codes and 3 codes under time spreading codes ($C_{1,5}$, $C_{1,6}$), codes ($C_{1,12}$, $C_{1,13}$, $C_{1,13}$), codes ($C_{1,12}$, $C_{1,13}$, $C_{1,13}$), codes ($C_{1,25}$, $C_{1,26}$, $C_{1,27}$) using 8 rakes.

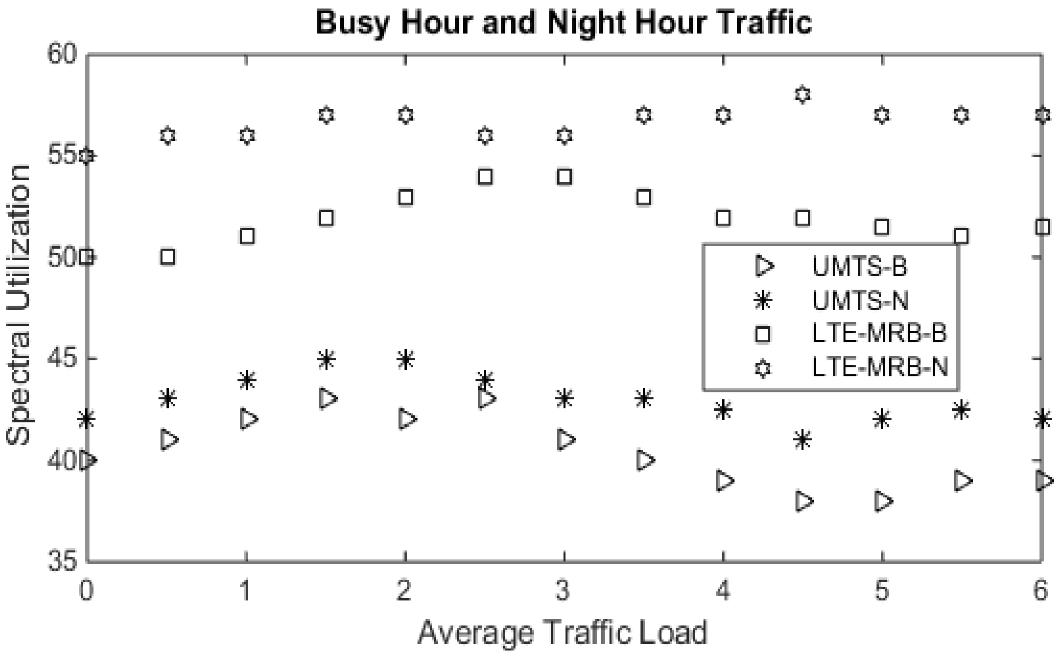


Figure 5.2. Spectral utilization of UMTS and LTE interface in Busy and Night Hours.

5.7 Results and Simulations

a) ***HLU Scheme:*** The arrival rate is average from 0 to 6. The arrival of calls during busy hours is mostly M-T (80%) and SG-T (20%). In the night hour's arrival of calls is mostly M-T (20%) and SG-T (80%). The average call duration of all traffic rates is exponentially

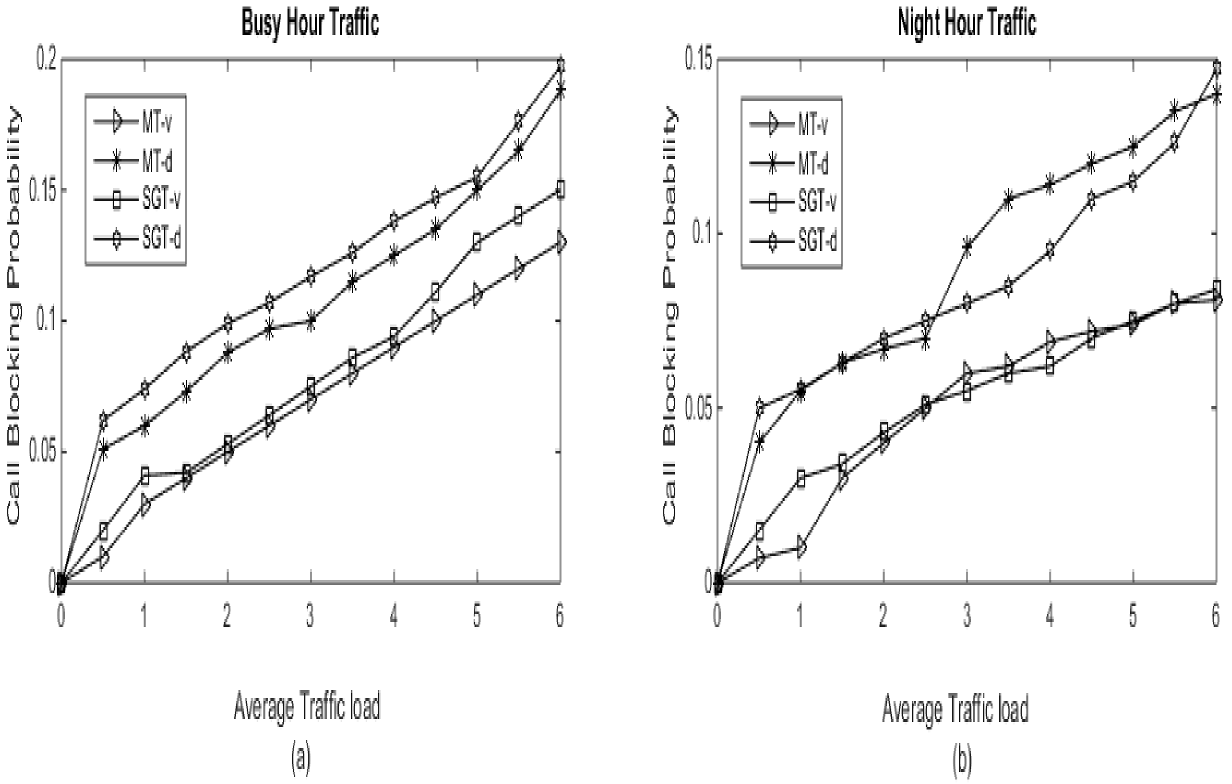
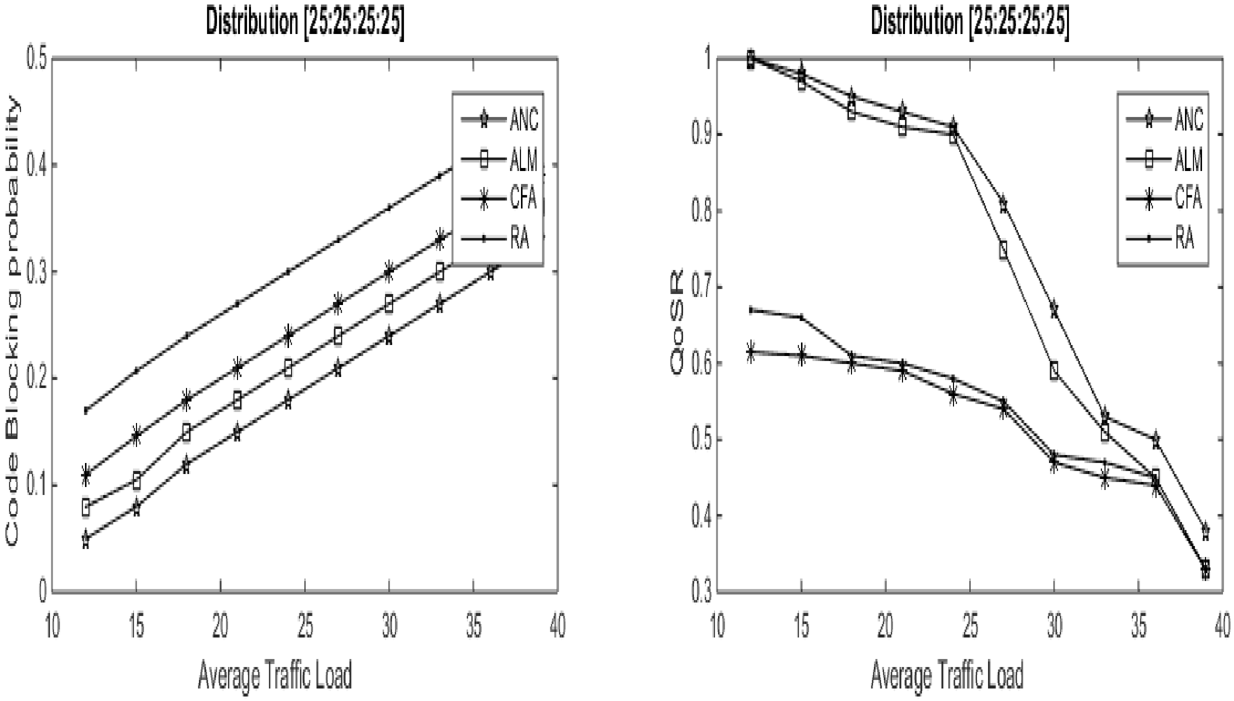


Figure 5.3. Call Blocking Probability of Mobile Traffic and Smart Grid Traffic *(a)* Busy Hour (*b)* Night Hour.

distributed with normalized mean value 1. The arrival distribution of rates [*R*, 2*R*, 4*R*, 8*R*]. The LTE interface capacity used is 345.6 Mb/s and of UMTS interface 256*R* (3.4Mb/s). Figure 5.2, determines the spectral utilization of *UMTS* and *LTE* interface in busy and night hour traffic. For a network handling only M-T, spectral utilization is around 50% and 33% respectively for *LTE* and *UMTS* interface, especially during night hours. The proposed scheme assigns resources to SG-T too, this increases spectral utilization of both interfaces. Also, during the night hours the maximum resource block (MRB) threshold increases from 3 to 6 for *LTE* interface. This considerably reduces the call blocking probability shown in Figure 5.3 for both M-T and SG-T data traffic denoted MT-d and SGT-d. The network gives preference to M-T in busy hours and SG-T in night hours. The SGT-d considered is metering information equivalent to a voice call when from the single meter and a data call when from an aggregator.

b) ***ANC Scheme:*** The performance of an *adaptive number of codes* (ANC) is compared with the crowded first assignment (CFA) and random assignment (RA) scheme proposed in (Tseng & Chao, 2002) and ALM approach in (Chang & Wu, 2009). For the performance comparison, the parameters used are code blocking probability and quality of service ratio (QoSR). The total capacity of the code tree is assumed to be 256*R*. The performance is compared for the downlink of the network and traffic arrived is of the variable rate. The number of rakes used is from 1 to 8.

The arrival rate (average) is from 12 to 39. The average call duration of all traffic rates is exponentially distributed with normalized mean value 1. The arrival distribution is assumed to be uniform *i.e* for rates [*R*, 2*R*, 4*R*, 8*R*], the percentage is equal to 25%. Figure 5.4 (*a*), illustrates the code blocking probability of the compared schemes. The code blocking probability of all the calls increases with traffic load. The reason is the fragmentation of vacant code in the code tree due to the random behaviour of arrival and departure of calls. The ANC scheme provides the minimum code blocking probability as it searches the complete code tree in absence of a single code of requested rate and utilizes the fragmented capacity in the code tree. Figure 5.4 (*b*), the quality of service ratio (QoSR), the QoSR of all schemes decreases with the increase of traffic load due to interference. The *ANC* scheme performs better than the compared scheme as it increases or decreases as the number of rakes required to handle the call. In other words, it decreases or increases code capacity which is handling the call shown in Figure 5.4.



(a)

(b)

Figure 5.4 (*a*) Code blocking probability in presence of variable traffic load (*b*) QoSR in presence of variable traffic load.

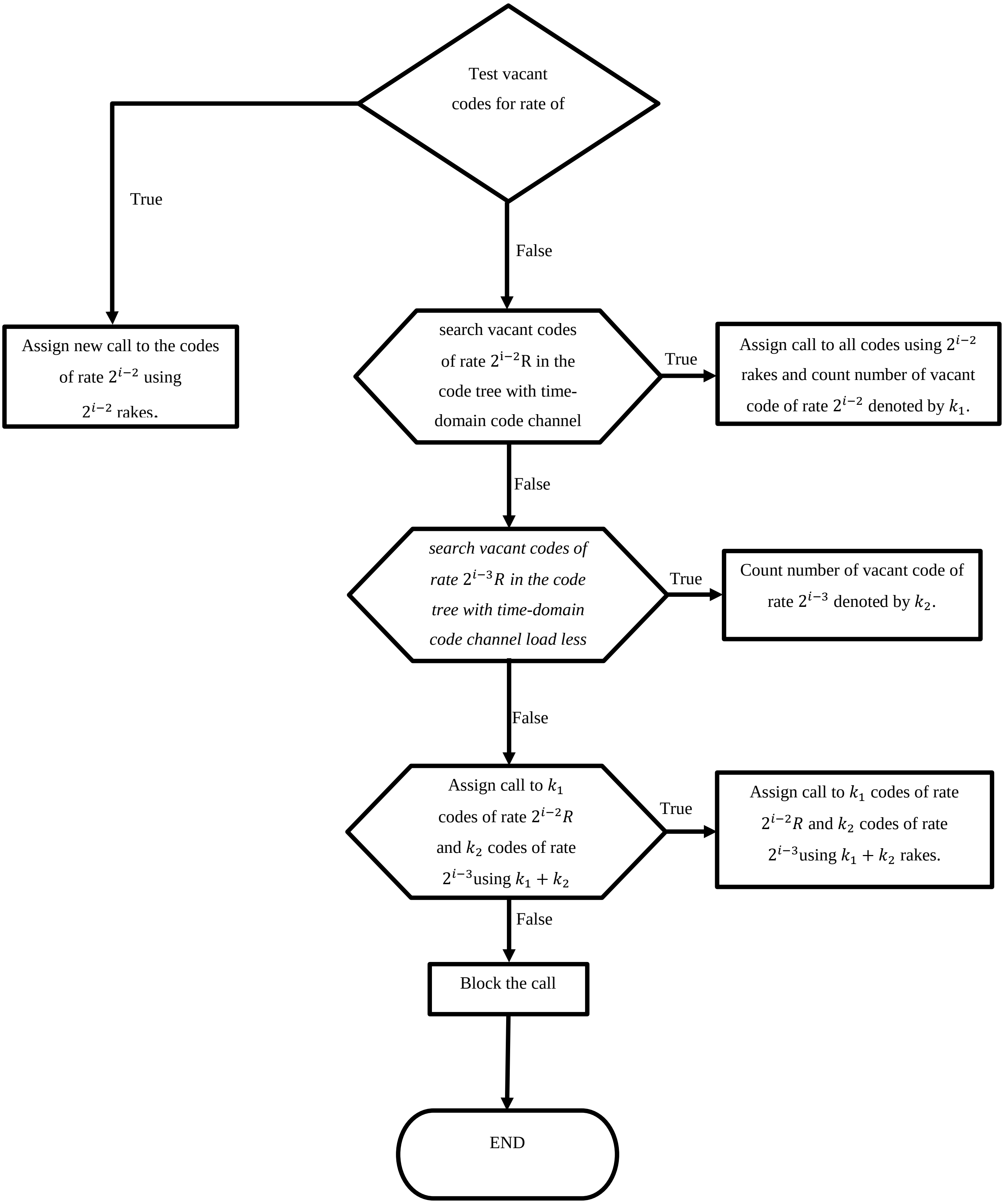


Figure 5.5 The flowchart diagram illustrate the code blocking probability algorithm described in paragraph 5.5 above.

5.8 Conclusion

The proposed scheme in this chapter assigns capacity available at LTE and UMTS interface to mobile and smart grid traffic, which improves spectral utilization of both interfaces. Further, during night hours when mobile users are inactive smart grid metering information available with aggregators is sent at a faster speed using LTE interface by assigning more RBs. The scheme also takes into consideration the effect of mobile user motion which leads to dynamics in the resource allocated or handoff of resources. The UMTS interface uses two- dimensional spreading of codes in time and frequency for mobile users with higher mobility. The ANC scheme manages the number of available rakes adaptively without influencing QoS and with reduced code blocking probability as compared to compared schemes. The ANC scheme also considers both location and direction of motion in the cell before the assignment. In future, work can be done to find complexity associated with changing the number of rakes during the duration of the call.

CHAPTER SIX

Fast Channel Load Algorithm for Downlink of Multi-Rate MC-DS-CDMA and Smart Grid Communication.[6]

6.1 Introduction

When electrical power grids joined with communication technologies the concept of SGs is evolved (Zheng et al., 2013). The well-developed wireless communication techniques focused the researcher's attention on implementing wireless communication as the communication medium for power grids and development of SGs. 3GPP (3rd Generation Partnership Project) proposed LTE as the technique to develop a smart grid. LTE is a widely accepted technique that provides connectivity to a mobile user at better speed and less latency. The SG communication network takes on a ranked architecture which broadly has three levels or three kinds of networks. The home area networks (HANs), neighbourhood area networks (NANs) and wide area networks (WANs). The NANs are basically the backbone communication network that manages the distribution of electricity from distribution units to end-users (Meng et al., 2014).

The Third- Generation Partnership Project (3GPP) has proposed an enhanced third-generation (3G) mobile communication, namely, 3.5G (3GPP, 2013). 3.5G adopts the high-speed downlink packet access (HSDPA) standard to provide a high data rate of 14 Mb/s. For accessing the fast service of cloud, the fourth (4G) cellular communications (Kottkamp, 2010), (913, 2011), are announced for the shared packet service. To anticipate the demand for the increase of future traffic, the fourth generation (4G) mobile communication systems have data rates of up to 100 Mb/s for high mobility and up to 1 Gb/s for low-mobility nomadic wireless access. Several communication technologies have been proposed i.e. Variable Spreading Factor- Orthogonal Frequency and Code Division Multiplexing (VSF-OFCDM) (Maeda et al., 2003), 3GPPs' (3GPP, 2013) LTE and LTE-Advanced (G. A. Daniel, 2010), orthogonal frequency division multiplexing (OFDM) etc. (Control & Group, n.d.), and OFCDM can operate at a broadband channel with approximately 100 MHz and supports the data rate ranging from 100 Mb/s to 5 Gb/s**.** OFCDM decreases multipath interference which is a serious issue and therefore leads to higher spectrum utilization than direct-sequence code division multiple access (DS-CDMA) (Adachi et al., 2005). The proposed variable spreading factor OFCDM (VSF-OFCDM) in (Atarashi & Ahashi, 2002) combines OFCDM with a variable spreading factor and used for a downlink transmission scheme.

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6.2 Work in Literature

Previously, several schemes are proposed in the literature to reduce code blocking in OVSF (Adachi et al., 1997) based networks. These schemes are broadly classified as single code assignment schemes and multi-code assignment schemes. Some of the schemes of single code assignment are: crowded first assignment (CFA) (Tseng & Chao, 2002), leftmost code assignment (LCA) (Tseng & Chao, 2002), fixed set partitioning (FSP) (Park, J. S., Lee, 2003) and recursive fewer codes blocked (RFCB) scheme (Rouskas et al., 2005). The schemes use 1-dimensional spreading but all of these schemes suffer from interference as they don't consider the effect of channel load (C*l*). The schemes in (Balyan & Saini, 2014), (Sharma & Saini, 2013), (Saini & Upadhyay, 2009), uses multiple codes to handle a single call which leads to a reduction in code blocking with higher radio resources wastage and higher complexity. In order to address these problems, the OVSF codes in two dimensions are allocated by VSF-OFCDM in two dimensions by UMTS. An adaptive load balancing (ALM) is proposed in (Balyan et al., 2010) this scheme suffers from higher code blocking problem as it uses Cl as a parameter to accept the call and assigns calls to a time domain tree for $Cl<Cl_{Threshold}$. The assignment most of the times lead to higher code blocking. The trade-off between the multicode interference and the frequency diversity gain has previously been investigated and analysed in (Chang & Wu, 2009). The scheme in (Maeda et al., 2005) uses a two-stage combining and code allocation scheme to decrease the multicode interference; but the method is inefficient as with the increase in the number of users, the number of orthogonal codes significantly reduces. An interference avoidance (IA+CF) scheme is proposed in (Kazuhiko Hasegawa, Ryuichiro Shimura, Tsutomu Ohno, Naoki Yoshimochi, 2005) which provide significant improvement of code blocking probability at better QoS. An adaptive reward-based selection of UMTS and LTE considering the effect of interference and mobility environments are proposed in (Wang et al., 2007) (Chang et al., 2013). A multicode scheme for OVSF codes is proposed in (Chang et al., 2015) which provides zero waiting time for real-time calls. The QoS requirements together with higher utilization are the demands of the Multi-Rate MC-DS-CDMA networks. The essential requirement to attain the potential advantages of SG is the productive implementation of a communication infrastructure that is secure, energy-aware, reliable and cost-effective too (Quang-Dung et al., 2013). The smart meters (SMs) are connected to the power outlet at homes and industrial units and they usually transmit at low power level using wireless communication medium to the gateways (GWs), gateways are sometimes base stations of cellular network or the SMs are connected to BSs in a two hop manner using Wireless LANs (WLANs). The data traffic is different from traditional cellular networks and enterprise data traffic (Quang-Dung et al., 2013). The data volume is also significantly low too (Luan et al., 2013) (Kuzlu et al., 2014) (Ramírez et al., 2015). The OCA scheme in this chapter addresses both the demands and also shows significant benefit.

This chapter proposes an optimum code assignment (OCA) scheme which meets the demand for quality of service (QoS) of a call with improved capacity utilization of the Downlink of Multi-Rate MC-DS-CDMA when used for SGs. The OCA scheme assigns incoming call requests to a vacant code which leads to minimum future code blocking while maintaining the QoS of ongoing calls and the new call. The incoming call requests in this chapter are differentiated on the basis of their type: quantized or non-quantized. To ensure efficient radio resource allocation, a quantized call is assigned to code with channel load (*Cl*) of time-domain tree less than threshold channel load ($Cl_{Threshold}$) after an incoming call is accepted. The numbers of time-domain tree with $Cl<Cl_{Threshold}$ are differentiated on the basis of code blocking probability, the time domain tree which provides minimum future blocking is selected. A nonquantized call request is handled using multiple rakes by first broken into quantized rate fractions and these fractions are assigned to time-domain trees for which $Cl<Cl_{Threshold}$ and future code blocking is minimum. Cellular technology with LTE-based Multi-Rate MC-DS-CDMA standards is used preferably for real-time and distributed control in SGs as LTE is widely used and has features of forward-looking technology. Implementation of LTE mobile network for mobile subscribers will lead to wastage in rural areas, the unused radio resources can be used for SG communication. The proposed OCA scheme, in this chapter assigns resources to both types of traffic. Simulation and results show that the proposed scheme provides better E_b/N_0 (energy per bit to noise power spectral density ratio) while maintaining low code blocking probability than other available schemes in the literature.

6.3 System Model

The system model in this section describes the notations used, identification of codes and formulae used to find *Cl* of a time-domain code. The OVSF code tree is generated from a complete binary tree with *L* layers, where$1 \leq l \leq L$. The binary tree is generated as in (Adachi et al., 2005) shown in Figure 6.1. A channelization code is denoted by C_{l,n_l}, where *l* denotes the layer number and n_l denotes its position in layer *l*, $1 \leq n_l \leq 2^{L-l}$ the spreading factor (*SF*) of code is 2^{L-l}. The maximum spreading factor of the code tree is $SF_{max} = 2^{L-1}$. The code positions are sequential from left to right. The rate supported by a code is determined by its *SF*, codes with smaller spreading factor support higher data rate requests and vice versa.

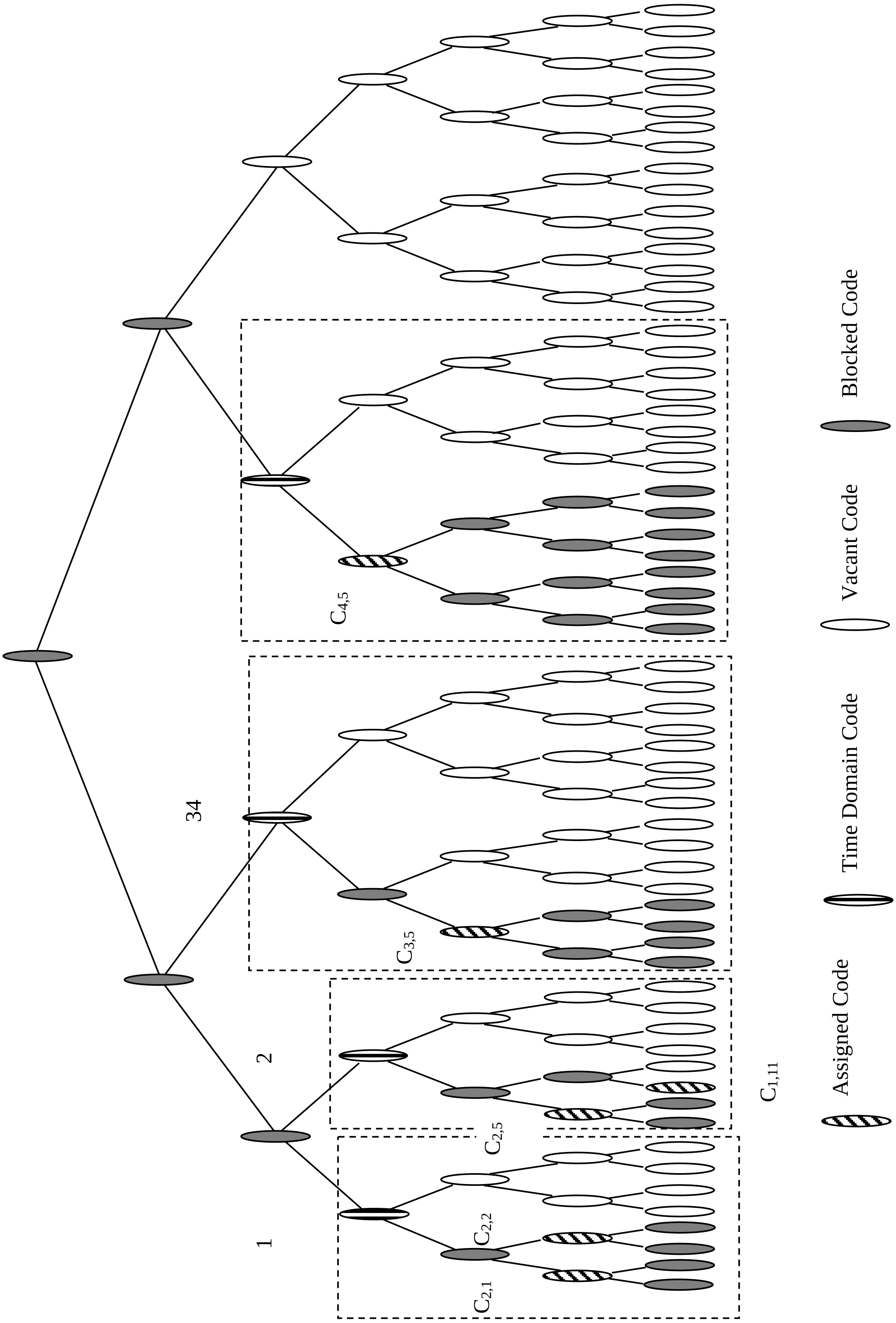

Figure 6.1. Illustration of Quantized and Non-Quantized Single code Approach.

The rate of a code is quantized and of the form $2^{l-1}R$. Due to the orthogonal nature of channelization codes, OVSF codes maybe in one the states namely *busy*, *vacant* or *blocked*. The blocked state is due to the orthogonal characteristic *i.e* a busy code blocks all its parents and children in all layers from an assignment. Therefore, a code can be assigned to a call, if and only if all its parent and children codes are vacant. This leads to fragmentation of available total capacity and leads to code blocking.

This chapter concentrates on the *Cl* and code blocking probability of Multi-Rate MC-DS-CDMA. A layer *l* channelization code C_{l,n_l} spreads both in time and frequency domains.

The nomenclature for different terms and notations used in the chapter is given in Table 6.1. The time-domain spreading code is denoted as $C_{2^{l_t-1},n_{l_t}}$ and frequency domain spreading code is denoted as $C_{2^{l_f-1},n_{l_f}}$. The 2-D spreading in time and frequency domain retains the orthogonal characteristics of channelization code. The relation between spreading factor of channelization code, time-domain code and frequency spreading code is:

Table 6.1 Nomenclature

Symbol	*Description*
l, l_t, l_f	Reference layer, time domain layer and frequency domain layer.
C_{l,n_l}	Code in layer *l* and n_l denotes position in layer *l*.
$C_{2^{l_t-1},n_{l_t}}$	Time domain code in layer l_t and n_{l_t} denotes its position in layer l_t.
$C_{2^{l_f-1},n_{l_f}}$	Frequency domain code in layer l_f and n_{l_f} denotes its position in layer l_f.
N_l	Number of ongoing calls of layer *l*.
Cl, $Cl_{Threshold}$	Channel load and threshold value of channel load.
m	Total number of rakes.
P_{B_i}	Probability of *i*th class.
P_B	Total code blocking probability.

$$2^{L-l} = 2^{k_t-1} \times 2^{k_f-1} \tag{6.1}$$

The characteristic of L, l, k_t and k_f should satisfy

$$L - l = (k_t + k_f - 2) \tag{6.2}$$

Where k_t and k_f denotes level index for time and frequency domains.

The characteristic of n_l, n_{l_t} and n_{l_f} should satisfy

$$n_l = n_{l_f} + (n_{l_t} - 1) \times 2^{k_f-1} \tag{6.3}$$

Where n_l, n_{l_t} and n_{l_f} denotes code index for OVSF code tree, time domain, and frequency domain.

For a new call request of rate *kR*, an optimum code is searched and assigned. An optimum code is defined as the code which leads the minimum code blocking, minimum reassignment and recombination in future with channel load of the time domain code within the threshold and this scheme as an optimum code allocation (OCA). The total channel load of code is due to the number of busy codes at each layer in subtree under it *i.e* from the lowest layer (*l*=1) to $(l = L - l_t)$, where $l_t = log_2(SF_{l_t} + 1)$, also SF_{l_t} is spreading factor of time-domain code at level $(L - l_t)$ above layer 1.

The *Cl* of a time-domain subtree at layer l_t with N_l busy codes of l^{th} layer is:

$$\frac{N_l \times 2^{l_t}}{2^{L-l+1}} \tag{6.4}$$

The *Cl* for a 8 layer tree is calculated for a different number of busy calls of different layers and is given in Table 6.2 with variable time-domain code. This is available at the base station (BS) which reduces the computation time of calculating *Cl*.

The calls generated by mobile network and SG network are not differentiated on the basis of the network; the assignment scheme assigns radio resources on the basis of call request data volume. The SG network is also assumed to request a call of rate γR.

Table 6.2 Calculation *of Cl for a 8 layer code tree with variable number of ongoing busy calls*

Time domain SF_{k_t}	Ongoing call layer number (*l*)	Number of ongoing calls of layer *l* (n_l)	Cl_i	Cl_f after accepting call of layer		
				1	2	3
32	1	1	$1/2^2$	$1/2$	$3/2^2$	AT
		2	$1/2$	$3/2^2$	AT	AT
		3	$3/2^2$	AT	$3/2$	AT
	2	1	$1/2$	$3/2^2$	AT	AT
		2	AT	AT	AT	AT
16	1	1	$1/2^3$	$1/2^2$	$3/2^3$	$5/2^3$
		2	$1/2^2$	$3/2^3$	$1/2$	$3/2^2$
		3	$3/2^3$	$1/2^2$	$5/2^3$	$7/2^3$
		4	$1/2$	$5/2^3$	$3/2^2$	AT
	2	1	$1/2^2$	$3/2^3$	$1/2$	$3/2^2$
		2	$1/2$	$5/2^3$	$3/2^2$	AT
		3	$3/2^2$	$7/2^3$	AT	AT
	3	1	$1/2$	AT	AT	AT
8	1	1	$1/2^4$	$1/2^3$	$3/2^3$	$5/2^4$
		2	$1/2^3$	$3/2^4$	$1/2^2$	$3/2^3$
		3	$3/2^4$	$1/2^2$	$5/2^4$	$7/2^4$
		4	$1/2^2$	$5/2^4$	$3/2^3$	$1/2$
		5	$5/2^4$	$3/2^3$	$7/2^4$	$9/2^4$
		6	$3/2^3$	$7/2^4$	$1/2$	$5/2^3$
		7	$7/2^4$	$1/2$	$9/2^4$	$11/2^4$
		8	$1/2$	$9/2^4$	$5/2^3$	$3/2^2$
		9	$9/2^4$	$5/2^3$	$11/2^4$	$13/2^4$
		10	$5/2^3$	$11/2^4$	$3/2^2$	AT
		11	$11/2^4$	$3/2^4$	AT	AT
	2	1	$1/2^3$	$3/2^4$	$1/2^2$	$3/2^3$
		2	$1/2^2$	$5/2^4$	$3/2^3$	$1/2$
		3	$1/2^3$	$7/2^4$	$1/2$	$5/2^3$
		4	$1/2$	$9/2^4$	$5/2^3$	$3/2^2$
		5	$5/2^3$	$11/2^4$	$3/2^2$	$7/2^3$
		6	$3/2^2$	$13/2^4$	$7/2^3$	AT
	3	1	$1/2^2$	$5/2^4$	$3/2^3$	$1/2$
		2	$1/2$	$9/2^4$	$5/2^3$	$3/2^2$
		3	$3/2^2$	$13/2^4$	$7/2^3$	AT
	4	1	$1/2$	$9/2^4$	$5/2^3$	$3/2^2$
		2	AT	AT	AT	AT

AT: Above threshold

6.4 Single Code Assignment Approach

In this section, two assignment schemes are proposed which depends upon the type of call request arriving in the system. The basic idea of the schemes is to reduce code blocking which reduces system utilization. The higher utilization of orthogonal frequency domain codes under a time-domain tree (code) increases channel load (*Cl*) or multi-code interference increases which affects QoS requirements of ongoing calls.

To allocate the radio resources to the incoming calls of variable rates for higher utilization and to meet QoS requirements, the call requests are classified into two types: quantized and non-quantized call requests. The rate requested by the calls are of type $\gamma^Q R$ $\{\gamma^Q = 2^j, j \in I: integer\}$ for quantized and $\gamma^{NQ} R$ $\{\gamma^{NQ} \in [1-15] - 2^j, j \in [1-3]\}$ for non-quantized. The algorithm starts searching busy subtrees, when no optimum code is available vacant subtrees are searched. For a vacant sub tree lowest possible time spreading code is selected and is recombined with other time spreading codes to accommodate a higher number of calls when $Cl > Cl_{Threshold}$ with higher frequency domain *SF*.

6.4.1 Call Request: Quantized

For a quantized call request of rate $\gamma^Q R$, $\gamma^Q R\{\gamma^Q = 2^{l-1}\}$ a vacant code of layer $l^{\gamma^Q} \big| l^{\gamma^Q} = (log_2 \gamma^Q + 1) = I: integer$ is assigned which leads to the total capacity utilization of code.

The algorithm to locate an optimum code for quantized call works as follows.

1. Find, if $UC + \gamma^Q R \leq 2^{L-1} R$ $i.e$ sum of the used capacity (*UC*) with the rate of an incoming call ($\gamma^Q R$) is lesser than the maximum capacity of the code tree, then call can be assigned to any vacant code.
2. Let m_{γ^Q} denotes the number of vacant codes in layer l^{γ^Q}. Find, if $m_{\gamma^Q} \geq 1$.
3. Yes, calculate channel load (*Cl*) of associated time-domain codes of these vacant codes as

$$Cl_{\gamma^Q,v} = \frac{N_1 \times 2^{l_t}}{2^{L-1+1}} + \frac{N_2 \times 2^{l_t}}{2^{L-2+1}} + \frac{N_3 \times 2^{l_t}}{2^{L-3+1}} + \cdots + \frac{N_{L-l_t} \times 2^{l_t}}{2^{L-(L-l_t)+1}}, 1 \leq v \leq m_{\gamma^Q} \tag{6.5}$$

or,

$$Cl_{\gamma^Q,v} = \sum_{i=1}^{L-l_t} \frac{N_i \times 2^{l_t}}{2^{L-i+1}} \tag{6.6}$$

$Cl_{\gamma^Q,v}$ here is computed by considering the inclusion of a new call.

4. When $m_{\gamma^Q} = 1$ && $Cl_{\gamma^Q, m_{\gamma^Q}} < Cl_{Threshold}$, where $Cl_{Threshold}$ denotes the threshold channel load. The call will be assigned to the available single vacant code.
5. For $m_{\gamma^Q} > 1$ && $Cl_{\gamma^Q, m_{\gamma^Q}} < Cl_{Threshold}$

The OCA scheme consists of three levels.

6.4.1.1 Level 1: When $\exists v: Cl_{\gamma^Q,v} < Cl_{Threshold}$, select code(s) with max $\sum_{i=1}^{L-l_t} N_i$, This uses the maximum busy time-domain tree and will lead to minimum blocking. For a unique code assign a call to it, otherwise, go to level 2.

6.4.1.2 Level 2: For all $v: Cl_{\gamma^Q,v} < Cl_{Threshold}$, find code with max($n_{l^{\gamma^Q}}$), $\forall n_{l^{\gamma^Q}} > 0$ and assign the call to a unique code. The algorithm search for a time-domain code with the maximum number of calls of the same rate. This leads to the reduction in code blocking of future calls, as the unused capacity of already blocked codes will be utilized. For a unique code assign a call to it, otherwise, go to level 3.

6.4.1.3 Level 3: For all $v: Cl_{\gamma^{Q},v} < Cl_{Threshold}$, find code with $\max\limits_{[1,(L-l_t)],i \neq l^{\gamma^{Q}}}(N_i)$. This also reduces code blocking by using the unused capacity of the higher layer and lower layer codes.

The algorithm is explained with the help of status of code tree in Figure 6.1 when a call of rate *R* arrives the *Cl* of all the subtrees is calculated again using the Table 6.2 available at BS, the new channel load will be 0.625, 0.5, 0.3125 and 0.5625 for subtree 1,2,3 and 4 respectively. If *Cl* is the only parameter used to decide the optimum code for the assignment, then subtree 3 is selected. However, this leads to future blocking of the higher rate. The proposed scheme selects subtree 2 for assignment and code $C_{1,12}$. This leads to full capacity utilization of codes $C_{2,6}$ and $C_{3,3}$ in higher layers with *Cl* = 0.5. In a similar way, when a call of rate 2*R* arrives code $C_{2,7}$ will be selected for the assignment, which leads to minimum future code blocking with *Cl*=0.625.

6.4.2 Call Request: Non-Quantized

When the incoming call rate is non-quantized and $\gamma^{NQ}R, (l^{\gamma^{NQ}} = (log_2\gamma^{NQ} + 1)) \neq I$calls. If a call is assigned to a quantized code of rate $(2^{\lceil l^{\gamma^{NQ}} \rceil - 1})R$, it will lead to wastage of $(2^{\lceil l^{\gamma^{NQ}} \rceil - 1} - \gamma^{NQ})R$ amount of capacity or increased internal fragmentation. This further reduces system utilization. For improvement in code capacity utilization, non-quantized calls are treated differently in this chapter. The system parameters are all the same except that a

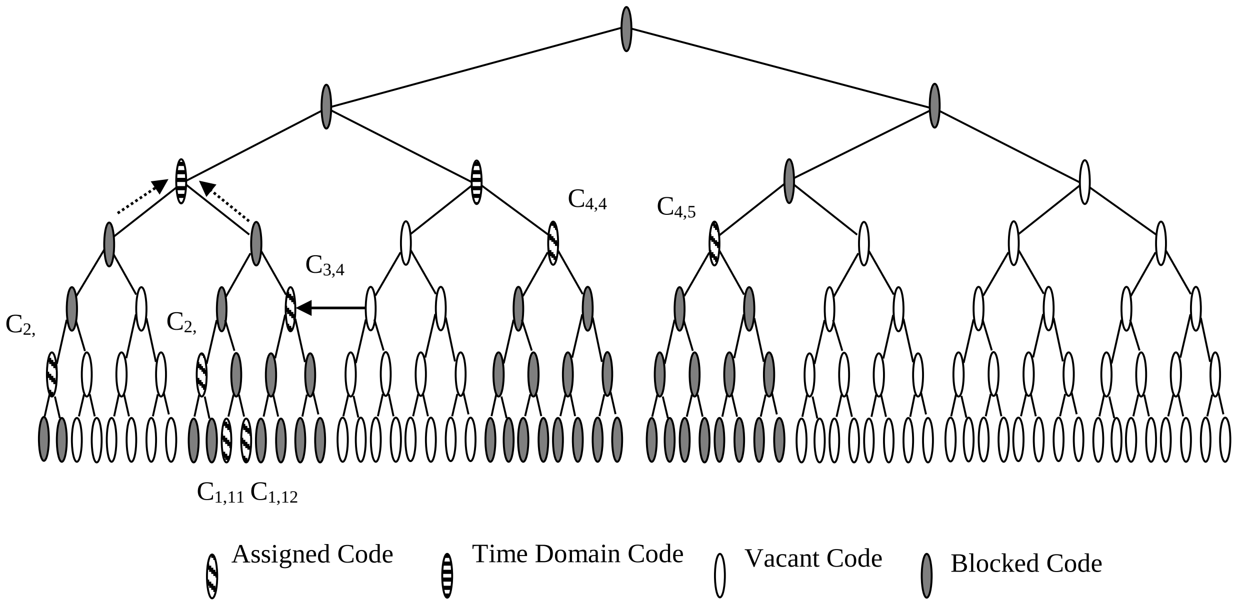

Figure 6.2 Illustration of Non-Quantized Single code Approach after reassignment.

non-quantized call is broken down into rate fractions before the assignment. To handle a new call multiple codes (rakes) are used. Let the system is equipped with *m* rakes. The algorithm to locate an optimum code for non-quantized call works as follows.

```
1. Initialize the number of rakes required to handle the new call as r=0.
2. Break incoming call $\gamma^{NQ}R$ into two fractions:$f_1 = 2^{(\lceil l^{\gamma^{NQ}} \rceil - 1) - 1}$and$f_2 = (\gamma^{NQ} - 2^{(\lceil l^{\gamma^{NQ}} \rceil - 1) - 1})$.
3. If $f_2 == I$,
      Search vacant codes for rate $f_1R$ and $f_2R$ using an approach similar to quantized calls such that their $Cl < Cl_{Threshold}$ and assign the calls to them and update $r = r + 2$.
   Else
      r=2.
      While($l^f == I$), where $l^f = (log_2 f_2 + 1)$
         Break $f_2R$ into two fractions:$f_{21} = 2^{(\lceil l^f \rceil - 1) - 1}$and$f_{22} = (f_2 - 2^{(\lceil l^f \rceil - 1) - 1})$.
         $f_2 = f_{22}$, r=r+2;
      End.
   End.
4. Find whether if $r \leq m$?
      Yes, handle call using r rakes.
5. Else if
      Combine fractions such that $c_f = \sum_{i=1}^{n_f} f_i$ with condition $l^{c_f} = (log_2 c_f + 1)$ and $(2^{\lceil l^{c_f} \rceil - 1} - \gamma)R$ is minimum and use $(r - n_f + 1)$ rakes to handle a new call.
```

Table 6.3 Simulation Parameters and Assumptions

<table>
<tr><th><i>Parameters</i></th><th><i>Value/Range</i></th></tr>
<tr><td>User Classes</td><td>$R,2R,3R,4R,5R,6R,7R,8R$</td></tr>
<tr><td>Arrival rate (λ) is Poisson Distributed</td><td>Mean value varying from 0-4 calls/minute</td></tr>
<tr><td>Call duration (1/μ) is Exponentially Distributed</td><td>Mean value of 1 minutes.</td></tr>
<tr><td>Total Capacity of Code tree</td><td>256R</td></tr>
<tr><td>Number of users</td><td>10000</td></tr>
<tr><td>Results average</td><td>10</td></tr>
<tr><td>Arrival rate and service rate for i^{th} class</td><td>λ_i and μ_i , $i \in [1,8]$</td></tr>
<tr><td>Average Traffic Load</td><td>$\rho = \sum_{i=1}^{8} \lambda_i / \mu_i = \sum_{i=1}^{8} \lambda_i$</td></tr>
<tr><td>$Cl_{Threshold}$</td><td>0.75</td></tr>
<tr><td colspan="2">The same data bits carrying subcarriers are assumed to experience independent flat Rayleigh fading. The background noise is modelled by white Gaussian noise with double-sided power spectrum density of N0/2 and the transmitting Eb/N0 = 12 dB.</td></tr>
</table>

```
6. Else
   Block call.
7. End.
```

The algorithm is demonstrated with the help of the status of the code tree in Figure 6.1 when a non- quantized call of rate 9*R* arrives, the call is first broken into two fractions 8 and 1, the vacant codes for these fractions are searched and the *Cl* of all the subtrees which have the capacity to handle these fractions is calculated again using the table available at base station (BS), the new channel load for *R* rate will be 0.625, 0.5, 0.3125 and 0.5625 for subtree 1, 2, 3 and 4 respectively. For 8*R* rate, *Cl* will be 0.75 and 1 respectively for subtree 3 and 4. A vacant subtree is available for assignment; however, the proposed scheme in this chapter tries to utilize the unused capacity of the used subtree. The time-domain tree 1, 2 and 3 can be used to handle these calls by reassigning ongoing calls and changing the time-domain code position in the tree. The time-domain tree 1 and 2 are merged together with time-domain shifted up by one layer as shown in Figure 6.2 and call at code $C_{3,5}$ is shifted to $C_{3,4}$. Codes $C_{1,12}$ and $C_{4,4}$ are used to handle the rate fractions *R* and 8*R* respectively. The simulations parameters are given in Table 6.3.

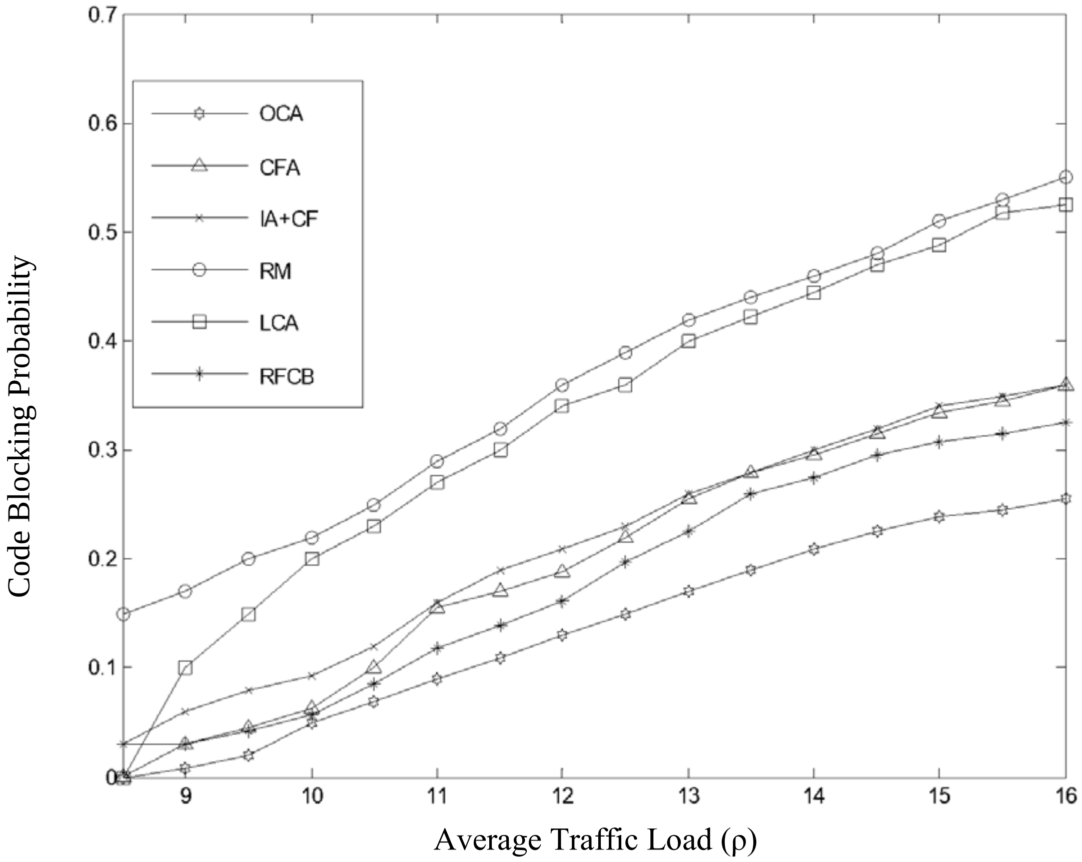

Figure 6.3. Comparison of code blocking probability for uniform distribution of Quantized arrival rates [*R*,2*R*,4*R*,8*R*].

6.5 Simulations and Results

The section evaluates the performance of the proposed scheme for the MC DS-CDMA system in the single-cell environment. The compared schemes includes the popular 3GPP UMTS random assignment (RM) (Atarashi & Ahashi, 2002) crowded first assignment (CFA) (Tseng & Chao, 2002), left code assignment (LCA) (Tseng & Chao, 2002), recursive fewer code blocked (RFCB) (Tseng & Chao, 2002) and IA+CF (Balyan & Bansal, 2017). RA, CFA, LCA, and RFCB carried out the assignment without considering the effect *CI*. The IA+CF scheme used for load considers the effect of *CI*. The simulation network and traffic parameters are given in Table 6.3. The basic data rate is *R* and the total capacity of the UMTS OVSF code tree is 256*R*. The chapter uses multiple classes of traffic arrival rate $\gamma R, [1 \leq \gamma \leq 8]$. The arrival traffic quantized rates are [*R*,2*R*,4*R*,8*R*] and non-quantized rates are [3*R*,5*R*,6*R*,7*R*] effectiveness of the proposed assignment scheme for the MC-DS-CDMA system.

The schemes RA, CFA, LCA, RFCB, IA+CF and proposed OCA scheme evaluated for code

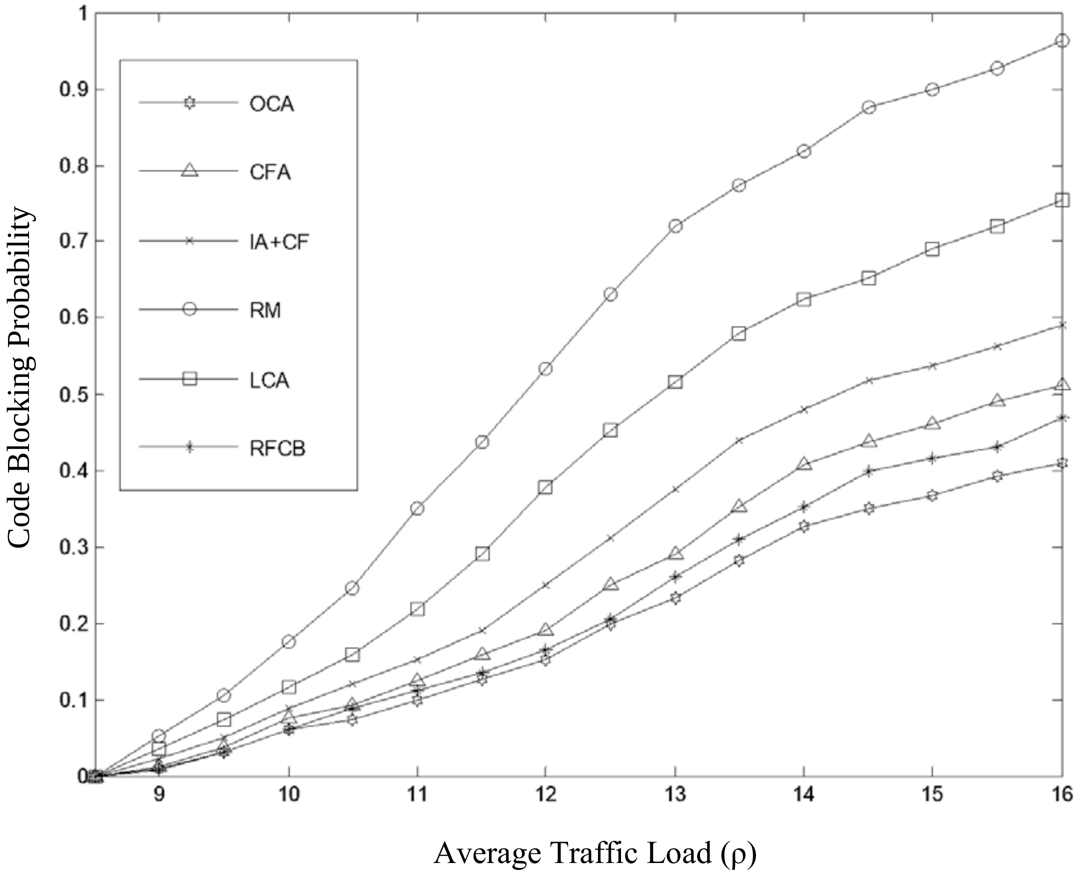

Figure 6.4. Comparison of code blocking probability for uniform distribution of Quantized rates and Non-quantized rates both [*R*- 8*R*]

blocking probability and Eb/N0 in Figure 6.3, Figure 6.4 and Figure 6.5. For simulation, the average arrival rate (λ) is from 8.5 to 16. The average holding time of all the classes of traffic is exponentially distributed, and the mean is normalized to 1. The results indicate that the OCA scheme provides optimum utilization of the code tree while maintaining QoS. The code blocking probability of all schemes increases as the arrival rate increases.

The average code blocking for a 8 class system is defined as

$$P_B = \sum_{i=1}^{8}(\lambda_i P_{B_i}/\lambda) \tag{6.7}$$

where P_{B_i} is the code blocking probability of i^{th} class.

The OCA schemes yield the lowest code blocking probability as it selects a time-domain tree which leads to minimum blocking of future calls and leads to higher utilization of code tree. In 6.3, the schemes are compared for quantized rates of arrival traffic rate while Figure 6.4 non quantized arrival traffic rate is considered. In Figure 6.4, the arrival of non-quantized rate leads to an increase in code blocking probability of all the schemes. However, the OCA scheme provides assignment of radio resources on the basis of their type which reduces internal fragmentation and eventually leads to lesser code blocking. Figure 6.5, shows the received Eb/N0 with the average traffic load. The following observations are made from it. First, comparing with those schemes whose performance in code blocking probability is close

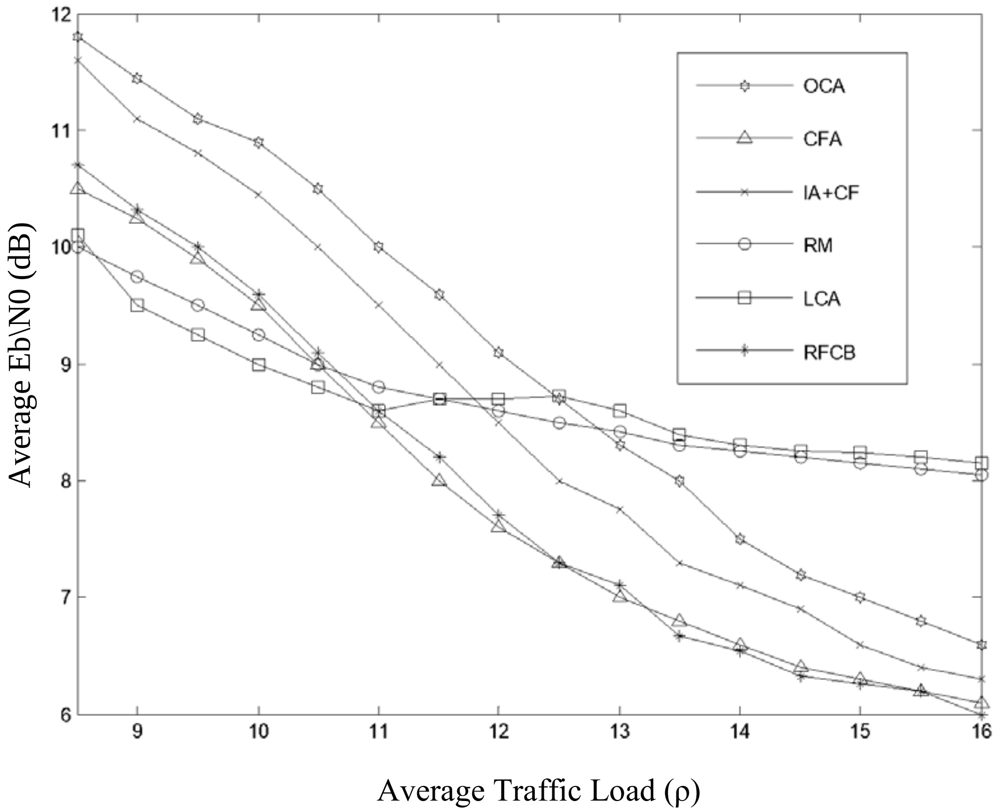

Figure 6.5 Comparison of average received Eb\N0 (dB) for uniform distribution of Quantized arrival rates.

to OCA scheme. RFCB, CFA, and IA+CF all schemes have lower received Eb/N0 for total average arrival rate ($8.5 \leq \rho \leq 16$). The LCA and RM schemes provide better received Eb/N0 for $12.5 \leq \rho \leq 16$, this is due to the accommodation of more number of calls in OCA scheme, also due to the number of rakes used by OCA scheme which influences Eb/N0 significantly. For both, LCA and RM schemes code tree vacant capacity is scattered due to the nature of the assignment process due to which both suffer from high code blocking. These schemes handle fewer calls in given intervals; therefore provide better received Eb/N0.

Figure 6.6 compares the complexity analysis of different schemes in the form of the number of code searches for uniform distribution of call arrival. The computation time required for code searches for the OCA scheme is given in the Appendix. For analysis RFCB, CFA, LCA, RM and IA+CF number of code searches are derived from the articles in (Saini & Balyan, 2014) and (Chang & Wu, 2009). The result shows that the number of code searches for OCA scheme is lesser then CFA, RFCB, and IA+CF schemes, as these schemes check the complete code tree for new call arrival. The scheme is ideal for mobile network and SG network traffic originating together. The IA+CF uses CFA with interference avoidance due to this requires a maximum number of code

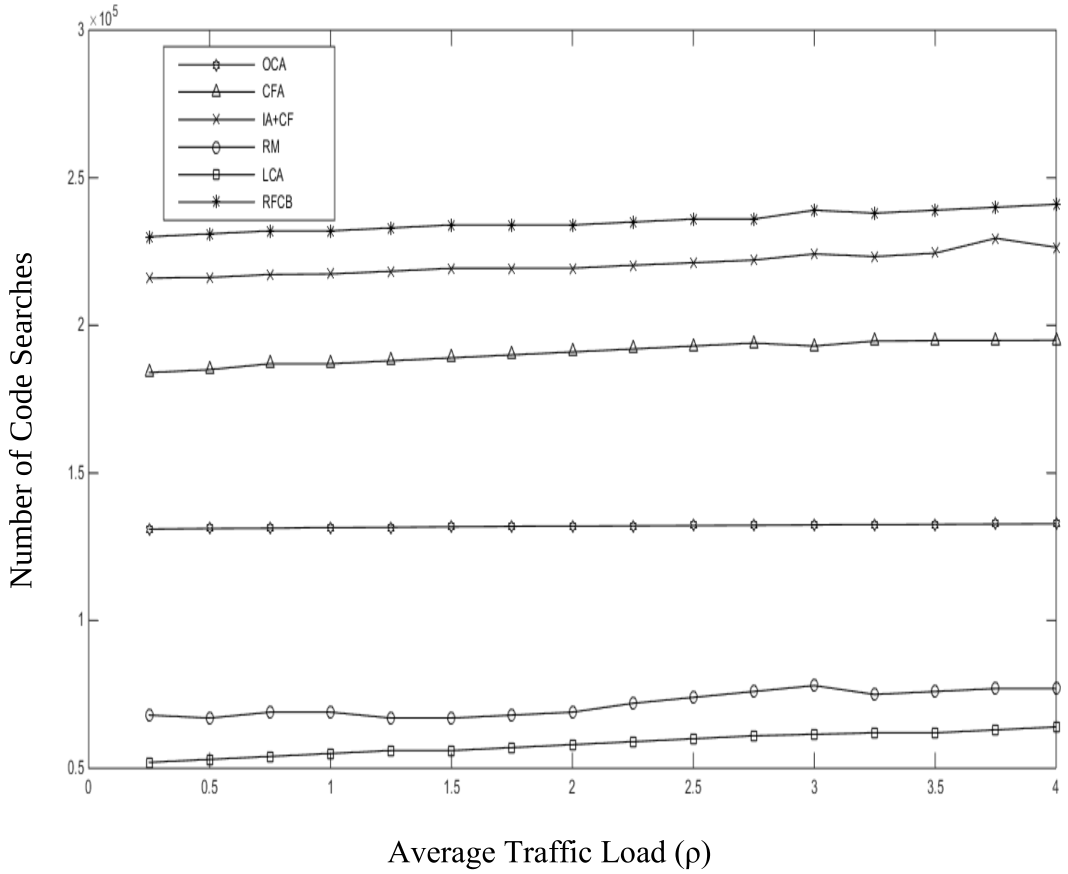

Figure 6.6 Comparison of code blocking probability for uniform distribution of non–quantized arrival rates.

searches. Also, the computation time is higher for IA+CF which is most comparable with OCA, it searches the same codes again in case of ties. The RFCB and CFA also repeat the searches in case of a tie. The OCA scheme most of the time searches only those codes which are in a busy sub tree or time-domain tree. The LCA and RM computation time or a number of code searches are minimum, with higher code blocking probability.

6.6 Conclusion

To maximize the utilization of available radio resource for the downlink of Multi-Rate MC-DS-CDMA, the proposed OCA scheme in this chapter handles a quantized and non-quantized call differently. The SG traffic is also handled by the OCA scheme, in rural areas leads to improved spectrum utilization. The non-quantized call is first broken into multiple quantized rates. The quantized rate call(s) are allocated to a time-domain tree(s) which leads to minimum future blocking and CI less than the threshold value. The number of quantized rates is lesser than or equal to the number of available rakes. By simulations and analysis, the benefits of OCA schemes are demonstrated which shows that the scheme is adaptive and ability to counter with current and future higher rate demands. In future work, can be done to use unused rakes of ongoing calls.

CHAPTER SEVEN

SMART UTILIZATION OF LTE-UMTS SPECTRUM IN SMART GRIDS FOR COMMUNICATION[7]

7.1 INTRODUCTION

The current advancement of power transmission using SGs makes them fully automated and interconnected medium voltage level electrical networks. These SGs provides operation of complex power grids in a safe and reliable way, with remote monitoring and control applications. This requires the exchange of measurement data in real-time. With the expansion of SGs the exchange of information critical for protection is massive and might need urgent attention which requires a communication technology that is fast and reliable too. There are many wireless technologies available like cognitive radio networks (CRNs), LTE and 3GPP release etc. The CRNs are unlicensed technology that suffers from a lower quality of service (QoS) and high latency problems. LTE and 3GPP releases is a promising licensed technology which addresses issues of QoS and latency, one of the technology which can address all these issues (Kalalas, Vazquez-Gallego, et al., 2016) and (Standard, 2003). By utilization of LTE existing networks reduces the cost of operation and expansion which will be needed to implement a communication network for SGs. Some work is available in the literature to ascertain the viability of LTE as a communication technology for SGs applications. For applications related to distributed automation LTE 3GPP release 8 is used in (Peng Cheng et al., 2011) and encourages the use of LTE for SGs. The paper in (Peng Cheng et al., 2011) uses the ns-3 simulator, which simulates smart metering and remote control applications traffic. This traffic is sent over an LTE network handling radio network load also. The LTE network handles calls while maintaining its QoS. it has been found that the QoS (Quality of Service) management of LTE is strongly recommended in order to meet the desired time deadline (Elattar, 2015). In (Brown & Khan, 2012), a comparison between LTE Time Division Duplex (TDD) and Frequency Division Duplex (FDD) when used for smart grid communications is presented, and FDD is shown to lead to a better uplink performance in terms of latency. However, FDD was shown to control channel limited for small infrequent packets. In (Anon, n.d.), this problem is addressed by proposing contention-based random access over orthogonal frequency division multiple access (OFDMA) using any available free cellular spectrum. A novel Random access for distribution automation (RADA) is proposed in (Kalalas, Vazquez-Gallego, et al., 2016) to the contention with better support to distribution automation

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(DA) services with minimum degradation in the handling of LTE subscriber services. A Lotka-Volterra (LV) resource allocation scheme is defined in (Webster et al., 2016), which modelled each class of traffic as a species and they try for available LTE resources. The constraints are also placed on service classes for bringing fairness. The use of LTE radio resource management is investigated in (Yaacoub & Kadri, 2015) for automatic meter reading in regions of advance meter infrastructures. The proposed scheme can be used to both methods transmission from smart metres to base station (BS) or for transmission of aggregated data at aggregators to the BSs. The author of paper (Parvez et al., 2016) uses a hybrid of ZigBee on unlicensed 2.4 GHz and LTE networks. This hybrid provides more spectrums to LTE operation due to the transmission of the meter to meter information on ZigBee network using low power. The chapter focuses on the utilization of LTE-UMTS resources for communication or calls within SGs to relay metering information or other data required. The LTE resource blocks (RBs) or UMTS codes are assigned to the SGs calls when they arrive in real-time. The SGs network relies on dynamic servers (mobiles or workstations) which stores the information send to them. In this chapter, each server will account for metering loads of five nearby meters. The proposed scheme aims to reduce the loading of the LTE-UMTS interface at the base station (BS) to increase call capacity. The proposed scheme is compared with the related article in literature in real-time conditions. The calls (information) sent using LTE-UMTS provide fault detection and fast recovery, the server is usually serving five nearby domestic users. The metering information at servers will be available to domestic users and the electricity providers both. The result shows that using mobiles and PCs as servers reduces the load of BS and handle a significantly larger number of SGs calls.

This chapter proposes an assignment scheme for handling the SGs traffic (SGT) and radio traffic (RT) on LTE based network. The LTE based network uses two interfaces to handle both kinds of traffic. The proposed scheme also uses mobile or workstations as servers to store the metering or periodic data of meters.

7.2 System Model and Parameters

The system model consists of a BS equipped with two interfaces LTE_{int} and $UMTS_{\text{int}}$ which are handling both SGT and RT. The mobile or workstations acting as the server can be applied for network-based in urban areas where more number of RT users is available. The metering information or periodic updates to these mobiles or workstations in the same area can be sent in bulk or sequentially depending upon the available spectrum. In rural areas, the number of RT users are less. In particular, users requiring higher speed or in other words the users competing for LTE interface are less. The metering information in rural areas can be sent directly using LTE_{int}.

The *LTE*int has 10 subframes in the time domain and two slots are available in each subframe. With every subframe 14 OFDM symbols can be carried as shown in Figure 4.2. In the frequency domain, 12 subcarriers are available in a subchannel. The number of subchannels depends upon the bandwidth spectrum e.g, for a 3MHz spectrum the number of subchannels is 15. The relation between channel bandwidth and the number of subchannels is given in Table 5.1.

The transmission unit for a MS is defined by resource block (RB) within a subframe(for time)and a subchannel (for frequency)for LTE interface. The LTE interface uses spatial multiplexing with four antennas and the eNodeB for every channel pilot symbol is used as the individual reference signal symbol.

For multiuser access in OFDMA, a subframe RBs can be allocated to different MSs. For single-user access in OFDM, the RMs of the subframe can be allocated to one MS, they cannot be allocated to different MSs (A. Ghosh, R. Ratasuk, B. Mondal, 2010), (C. Gessener, n.d.), (913, 2011), (Shadmand & Shikh-bahaei, 2010). For LTE using OFDMA, a MS will be allocated at least one RB and in the same subframe duration different MSs can use the number of RBs allocated to them by eNodeB.

The offered total data rate of the downlink a PHY frame of LTE is given by:

$$R_{DL} = (N_{RB}\left(N_{NSC} \times N_{NSS} \times N_{bit}^{AMC}\right)) \times N_{TTI} \tag{7.1}$$

where

N_{RB}: denotes the allowed number of RBs within a subframe time.

N_{NSC}: denotes the subcarriers in a subchannel.

N_{NSS}: denotes the subframe OFDM symbols

N_{bit}^{AMC}: denotes bits in a symbol.

N_{TTI}: LTE PHY frame transmission time interval (*TTI*).

N_{bit}^{AMC} values with different modulation schemes are given in Table 5.1.

The different modulation schemes are used for different location of RT and SGT.

The UMTS interface is equipped with orthogonal variable spreading factor codes (OVSF) which spreads in both time and frequency domain. The *UMTS*int is used for handling RT and for sending periodic updates of SGT. The *UMTS*int is having a code tree of layer *L* with a total capacity of the code tree $2^{L-1}R, L = 9$.

7.3 Proposed Scheme

The proposed scheme for RT and SGT uses *LTE*int or *UMTS*int depending upon the arrival of the call request.

7.3.1 RT Request

For a RT voice call of rate $2^{l-1}R, 1 \leq l \leq L$.

i. Search the vacant code in layer *l* of rate $2^{l-1}R$, using CFA scheme define in (Tseng & Chao, 2002).

ii. Assign a vacant code.

iii. If no vacant code available of rate available block the call.

For a RT data call of rate $2^{l-1}R, 1 \leq l \leq L.$ The algorithm assigns RBs depending upon its location in the cell. For example, if 3MHz channel bandwidth (BW) is used by the LTE system and it contains 150 RBs in one frame of PHY. Then the data rate of a RB using QPSK as AMC modulation scheme is calculated as

Table 7.1. Total number of resource blocks (RBs) used within a subframe.

Channel bandwidth (MHz)	Number of RBs within a subframe time
1.4	6
3	15
5	25
10	50
15	75
20	100

$\text{Rate}_{\text{RB}} = 12\text{subcarriers} \times 12 \text{ symbols} \times 2\text{bits/symbol} \times 10^3$

= 288 Kbps

In a similar way, the offered data rate of a RB for every AMC modulation scheme can be determined as given in Table 5.1. Consider a call of rate 8R arrives, the number of RBs (n_{RB}) required by it depends upon its location in the cell.

i. Closer to BS, AMC scheme used 64QAM and $n_{RB} = \frac{8.144}{864} = 1.33 \cong 1.$

ii. Distance closer (a), AMC scheme used 16QAM, $n_{RB} = \frac{8.144}{288} = 4.$

iii. Distance closer (b), AMC scheme used QPSK, $n_{RB} = \frac{8.144}{144} = 8.$

iv. Closer to end of the cell, AMC scheme used is BPSK, UMTS_{int} is preferred else reject the request.

The system can assign the required RBs still it is preferred to set a maximum limit on the number of RBs that can be assigned denoted by n_{RB}^{max}=4. If $n_{RB} \leq n_{RB}^{max}$, handle RT using LTE_{int} otherwise block it.

7.3.2 SGT Request

The SGT can be broadly divided into three types:

i. Metering information one hop.

The metering one hop messages are small data messages or data calls, which can be sent using $UMTS_{int}$. These messages usually contain meter details of power utilization by a home user in past one hour and are sent to its server (close by neighbour). They are treated as voice calls, if blocked retry for spectrum access after waiting for some time.

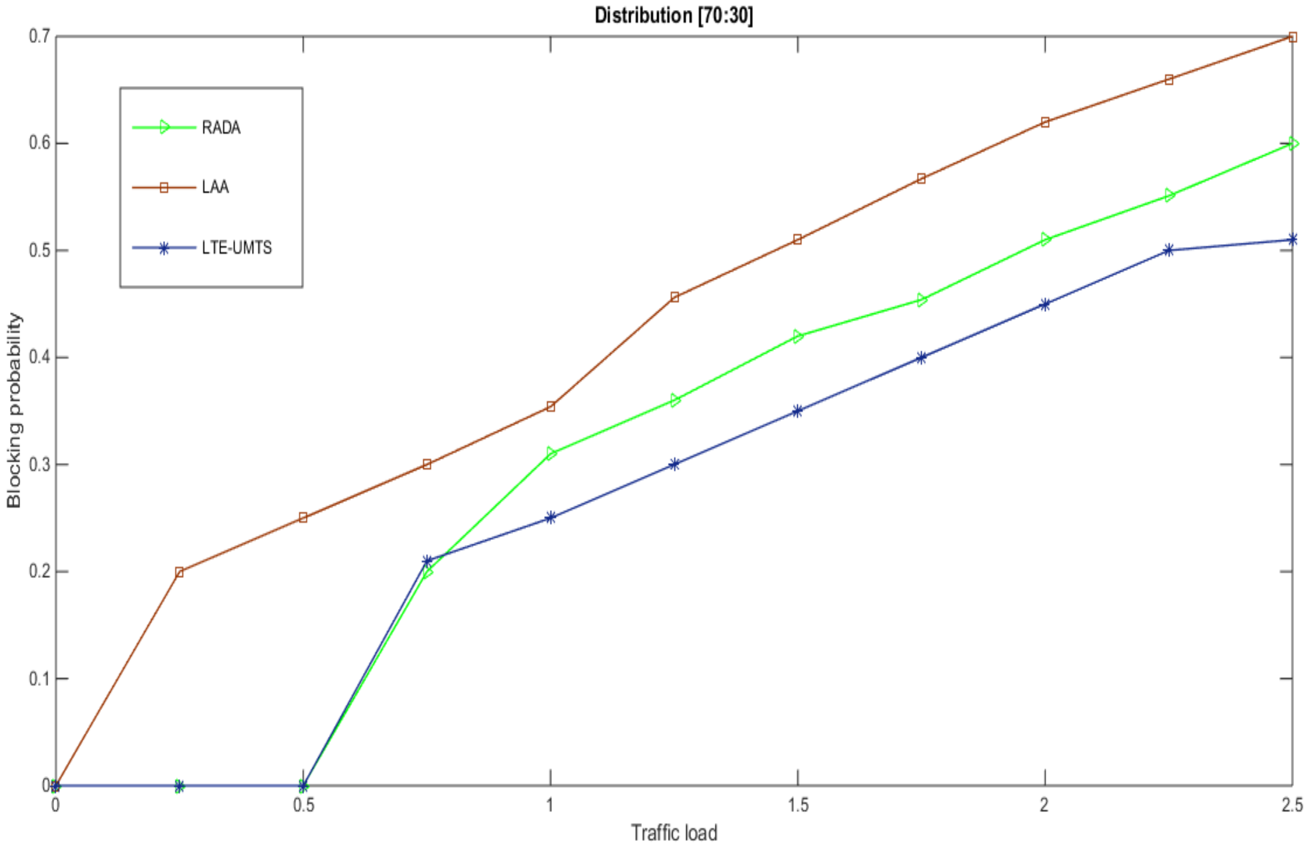

Figure 7.1. Comparison of a blocking probability for a distribution of 70:30.

ii. Metering information from Mobile servers or work stations to BS.

This is a collection of metering information of five or more domestic users in close vicinity to each other and requires high-speed transmission. If sent with delay or lower QoS, it requires headers which increases data load on the network. In this chapter, they are considered as LTE data calls.

iii. Periodic messages about the status of the grid.

These messages are usually sent from one sensor to another for scheduling and messages informing about faults. The periodic messages are forwarded from one sensor to another. These messages contain small data and in peak hours can be discarded to reduce the load

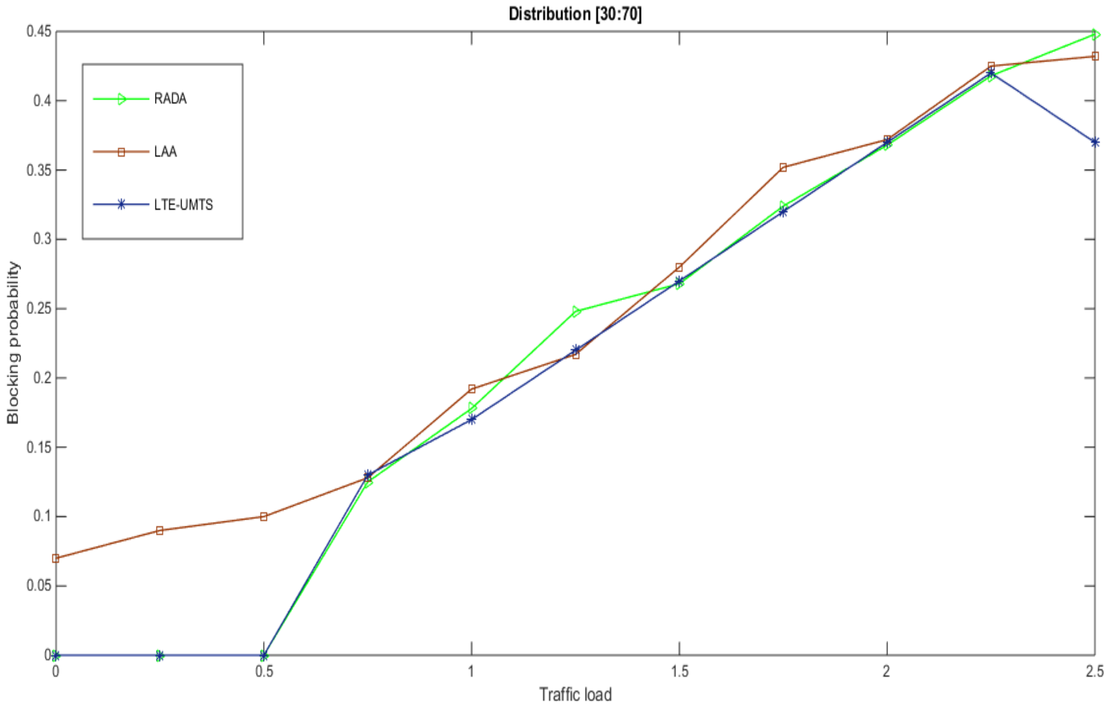

Figure 7.2. Comparison of blocking probability for distribution 30: 70.

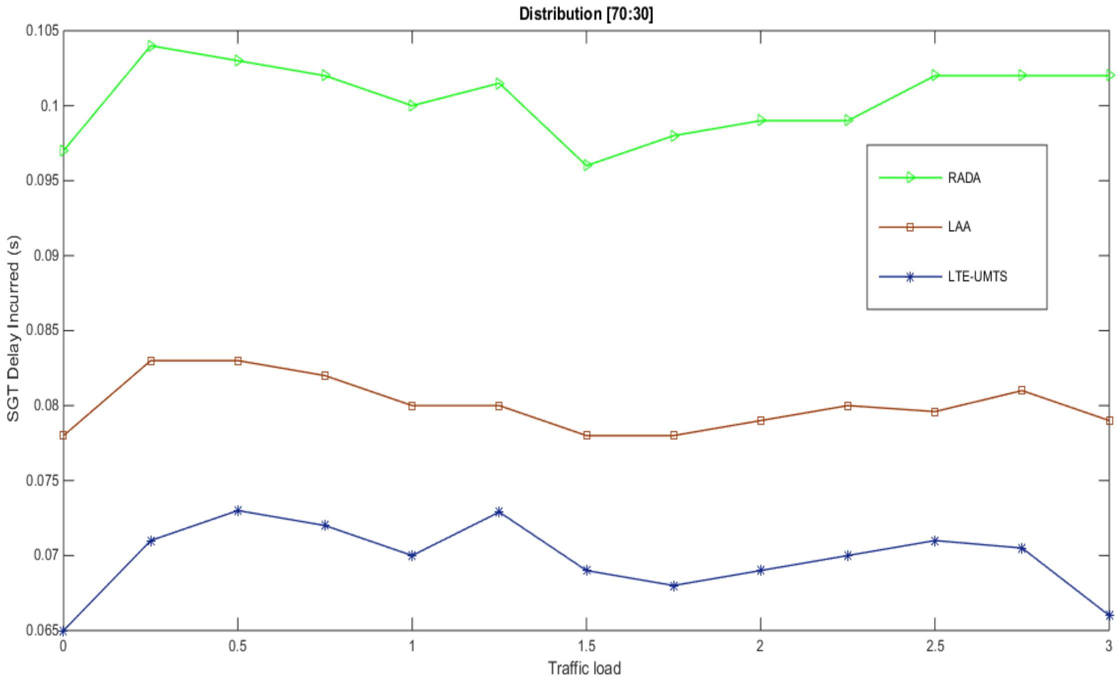

Figure 7.3. Comparison of blocking probability for distribution 70:30 with delay.

on BS, if same as the previous periodic message. A fault in a power distribution unit requires immediate attention and are handled using LTE$_{int}$.

7.4 Results and Simulations

To test the performance of the proposed scheme (LTE-UMTS) is compared with other schemes RADA (Kalalas, Vazquez-Gallego, et al., 2016) and LAA (Parvez et al., 2016) for blocking probability and delay of SGT. The schemes are compared for two different traffic distributions:

i. Peak traffic distribution of RT.
ii. Low traffic distribution of RT.

In peak traffic distribution scenario RT=70% and SGT=30%, periodic messages are discarded when they are similar to previous messages, it increases complexity due to more computation. For low traffic distribution RT=30% and SGT=70%. The arrival of both types of calls RT and SGT is assumed to be Poisson's distributed and the departure of calls is assumed to be exponentially distributed in interval (0,4] minutes. The result in Figure 7.1, compares the blocking probability when RT arrival is higher and SGT lower, LTE-UMTS provides minimum blocking probability as it discarded periodic messages and stores metering information in MSs and workstation which are sent together as one data call. For the result in Figure 7.2, RT arrival is low and SGT higher, LTE-UMTS provides blocking probability comparable to LAA and RADA, the network is handling only SGT calls which comprises periodic messages in higher frequency. The result in Figure 7.3 and Figure 7.4, compares the SGT delay incurred, it's due the reason the SGT sent its request again after waiting for sometimes and LTE-UMTS scheme calls needs minimum. In LTE-UMTS, the periodic messages are discarded which leads to more spectrum availability.

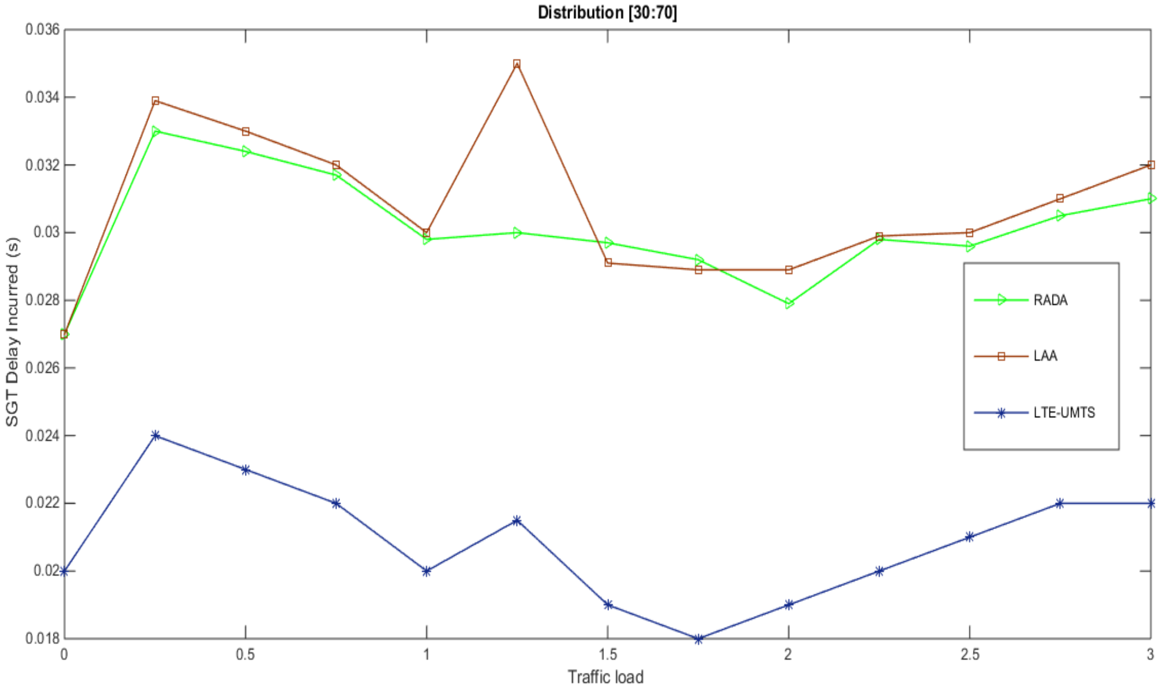

Figure 7.4. Comparison of blocking probability for distribution 30: 70 with delay.

7.5 Conclusion

For efficient management of SGs, communication technologies like LTE, CRNs etc play an integral role. Utilization of these technologies will play an important role in the control and operation of future SGs providing electrical transmission for domestic use. This thesis uses LTE-UMTS cellular communication network for handling SGTs in presence of RTs efficiently. The MSs also acted as a server which reduces the load on BS. The blocking probability of SGT and RT is relatively low as compared to other schemes. The completion time of SGT also reduces. The work in the future can be done to find the share of the revenue for storing metering information to MSs and workstations usually in neighbourhood. The periodic messages forwarding also increases SGT, work can be done to reduce this traffic.

CHAPTER EIGHT

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK.

8.1 Conclusion

The main objective of the research was to investigate the current South African communication infrastructure and communication network topologies to ultimately propose solutions for the integration and application of these technologies in potential future SGs for the transmission of data or information related to SGs. Particular aims were outlined and carried out in order to achieve the objective of the research. A literature review in chapter two of the past and present communication topologies deployed for condition monitoring within SGs. In chapter 3, the CR technology is investigated for SG networks, the result shows that the CR network shows good performance in terms of blocking performance for lower arrival rates. The CR network suffers from the license problem for channel assignment, which will lead to more waiting time for data calls (SG calls). The LTE network is used for handling the communication of SG networks. The LTE interface provides faster communication but has limited bandwidth which requires careful access schemes. The work in researched literature uses only LTE interface to handle SG and mobile traffic which leads to more waiting time for SG traffic. We are using a 3G interface which is already available on Base stations and is used by voice calls only. This BW or capacity is available most of the time. This interface has OVSF codes that are spread in time and frequency. They can be assigned in one dimension but we spread it across two dimensions in order to improve quality of service (QoS). The use of a 3G interface provides better services to SG traffic in the absence of LTE traffic and also uses LTE interface during non-busy hours. These schemes together with LTE communication are show optimum as compare to other schemes in the literature.

The simulations and results indicate that the proposed scheme is ideal for both mobile network and SG network traffic originating together.

To maximize the utilization of available radio resource for the downlink of Multi-Rate MC-DS-CDMA, the proposed OCA scheme in this chapter handles a quantized and non-quantized call differently. The SG traffic is also handled by the OCA scheme, in rural areas leads to improved spectrum utilization. The non-quantized call is first broken into multiple quantized rates. The quantized rate call(s) are allocated to a time-domain tree(s) which leads to minimum future blocking and CI less than the threshold value. The number of quantized rates is lesser than or equal to the number of available rakes. By simulations and analysis, the benefits of OCA schemes are demonstrated which shows that the scheme is adaptive and ability to counter with current and future higher rate demands. In future work, can be done to use unused rakes of ongoing calls.

The 3G and 4G/LTE interfaces are integrated for normal mobile communication. The 3G interface is used for data calls in mobile communication when no RB of LTE interface is available. However, it suffers from complexity when switchover takes place between them due to mobility. In our case, smart grid nodes are usually stationary and can easily use the 3G interface for transferring small to moderate data. For a higher amount of data, LTE interface is used, this leads to lower call blocking.
The only difference is variation in mobile traffic and SG traffic, in order to test the performance of the communication technology in case one of the traffic is higher and overall impact.

The communication technologies used in the thesis are cognitive radio and LTE. The LTE work available is further improved by using the 3G interface for SG traffic. The smart grids require efficient communication technology for handling communication between two nodes. The grids are combined with LTE to provide synergy. The LTE communication is used to handle the calls, data transfer requests etc emerging from grids.

8.2 Recommendations

The most appropriate and most effective communication technology topology for potential SGs in SA was determined by mathematical modelling and simulation of CRNs, UMTS' and LTE technologies.

The conclusions show that each system investigated has certain shortcomings and is dependent on exactly what the requirements of the SG is in terms of delivering relevant data and information to maintain a fast, secure and highly reliable with good QoS.

Consequently, it is recommended that the optimum code assignment (OCA) scheme which meets the demand of quality of service (QoS) of a call with an improved capacity utilization of the Downlink of Multi-Rate MC-DS-CDMA during the transfer of high priority data in SGs, supported by the proposed handoff LTE-UMTS (HLU) scheme for a base station (BS) having both UMTS and LTE interface for a 4G network handling mobile traffic (M-T) and smart grid traffic (SG-T).

Less important data that do not require an immediate response can utilise CR technology or UMTS-LTE basic integrated technologies

8.3 Future work

Possible future work to ensure fast, secure and reliable transmission of fault condition data in SGs the following work should be considered. With reference to CR work can be done to analyse the blocking at specific nodes of SG, serial transfer of metering information from one sensor node to another and added metering information at each node or sending metering information on CRNs at the time of the day when PU arrivals are at a minimum. It can also be extended to calculate waiting time in the buffer, by varying information size in each type of data SU_1, SU_2, and SU_3. Considering the LTE technology, the present 4G networks suffer from handover issues that arise not due to mobility but inter handover i.e. from 3G to 4G and 4G to 3G. Further future work can be done to address and resolve these problems. In terms of the handoff LTE-UMTS (HLU) scheme for a base station (BS) having both UMTS and LTE interface for a 4G network handling mobile traffic (M-T) and smart grid traffic (SG-T) the ANC scheme manages the number of available rakes adaptively without influencing QoS and with reduced code blocking probability as compared to compared schemes. The ANC scheme also considers both location and direction of motion in the cell before the assignment. In future, work can be done to find complexity associated with changing the number of rakes during the duration of the call.

- Determine the most appropriate and most effective communication technology topology for potential SGs in SA by mathematical modelling and simulation of CRNs, UMTS' and LTE technologies.
- Based on the simulation results, investigate, analyse and recommend the most appropriate communication topology for potential SGs in SA.
- Recommend possible future work to ensure fast, secure and reliable transmission of fault condition data in SGs

APPENDICES

APPENDIX A: Additions to Chapter Six

For an *L* layer code tree and the total number of channelization code that can be assigned to a new call is 2^{L-1}. Let the computation time for searching one code is denoted by $T(1)$.

If all the codes are blocked or busy in a worst-case scenario then the number of codes searched

$N_s = 2^{l-1}, 1 \leq l \leq L$ A.1

The computation time for 2-D spreading

$T_{2D} = T(N_s.L)$ A.2

The *CI* of all the combinations is given in Table 6.2, checking *CI* of available optimum codes $T(1)$.

For *v* vacant codes available, the computation time is= $T(v)$.

The OCA quantized scheme consists of three levels.

The computation time for level 1= $T(N_s.L) + T(v)$ A.3

For a tie at level 1 between v_1 codes

The computation time for level 2= $T(N_s.L) + T(v) + T(v_1)$ A.4

For a tie at level 2 between v_2 codes

The computation time for level 3= $T(N_s.L) + T(v) + T(v_1) + T(v_2)$ A.5

For a non-quantized call, the computation time will become

$m.(T(N_s.L) + T(v) + T(v_1) + T(v_2))$ A.6

Where *m* denotes the number of rakes.

Codes of Network

```
clear;
clear global
global n mn rrr arrtime servtime totaltime  CFAte r cused t3 t4 x w1
global no_of_searches_RA no_of_searches_ALM no_of_searches_ANC
no_of_searches_adjacentn no_of_searches_adjacentn no_of_searches_fcb
no_of_searches_CFA
CFAte=zeros(1,n);arrtime=zeros(4,16,n);servtime=zeros(4,16,n);totaltime=zer
os(4,16,n);
t3=zeros(255,11);t1=zeros(255,1);t2=zeros(1,255);z=zeros(255,4);rrr=zeros(4
,n);
tCFAte=0;



calls_hand_ALM(1:4,1:16)=0;calls_block_ALM(1:4,1:16)=0;block_prob_ALM=zeros
(4,16);code_blocking_ALM=zeros(4,16);
calls_hand_RA(1:4,1:16)=0;calls_block_RA(1:4,1:16)=0;block_prob_RA=zeros(4,
16);code_blocking_RA=zeros(4,16);
calls_hand_ANC(1:4,1:16)=0;calls_block_ANC(1:4,1:16)=0;block_prob_ANC=zeros
(4,16);code_blocking_ANC=zeros(4,16);
calls_hand_adjacentn(1:4,1:16)=0;calls_block_adjacentn(1:4,1:16)=0;block_pr
ob_adjacentn=zeros(4,16);code_blocking_adjacentn=zeros(4,16);
calls_hand_CFA(1:4,1:16)=0;calls_block_CFA(1:4,1:16)=0;block_prob_CFA=zeros
(4,16);code_blocking_CFA=zeros(4,16);
calls_hand_fcb(1:4,1:16)=0;calls_block_fcb(1:4,1:16)=0;block_prob_fcb=zeros
(4,16);code_blocking_fcb=zeros(4,16);

no_of_searches_RA=zeros(4,16);no_of_searches_RA1=zeros(4,16);
no_of_searches_ALM=zeros(4,16);no_of_searches_ANC=zeros(4,16);
no_of_searches_ALM1=zeros(4,16);no_of_searches_ANC1=zeros(4,16);
no_of_searches_adjacentn=zeros(4,16);no_of_searches_adjacentn1=zeros(4,16);
no_of_searches_fcb=zeros(4,16);no_of_searches_fcb1=zeros(4,16);
no_of_searches_CFA=zeros(4,16);no_of_searches_CFA1=zeros(4,16);




n=50;mn=2;avg=1;w1(n,3)=0;
for ff=1:avg%1

    calls_hand_ALM(1:4,1:16)=0;calls_block_ALM(1:4,1:16)=0;
    calls_hand_RA(1:4,1:16)=0;calls_block_RA(1:4,1:16)=0;
    calls_hand_ANC(1:4,1:16)=0;calls_block_ANC(1:4,1:16)=0;
    calls_hand_adjacentn(1:4,1:16)=0;calls_block_adjacentn(1:4,1:16)=0;
    calls_hand_CFA(1:4,1:16)=0;calls_block_CFA(1:4,1:16)=0;
    calls_hand_fcb(1:4,1:16)=0;calls_block_fcb(1:4,1:16)=0;

    for g=1:4%2
        for xx=1:1:16%3
            [rrr]=CFAtefun_final;
            [arrtime,servtime,totaltime]=timefun_final;
            if g==1;CFAte=rrr(1,1:n);
            elseif g==2;CFAte=rrr(2,1:n);
            elseif g==3;CFAte=rrr(3,1:n);
            else CFAte=rrr(4,1:n);
            end
            cused(g,xx)=0;w2(1:255,1:3)=0;[x,y]=ntree(2,7);t3(:,9:11)=0;
            z=allnodes(x,'deppos');
            for k1=1:255
                zz(k1,1)=8-z(k1,1);
                zz(k1,2)=z(k1,2)+1;
```

```
            end
            zz(1:255,3:7)=0;
            t1(1:255)=1:1:255;t3=[w2 t1 zz];
            for k1=1:n
                
w1(k1,1)=arrtime(xx,k1);w1(k1,2)=servtime(xx,k1)*(2^log2(CFAte(k1)));w1(k1,
3)=w1(k1,1)+w1(k1,2);
            end
            
            %ALM============================
            
            cused(g,xx)=0;tCFAte=0;
            t3(1:255,7:8)=0;t3(1:255,1:3)=0;
            for i1=1:n
                tCFAte=tCFAte+CFAte(i1);
                codefree_final(i1,g,xx);
                if CFAte(i1)==16
                    r1=8;r2=9;
                elseif CFAte(i1)==8
                    r1=20;r2=21;
                elseif CFAte(i1)==4
                    r1=44;r2=47;
                elseif CFAte(i1)==2
                    r1=96;r2=111;
                else
                    r1=224;r2=255;
                end
                if cused(g,xx)+CFAte(i1)<129
                    if  any(t3(r1:r2,7)==0)
                        ALM2(i1,g,xx);
                        calls_hand_ALM(g,xx)=calls_hand_ALM(g,xx)+1;
                    else
                        calls_block_ALM(g,xx)=calls_block_ALM(g,xx)+1;
                    end
                else
                end
            end
            
block_prob_ALM(g,xx)=block_prob_ALM(g,xx)+calls_block_ALM(g,xx)/(calls_bloc
k_ALM(g,xx)+calls_hand_ALM(g,xx));
%ANCp============
            
            cused(g,xx)=0;tCFAte=0;
            t3(1:255,7:8)=0;t3(1:255,1:3)=0;
            for i1=1:n
                tCFAte=tCFAte+CFAte(i1);
                codefree_final(i1,g,xx);
                if CFAte(i1)==16;r1=8;r2=15;
                elseif CFAte(i1)==8;r1=16;r2=31;
                elseif CFAte(i1)==4;r1=32;r2=63;
                elseif CFAte(i1)==2;r1=64;r2=127;
                else r1=128;r2=255;
                end
                if ((cused(g,xx)+CFAte(i1))<129)
                    if  any(t3(r1:r2,7)==0)
                        ANC(g,xx,i1);
                        calls_hand_ANC(g,xx)=calls_hand_ANC(g,xx)+1;
                    else
                        calls_block_ANC(g,xx)=calls_block_ANC(g,xx)+1;
                    end
                else
                end
            end
```

```
block_prob_ANC(g,xx)=block_prob_ANC(g,xx)+calls_block_ANC(g,xx)/(calls_block_ANC(g,xx)+calls_hand_ANC(g,xx));
% adjacent===========

            %RA================================
            cused(g,xx)=0;tCFAte=0;
            t3(1:255,7:8)=0;t3(1:255,1:3)=0;
            for i1=1:n
                tCFAte=tCFAte+CFAte(i1);
                codefree_final(i1,g,xx);
                if CFAte(i1)==16
                    r1=8;r2=15;
                elseif CFAte(i1)==8
                    r1=16;r2=31;
                elseif CFAte(i1)==4
                    r1=32;r2=63;
                elseif CFAte(i1)==2
                    r1=64;r2=127;
                else
                    r1=128;r2=255;
                end
                if ((cused(g,xx)+CFAte(i1))<129)
                    if  any(t3(r1:r2,7)==0)
                        RA(g,xx,i1);
                        calls_hand_RA(g,xx)=calls_hand_RA(g,xx)+1;
                    else
                        calls_block_RA(g,xx)=calls_block_RA(g,xx)+1;
                    end
                else
                end
            end

block_prob_RA(g,xx)=block_prob_RA(g,xx)+calls_block_RA(g,xx)/(calls_block_RA(g,xx)+calls_hand_RA(g,xx));
            %======================ANCp=======
            %%%%%%%%%fcb
            cused(g,xx)=0;tCFAte=0;
            t3(1:255,7:8)=0;t3(1:255,1:3)=0;
            for i1=1:n
                tCFAte=tCFAte+CFAte(i1);
                codefree_final(i1,g,xx);
                if CFAte(i1)==16
                    r1=8;r2=15;
                elseif CFAte(i1)==8
                    r1=16;r2=31;
                elseif CFAte(i1)==4
                    r1=32;r2=63;
                elseif CFAte(i1)==2
                    r1=64;r2=127;
                else
                    r1=128;r2=255;
                end
                if ((cused(g,xx)+CFAte(i1))<129)
                    if  any(t3(r1:r2,7)==0)
                        fcb(g,xx,i1);
                        calls_hand_fcb(g,xx)=calls_hand_fcb(g,xx)+1;
                    else
                        calls_block_fcb(g,xx)=calls_block_fcb(g,xx)+1;
                    end
                else
                end
            end
```

```
block_prob_fcb(g,xx)=block_prob_fcb(g,xx)+calls_block_fcb(g,xx)/(calls_bloc
k_fcb(g,xx)+calls_hand_fcb(g,xx));
            %%
            cused(g,xx)=0;tCFAte=0;
            t3(1:255,7:8)=0;t3(1:255,1:3)=0;
            for i1=1:n
                tCFAte=tCFAte+CFAte(i1);
                codefree_final(i1,g,xx);
                if CFAte(i1)==16
                    r1=8;r2=15;
                elseif CFAte(i1)==8
                    r1=16;r2=31;
                elseif CFAte(i1)==4
                    r1=32;r2=63;
                elseif CFAte(i1)==2
                    r1=64;r2=127;
                else
                    r1=128;r2=255;
                end
                if ((cused(g,xx)+CFAte(i1))<129)
                    if  any(t3(r1:r2,7)==0)
                        CFA(g,xx,i1);
                        calls_hand_CFA(g,xx)=calls_hand_CFA(g,xx)+1;
                    else
                        calls_block_CFA(g,xx)=calls_block_CFA(g,xx)+1;
                    end
                else
                end
            end

block_prob_CFA(g,xx)=block_prob_CFA(g,xx)+calls_block_CFA(g,xx)/(calls_bloc
k_CFA(g,xx)+calls_hand_CFA(g,xx));
            %%% CFA
        end%3
    end%2
end%1

code_blocking_ALM=block_prob_ALM/avg;
code_blocking_RA=block_prob_RA/avg;
code_blocking_ANC=block_prob_ANC/avg;
code_blocking_adjacentn=block_prob_adjacentn/avg;
code_blocking_CFA=block_prob_CFA/avg;
code_blocking_fcb=block_prob_RA/avg;




no_of_searches_RA1=(no_of_searches_RA)/avg;
no_of_searches_ALM1=(no_of_searches_ALM)/avg;
no_of_searches_ANC1=(no_of_searches_ANC)/avg;
no_of_searches_adjacentn1=(no_of_searches_adjacentn)/avg;
no_of_searches_fcb1=(no_of_searches_fcb)/avg;
no_of_searches_CFA1=(no_of_searches_CFA)/avg;






figure
subplot(2,2,1);
xaxis=.25:.25:4;
```

```
plot(xaxis,no_of_searches_ANC1(1,1:16),'kp-
',xaxis,no_of_searches_ALM1(1,1:16),'ks-
',xaxis,no_of_searches_RA1(1,1:16),'k.-
',xaxis,no_of_searches_CFA1(1,1:16),'k*-')
xlabel('Average Traffic Load (a)');ylabel('Code Blocking
Probability');title('Distribution [25,25,25,25,25]');
h=legend('ANC','ALM','RA','CFA',2);


subplot(2,2,2);
xaxis=.25:.25:4;
plot(xaxis,no_of_searches_ANC1(1,1:16),'kp-
',xaxis,no_of_searches_ALM1(1,1:16),'ks-
',xaxis,no_of_searches_RA1(1,1:16),'k.-
',xaxis,no_of_searches_CFA1(1,1:16),'k*-')
xlabel('Average Traffic Load (a)');ylabel('Code Blocking
Probability');title('Distribution [25,25,25,25,25]');
h=legend('ANC','ALM','RA','CFA',2);


subplot(2,2,3);
xaxis=.25:.25:4;
plot(xaxis,no_of_searches_ANC1(1,1:16),'kp-
',xaxis,no_of_searches_ALM1(1,1:16),'ks-
',xaxis,no_of_searches_RA1(1,1:16),'k.-
',xaxis,no_of_searches_CFA1(1,1:16),'k*-')
xlabel('Average Traffic Load (a)');ylabel('Code Blocking
Probability');title('Distribution [25,25,25,25,25]');
h=legend('ANC','ALM','RA','CFA',2);



subplot(2,2,4);
xaxis=.25:.25:4;
xaxis=.25:.25:4;
plot(xaxis,no_of_searches_ANC1(1,1:16),'kp-
',xaxis,no_of_searches_ALM1(1,1:16),'ks-
',xaxis,no_of_searches_RA1(1,1:16),'k.-
',xaxis,no_of_searches_CFA1(1,1:16),'k*-')
xlabel('Average Traffic Load (a)');ylabel('Code Blocking
Probability');title('Distribution [25,25,25,25,25]');
h=legend('ANC','ALM','RA','CFA',2);
```

Other Codes

```
classdef fixed_rate_tm < handle
% GM traffic models


properties
    packet_size         % size of generated packet
    waiting_time        % periode of packet generation
    packet_buffer       % packet buffer
    rand_start_TTI      % random start of packet generation
    type = 'car';
    packet_stats;       % stores statistics of transmitted packets
    pack_num = 0;       % number of valid packets in the buffer
    store_num = 0;      % number of stored packet statistics of already
transmitted packets
%     unicast_mode        % whether unicast or multicast transmission is
used
    served_UEs          % indices of the users that receive data from this
traffic model
    n_served_UEs        % number of served UEs
    source_UE           % the UE to which the traffic model is associated
to (this would be in the uplink but is not simulated here)
    synch = false;      % synchronized packet generation at TTI 1
    is_fullbuffer = false; % indicator that this is not a full buffer
traffic model
end

methods

    % class constructor
    function obj =
fixed_rate_tm(packet_size,packet_periode,N_subframes,served_UEs,source_UE,v
arargin)
        obj.packet_size = packet_size;
        obj.waiting_time = packet_periode;
        if ~obj.synch
            if ~isempty(varargin) % a random number stream has been
provided
                obj.rand_start_TTI = randi(varargin{1},packet_periode,1,1);
            else
                obj.rand_start_TTI = randi(packet_periode,1,1);
            end
        else
            obj.rand_start_TTI = 1;
        end
        obj.served_UEs = served_UEs;
        obj.source_UE = source_UE;
        obj.n_served_UEs = length(served_UEs);

        temp_packet_stats =
struct('used_RBs',Inf,'required_TTIs',Inf,'origin_TTI',Inf,'submission_TTIs
',Inf);  % store statistics of the packets
%         max_pack_num = ceil(N_subframes/packet_periode); % maximum number
of generated packets in N_subframes TTIs
        max_pack_num = 1; % a new packet replaces an old packet --> at most
one packet in the buffer
```

```
%         for bb = 1:obj.nBS
%             for uu = 1:obj.nUE % in case of unicast the traffic is
individually sent to each UE (each UE needs its own buffer)
        for uu = 1:obj.n_served_UEs
                obj.packet_stats{uu} =
repmat(temp_packet_stats,max_pack_num,1);
        end
%             end
%         end

        temp_packet = traffic_models.simple_data_packet(-Inf,Inf);
%         for bb = 1:obj.nBS
%             for uu = 1:obj.nUE
        for uu = 1:obj.n_served_UEs
                for pp = 1:max_pack_num
                    obj.packet_buffer{uu,pp} = copy(temp_packet);
                end
        end
%             end
%         end
        obj.pack_num = zeros(1,obj.n_served_UEs); % counter for the number
of valid packets in the buffer packet_buffer
        obj.store_num = zeros(1,obj.n_served_UEs); % counter for the number
of packet statistics already stored in packet_stats
    end

    % determine number of bits in buffer and packet origin TTIs
    function [size,origin] = get_buffer_data(obj,ue_ind)
        size = Inf*ones(1,obj.pack_num(1,ue_ind));
        origin = Inf*ones(1,obj.pack_num(1,ue_ind));
        for pp = 1:obj.pack_num(1,ue_ind)
            size(pp) = obj.packet_buffer{ue_ind,pp}.get_size;
            origin(pp) = obj.packet_buffer{ue_ind,pp}.get_origin_TTI;
        end
    end

    % decrease size of packet according to assigned resources and store
    % statistics in case the transmission is completed
    function
decrease_packet_size(obj,Nbits,assigned_RBs,current_TTI,ue_ind)
        ue_ind = find(obj.served_UEs == ue_ind);
        [packet_done,total_RBs_used,origin_TTI,submission_TTIs] =
obj.packet_buffer{ue_ind,1}.decrease_packet_size(Nbits,current_TTI,assigned
_RBs);
        if packet_done % throw away the finished packet and store
transmission statistics
            obj.store_num(1,ue_ind) = obj.store_num(1,ue_ind) + 1;
            temp_packet = traffic_models.simple_data_packet(-Inf,Inf);
            obj.packet_buffer{ue_ind,1} = temp_packet;
            obj.packet_buffer(ue_ind,:) =
obj.packet_buffer(ue_ind,[2:end,1]);
            obj.pack_num(1,ue_ind) = obj.pack_num(1,ue_ind) - 1;
            % store packet transmission statistics
            obj.packet_stats{1,ue_ind}(obj.store_num(1,ue_ind)).used_RBs =
total_RBs_used;

obj.packet_stats{1,ue_ind}(obj.store_num(1,ue_ind)).required_TTIs =
current_TTI-origin_TTI+1;
            obj.packet_stats{1,ue_ind}(obj.store_num(1,ue_ind)).origin_TTI
= origin_TTI;

obj.packet_stats{1,ue_ind}(obj.store_num(1,ue_ind)).submission_TTIs =
unique(submission_TTIs);
```

```
        end
    end

    % check if new data packet should be generated and deliver the packet
    % buffer details
    function [packet_data] = get_packet_data(obj,ue_ind)
%         if ~mod(TTI-obj.rand_start_TTI,obj.periode) % time for a new
packet?
% %             obj.pack_num(bs_ind,ue_ind) = obj.pack_num(bs_ind,ue_ind) +
1;
%             obj.pack_num(1,ue_ind) = 1; % the new packet replaces the old
packet in case it has not yet been transmitted
%             packet =
traffic_models.simple_data_packet(obj.packet_size,TTI);
%             obj.packet_buffer{1,ue_ind,obj.pack_num(1,ue_ind)} = packet;
%         end
        [size,origin] = obj.get_buffer_data(ue_ind);
        packet_data.size = size;
        if isempty(origin)
            packet_data.origin = Inf;
        else
            packet_data.origin = origin;
        end
    end

    function check_TTI(obj,TTI)
        if ~mod(TTI-obj.rand_start_TTI,obj.waiting_time) % time for a new
packet?
            obj.pack_num(1,:) = 1; % the new packet replaces the old packet
in case it has not yet been transmitted
            packet =
traffic_models.simple_data_packet(obj.packet_size,TTI);
            for uu = 1:obj.n_served_UEs
                if ~isinf(obj.packet_buffer{uu,1}.size)
                    [~,total_RBs_used,origin_TTI,submission_TTIs] =
obj.packet_buffer{uu,1}.decrease_packet_size(0,Inf,0);
                    obj.store_num(1,uu) = obj.store_num(1,uu) + 1;
                    obj.packet_stats{1,uu}(obj.store_num(1,uu)).used_RBs =
total_RBs_used;

obj.packet_stats{1,uu}(obj.store_num(1,uu)).required_TTIs = Inf;   % packet
not fully transmitted
                    obj.packet_stats{1,uu}(obj.store_num(1,uu)).origin_TTI
= origin_TTI;

obj.packet_stats{1,uu}(obj.store_num(1,uu)).submission_TTIs =
unique(submission_TTIs);
                end
                obj.packet_buffer{uu,1} = copy(packet);
            end
        end
    end

end

end
```

```
function[]=codefree_final(i1,h,v)
global cused t3 w1 x fr
for i3=7:254
    if((w1(i1,1)>=t3(i3+1,3))&&(t3(i3+1,3)~=0))
        t3(i3+1,1:3)=0;t3(i3+1,7)=0;p1=nodeasc(x,i3);
        p3=length(p1);p2=nodedesc(x,i3);p4=length(p2);
        if p4>1
            t3(p2(2:p4)+1,7)=0;
        end
        if t3(i3+1,8)==1
            cused(h,v)=cused(h,v)-1;
        elseif t3(i3+1,8)==2
            cused(h,v)=cused(h,v)-2;
        elseif t3(i3+1,8)==4
            cused(h,v)=cused(h,v)-4;
        elseif t3(i3+1,8)==8
            cused(h,v)=cused(h,v)-8;
        elseif t3(i3+1,8)==16
            cused(h,v)=cused(h,v)-16;
        end
        t3(i3+1,8)=0;
    end
end
```

```
function[]=cfa(g,xx,i1)
global t3 cused rate w1 x no_of_searches_cfa
options=zeros(64,1);opt=0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if(rate(i1)==16)
    for i2=7:14
        if(t3(i2+1,7)==0) %check parent
            pa1=nodeasc(x,i2);
            if(t3(pa1(2)+1,7)==2)
                opt=opt+1;
                options(opt,1)=i2;
            end
        end
    end
 no_of_searches_cfa(g,xx)=no_of_searches_cfa(g,xx)+0.5*i2+opt*22+0.4*i1;
    if(opt>0)
        for oc=1:opt-1
            ic1=options(oc,1);ic2=options(oc+1,1);
            pc1=nodeasc(x,ic1);pc3=length(pc1);
            pc2=nodeasc(x,ic2);pc4=length(pc2);
            for ec=2:pc3
                if(t3(pc1(ec)+1,8)<t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc2(1);
                    options(oc,1)=pc1(1);
                elseif(t3(pc1(ec)+1,8)>t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                elseif ec==pc3
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                end
            end
        end
        ic2=options(opt,1);

t3(ic2+1,7)=1;t3(ic2+1,8)=16;p1=nodeasc(x,ic2);p2=nodedesc(x,ic2);p3=length
(p1);
        p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=16;
        t3(p1(2:p3)+1,7)=2;
        for(pp=2:p3)
            t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+16;  %why blocked?
        end
        t3(ic2+1,1:3)=w1(i1,1:3);
        cused(g,xx)=cused(g,xx)+16;
        return
    elseif(opt==0)
        for i2=7:14
            if(t3(i2+1,7)==0) %check parent
                pa1=nodeasc(x,i2);
                if(t3(pa1(2)+1,7)==0)

t3(i2+1,7)=1;t3(i2+1,8)=16;p1=nodeasc(x,i2);p2=nodedesc(x,i2);p3=length(p1)
;
                    p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=16;
                    t3(p1(2:p3)+1,7)=2;
                    for(pp=2:p3)
                        t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+16;  %why blocked?
                    end
                    t3(i2+1,1:3)=w1(i1,1:3);
                    cused(g,xx)=cused(g,xx)+16;
                    return
```

```
                end
            end
        end
    end
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
elseif(rate(i1)==8)
    for i2=15:30
        if(t3(i2+1,7)==0) %check parent
            pa1=nodeasc(x,i2);
            if(t3(pa1(2)+1,7)==2)
                opt=opt+1;
                options(opt,1)=i2;
            end
        end
    end
 no_of_searches_cfa(g,xx)=no_of_searches_cfa(g,xx)+0.4*i2+opt*9+0.4*i2;

    if(opt>0)
        for oc=1:opt-1
            ic1=options(oc,1);ic2=options(oc+1,1);
            pc1=nodeasc(x,ic1);pc3=length(pc1);
            pc2=nodeasc(x,ic2);pc4=length(pc2);
            for ec=2:pc3
                if(t3(pc1(ec)+1,8)<t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc2(1);
                    options(oc,1)=pc1(1);
                elseif(t3(pc1(ec)+1,8)>t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                elseif ec==pc3
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                end
            end
        end
        ic2=options(opt,1);

t3(ic2+1,7)=1;t3(ic2+1,8)=8;p1=nodeasc(x,ic2);p2=nodedesc(x,ic2);p3=length(
p1);
        p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=8;
        t3(p1(2:p3)+1,7)=2;
        for(pp=2:p3)
            t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+8;  %why blocked?
        end
        t3(ic2+1,1:3)=w1(i1,1:3);
        cused(g,xx)=cused(g,xx)+8;
        return
    elseif(opt==0)
        for i2=15:30
            if(t3(i2+1,7)==0) %check parent
                pa1=nodeasc(x,i2);
                if(t3(pa1(2)+1,7)==0)

t3(i2+1,7)=1;t3(i2+1,8)=8;p1=nodeasc(x,i2);p2=nodedesc(x,i2);p3=length(p1);
                    p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=8;
                    t3(p1(2:p3)+1,7)=2;
                    for(pp=2:p3)
                        t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+8;  %why blocked?
                    end
                    t3(i2+1,1:3)=w1(i1,1:3);
                    cused(g,xx)=cused(g,xx)+8;
                    return
                end
```

```
            end
        end
    end
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
elseif(rate(i1)==4)
    for i2=31:62
        if(t3(i2+1,7)==0) %check parent
            pa1=nodeasc(x,i2);
            if(t3(pa1(2)+1,7)==2)
                opt=opt+1;
                options(opt,1)=i2;
            end
        end
    end
 no_of_searches_cfa(g,xx)=no_of_searches_cfa(g,xx)+0.2*i2+opt*6+0.4*i2;

    if(opt>0)
        for oc=1:opt-1
            ic1=options(oc,1);ic2=options(oc+1,1);
            pc1=nodeasc(x,ic1);pc3=length(pc1);
            pc2=nodeasc(x,ic2);pc4=length(pc2);
            for ec=2:pc3
                if(t3(pc1(ec)+1,8)<t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc2(1);
                    options(oc,1)=pc1(1);
                elseif(t3(pc1(ec)+1,8)>t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                elseif ec==pc3
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                end
            end
        end
        ic2=options(opt,1);

t3(ic2+1,7)=1;t3(ic2+1,8)=4;p1=nodeasc(x,ic2);p2=nodedesc(x,ic2);p3=length(
p1);
        p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=4;
        t3(p1(2:p3)+1,7)=2;
        for(pp=2:p3)
            t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+4;  %why blocked?
        end
        t3(ic2+1,1:3)=w1(i1,1:3);
        cused(g,xx)=cused(g,xx)+4;
        return
    elseif(opt==0)
        for i2=31:62
            if(t3(i2+1,7)==0) %check parent
                pa1=nodeasc(x,i2);
                if(t3(pa1(2)+1,7)==0)

t3(i2+1,7)=1;t3(i2+1,8)=4;p1=nodeasc(x,i2);p2=nodedesc(x,i2);p3=length(p1);
                    p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=4;
                    t3(p1(2:p3)+1,7)=2;
                    for(pp=2:p3)
                        t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+4;  %why blocked?
                    end
                    t3(i2+1,1:3)=w1(i1,1:3);
                    cused(g,xx)=cused(g,xx)+4;
                    return
                end
            end
```

```
        end
    end
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
elseif(rate(i1)==2)
    for i2=63:126
        if(t3(i2+1,7)==0) %check parent
            pa1=nodeasc(x,i2);
            if(t3(pa1(2)+1,7)==2)
                opt=opt+1;
                options(opt,1)=i2;
            end
        end
    end
 no_of_searches_cfa(g,xx)=no_of_searches_cfa(g,xx)+opt*2.5+0.4*i2;

    if(opt>0)
        for oc=1:opt-1
            ic1=options(oc,1);ic2=options(oc+1,1);
            pc1=nodeasc(x,ic1);pc3=length(pc1);
            pc2=nodeasc(x,ic2);pc4=length(pc2);
            for ec=2:pc3
                if(t3(pc1(ec)+1,8)<t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc2(1);
                    options(oc,1)=pc1(1);
                elseif(t3(pc1(ec)+1,8)>t3(pc2(ec)+1,8))
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                elseif ec==pc3
                    options(oc+1,1)=pc1(1);
                    options(oc,1)=pc2(1);
                end
            end
        end
        ic2=options(opt,1);

t3(ic2+1,7)=1;t3(ic2+1,8)=2;p1=nodeasc(x,ic2);p2=nodedesc(x,ic2);p3=length(
p1);
        p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=2;
        t3(p1(2:p3)+1,7)=2;
        for(pp=2:p3)
            t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+2;  %why blocked?
        end
        t3(ic2+1,1:3)=w1(i1,1:3);
        cused(g,xx)=cused(g,xx)+2;
        return
    elseif(opt==0)
        for i2=63:126
            if(t3(i2+1,7)==0) %check parent
                pa1=nodeasc(x,i2);
                if(t3(pa1(2)+1,7)==0)

t3(i2+1,7)=1;t3(i2+1,8)=2;p1=nodeasc(x,i2);p2=nodedesc(x,i2);p3=length(p1);
                    p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=2;
                    t3(p1(2:p3)+1,7)=2;
                    for(pp=2:p3)
                        t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+2;  %why blocked?
                    end
                    t3(i2+1,1:3)=w1(i1,1:3);
                    cused(g,xx)=cused(g,xx)+2;
                    return
                end
            end
        end
```

```
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    elseif(rate(i1)==1)
        for i2=127:254
            if(t3(i2+1,7)==0) %check parent
                xx16=i2-126;
                pa1=nodeasc(x,i2);
                if(t3(pa1(2)+1,7)==2)
                    opt=opt+1;
                    options(opt,1)=i2;
                end
            end
        end
     no_of_searches_cfa(g,xx)=no_of_searches_cfa(g,xx)+xx16+0.4*i2;
         if(opt>0)
            for oc=1:opt-1
                ic1=options(oc,1);ic2=options(oc+1,1);
                pc1=nodeasc(x,ic1);pc3=length(pc1);
                pc2=nodeasc(x,ic2);pc4=length(pc2);
                for ec=2:pc3
                    if(t3(pc1(ec)+1,8)<t3(pc2(ec)+1,8))
                        options(oc+1,1)=pc2(1);
                        options(oc,1)=pc1(1);
                    elseif(t3(pc1(ec)+1,8)>t3(pc2(ec)+1,8))
                        options(oc+1,1)=pc1(1);
                        options(oc,1)=pc2(1);
                    elseif ec==pc3
                        options(oc+1,1)=pc1(1);
                        options(oc,1)=pc2(1);
                    end
                end
            end
            ic2=options(opt,1);

    t3(ic2+1,7)=1;t3(ic2+1,8)=1;p1=nodeasc(x,ic2);p2=nodedesc(x,ic2);p3=length(
    p1);
            %   p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=2;
            t3(p1(2:p3)+1,7)=2;
            for(pp=2:p3)
                t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+1;  %why blocked?
            end
            t3(ic2+1,1:3)=w1(i1,1:3);
            cused(g,xx)=cused(g,xx)+1;
            return
        elseif(opt==0)
            for i2=127:254
                if(t3(i2+1,7)==0) %check parent
                    pa1=nodeasc(x,i2);
                    if(t3(pa1(2)+1,7)==0)

    t3(i2+1,7)=1;t3(i2+1,8)=1;p1=nodeasc(x,i2);p2=nodedesc(x,i2);p3=length(p1);
                        %
    p4=length(p2);t3(p2(2:p4)+1,7)=2;t3(p2(2:p4)+1,8)=2;
                        t3(p1(2:p3)+1,7)=2;
                        for(pp=2:p3)
                            t3(p1(pp)+1,8)=t3(p1(pp)+1,8)+1;  %why blocked?
                        end
                        t3(i2+1,1:3)=w1(i1,1:3);
                        cused(g,xx)=cused(g,xx)+1;
                        return
                    end
                end
            end
```

```
    end
end
function[rrr]=ratefun_final
global n

for i=1:n
    r(i)=rand(1);
    if (0<=r(i))&(r(i)<0.516)
        ratea(i)=1;
    elseif (0.516<=r(i))&(r(i)<0.774)
        ratea(i)=2;
    elseif (0.774<=r(i))&(r(i)<0.903)
        ratea(i)=4;
    elseif (0.903<=r(i))&(r(i)<0.967)
        ratea(i)=8;
    else
        ratea(i)=16;
    end
    rra(i)=ratea(i);%title('distribution [10,15,25,25,25] ');
end
for i=1:n
    r(i)=rand(1);
    if (0<=r(i))&(r(i)<0.42)
        rateb(i)=1;
    elseif (0.42<=r(i))&(r(i)<0.63)
        rateb(i)=2;
    elseif (0.63<=r(i))&(r(i)<0.735)
        rateb(i)=4;
    elseif (0.735<=r(i))&(r(i)<0.8925)
        rateb(i)=8;
    else
        rateb(i)=16;
    end
    rrb(i)=rateb(i);%title('distribution [20,20,20,20,20]');
end
for i=1:n
    r(i)=rand(1);
    if (0<=r(i))&(r(i)<0.674)
        ratec(i)=1;
    elseif (0.674<=r(i))&(r(i)<0.927)
        ratec(i)=2;
    elseif (0.927<=r(i))&(r(i)<0.97)
        ratec(i)=4;
    elseif (0.97<=r(i))&(r(i)<0.99)
        ratec(i)=8;
    else
        ratec(i)=16;
    end
    rrc(i)=ratec(i);%title('distribution [40,30,10,10,10]');
end
for i=1:n
    r(i)=rand(1);
    if (0<=r(i))&(r(i)<0.436)
        rated(i)=2;
    elseif (0.436<=r(i))&(r(i)<0.727)
        rated(i)=1;
    elseif (0.727<=r(i))&(r(i)<0.8725)
        rated(i)=4;
    elseif (0.8725<=r(i))&(r(i)<0.982)
        rated(i)=8;
    else
        rated(i)=16;
    end
```

```
    rrd(i)=rated(i);%title('distribution [10,30,20,30,10]');
end
rrr(1,1:n)=rra;rrr(2,1:n)=rrb;rrr(3,1:n)=rrc;rrr(4,1:n)=rrd;
```

```
function[arrtime,servtime,totaltime]=timefun_final
global mn n ff
for i=1:16
    f=1/i;arrtime(i,1)=0;servtime(i,1)=-
mn*log(rand(1));totaltime(i,1)=arrtime(i,1)+servtime(i,1);
    for j=2:n
        arrtime(i,j)=arrtime(i,j-1)+f;
        servtime(i,j)=-mn*log(rand(1));
        totaltime(i,j)=arrtime(i,j)+servtime(i,j);
    end
end
```

REFERENCES AND BIBLIOGRAPHY

3GPP. 2013. About 3GPP.

3GPP. 2010. IMS Multimedia telephony communication service and supplementary services; Stage 3. , 0(24.173): 0–60.

913, E.T. 136. 2011. Terrestrial Radio Access (E-UTRA) (LTE-Advanced). , 0: 0–16.

A. Ghosh, R. Ratasuk, B. Mondal, T.T. 2010. LTE-A DVANCED : N EXT -G ENERATION W IRELESS B ROADBAND T ECHNOLOGY. *IEEE Wireless Communications*, (June): 10–22.

Adachi, F., Garg, D., Takaoka, S. & Takeda, K. 2005. Broadband CDMA techniques. *IEEE Wireless Communications*, 12(2): 8–18.

Adachi, F., Sawahashi, M. & Okawa, K. 1997. Tree-structured generation of orthogonal spreading codes with different lengths for forward link of DS-CDMA mobile radio. *Electronics Letters*, 33(1): 27.

Aiello, M. 2016. The Smart Grid ' s Data Generating Potentials. *2014 Federated Conference on Computer Science and Information Systems*, 2: 9–16.

Akyildiz, I.F., Lee, W.Y., Vuran, M.C. & Mohanty, S. 2006. NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey. *Computer Networks*, 50(13): 2127–2159.

Amin, S.M. & Wollenberg, B.F.F. 2005. Toward a smart grid: power delivery for the 21st century. *IEEE Power and Energy Magazine*, 3(5): 34–41.

Anon. Automatic Meter Reading in the Smart Grid Contention Based Random over the Free Cellular Spectrum.

Anon. Home SmartGrid_gov.

Anon. Research on the Architecture of Electric Power Information Comms Networks for SGs.

Anon. *www.allitebooks.com*.

Arrivals, M., Service, P., Tang, S., Member, S., Mark, B.L. & Member, S. 2009. Analysis of Opportunistic Spectrum Sharing with. , 8(6): 3142–3150.

Atarashi, H. & Ahashi, M.S.A.W. 2002. VARIABLE SPREADING FACTOR ORTHOGONAL FREQUENCY AND CODE DIVISION MULTIPLEXING (VSF-OFCDM). : 113–114.

Baimel, D. & Tapuchi, S. 2016. Smart Grid Communication Technologies- Overview , Research Challenges and Opportunities. *2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*: 116–120.

Balyan, V. & Bansal, R. 2017. Adjacency and channel load of ongoing calls for downlink of multi-rate MC-DS-CDMA to locate vacant code. *Proceeding - IEEE International Conference on Computing, Communication and Automation, ICCCA 2016*: 1382–1386.

Balyan, V. & Saini, D.S. 2014. Same rate and pattern recognition search of orthogonal variable spreading factor code tree for wideband code division multiple access networks. , 8(April):

2366–2374.

Balyan, V. & Saini, D.S. 2013. Vacant codes grouping and fast OVSF code assignment scheme for WCDMA networks. *Telecommunication Systems*, 52(4): 1719–1729.

Balyan, V., Saini, D.S., Solan, D. & Pradesh, H. 2010. An efficient multi code assignment scheme to reduce call establishment delay for WCDMA networks. : 278–283.

Bartoli, A. & Hern, J. 2010. Secure Lossless Aggregation for Smart Grid M2M Networks. : 333–338.

Bautista, J.E.V., Sawhney, S., Shukair, M., Singh, I., Govindaraju, V.K. & Sarkar, S. 2013. Performance of CS fallback from LTE to UMTS. *IEEE Communications Magazine*, 51(9): 136–143.

Bawaba, A. 2017. *South Africa : Update on signing of Independent Power Producers and Power Purchase Agreement*. London.

Bera, S., Misra, S. & Obaidat, M.S. 2014. Energy-efficient smart metering for green smart grid communication. *2014 IEEE Global Communications Conference, GLOBECOM 2014*: 2466–2471.

Brown, J. & Khan, J.Y. 2012. Performance Comparison of LTE FDD and TDD Based Smart Grid Communications Networks for Uplink Biased Traffic. *2012 IEEE Third International Conference on Smart Grid Communications (SmartGridComm)*: 276–281.

Bu, S. & Yu, F.R. 2012. Dynamic Energy-Efficient Resource Allocation in Cognitive Heterogeneous Wireless Networks with the Smart Grid. *2012 IEEE Global Communications Conference (GLOBECOM)*: 3032–3036.

Bu, S., Yu, F.R., Cai, Y. & Liu, P.X. 2012. Dynamic Operation of BSs in Green Wireless Cellular Networks Powered by the Smart Grid. *2012 IEEE Global Communications Conference (GLOBECOM)*: 5201–5205.

C. Gessener, (Rhode & Schwarz). UMTS Long Term Evolution (LTE) - Technology Introduction Application Note Products :

Cacciapuoti, A.S., Caleffi, M., Marino, F. & Paura, L. 2014. Sensing-time optimization in cognitive radio enabling Smart Grid. *2014 Euro Med Telco Conference - From Network Infrastructures to Network Fabric: Revolution at the Edges, EMTC 2014*.

Capar, E., Martoyo, I., Weiss, T. & Jondral, E. 2002. Comparison of Bandwidth Utilization for Controlled and Uncontrolled Channel Assignment in a Spectrum Pooling System. : 1069–1073.

Chang, B.-J., Liang, Y.-H. & Cao, K.-X. 2013. Reward-Based Radio Interface Selection for Hybrid 4G UMTS and LTE Communications. *2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing*: 7–12. http://ieeexplore.ieee.org/document/6603642/.

Chang, B., Liang, Y. & Cao, K. 2015. Adaptive radio resource management for maximizing reward and balancing loads in 4G hybrid universal mobile telecommunications system and long term evolution communications. , (March 2013): 510–526.

Chang, B.J. & Chang, P.S. 2006. Multicode-based WCDMA for reducing waste rate and reassignments in mobile cellular communications. *Computer Communications*, 29(11): 1948–1958.

Chang, B.J. & Wu, C.H. 2009. Adaptive load balancing MDP-based approach of two-dimensional spreading for VSF-OFCDM in 4G next-generation cellular communications. *IEEE Transactions on Vehicular Technology*, 58(3): 1143–1156.

Chatterton, B. *NETWORK RELIABILITY MEASUREMENT , REPORTING , BENCHMARKING AND ALIGNMENT WITH INTERNATIONAL PRACTICES*.

Commission, I.E. Iec: bringing the information age to the grid.

Communication, H., Quickest, A., Algorithm, E. & Networks, G. 2014. Guest Editorial : Smart Grid Communications Systems. , 8(2): 417–421.

Control, T. & Group, S. OFDM Performance Evaluation Over Measured Indoor Radio Propagation Channels. , (2): 968–972.

Cordeiro, C., Challapali, K. & Birru, D. 2006. IEEE 802 . 22 : An Introduction to the First Wireless Standard based on Cognitive Radios. , 1(1): 38–47.

Craib, A., Topham, G., Mccurrach, R. & Mccurrach, R. 2013. *Standard Group Technology Title : STANDARD FOR THE INTERCONNECTION Unique Identifier : Alternative Reference Number : Part : Area of Applicability : Documentation Type : Revision : Total Pages : Next Review Date : Standard October 2018 Disclosure Classifi*.

Dehalwar, V., Kalam, A. & Zayegh, A. 2014. Infrastructure for real-time communication in smart grid. *2014 Saudi Arabia Smart Grid Conference, SASG 2014*: 2–5.

Dehalwar, V., Kolhe, M. & Kolhe, S. 2012. Cognitive Radio Application for Smart Grid. *international Journal of Smart Grid and Clean Energy*.

Dhasian, H.R. & Balasubramanian, P. 2013. Survey of data aggregation techniques using soft computing in wireless sensor networks. , 7(December 2012): 336–342.

Dong, X., Jing, X., Qian, K. & Jiang, W. 2013. A smart grid needs smart monitoring.

Ejaz, W., Hasan, N.U., Lee, S. & Kim, H.S. 2013. Intelligent spectrum sensing scheme for cognitive radio networks. *Eurasip Journal on Wireless Communications and Networking*, 2013(1): 1–10.

Ekström, H. 2009. QoS control in the 3GPP evolved packet system. *IEEE Communications Magazine*, 47(2): 76–83.

Elattar, M. 2015. Using LTE as an Access Network for Internet-Based Cyber-Physical Systems. : 1–7.

Eris, C., Saimler, M., Gungor, V.C., Fadel, E. & Akyildiz, I.F. 2014. Lifetime analysis of wireless sensor nodes in different smart grid environments. *Wireless Networks*, 20(7): 2053–2062.

Erol-Kantarci, M. & Mouftah, H.T. 2015. Energy-Efficient Information and Communication Infrastructures in the Smart Grid: A Survey on Interactions and Open Issues. *IEEE Communications Surveys and Tutorials*, 17(1): 179–197.

Erol-Kantarci, M. & Mouftah, H.T. 2011. Wireless multimedia sensor and actor networks for the next generation power grid. *Ad Hoc Networks*, 9(4): 542–551.

ETP SmartGrids. 2006. *European technology platform smart grids: vision and strategy for Europe’s electricity networks of the future*.

Fang, X., Misra, S., Xue, G. & Yang, D. 2012. Smart grid - The new and improved power grid:

A survey. *IEEE Communications Surveys and Tutorials*, 14(4): 944–980.

G. A. Daniel, S.I. and S.B. 2010. *LTE and LTE Advanced.*

Germán Fernández. 2019. Cost Effective Industrial Wireless Communication for Smart Grids Requirements for Communication Networks for Smart Grid Data Applications. *Belden Inc. and its subsidiary companies and brands include: Belden Deutschland GmbH; Hirschmann Automation and Control GmbH; Belden Wire & Cable B.V.; GarrettCom; Lumberg Automation, and Tofino Security.*

Gertmar, L., Karlsson, P. & Samuelsson, O. 2005. On DC injection to AC grids from distributed generation. *2005 European Conference on Power Electronics and Applications*: 10 pp.-P.10.

Ghassemi, A., Bavarian, S. & Lampe, L. 2010. Cognitive Radio for Smart Grid Communications. : 297–302.

GreenCape. 2017. Market Intelligence Report : Renewable Energy. : 1–17.

GSMA IR.92 v8.0. 2014. IMS Profile for Voice and SMS. *Gsma Ir.92*: 1–35.

Gungor, V.C., Lu, B. & Hancke, G.P. 2010. Opportunities and Challenges of Wireless Sensor Networks in Smart Grid. *IEEE Transactions on Industrial Electronics*, 57(10): 3557–3564.

Gungor, V.C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C. & Hancke, G.P. 2013. A Survey on smart grid potential applications and communication requirements. *IEEE Transactions on Industrial Informatics*, 9(1): 28–42.

Güzelgöz, S., Arslan, H., Islam, A. & Domijan, A. 2011. A review of wireless and PLC propagation channel characteristics for smart grid environments. *Journal of Electrical and Computer Engineering*, 2011(7).

Heinzelman, W.R., Chandrakasan, A. & Balakrishnan, H. 2000. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. , 00(c): 1–10.

Homes, S., Sahin, D., Kocak, T., Ergüt, S., Buccella, C., Cecati, C. & Hancke, G.P. 2012. [IEEEMagazine2012] - Smart Grid and Smart Home - key players and pilot projects.pdf. , (December): 18–34.

Hongjian Sun, Arumugam Nallanathan, Bo Tan, John S. Thompson, J.J. and H.V.P. 2012. Relaying Technologies for Smart Grid Communications. *IEEE Wireless Communications*, (December): 52–59.

Hwang, R.H., Chang, B.J., Chen, M.X. & Tsai, K.C. 2006. An efficient adaptive grouping for single code assignment in WCDMA mobile networks. *Wireless Personal Communications*, 39(1): 41–61.

IEEE Std 2030-2011. 2011. *IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads*.

Infield, D. & Li, F. 2008. Integrating Micro-Generation into Distribution Systems – a review of recent research. : 1–4.

Intanagonwiwat, C. Directed Diffusion : A Scalable and Robust Communication Paradigm for Sensor Networks.

Ipakchi, A. & Albuyeh, F. 2009. The Grid of The Future. *IEEE Power and Energy Magazine*, (march/april): 52–62.

Jin, H., Uludag, S., Lui, K. & Nahrstedt, K. 2014. Secure Data Collection in Constrained Tree-Based Smart Grid Environments. *2014 IEEE International Conference on Smart Grid Communications (SmartGridComm)*: 308–313.

Joffe, H. 2012. Challenges for South Africa ' s Electricity Supply Industry. *Helen Suzman Foundation Focus*, 64: 32–37.

Joint, E., Group, W. & Grids, S. 2011. *Standards for Smart Grids Joint Working Group on Standards for Smart Grids*.

Kalalas, C., Thrybom, L. & Alonso-Zarate, J. 2016. Cellular Communications for Smart Grid Neighborhood Area Networks: A Survey. *IEEE Access*, 4: 1469–1493.

Kalalas, C., Vazquez-Gallego, F. & Alonso-Zarate, J. 2016. Handling mission-critical communication in smart grid distribution automation services through LTE. *2016 IEEE International Conference on Smart Grid Communications, SmartGridComm 2016*: 399–404.

Kannappa, S.M. & Saquib, M. 2010. Performance Analysis of a Cognitive Network with Dynamic Spectrum Assignment to Secondary Users.

Karimi, B., Namboodiri, V. & Jadliwala, M. 2015. Scalable Meter Data Collection in Smart Grids Through Message Concatenation. *IEEE Transactions on Smart Grid*, 6(4): 1697–1706.

Kazičková, T. & Buhnova, B. 2016. ICT architecture for the Smart Grid: Concept overview. *2016 Smart Cities Symposium Prague, SCSP 2016*: 16–19.

Kazuhiko Hasegawa, Ryuichiro Shimura, Tsutomu Ohno, Naoki Yoshimochi, and J.S. 2005. OVSF Code Allocation and Two-stage Combining Method to reduce Inter-code Interference in OFCDM System. : 2500–2504.

Khan, A.A., Rehmani, M.H. & Reisslein, M. 2015. Cognitive Radio for Smart Grids : Survey of Architectures , Spectrum Sensing Mechanisms , and Networking Protocols. , 18(c): 1–41.

Khan, R.H. & Khan, J.Y. 2013. A comprehensive review of the application characteristics and traffic requirements of a smart grid communications network. *Computer Networks*, 57(3): 825–845.

Khedo, K., Doomun, R. & Aucharuz, S. 2010. READA : Redundancy Elimination for Accurate Data Aggregation in Wireless Sensor Networks. , 2010(April): 300–308.

Kottkamp, M. 2010. LTE-Advanced Technology Introduction White Paper. *Rohde & Schwarz*.

Kuo, C., Member, S., Sheen, W., Chang, C., Hsiao, C.L. & Transmitter-based, A. 2008. On the Transmitter-Based Preprocessing for 2-D Over Time-Varying Rayleigh Fading Channels. *Channels*, 57(3): 1968–1974.

Kursawe, K., Danezis, G. & Kohlweiss, M. 2020. Privacy-Friendly Aggregation for the Smart-Grid. : 175–176.

Kuzlu, M., Pipattanasomporn, M. & Rahman, S. 2014. Communication network requirements for major smart grid applications in HAN, NAN and WAN. *Computer Networks*, 67: 74–88.

Lameez Omarjee (Fin24). 2019. Radebe : Renewable Energy Independent Power Producers are ' cost neutral ' to Eskom More From.

Lewin, P.L., Davies, J.S. & Rowland, S.M. 2013. The State of the Art of Condition Monitoring: Where do we go from here? In *INSUCON 2013, The Electrical Insulation Association 2*.

Li, Fangxing, Qiao, W. 2010. Smart Transmission Grid : Vision and Framework. , 1(2): 168–177.

Lmdsey, S. & Raghavendra, C.S. 2001. PEGASIS : Power-Efficient GAthering in Sensor Information Systems '. : 1125–1130.

Luan, W., Sharp, D. & Laroy, S. 2013. Data traffic analysis of utility smart metering network. *IEEE Power and Energy Society General Meeting*: 1–4.

Ma, R., Chen, H.H., Huang, Y.R. & Meng, W. 2013. Smart grid communication: Its challenges and opportunities. *IEEE Transactions on Smart Grid*, 4(1): 36–46.

Ma, X., Li, H. & Djouadi, S. 2011. Networked system state estimation in smart grid over cognitive radio infrastructures. *2011 45th Annual Conference on Information Sciences and Systems, CISS 2011*: 1–5.

Madueno, G.C., Nielsen, J.J., Kim, D.M., Pratas, N.K., Stefanovic, C. & Popovski, P. 2016. Assessment of LTE Wireless Access for Monitoring of Energy Distribution in the Smart Grid. *IEEE Journal on Selected Areas in Communications*, 34(3): 675–688.

Maeda, N., Kishiyama, Y., Atarashi, H. & Sawahashi, M. 2005. Variable spreading factor-OFCDM with two dimensional spreading that prioritizes time domain spreading for forward link broadband wireless access. *IEICE Transactions on Communications*, E88–B(2): 487–497.

Maeda, N., Kishiyama, Y., Higuchi, K., Atarashi, H. & Sawahashi, M. 2003. Experimental evaluation of throughput performance in broadband packet wireless access based on VSF-OFCDM and VSF-CDMA. *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, 1: 6–11.

Maraiya, K., Kant, K. & Gupta, N. 2011. Wireless Sensor Network : A Review on Data Aggregation. , 2(4): 1–6.

Mark, Jon W., Z.W. 2003. *Wireless Communications and Networking*. Upper Saddle River, NJ, USA: Prentice Hall.

Meng, W., Ma, R. & Chen, H.-H. 2014. Smart grid neighborhood area networks: a survey. *IEEE Network*, 28(1): 24–32.

Modern, N., Strategy, G. & Economy, C. 2008. *Advanced Metering Infrastructure*.

Mohn, T. & Piasecki, R. 2011. A smarter grid enables communal microgrids. *2011 IEEE Green Technologies Conference, Green 2011*.

NETL. 2010. Understanding the Benefits of the Smart Grid. *Strategy*, 43(9B): 6793–6798.

Noroozoliaee, M., Hamdaoui, B., Cheng, X., Znati, T. & Guizani, M. 2014. Analyzing Cognitive Network Access Efficiency Under Limited Spectrum Handoff Agility. , 63(3): 1402–1407.

Omer, A.M. 2008. Green energies and the environment. *Renewable and Sustainable Energy Reviews*, 12(7): 1789–1821.

Ondral, F.R.K.J. & Arlsruhe, U.N.K. 2004. Spectrum Pooling : An Innovative Strategy for the Enhancement of. , (March): 8–14.

Quang-Dung, H., Yue, G. & Tho, L.-N. 2013. Challenges and research opportunities in wireless communication networks for smart grid. *IEEE Wireless Communications*, 20(3): 89–95.

Park, J. S., Lee, D.C. 2003. Enhanced fixed and dynamic code assignment policies for OVSF-CDMA systems. In *Proc. Int. Conf. ICWN, Las Vegas*. 620–625.

Parvez, I., Islam, N., Rupasinghe, N., Sarwat, A.I. & Guvenc, I. 2016. LAA-based LTE and ZigBee coexistence for unlicensed-band smart grid communications. *Conference Proceedings - IEEE SOUTHEASTCON*, 2016–July.

Patel, D., Mohamed, M.I.N., Mehdi, S.Z.R., Williams, F., Sadu, A., Ponci, F. & Monti, A. 2016. Investigating the performance of QoS enabled LTE networks for IEC 61850 based smart grid applications. *2016 IEEE International Energy Conference (ENERGYCON)*: 1–6.

Peng Cheng, Li Wang, Bin Zhen & Shihua Wang. 2011. Feasibility study of applying LTE to Smart Grid. *2011 IEEE First International Workshop on Smart Grid Modeling and Simulation (SGMS)*: 108–113.

Qiu, R.C., Hu, Z., Chen, Z., Guo, N., Ranganathan, R., Hou, S. & Zheng, G. 2011. Cognitive radio network for the Smart Grid: Experimental system architecture, control algorithms, security, and Microgrid testbed. *Smart Grid, IEEE Transactions on*, 2(4): 724–740.

Quang-Dung, H., Yue, G. & Tho, L.-N. 2013. Challenges and research opportunities in wireless communication networks for smart grid. *IEEE Wireless Communications*, 20(3): 89–95.

Ramírez, D.F., Céspedes, S., Becerra, C. & Lazo, C. 2015. Performance evaluation of future AMI applications in Smart Grid Neighborhood Area Networks. *2015 IEEE Colombian Conference on Communications and Computing, COLCOM 2015 - Conference Proceedings*.

Raventós, G.V. 2015. *Redundancy Elimination for Data Aggregation in Wireless Sensor Networks Redundancy Elimination for Data Aggregation in Wireless Sensor Networks*. Tehcnische Universität Chemnitz.

Rekola, J. 2012. DC distribution and power electronics applications in Smart Grids. *Webhotel2.Tut.Fi*: 27.

Rouskas, A.N., Skoutas, D.N. & Member, S. 2005. Management of Channelization Codes at the Forward Link of WCDMA. , 9(8): 679–681.

Saghezchi, F., Radwan, A., Rodriguez, J. & Dagiuklas, T. 2013. Coalition formation game toward green mobile terminals in heterogeneous wireless networks. *IEEE Wireless Communications*, 20(5): 85–91.

Saini, D.S. & Balyan, V. 2016. An Efficient Multicode Design for Real Time QoS Support in OVSF Based CDMA Networks. *Wireless Personal Communications*, 90(4): 1799–1810.

Saini, D.S. & Balyan, V. 2014. Top Down Code Search to Locate An Optimum Code and Reduction in Code Blocking for CDMA Networks. : 465–482.

Saini, D.S. & Upadhyay, M. 2009. Multiple Rake Combiners and Performance Improvement in 3G and Beyond WCDMA Systems. , 58(7): 3361–3370.

Sauter, T.. b & Lobashov, M.. 2011. End-to-end communication architecture for smart grids. *IEEE Transactions on Industrial Electronics*, 58(4): 1218–1228.

Sebaali, G. & Evans, B.L. 2015. Design tradeoffs in joint powerline and wireless transmission for smart grid communications. *2015 IEEE International Symposium on Power Line Communications and Its Applications, ISPLC 2015*, 3: 83–88.

Shadmand, A. & Shikh-bahaei, M. 2010. Multi-user Time-Frequency Downlink Scheduling and Resource Allocation for LTE Cellular Systems. In *2010 IEEE Wireless Communication and Networking Conference*. IEEE: 1–6.

Sharif, H. 2013. A Survey on Smart Grid Communication Infrastructures : Motivations , Requirements and Challenges A Survey on Smart Grid Communication Infrastructures : Motivations , Requirements and Challenges. *IEEE Communications Surveys and Tutorials*, 15(1): 1–16.

Sharma, N. & Saini, D. 2013. Reduction in code blocking using scattered vacant codes for orthogonal variable spreading factor-based wideband code division multiple access networks. *IET Communications*, 7(1): 40–48.

Singh, S.N. & Jain, N. 2009. Distributed Generation in Power Systems : An Overview and Key Issues. *24rth Indian Engineering Congress, NIT Surathkal, Kerala, December 10-13, 2009*.

Sivaranjani, S., Radhakrishnan, S. & Thangaraj, C. 2013. Adaptive Delay and Energy Aware Data Aggregation. : 41–42.

Smart Grid Interoperability Panel. 2012. *Electromagnetic Compatibility and Smart Grid Interoperability Issues*.

Specification, T. & Services, G. 2014. 3gpp tr 22.953. , 0(Release 12).

Specification, T. & Services, G. 2011. 3gpp ts 23.279. , 0.

Standard, I. 2003. 61850-7-2. , 2003: 14.

Standards, I., Committee, C., Generation, D. & Storage, E. 2011. *IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications , and Loads IEEE Standards Coordinating Committee 21 Sponsored by the*.

Standards Institutions. 2012. IMS Profile for Conversational Video Service V3.0. *1207*: 1–15.

Sweta & Samir, M. 2013. A Generalized Overview of Distributed Generation. *International Journal of Emerging Research in Management & Technology*, 2(12): 1–6.

Tavasoli, M., Yaghmaee, M.H. & Mohajerzadeh, A.H. 2016. Optimal Placement of Data Aggregators in Smart Grid on Hybrid Wireless and Wired Communication. *2016 IEEE Smart Energy Grid Engineering (SEGE)*: 332–336.

Tsai, Y.R. & Lin, L.C. 2009. Quality-based OVSF code assignment and reassignment strategies for WCDMA systems. *IEEE Transactions on Vehicular Technology*, 58(2): 1027–1031.

Tseng, Y.C. & Chao, C.M. 2002. Code placement and replacement strategies for wideband CDMA OVSF code tree management. *IEEE Transactions on Mobile Computing*, 1(4): 293–302.

Tu, G.-H., Peng, C., Wang, H., Li, C.-Y. & Lu, S. 2013. How voice calls affect data in operational LTE networks. *the 19Th Annual International Conference*: 12–87.

Tuballa, M.L. & Abundo, M.L. 2016. A review of the development of Smart Grid technologies. *Renewable and Sustainable Energy Reviews*, 59: 710–725.

Tumuluru, V.K., Wang, P. & Niyato, D. 2011. A Novel Spectrum-Scheduling Scheme for Multichannel Cognitive Radio Network and Performance Analysis. , 60(4): 1849–1858.

Uludag, S., Lui, K.S., Ren, W. & Nahrstedt, K. 2016. Secure and scalable data collection with time minimization in the smart grid. *IEEE Transactions on Smart Grid*, 7(1): 43–54.

Wang L., Wang C., and K.F. 2011. A Queueing -Theoretical Framework For Qos-Enhanced Spectrum Management in Cognitive Radio Networks. , (December): 18–26.

Wang, L., Chang, C. & Huang, H. 2007. An Interference Avoidance Code Assignment Strategy for Downlink Multi-Rate MC-DS-CDMA with TF-Domain Spreading. , 6(7): 2508–2518.

Wang, S. 2009. Distributed Generation and its effect on Distribution Network System. , (0110): 8–11.

Wang, W., Xu, Y. & Khanna, M. 2011. A survey on the communication architectures in smart grid. *Computer Networks*, 55(15): 3604–3629.

Webster, R., Munasinghe, K. & Jamalipour, A. 2016. Optimized resource allocation in LTE networks incorporating delay-sensitive smart grid traffic. *2016 IEEE International Conference on Smart Grid Communications, SmartGridComm 2016*: 423–428.

Wong, E.W.M., Member, S., Foh, C.H. & Member, S. 2009. Analysis of Cognitive Radio Spectrum Access with Finite User Population. , 13(5): 294–296.

Xing, Y., Chandramouli, R. & Mangold, S. 2006. Dynamic Spectrum Access in Open Spectrum Wireless Networks. , 24(3): 626–637.

Yaacoub, E. & Kadri, A. 2015. LTE Radio Resource Management for Real-Time Smart Meter Reading in the Smart Grid. : 2000–2005.

Yan, Y., Qian, Y., Sharif, H. & Overview, A.S. 2011. A Secure Data Aggregation and Dispatch Scheme for Home Area Networks in Smart Grid. *2011 IEEE Global Telecommunications Conference - GLOBECOM 2011*: 1–6.

Yan, Y., Qian, Y., Sharif, H. & Tipper, D. 2013. A survey on smart grid communication infrastructures: Motivations, requirements and challenges. *IEEE Communications Surveys and Tutorials*, 15(1): 5–20.

Yang, L., Song, S.H. & Letaief, K.B. 2014. Cognitive Spectrum Access in Macro-Femto Heterogeneous Networks. : 4269–4274.

Yigit, M., Gungor, V.C. & Baktir, S. 2014. Cloud Computing for Smart Grid applications. *Computer Networks*, 70: 312–329.

Yiğit, M., Incel, Ö.D. & Güngör, V.Ç. 2014. On the interdependency between multi-channel scheduling and tree-based routing for WSNs in smart grid environments. *Computer*

Networks, 65: 1–20.

Yiqing Zhou, Tung-Sang Ng, Jiangzhou Wang, K.H. and M.S. 2008. OFCDM: A Promising Broadband Wireless Access Technique. *IEEE Communications Magazine*, (March): 38–49.

Yu, C.W., Ouyang, W., Wang, C.Y., Liu, M.T. & Chang, Y.W. 2010. Graph model for OVSF code placement. *2010 5th International Conference on Future Information Technology, FutureTech 2010 - Proceedings*, (Figure 1).

Yu, R., Zhang, Y., Gjessing, S., Yuen, C. & Xie, S. 2011. Cognitive radio based hierarchical communications infrastructure for smart grid. *Ieee*, (October): 2–10.

Zaballos, A., Vallejo, A. & Selga, J.M. 2011. Heterogeneous communication architecture for the smart grid. *IEEE Network*, 25(October): 30–37.

Zhang, N., Liang, H., Cheng, N., Tang, Y., Mark, J.W. & Shen, X.S. 2014. Dynamic spectrum access in multi-channel cognitive radio networks. *IEEE Journal on Selected Areas in Communications*, 32(11): 2053–2064.

Zhang, Y. 2008. Dynamic Spectrum Access in Cognitive Radio Wireless Networks. : 4927–4932.

Zhang, Z. & Jiang, H. 2012. Cognitive Radio with Imperfect Spectrum Sensing : , 1(2): 133–136.

Zheng, J., Gao, D.W. & Lin, L. 2013. Smart meters in smart grid: An overview. *IEEE Green Technologies Conference*: 57–64.

Zhou, Y., Wang, J. & Ng, T.S. 2008. Downlink transmission of broadband OFCDM systems - Part V: Code assignment. *IEEE Transactions on Wireless Communications*, 7(11): 4546–4557.

Zhu, X., Shen, L. & Yum, T.P. 2007. Analysis of Cognitive Radio Spectrum Access with Optimal Channel Reservation. , 11(4): 304–306.

Publications in International Journals

1 B. Groenewald, V. Balyan and MTE Kahn, “Smart Grids and Mobile Traffic Communication for Improved Spectral Efficiency of LTE systems”, International Journal of Applied Engineering Research Volume 12, Number 22 (2017) pp. 11803-11811, ISSN 0973-4562.

2 B. Groenewald, V. Balyan and MTE Kahn, “Fast Channel Load Algorithm for Downlink of Multi-Rate MC-DS-CDMA and Smart Grid Communication”, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 20 (2018) pp. 14607-14617

Publications in International Conferences

3 V. Balyan and B. Groenewald, “Voice Secondary User Call Prioritize Cognitive Radio Networks with Buffering, International Conference on Microelectronics and Telecommunication Engineering (ICMETE) 2016, pp. 271-275. IEEE ISBN-13: 978-1-5090-3411-6

4 V. Balyan and B. Groenewald, "UMTS and LTE interfaces utilization improvement with QoS in mobile communication systems," 2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, 2016, pp. 1-4. IEEE ISBN No. is 978-1-5090-2807-8.

5 B. Groenewald, V. Balyan, 25th Southern African Universities Power Engineering Conference (SAUPEC-2017), 31 January – 01 February. “Smart Grid Communications using Cognitive Radio with Prioritize Utilization of Available Spectrum, pp502 – 506, ISBN 978-0-620-74503-1.

6 B. Groenewald, V. Balyan and MTE Kahn, 25th Domestic Use of Energy Conference (DUE-2017), April 3- 5, pp. 272-275 “Smart Utilization LTE-UMTS Spectrum in Smart Grids for communication”, IEEE, ISBN 978-0-9946759-2-7.