CALL ADMISSION CONTROL FOR INTERACTIVE MULTIMEDIA SATELLITE NETWORKS

By

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Submitted to the School of Electrical, Electronic and Computer Engineering

In fulfillment of the requirements for the degree of

Master of Science in Engineering (MScEng)

At the University of KwaZulu-Natal,

Durban, South Africa

November 2015

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DECLARATION

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PREFACE

As the supervisor to the candidate, I agree/do not agree to the submission of this thesis

Supervisor's Signature: ____

The research work performed in this thesis was performed by Olugbenga Imole, under the supervision of Dr. Tom Walingo and Prof. Fambirai Takawira at the School of Electrical, Electronic and Computer Engineering's Research Centre for Radio Access and Rural Technologies, University of KwaZulu-Natal, Durban. The work was partially sponsored by Telkom.

ACKNOWLEDGEMENT

I like to appreciate the guidance of my Supervisors Prof. Fambirai Takawira and Dr. Tom Walingo for your guidance and support towards the completion of this degree. I am deeply indebted to you for your encouragement and motivation towards completing the work.

My sincere appreciation goes to my wife Hannah for her immeasurable support, encouragement, sacrifice and prayers throughout this research work. It is obvious that your support has helped me to complete it. I also want to appreciate my little Princess Victoria for her endurance and the unconditional show of affection. May God bless you.

I also like to acknowledge the sincere love and support of my Dad and siblings Kayode, Dare and Kemi; I appreciate your love, kindness and support. Your sacrifices have contributed immensely to the completion of this work. May God reward you with brilliant success, amen.

Lastly, I want to appreciate the friends and colleagues in the Deeper Life Campus Fellowship (DLCF). Thanks for your prayer and support. I will not forget to mention all friends in the discipline of Electrical, Electronic and Computer Engineering for the interactions and discussions. I really appreciate you all.

ABSTRACT

Satellite communication has become an integral component of global access communication network due mainly to its ubiquitous coverage, large bandwidth and ability to support for large numbers of users over fixed and mobile devices. However, the multiplicity of multimedia applications with diverse requirements in terms of quality of service (QoS) poses new challenges in managing the limited and expensive resources. Furthermore, the time-varying nature of the propagation channel due to atmospheric and environmental effects also poses great challenges to effective utilization of resources and the satisfaction of users' QoS requirements. Efficient radio resource management (RRM) techniques such as call admission control (CAC) and adaptive modulation and coding (AMC) are required in order to guarantee QoS satisfaction for user established connections and realize maximum and efficient utilization of network resources.

In this work, we propose two CAC policies for interactive satellite multimedia networks. The two policies are based on efficient adaptation of transmission parameters to the dynamic link characteristics. In the first policy which we refer to as Gaussian Call Admission Control with Link Adaptation (GCAC-LA), we invoke the central limit theorem to statistically multiplex rate based dynamic capacity (RBDC) connections and obtain an aggregate bandwidth and required capacity for the multiplex. Adaptive Modulation and Coding (AMC) is employed for transmission over the time-varying wireless channel of the return link of an interactive satellite network. By associating users' channel states to particular transmission parameters, the amount of resources required to satisfy user connection requirements in each state is determined. Thus the admission control policy considers in its decision, the channel states of all existing and new connections. The performance of the system is investigated by simulation and the results show that AMC significantly improves the utilization and call blocking performance by more than twice that of a system without link adaptation. In the second policy, a Game Theory based CAC policy with link adaptation (GTCAC-LA) is proposed. The admission of a new user connection under the GTCAC-LA policy is based on a non-cooperative game that is played between the network (existing user connections) and the new connection. A channel prediction scheme that predicts the rain attenuation on the link in successive intervals of time is also proposed. This determines the current resource allocation for every source at any point in time. The proposed game is played each time a new connection arrives and the strategies adopted by players are based on utility function, which is estimated based on the required capacity and the actual resources allocated. The performance of the CAC policy is investigated for different prediction intervals and the results show that multiple interval prediction scheme shows better performance than the single interval scheme. Performance of the proposed CAC policies indicates their suitability for QoS provisioning for traffic of multimedia connections in future 5G networks.

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LIST OF ACRONYMS

AC	Adaptive Coding
AMC	Adaptive Modulation and Coding
ARC	Adaptive Rate Control
AVDBC	Absolute Volume Based Dynamic Capacity
BoD	Bandwidth on Demand
BER	Bit Error Rate
CAC	Call/Connection Admission Control
CDMA	Code Division Multiple Access
CLT	Central Limit Theorem
CP	Complete Partitioning
CR	Capacity Request
CRA	Continuous Rate Assignment
CS	Complete Sharing
DS	Deep Shadowing
DVB	Digital Video Broadcasting
DVB-RCS	Digital Video Broadcasting Return Channel via Satellite
DVB-RCS2	Digital Video Broadcasting Return Channel via Satellite Second Generation
DVB-S	DVB-S - Digital Video Broadcasting – Satellite
DVB-S2	Digital Video Broadcasting –Satellite Second Generation
EDP	Excess Demand Probability
ETSI	European Telecommunication Standards Institute
FDMA	Frequency Division Multiple Access
FMT	Fade Mitigation Technique
FRA	Free Capacity Assignment

GEO	Geostationary Earth Orbit
GM	Guaranteed Minimum
HEO	High Elliptical Orbit
LEO	Low Earth Orbit
LOS	Line of Sight
MC	Markov Chain
MEO	Medium Earth Orbit
MF-TDMA	Multiple Frequency Time Division Multiple Access
MODCOD	Modulation and Coding Format
NCC	Network Control Centre
NLOS	Non-Line-of-Sight
PAC	Power Allocation and Control
PDR	Peak Data Rate
PLR	Packet Loss Ratio
QoS	Quality of Service
RBDC	Rate Based Dynamic Capacity
RCS	Return Channel via Satellite
RCST	Return Channel System Terminal
RF	Radio Frequency
RRM	Radio Resource Management
RT	Real Time
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
TR	Trunk Reservation
VBR	Variable Bit Rate

VBDBC	Volume Based Dynamic Capacity

LIST OF SYMBOLS

W	State Probability Matrix
P	Transition Probability Matrix
δ_t	Instantaneous SNR at time *t*
δ_m	SNR threshold for mode *m*
t	time
M	Number of Channel States
R_m	Maximum Achievable bitrate in channel state *m*
$\bar{M}$	Mean Bitrate of an RBDC (Video) source
$\overline{SD}$	Standard Deviation of the Bitrate of an RBDC (Video) source
$\bar{M}_{aggr}$	Aggregate mean bitrate of multiplexed RBDC sources
$\overline{SD}_{aggr}$	Aggregate Standard deviation of bitrate of multiplexed RBDC sources
BR_{CRA}	Bandwidth request of a CRA source (in Kbits/s)
N_{CRA}	Number of timeslots required by a CRA Source
N_{RBDC}^{k}	Number of timeslots required by RBDC sources on RCST k
BR_{RBDC}^{k}	Bandwidth required by RBDC source in RCST k
K	Number of RCSTs handling RBDC connections
N_R	Number of timeslots required by a generic source
B_R	bandwidth requirement of a generic source
N_T	Network capacity (timeslots)
N_{CRA}	Capacity allocation to CRA connections
N_{RBDC}	Capacity allocation to RBDC connections
b	Fixed capacity of a timeslot (in Kbits/s)
β	Burstiness of a voice source
G	Link Capacity

A_V	Activity factor of a voice source
P	Peak data rate of a mini-source
x	Time spent by a mini-source in ON state
y	Time spent by a mini-source in OFF state
T_s	Time interval between successive timeslots
a	auto-covariance function of bit rate generated by video source
Ω	Probability of a voice source's transition from ON state to OFF state
ς	Probability of a voice source's transition from OFF state to ON state
Δt	Duration of the period for which rain attenuation is predicted
$A_{R,n\Delta t}$	Rain attenuation predicted for period $n\Delta t$
8PSK	Eight Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
C_T	Total Network Capacity
C_{RT}	Total capacity already allocated to RT connections
C_{NRT}	Total capacity already allocated to NRT connections
C_{RT}^M	Capacity of RT connection in mode m
C_{NRT}^M	Capacity of RT connection in mode m
$U(c,m)$	Utility Function
S_{NC}	Set of strategies for new connection
S_{NET}	Set of strategies for the existing network connections
Q	Maximum resources that can be extracted from NRT connections
U_{b_q}	Utility of the ongoing RT and NRT in the network when b_q resources are extracted form NRT connections
U_B	Utility of new connection
U_A	Utility of new connection when the 'accept' strategy is adopted
U_R	Utility of new connection when the 'reject' strategy is adopted

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Introduction

The impact of space technology on our lives cannot be overemphasized. It directly or indirectly influences our daily routines through various services such as weather monitoring and forecasting, remote sensing and imaging, global positioning system (GPS), navigation and multimedia communication. At the core of the systems through which these services are delivered are satellites which provide the essential interconnectivity amongst the various components, devices and users in the respective systems. Satellites are artificial bodies that are launched into orbits around the earth for the purpose of communication and/or information collection. They are designed and equipped with transponders for the reception of signals that are transmitted from earth stations and broadcast of received signals towards earth stations within their coverage. Their use for communication stems from their ability to receive signals and retransmit them over large areas in unicast, multicast or broadcast modes. In addition to the transponders, satellites may also be provided with sensors to gather important measurements and transmit collected data towards earth stations where they are processed.

The first artificial satellite was launched into space on October 4, 1957. Its successful launch inspired engineers and scientists and provided a foundation for the technological and scientific advances that followed. Later on, in 1965, the first communication satellite (nicknamed Early Bird) was launched into space to provide television, telephone and fax services. Since then, many other satellites have been launched into space to provide commercial and military communication services over long distances. Applications of satellites now extend beyond the provision of television and telephone services to include fixed, mobile, maritime, aeronautical and internet services. Satellites can also integrate with other terrestrial networks to complement their coverage and reliability [1]. This integrated role of satellites will be more pronounced in the fifth generation wireless (5G) communication network whose development and standardization are currently being discussed. The objectives of 5G are to realize improved overall network performance through higher data rates and spectral efficiency, global coverage, low energy consumption and lower cost of information transmission [2]. Also, considering the growing multiplicity of users and devices as well as their demand for high-speed services, the role of satellites is indispensable in improving system capacity and realizing ‘anything, anywhere and anytime’ connectivity globally [2]. The many advantages of satellite communications are discussed in the following section. They include the major factors that have fueled the continuous relevance that satellite networks enjoy today.

1.2 Advantages of Satellite Communications

There are many reasons that influence the adoption of satellite networks for communication. These are discussed in the following [3].

- ***Ubiquitous coverage*:** This is a very significant feature of satellite networks. Satellites provide extended coverage that span areas as large as a region, nation, continent or the globe. They are the network of choice for sparsely populated regions where the installation of terrestrial infrastructure is technically and economically unfeasible [1].
- ***Large bandwidth*:** The huge capacity requirements of today's networking environment can be supported by satellite networks. Due to its large bandwidth, satellite networks are capable of supporting bandwidth-consuming applications such as video conferencing, voice and other real time services. The migration of satellite systems to higher frequency bands also provides improved capacity to the network.
- ***Flexible service model*:** With advances in technology, satellite operators are able to offer various service options to customers. These services may be tailored to meet the requirements and budget of different classes of customers. Examples of such services are pay-as-you-use and backup links for redundancy.
- ***Support for fixed and mobile users*:** Satellite networks are capable of providing fixed and mobile connectivity to users within its coverage. A large number of fixed and mobile terminals may be supported simultaneously by the network to access multimedia contents.
- ***Low cost*:** For the user, the relatively low network setup cost is also a major advantage of satellite communication. It cost less to setup a satellite network than it is when setting up a terrestrial microwave infrastructure. Also, from the satellite operator's perspective, he is able to connect any customer within its footprint without any additional costs. Thus he is able to price his service are reasonable costs.
- ***Connectivity*:** Satellites are capable of providing broadcasts and point-to-multipoint (multicast) connectivity and do not require complex routing protocols before such connectivity are achieved.
- ***Support for multimedia services:*** Users on a satellite network can access multiple multimedia services simultaneously. The network is capable of providing support for voice, video and web connections.
- ***Deployment and management*:** The operation of a satellite may commence after its launch and reaching its orbital position. The small form factor of earth station equipment such as modems and antenna makes it easy to set up the earth station faster and at lower costs.

1.3 Satellite Communication Networks

The block diagram of a satellite communication network is shown in Figure 1. Its components are divided into two, namely ground and space segments. The ground segment refers to all earth-based equipment necessary for the operation and control of the satellite network and includes all fixed and mobile equipment for transmission and reception of signals as well as other accompanying equipment. The space segment includes a satellite or a constellation of satellites as well as the links – both uplink and downlink. The uplink refers to the transmission path from the ground stations to the satellite while the downlink is the transmission path from the satellite to the ground stations. There are different types of satellites. Their classifications are discussed in the following subsections.

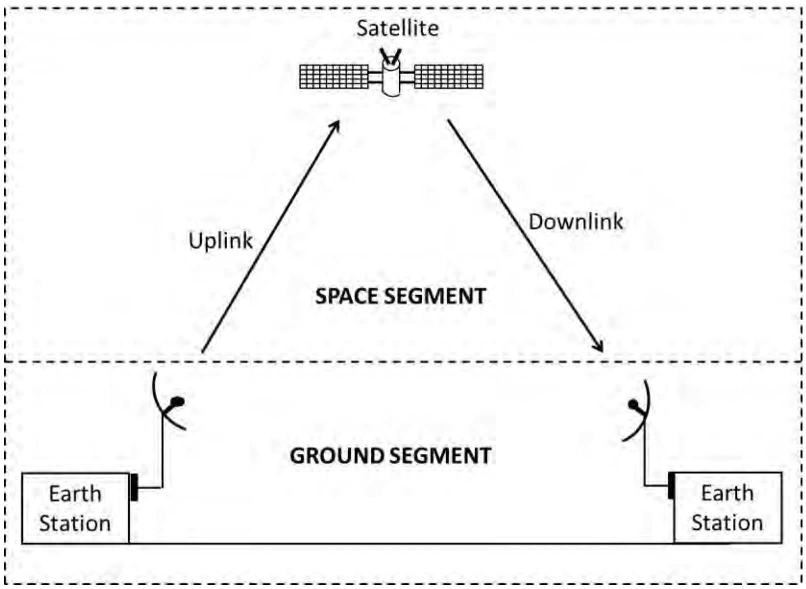

Figure 1: Block Diagram of a Satellite Network

1.3.1 Classification of Satellites

There are basically two classes of satellites namely passive and active satellites [4].

- ***Passive Satellites:*** A satellite is classified as passive if its operation is based on the principle of reflection. They simply reflect signals transmitted by source stations towards the receiver stations on the ground. Whereas the operating principle of these satellites is simple, their drawback lies in the fact that the received signal may suffer severe degradation due to the effects of atmospheric factors such as rain and fog.
- ***Active Satellites:*** Active satellites are developed to overcome the challenges of passive satellites. With active satellites, signals that are transmitted by source stations are first amplified aboard the satellite before they are transmitted towards the receiver on the ground.

Active satellites are further classified into two categories depending on the type of transponder in their payload [3]. The two categories of active satellites are bent-pipe and regenerative satellites.

- ***Bent-pipe Satellites*:** Bent-pipe satellites are the basic form of active satellites. They simply amplify the signals received at the satellite before retransmitting the amplified signal towards the receiver station on the ground. No other form of signal enhancement is carried out on the signal after it is amplified.
- ***Regenerative Satellites*:** Satellites categorized as regenerative are designed with that goal of improving the reliability and efficiency of signal transmission. When a signal is received at the satellite, it first demodulates and decodes it in order to recover the original signal. It then checks the condition of the downlink channel and based on its state, it selects appropriate transmission parameters that will ensure that the signal is sent reliably towards the ground-based receiving station. The advantage of regenerative satellites is that the uplink and downlink are decoupled, i.e. different modulation and coding may be used for both links. This isolates the noise and interference on both links from each other, resulting in a lower error rate and less complex terminal design. However, this functionality increases the weight, power and financial requirements of building such satellite. The architecture of the system proposed in the thesis is based on a regenerative satellite network. We propose to guarantee high transmission reliability for all users in the network, hence a regenerative satellite guarantees high quality for all signals received by the ground stations.

1.3.2 Classification of Satellite Orbits

All communication satellites are positioned in different orbits around the earth. On the basis of their altitudes and orbital positions, satellites may also be classified into four categories namely low earth orbit (LEO), medium earth orbit (MEO) geostationary earth orbit (GEO) and highly elliptical orbit (HEO) satellites [3] [5] [6]. The following is a discussion on the features of the different types of satellite orbits.

1.3.2.1 Low Earth Orbit (LEO) Satellites

Satellite are classified as LEO if their altitudes lie between 500 and 2000 km. Due to their close proximity to the earth, LEO satellites can transmit information with very small delay in the range of 10ms hence are suitable for real time communication. However, their short altitude results in very short visibility time (~15-20 mins.). To overcome this and realize 24 hours coverage, LEO satellites are operated as a constellation of satellites each of which are interconnected by inter-satellite links. But with many satellites in a constellation, frequent handovers may be required during a connection.

1.3.2.2 Medium Earth Orbit (MEO) Satellites

Satellites that are classified as MEO are those launched into orbits whose altitudes range from 8,000 to 12,000 km. Due to the higher altitude, their visibility time is higher than those of LEOs and ranges from two to four hours. They find application in navigation, global positioning system (GPS) and meteorological research [7].

1.3.2.3 Geostationary Earth Orbit (GEO) Satellites

GEO satellites are the most common types of satellites and are usually launched to the earth's equatorial plane at altitudes around 35,780 km. They have a rotation period and visibility time of 24 hours, which makes them stationary when viewed from any part of the earth. GEOs also have the largest coverage area so that with three of them strategically positioned in the equatorial plane, a global coverage can be achieved. These features have made GEOs best suitable for telecommunication services in providing high-speed multimedia and data transmission. However, in comparison with other satellite orbits, the propagation loss and delay experienced in geostationary satellite links is the highest due to their high altitude.

1.3.2.4 Highly Elliptical Orbit (HEO) Satellites

HEO satellites are a different class of satellites that are distinguished from LEO, MEO and GEO satellites by their non-circular orbits. They usually operate in non-circular orbits around the earth. HEOs are designed to swing very close to the earth around the regions they intend to cover. Examples of such regions are densely populated areas and regions around the northern and southern poles of the globe where GEO signal reception is weakest. Their orbits range from 18,000 to 35,000 km in altitude from the earth's surface [5]. Due to the nature of their orbit, it is difficult to achieve global coverage with HEO satellites. Global coverage is usually achieved by integrating them with MEOs and GEOs.

The features of the four satellite orbits types are summarized in Table 1 [3] [6], and a pictorial representation of the orbits is shown in Figure 2. In this research, the proposed systems adopt GEO regenerative satellite network architecture due to its coverage and 24-hour visibility.

Table 1: Summary of features of LEO, MEO, GEO and HEO Satellites

	LEO	MEO	GEO	HEO
Altitude	500 - 2000 Km	8,000 – 12,000 Km	35,780 Km	18 – 35,000 Km
Visibility Time / Orbital Period	15 - 20 mins.	2 – 4 hours	24 hours	8 – 12 hours
Number of Satellites for global Coverage	40 – 80	8-20	3	Fewer satellites to cover the earth than MEOs but can also integrate with GEOs and MEOs for global coverage
Lifetime	Short	Long	Long	Long
Channel Loss	Low	Medium	High	Medium
Propagation Delay	20 – 25 ms	110 -130 ms	250-280 ms	Variable

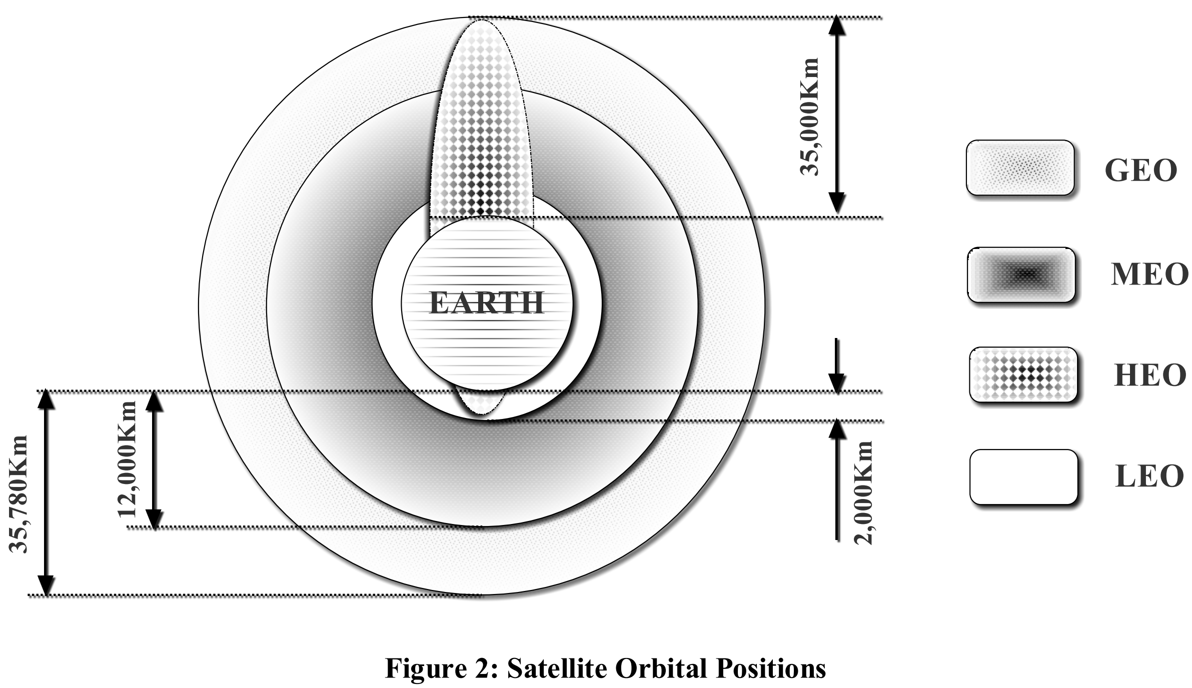

Figure 2: Satellite Orbital Positions

1.3.3 Satellite Frequency Bands

Generally, satellite communication systems operate in the microwave spectrum, which is commonly used for commercial and military communication. The different frequency bands have been designated for easy reference. In this designation, the bandwidth offered increases as the frequency of the band. The frequency bands and their application areas are listed in Table 2 [3]. A Ka band satellite system is considered in this research work due to its high capacity which makes is capable of supporting large number of connections of multimedia applications.

Table 2: Satellite Communication Frequency Bands

Band	Frequency	Application
L	1 -2 GHz	GPS Carriers, mobile phones
S	2 – 4 GHz	Weather radar, surface ship radar
C	4 – 8 GHz	Satellite communication, Satellite TV broadcasts to areas in the tropics, where rain fading are predominant
X	8 – 12 GHz	Military use
Ku	12 – 18 GHz	Satellite communication, direct broadcast satellite services
K	18 – 26 GHz	Radar and satellite communication
Ka	26 – 40 GHz	Satellite communications, close range targeting radars on military aircrafts
V	40 – 75 GHz	Scientific research, not heavily used

1.3.4 Multiple Access Techniques

With rising numbers of connected users, the demand for multimedia services and network resources is increased. Multiple access techniques are introduced to enable a large number of earth stations share the allocated bandwidth and simultaneously transmit their generated traffic over the satellite's transponder. The sharing involves dividing the bandwidth into non-overlapping segments and each of the segments is assigned for exclusive use by each of the users. This ensures that the utilization of network bandwidth is maximized. The following are common multiple access techniques.

- Frequency Division Multiple Access (FDMA),
- Time Division Multiple Access (TDMA),
- Code Division Multiple Access (CDMA) and
- A combination of any of the above techniques.

1.3.4.1 Frequency Division Multiple Access (FDMA)

FDMA is a very common multiple access technique in which the total bandwidth is divided into non-overlapping equal-sized frequency segments (carriers) each of which may be assigned to a station for its exclusive use (see Figure 3). In order to prevent interference, guard bands are introduced between each frequency segment. The system capacity is limited by the number of frequency segments while the capacities of stations are limited by the bandwidth of the frequency band allocated to them and their carrier power – to – Noise power ratio (C/N).

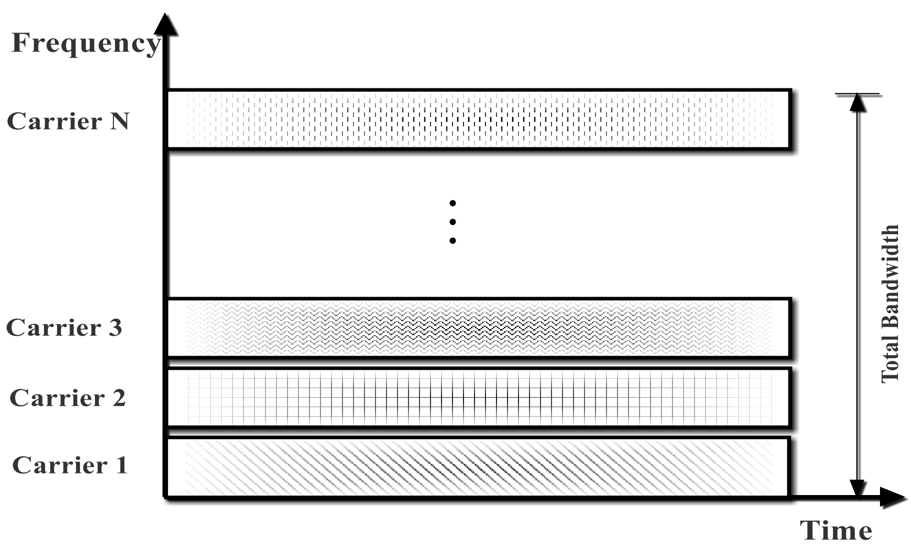

Figure 3: Frequency Division Multiple Access (FDMA)

1.3.4.2 Time Division Multiple Access (TDMA)

In TDMA, the total network bandwidth is shared by numerous stations by allocating time periods of short durations (timeslots) to each station. Within the period allocated, a station may transmit in bursts of signals using the entire transponder bandwidth. However, the allocation of timeslots is organized in a periodic fashion known as frame to ensure that the transponder receives only one burst within a timeslot. The structure of a TDMA technique is shown in Figure 4.

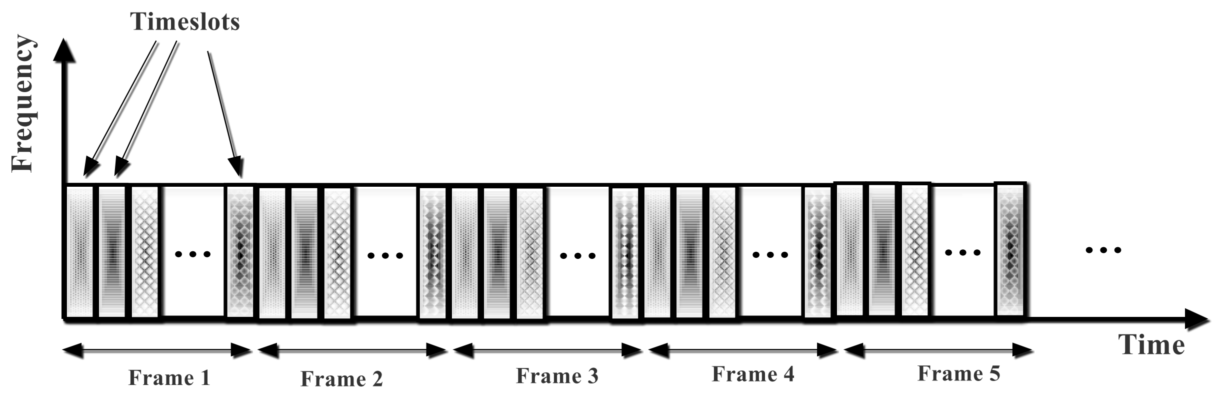

Figure 4: Time Division Multiple Access (TDMA)

1.3.4.3 Code Division Multiple Access (CDMA)

In CDMA, the signals to be transmitted are encoded in such a way that only a well synchronized station that knows the code used for transmission is able to detect and recover it. The basic idea in CDMA is the spreading of the transmitted signal over a band that is x times greater than the original one through an appropriate modulation based on pseudo-noise (PN) code. x is referred to as the processing gain and the higher its value, the wider the spreading bandwidth and the greater the system capacity. Two different CDMA techniques are considered in the following.

- ***Direct Sequence (DS) CDMA*****:** In DS-CDMA, the user's binary signal is multiplied by the PN code with bits that is x times smaller in length than the original bits. This modulation is well suited for modulation formats such as Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift keying (QPSK).
- ***Frequency Hopping (FH) CDMA*****:** In FH-CDMA, the frequency of the transmitted symbol is adjusted by using the PN code. If the frequency of the transmitted symbols changes for every symbol, it is referred to as fast hopping. On the other hand, it is referred to as slow hopping if the frequency changes after a certain number of symbols. This method is well suited for Frequency Shift Keying (FSK) modulation.

1.3.4.4 Combination of Multiple Access Techniques

Multiple access techniques can be combined to form a hybrid technique whose performance is better and overcomes the shortcomings of each of the combined techniques. For example, FDMA and TDMA can be combined to realize Multiple Frequency Time Division Multiple Access (MF-TDMA) technique that takes the benefits of both techniques [8]. In MF-TDMA, the transponder bandwidth is divided into a number of carriers and each carrier is further divided in time domain (see Figure 5). The spectrum is therefore dimensioned into frequency-time resources known as timeslots. Each station is allocated one or more timeslots depending on its bandwidth requirements. The MF-TDMA technique is well suited for transmission of multimedia traffic in satellite networks, hence it has been adopted as andard multiple access technique for the Digital Video Broadcasting Return Channel via Satellite (DVB-RCS) standard whose architecture is used in the proposed system of this work.

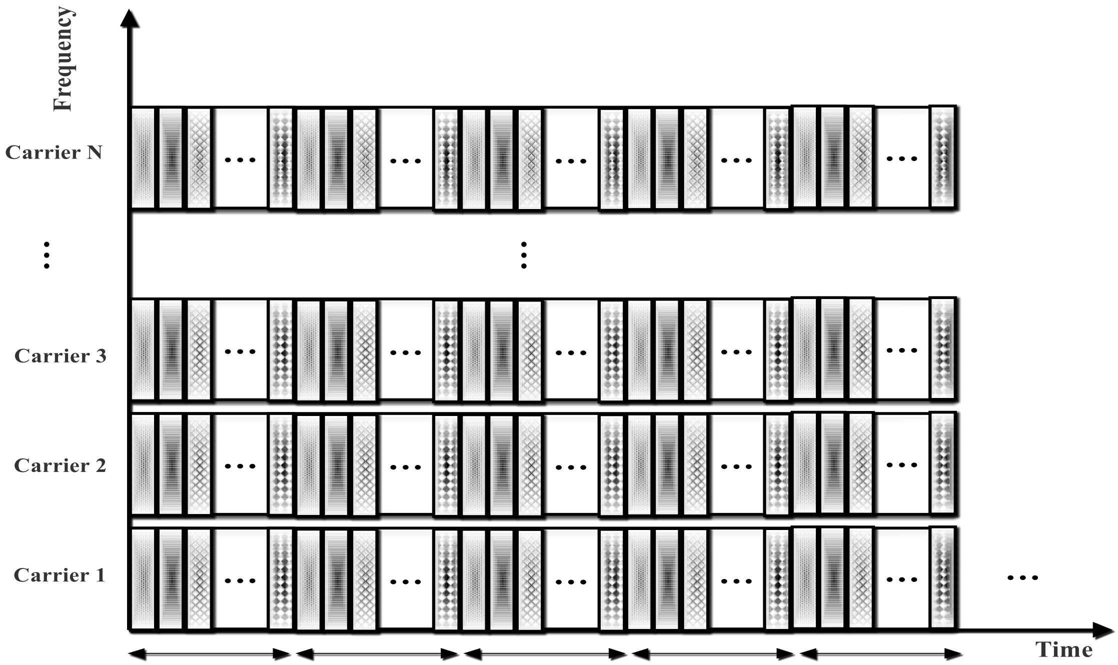

Figure 5: Multiple Frequency Time Division Multiple Access (MF-TDMA)

1.4 Challenges of Satellite Communication Networks

While the prospects for satellite communications remain very good, there are inherent challenges in the operation of the network. These are discussed in [3] [9] [10] and summarized below.

- ***Round Trip Propagation Delay*****:** The sum of delay along the propagation path in the uplink and downlink is referred to as the round trip propagation delay (RTPD). Its value for any satellite depends on the satellite's orbital position, i.e. its altitude from the surface of the earth. Satellites with higher altitudes have longer RTPD than those with low altitudes. Its value also increases with the elevation angle. RTPD is a major factor that must be considered since its value may affect the performance of real-time connections whose main quality of service (QoS) requirement is low delay.
- ***Atmospheric factors*****:** Atmospheric factors such as rain, gases, fogs, clouds and scintillation may affect the performance of satellite networks and should be considered in the design phase.

However, each of these factors will have varying effects on the system and their effects relates to the frequency in which the satellite is operated. When the operating frequency is greater than 10 GHz, rain attenuation is the most significant factor responsible for degradation in the quality of transmitted signals. This research addresses the effect of rain attenuation and mobility on the provision of QoS satisfaction for network connections.

- ***Finite Satellite lifetime*:** All satellites have an average lifespan in which they can reliably communicate with ground stations from their respective orbit. This is due to the fact that their various components age with time.
- ***Channel losses*:** The effects of the occurrence of the above-mentioned atmospheric effects is a rise in the bit error rate (BER) value, a parameter that indicates the amount of transmitted information that is lost due to these factors. By employing adaptive transmission techniques on the satellite and the ground stations, the BER may be prevented from dropping below an accepted rate.

In order to guarantee optimal performance of the satellite network, the factors discussed above must be given critical consideration when designing satellites and satellite networks. Rain is a critical factor causing attenuation and signal quality degradation in wireless communication systems operated beyond 8 GHz. While the attenuation is small between 8 and 10 GHz, its effect is significant is significant for systems operated beyond 10 GHz and thus should be mitigated [9]. Adaptive radio resource management (RRM) techniques are used to mitigate its effects, and are pursued in this work.

1.5 Radio Resource Management (RRM)

RRM is an important subject of research that focuses on addressing the challenges of satellite communication system. Also, the fact that satellite radio resources are finite and expensive necessitates that their management be done efficiently in order to maximize their utilization by traffic generated by connected users. In addition, the different applications and services requested by users are characterized by different QoS requirements which must be respected in order for users to enjoy their requested service. Based on these facts, we may summarize the challenges in satellite communications as those related to satisfying QoS requirements of different classes of traffic and maximizing the utilization of network resources. These are the goals sought to be achieved by RRM techniques.

RRM is an embodiment of techniques that are developed to ensure that bandwidth allocation and QoS are optimized for all connections accepted into the network [3]. It also ensures fairness in the allocation of network resources among the connections of the different traffic classes. A RRM technique includes protocols and algorithms that are designed to control system and users' QoS-related parameters such as power, data rate, modulation format, coding scheme, bandwidth allocation, etc. Common RRM techniques may be grouped in the following three classes [3]:

(i) ***Frequency/Time/Space Resource Allocation Schemes*****:** These refer to techniques for managing the air-interface of the satellite's transponder. They include bandwidth allocation, scheduling [11] adaptive coding [12], adaptive modulation and coding (AMC) [13] [14].

(ii) ***Power Allocation and Control (PAC) Schemes*****:** RRM techniques in this category use algorithms that adapt the transmit power according to some constraints. Such constraints may be related to the condition of the satellite uplink and/or downlink propagation channel [15] [16].

(iii) ***Call admission control (CAC)*****:** CAC algorithms are initiated whenever a connection request arrives at the network. Based on a set of predefined conditions and the current network load, the algorithm decides on whether an arriving connection should be accepted or rejected. CAC is an important RRM function because it ensures that the network's resources are efficiently utilized while the requirements of connections are satisfied. In this work, two policies that integrate link adaptation with CAC are developed. The first is based on Gaussian approximation for aggregating traffic from VBR sources while the second is developed based on Game theory concepts.

1.6 Link Adaptation in Satellite Networks

The need to increase system capacity in response to the rising number of connected users and surging demand for high-speed services has motivated the migration of satellite systems to higher frequency bands. However, signal transmissions at high frequencies (>10 GHz) are susceptible to being degraded as a result of time-varying atmospheric and environmental effects. Rain attenuation is the predominant source of degradation of signals transmitted at frequencies greater than 10 GHz. Provisioning QoS guarantees for network connections therefore require that appropriate fade mitigation techniques (FMT) be adopted. There are three categories of FMTs; these are power allocation and control (PAC), adaptive transmission and diversity techniques [9]. PAC techniques are employed to dynamically adjust carrier power at the ground station (uplink) or satellite (downlink) in response to variations in the condition of the satellite channel [16]. Diversity schemes mitigate signal fading by transmitting signals through multiple transmission channels (time, frequency or space) with different characteristics [17] [18]. Adaptive transmission techniques dynamically adapt transmission parameters such as modulation, coding rate and/or data rate in response to variations in fading condition of the channel. Common techniques in this category are adaptive coding (AC), adaptive rate control (ARC) and adaptive modulation and coding (AMC) [9]. In this research work, we consider AMC as the FMT technique to combat rain attenuation and mobility effects such as shadowing and multipath. Figure 6 indicates the operation of an AMC technique.

It is capable of increasing the link capacity (throughput) by employing spectrally efficient transmission parameters when transmitting signals over the time-varying satellite channel. Considering that the state of the channel is indicated by the received signal-to-noise ratio (SNR), an AMC scheme specifies a set of transmission modes for different ranges of SNR values. Each transmission mode is defined by a modulation format and coding rate pair (MODCOD) whose spectral efficiency guarantees that the bit error rate (BER) threshold will not be exceeded when the received SNR falls within its range. However, the transmit power is kept constant while the symbol rate is fixed to its maximum value [19]. The adaptation of transmission parameters to the varying channel condition causes the maximum achievable data rate to vary for each transmission mode. This is due to the difference in spectral efficiency of the transmission modes. System throughput is maximized by selecting the most spectrally efficient mode for transmission when the channel is in a very good condition (high SNR) and the least spectrally efficient mode adopted for transmission when the channel condition is worse. Thus, QoS satisfaction is guaranteed for all connection traffic through reliable transmission while the network resources are efficiently utilized.

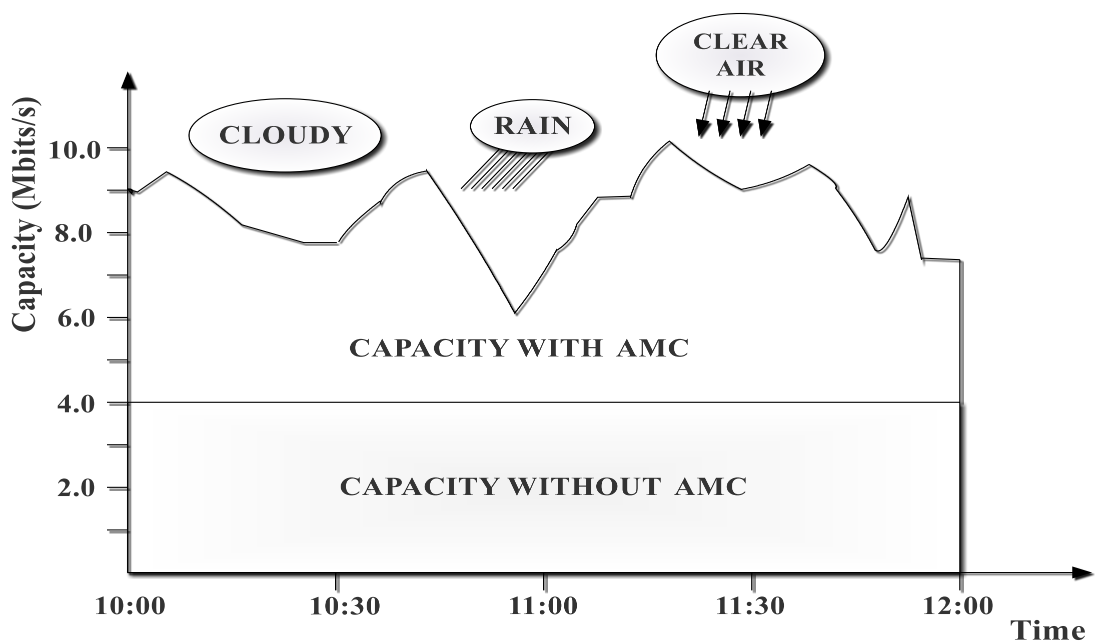

Figure 6: Adaptive modulation and coding (AMC) in satellite networks

1.7 Motivation for the research

Current trend indicates an increasing number of connected users in the wireless network. Most of these users are requesting access to multimedia services - voice, video and data. The different services requested by users have varied traffic profiles and requirements in terms of bandwidth and QoS satisfaction. These pose challenges to the users and the network. From the users' perspective, the satisfaction of specified QoS requirements of their connections must be guaranteed for the entire duration of connection. In other words, their connections must be supported with adequate bandwidth allocations at all times. On the other hand, due to the expensive and limited radio resources, the network requires maximum utilization of available resources at all times in order that the operators may maximize revenue. Therefore, the satisfaction of the QoS requirements of accepted connections and the efficient utilization of limited network resources are crucial issues that must be addressed [20].

Another issue of concern is the time-varying nature of the satellite propagation channel caused by atmospheric and environmental effects. We have also mentioned that rain attenuation is the predominant factor responsible for signal degradation in systems operated at frequencies greater than 10 GHz [9] [21]. Also, multipath and shadowing effects which occur due to the motion and environment of the satellite terminal also cause degradation in the quality of the transmitted signal [22]. In order to mitigate the effect of these factors, efficient FMT techniques should be adopted. An efficient FMT technique that mitigates the effects of these factors is the AMC technique which adapts the transmission parameters according to the condition of the satellite channel. This technique also improves the system capacity through the utilization of spectrally efficient transmission modes.

Based on the foregoing, it is convenient to state that the performance of the satellite networks may be assessed based on their ability to guarantee QoS for all connections, efficient utilization of allocated resources and protection of accepted connections from the degrading effects of atmospheric and environmental factors. We seek to achieve optimal performance of the satellite network through the combined operation of the CAC and AMC. Normally, CAC policies prevent network congestion by limiting the number of connections that accepted into the network. Such decision is based on the available network bandwidth and the bandwidth required by the new and existing connections. This basic approach is best suited for wire-line networks where bandwidth requirement is fixed for all connections. In satellite networks where the link is constantly evolving, utilizing adaptive techniques such as AMC introduces dynamic bandwidth requirements for connections when each of the different transmission modes is employed. A link adaptation based CAC is therefore preferred. Its decision is not only based on the bandwidth requirements of connections but also on the achievable bandwidth when any of the modes are selected for transmission. Therefore, the combined operation of CAC and AMC for the provision of QoS guarantees to network connections should be investigated. The CAC policy should guarantee adequate bandwidth allocation for all accepted connections while the AMC technique on its part, should monitor the dynamic satellite channel and adapt the transmission parameters based on the currently observed state. This thesis therefore focuses on development of link adaptation- based admission control schemes for providing QoS for traffic of the different classes of multimedia connections in satellite networks. It also investigates the performance of the system.

1.8 Contribution of the Thesis

The contributions of this thesis are highlighted as follows:

- Design of a link adaptation based CAC policy based on Normal distribution for the multiplexing of variable bit rate sources and AMC with three transmission modes. Methods for estimating required capacity for different classes of traffic are also developed for the policy.
- Design of a Game theory-based admission control policy for real-time and non-real-time connections in satellite networks. A channel prediction scheme based on Markov chain is also developed to predict the rain attenuation along the link at regular periods. The predicted attenuation determines the transmission mode employed for transmission in each of the periods within the duration of a call.

1.9 Organization of the Thesis

Chapter Two provides a general overview of interactive satellite multimedia networks for communication. Firstly, the model for the interactive satellite network is discussed before a presentation of the different Digital Video Broadcasting (DVB) standards for satellite networks are presented. Since the thesis is focused on the return channel, we discuss in detail the specifications of the air-interface of the Digital Video Broadcasting- Return channel via Satellite (DVB-RCS) standard, the de-facto standard for the return link of interactive satellite networks.

In Chapter Three, we present an introduction to satellite call admission control (CAC). We first discuss the admission control mechanism and then examine the various ways for the classification of existing CAC policies. Then we present a review of existing satellite admission control policies, highlighting their merits and demerits. We conclude with the need to introduce link adaptation with admission control in order to improve on the performance of the system.

In Chapter Four, we present the proposed admission control policy which we christen as Gaussian CAC based on link adaptation (GCAC-LA). Our method for estimating the resources required to support each class of connection in the different states of the propagation channel is first presented before introducing the GCAC-LA policy. The results of the proposed admission control policy are then presented and compared with those of the basic system without link adaptation before a conclusion is drawn from the results.

Chapter Five presents a game theoretic admission control policy for multimedia satellite networks. Starting with a background on game theory concepts, we move on to describe the channel state prediction system and the method for estimating required resources for user connections. Next, we present the game theory based admission control scheme and the method for degrading non-real time (NRT) connections should the available resources be insufficient to admit a real time (RT) connection. The results are then presented and a conclusion is drawn from them.

The thesis concludes in Chapter Six with a summary of the proposed policies and a recommendation for future work.

1.10 Publications

Parts of the work presented in this thesis have been submitted and accepted for publication. These include the following:

1. Olugbenga Imole, Tom Walingo and Fambirai Takawira; 'Call Admission Control for Multimedia Connections in Interactive Satellite Networks', IEEE AFRICON 2015 Proceedings, September 2015.
2. Olugbenga Imole and Tom Walingo; 'Efficient Connection Admission Control Policy for 5G-Satellite Networks' Paper submitted to Electronics and Telecommunications Research Institute (ETRI) Journal, (Under review).
3. Olugbenga Imole and Tom Walingo, 'Game Theory Based Call Admission Control for Multimedia Satellite Networks', Paper submitted to IEEE Vehicular Technology Conference (VTC) (Under review).

CHAPTER TWO
INTERACTIVE SATELLITE MULTIMEDIA NETWORKS

2.1 Introduction

The application of Geostationary Satellites for digital broadcasting of radio and television content is a huge success. As a result of this, satellite network operators sought for better ways of expanding the system to incorporate data for interactive applications. One requirement for interactive application was the creation of a return channel which must be established from every user terminal towards the operator's network. The interactive network would provide two-way satellite communication between users' terminals and operator's network. In order to support multimedia applications, high-speed return links would also be required. The digital video broadcasting – return channel via satellite (DVB-RCS) [23] was standardized to define specifications for a high-speed return link between users' terminals and the service provider's network. The standard provides definitions and specifications for the forward link which is based on digital video broadcasting - satellite (DVB-S) [24] and its second generation improvement, DVB-S2 [25] and Physical (PHY) and Media Access Control (MAC) layer specifications for the return link. The forward link is partitioned among all terminals using DVB-S or DVB-S2 standards and is based on Time Division Multiple Access (TDMA). The DVB-S2 supports adaptive modulation and coding (AMC), a feature that offers adaptive transmissions in order to overcome the variations in channel conditions. AMC can be activated in both forward and return links so that the effect of rain attenuation, a major attenuation factor in high-frequency transmission, is mitigated.

2.2 System Model of the Satellite Interactive Multimedia Network

The system model of the satellite interactive network which is used within DVB is shown in Figure 7. In this model, two channels are established between the service provider and the user, namely broadcast channel and interaction channel [23].

***Broadcast channel*:** This is a unidirectional broadband channel that is established from the service provider's network to the user stations. Usually, it is used to broadcast voice, video and data to the users. The forward channel may also include a forward interaction channel which we describe in the next section.

***Interaction channel*:** This is a bidirectional interaction channel that is setup between the service provider's station and the users' terminals for interactive communication. It is constituted by:

– ***Return interaction path***; a transmission path originating from the user towards the service provider's network; it is employed by the user to transmit requests to the service provider or other users in response to requests or to transfer data and

– ***Forward interaction path*:** a path established from the service provider to the user to provide information from service provider/user to the user(s) and any other required communication for provision of the interactive communication. This interaction path may be integrated with the broadcast channel or it may be omitted when the broadcast channel is used for transmitting data to the user.

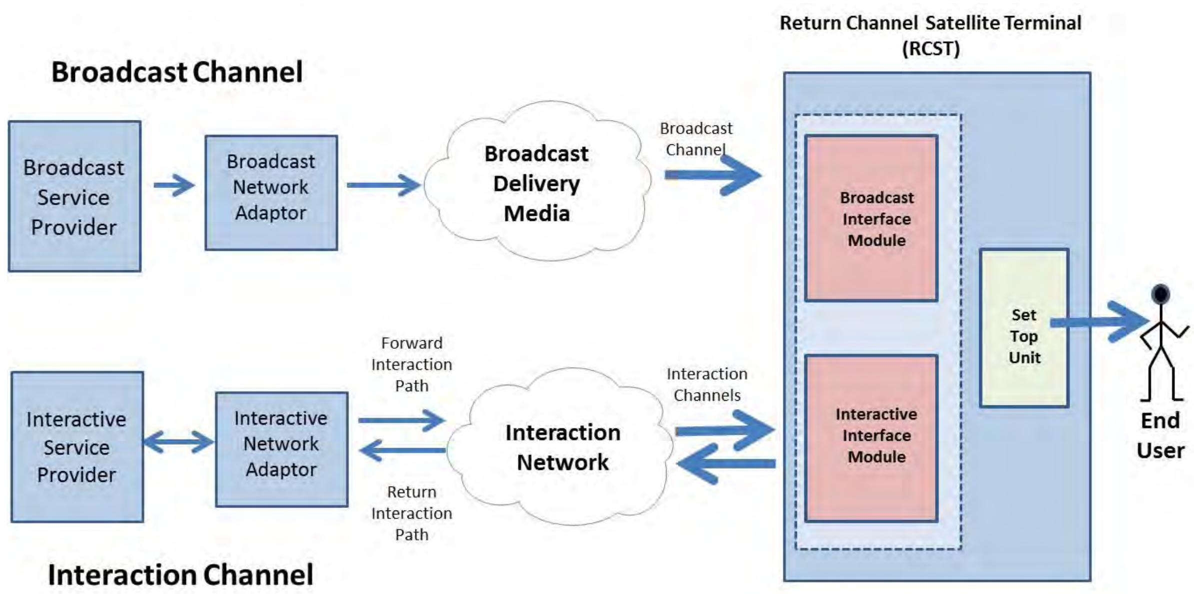

Figure 7: System Model of the Interactive Satellite Network

A return channel satellite terminal (RCST) is formed by the Network Interface Unit (which consists of Broadcast Interface and interactive Interface Modules) and the Set Top Unit. The RCST provides an interface for both Broadcast and Interaction Channels. An Interactive Interface Module links the RCST to the interaction network.

2.3 Reference Model of the Interactive Satellite Network

An interactive satellite network will provide two-way connectivity for a large number of RCSTs over the satellite network. The reference model of the interactive satellite network is shown in Figure 8 and is composed of the following components:

- **Network Control Centre (NCC):** The NCC provides Control and Monitoring Functions (CMF) for all components of the network. It generates control and timing signals which are transmitted by one or several Feeder Stations to all entities within the network.

- **Traffic Gateway:** A traffic gateway is responsible for providing interactive connectivity between the RCST and external networks (e.g. PSTN, ISDN or Internet) or service providers (e.g. Pay-per-view video services, online gaming, online banking/shopping, e.t.c.). In addition, it provides accounting records of interactions between the RCST and the external networks.
- **Feeder:** A Feeder transmits the forward link signal, which is a standard satellite digital video broadcast (DVB-S or DVB-S2) uplink, onto which are multiplexed the user data and/or the control and timing signals needed for the operation of the Satellite Interactive Network.
- **Return Channel Satellite Terminal (RCST):** An RCST allow users to access the satellite network so that they can communicate with other users within and outside the service provider's network. It consists of two main units, namely, an indoor unit (IDU) and an outdoor unit (ODU). The IDU incorporates a DVB-S/DVB-RCS modem as well as the interface that connects to the local network. The ODU on the other hand consists of an RF transmitter, an antenna and one or more radio frequency (RF) receivers.

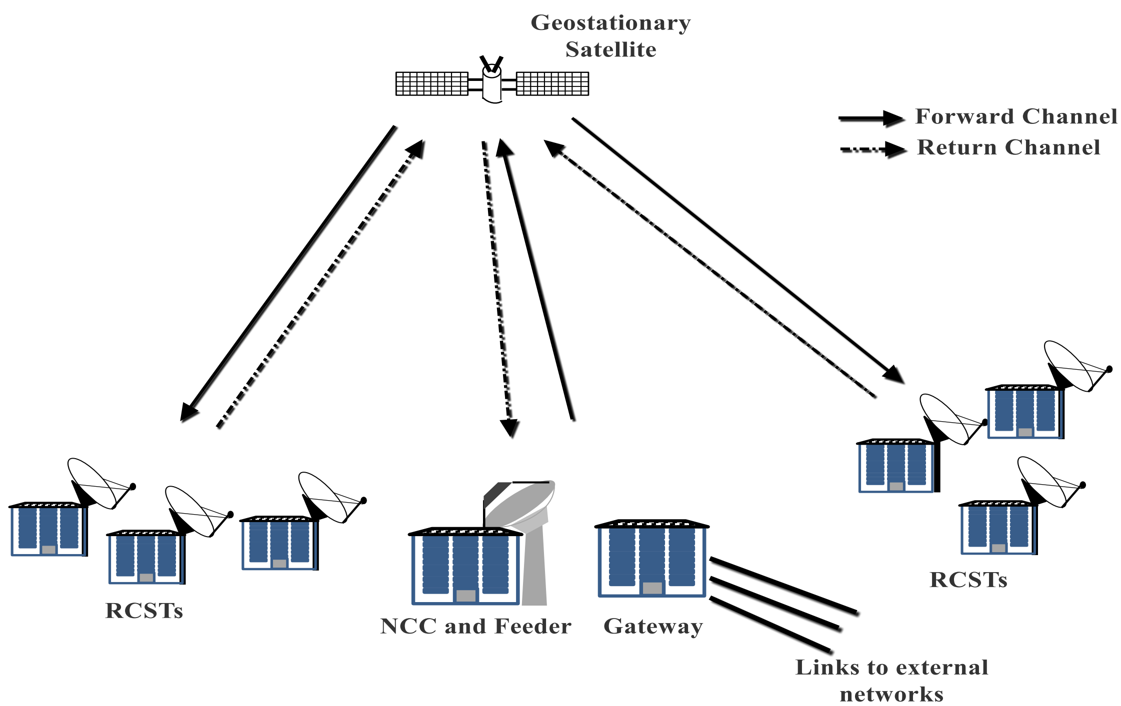

Figure 8: Reference Architecture of the Interactive Satellite Network

The forward link transmits signaling information from the NCC and user traffic to RCSTs. Both the user traffic and NCC-generated control signals needed for the operation of the satellite system can be carried over different forward link signals. The return link on the other hand transmits data and information requests from the RCST towards the NCC and traffic gateway. In the following section, we discuss the different standards for satellite communication.

2.4 Digital Video Broadcasting (DVB) Standards for Satellite Communication

DVB is a set of international open standards that provide specification for digital broadcasts using satellites, cable and terrestrial infrastructures. DVB standards are ratified and published by a Joint Technical Committee (JTC) of the European Telecommunications Standards Institute (ETSI). All specifications are put together by the DVB Project, an international industry consortium with over 220 members from more than 29 countries worldwide. A DVB standard document provides comprehensive details of the physical and data link layers of any system. It also specifies the procedure for interaction between these two layers in the system. Common DVB standards for satellite communication include

- Digital Video Broadcasting – Satellite (DVB-S)
- Digital Video Broadcasting – Satellite – Second Generation (DVB-S2)
- Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS)
- Satellite – Universal Mobile Telecommunications System (S-UMTS)

2.4.1 DVB-S

The DVB-S is the original standard for satellite television. Its air-interface specifications are published by the ETSI in [24]. The document contains specifications for physical link characteristics and framing and those of the transport layer. DVB-S transports data in a stream using motion picture expert group version 2 (MPEG-2) packet structure in its transport layer and is suitable for direct broadcast satellite in any of two transmission modes, namely, multiple channel per carrier (MCPC) and single channel per carrier (SCPC).

2.4.2 DVB-S2

The DVB-S2 standard was published by ETSI in [25] as an improvement on the DVB-S standard to accommodate broadcast services for standard television, high definition television (HDTV), interactive services such as internet and data content distribution. There are two key features of DVB-S2 that were not specified in the original DVB-S standard. These are

(i) A highly efficient coding scheme based on modern LDPC codes which are renowned for low complexity encoding and,

(ii) Variable coding and modulation (VCM) and adaptive modulation and coding (AMC) schemes which helps to achieve optimal spectrum utilization by dynamically adjusting transmission parameters according to variations in conditions on the satellite channel. This increases the achievable bit rate in the system by up to 30%.

Other features that were incorporated to the DVB-S2 standard include the use of enhanced modulation formats up to 32APSK, more code rates and the specification of a generic transport stream for IP packet data and MPEG-4 audio-video streams. Notwithstanding, the system is still compatible with the MPEG-2 based transport stream.

2.4.3 DVB-RCS/DVB-RCS2

The DVB-RCS standard is published as EN 301 790 in [23] and provides specification for interactive satellite multimedia (ISM) communication systems. It was created to address the need for an interactive (two-way) satellite network for multimedia communication which was non-existent at that time of its creation. Basically, the standard provides air-interface specification for a satellite return channel for interactive communication. DVB-RCS uses and modifies the specifications of the DVB-S or DVB-S2 standards; however, they operate on different frequencies and employ different multiple access techniques for channel access. A second generation version (DVB-RCS2) has recently been published in [26] [27] [28] with features that improve on its first generation version. Its main addition includes the introduction of random access for return link access, support for multiple security systems and application with widely varied requirements, and return channel adaptability which results in improved bandwidth efficiency of about 30%. This work focuses on the management of resources and provisioning of QoS guarantees for user connections in the return channel. Hence, further details of the DVB-RCS satellite network are presented in the next section.

2.4.4 S-UMTS

S-UMTS is the satellite component of the Universal Mobile Telecommunication System (UMTS). The system is designed to complement terrestrial UMTS (T-UMTS) systems and has the capability to connect with other IMT-2000 networks through the UMTS core network. In terms of functionality, S-UMTS network delivers third generation (3G) mobile services via satellite through highly integrated multi-mode user terminals to provide seamless multimedia communication. Details of the S-UMTS standard are published by the ETSI in [29] [30] [31] [32] [33] [34].

2.5 Digital Video Broadcasting – Return Channel System (DVB-RCS) Standard

DVB-RCS is a technical standard for satellite communication that is created by the ETSI. It is an open standard, which defines in details the air-interface specification for two-way interactive broadband satellite communication systems. The standard was published by the ETSI as EN 301 790 [23] with its first version released in 2001 and has been revised and broadened several times since then. The specifications of the DVB-RCS standard adopts and modifies that of ETSI's digital video broadcasting - satellite (DVB-S) [24] or its second generation version (DVB-S2) [25] but operate on a different frequency and multiple access technologies. The DVB-S or DVB-S2 is referred to as the forward channel which is the transmission link from the service provider's network to the receiver at the end-user's terminal. DVB-RCS refers to the return channel which is the transmission link from the transmitter at the end-user's terminal to the receiver at the service provider's network. The capacity of the return channel is usually small compared to that of the forward channel and varies from system to system. Furthermore, the bandwidth allocated to the return link is segmented and managed based on multiple frequency time division multiple access (MF-TDMA) technology, which divides the entire bandwidth into a number of carriers and each carrier is further divided in time domain. Therefore, the resources that will be allocated to RCSTs are bandwidth-time units otherwise known as timeslots and the number of which is allocated to any RCST is determined by the bit rate of the service requested. A typical architecture of the DVB-RCS satellite network conforms to the architecture of the system shown previously in Figure 8.

2.5.1 DVB-RCS Air-interface

As with any wireless network, radio frequency resources are limited and expensive, hence it is essential that the allocated bandwidth is efficiently utilized. DVB-RCS uses bandwidth on demand (BoD) schemes to achieve high efficiency in the utilization of network resources notwithstanding the variety of classes of traffic present in the network. BoD constitutes protocols and algorithms that allow an RCST to request capacity from the NCC whenever it intends to transmit generated traffic. The transmission on the return link is according to MF-TDMA technology, which organizes the resources into timeslots, frames and superframes [23]. It is possible to design the MF-TDMA air-interface such that the carriers have similar or different timeslot structure giving rise to fixed or dynamic timeslot structure. However, in the dynamic timeslot systems, carrier bandwidth, timeslot duration and consequently the number of timeslots per carrier are dynamic. Furthermore, transmission parameters such as data rate and code rate can also be adapted according to the requirements of the service and other conditions that affect the quality of transmitted signals. When a service is desired, an application sends a request to its RCST. On analyzing this request, the RCST estimates the capacity required for the connection to be set up and forwards a capacity request (CR) message to the NCC. The message contains, among other information, details on the type of service requested and its required capacity. On approval, the NCC forwards and allocates the requested capacity to the requesting RCST which in turn shares the allocated capacity among all connections initiated from it.

2.5.2 DVB-RCS Multiple Access

As previously indicated, the DVB-RCS air-interface is based on multiple frequency time division multiple access (MF-TDMA). MF-TDMA allows a group of RCSTs to share the allocated bandwidth and communicate with the gateway by dividing the bandwidth into a set of carrier frequencies and each carrier divided in time domain into timeslots. Capacity is allocated to each RCST by assigning to it a series of bursts defined by a frequency, bandwidth, start time and duration. The DVB-RCS standard recognizes two MF-TDMA types, namely fixed or dynamic slot MF-TDMA.

2.5.2.1 Fixed Slot MF-TDMA

In fixed timeslot MF-TDMA, the bandwidth and duration of all traffic slots used by RCSTs are fixed. The proposed system is based on a fixed timeslot system. However, with AMC, we may utilize the bandwidth better through efficient modulation and coding formats. By employing efficient MODCODs for transmission, the data required to be transmitted may be transmitted within fractions of the timeslots that should be allocated to it under a fixed (constant) modulation and coding system. System capacity is therefore increased since fewer number of timeslots will be allocated when highly efficient MODCODs are used.

2.5.2.2 Dynamic MF-TDMA

The Dynamic MF-TDMA is an optional specification of the DVB-RCS standard. Its implementation requires that RCSTs be more flexible and capable of varying the bandwidth and duration of consecutive timeslots allocated to it. Also, dynamic MF-TDMA also affords the RCST the opportunity to change transmission rate and coding rate between consecutive slots in order to adapt to time-varying conditions of the satellite propagation channel. Channel adaptation is achieved by designing the carriers of the MF-TDMA link with different bandwidths. Each set of carriers is then scheduled for transmission in the different channel states.

2.5.3 Segmentation of the Return Link

The DVB-RCS standard uses MF-TDMA to divide the allocated spectrum and allow multiple RCSTs to be connected at any time. MF-TDMA divides the bandwidth into timeslots hence the timeslots are the resources with which capacity is assigned to RCSTs. The timeslots are structured and numbered for easy reference to ease the process of allocating them to RCSTs. The structure and arrangement of the timeslots are described in the following sections.

2.5.3.1 Superframes

A superframe is simply a portion of time and frequency of the MF-TMA return link that is accessed by a given set of RCSTs. It comprises a set of carrier frequencies which the RCSTs may access to communicate over the return link. Each superframe has a unique identifier known as Superframe_ID that identifies the set of carriers which the RCSTs may access. Thus the overall system capacity is segmented amongst the set of Superframe_IDs which are managed independently by the network. Furthermore, each Superframe_ID is composed of superframes which are contiguous in time. The superframes are tagged with a number known as superframe_counter. In order to allocate resources to RCSTs, the NCC communicates to it the Superframe_ID and the timeslots within which it transmits bursts. This communication is sent through the Terminal Burst Time Plan (TBTP). The superframe structure is shown in Figure 9 below.

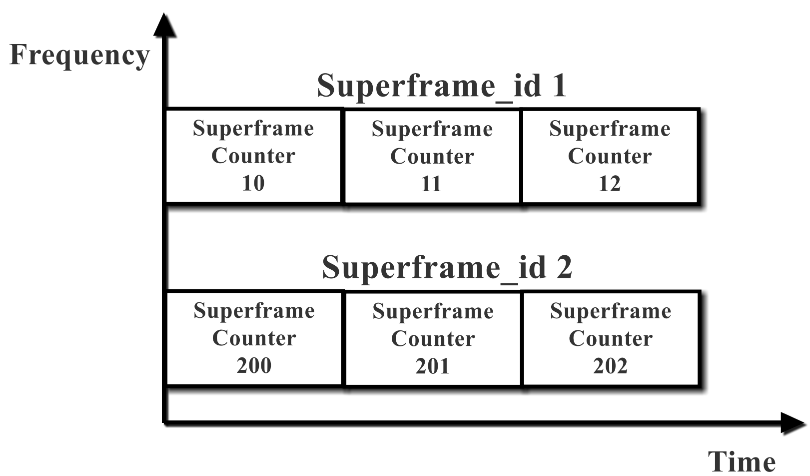

Figure 9: Structure of Superframes

2.5.3.2 Frames

The return link is composed of superframes which are composed of frames. The frames are introduced to achieve better signaling so they do not form the basis for the allocation of timeslots to RCSTs. The frames of a superframe are numbered from 0 to $N\ \{N \leq 31\}$ where N is the maximum number of frames in the superframe. Also, frames of a superframe may not all have the same bandwidth, and timeslot configurations. The frame structure is shown in Figure 10.

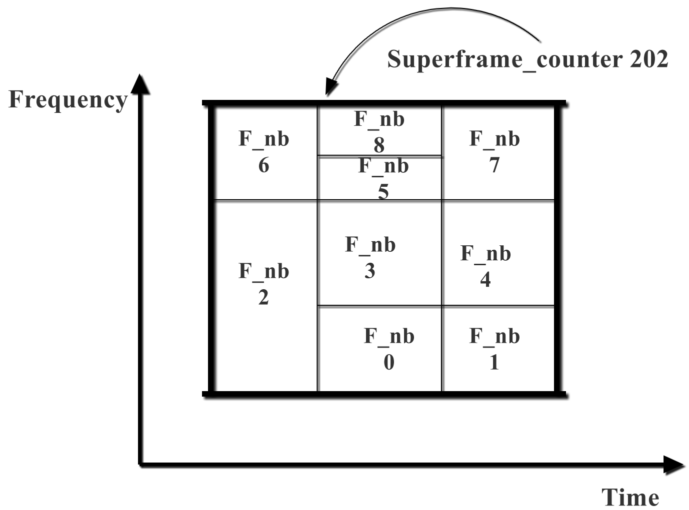

Figure 10: Frames of a Superframe

2.5.3.3 Timeslots

A frame in a superframe is composed of timeslots within which RCSTs transmit their bursts. Timeslots within a frame are tagged with numeric identifiers starting from 0 to a maximum value of M $\{M \leq 2047\}$. On the global return link, each timeslot is uniquely identified by a Superframe_ID, Superframe_counter, Frame_number and Timeslot_number. A typical timeslot composition of a frame is shown in Figure 11.

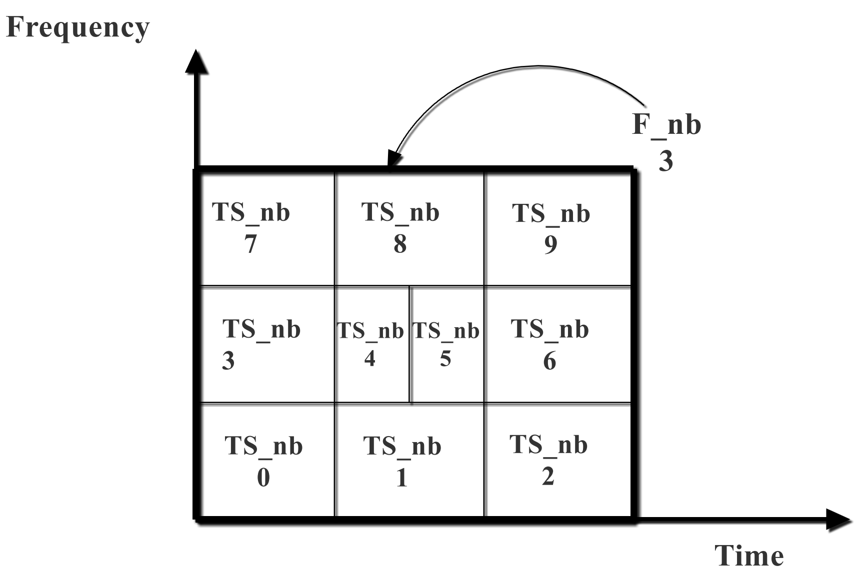

Figure 11: Timeslot composition within a frame

2.5.4 DVB-RCS Traffic Classes

The DVB-RCS anticipates four classes of traffic with different priorities that relates to their QoS requirements [3]. They are:

2.5.4.1 Real Time (RT) Traffic

This class refers to applications that have the most stringent QoS requirements. They usually require a fixed (static) bandwidth allocation to be guaranteed for the duration of their connections which makes it easy to manage them. Common applications in this category include voice and video.

2.5.4.2 Variable Bit Rate – Real Time (VBR-RT) Traffic

This class includes applications whose bitrate profile varies with time but are very sensitive to delay variations. Due to their varying bitrate profile, it is quite challenging to manage these types of services. Special approach must be employed to estimate the capacity required for these connections in order to avoid excessive or insufficient capacity allocation. Video conferencing, streaming audio and video are examples of applications in this class of traffic.

2.5.4.3 Variable Bit Rate –Non-Real Time (VBR-NRT) Traffic

This class of traffic is similar to the VBR-RT traffic class in terms of varying bitrates; however, they are insensitive to variations in delay. A typical example is the file transfer protocol (FTP) service.

These supported traffic classes highlighted above fit the description of all types of connections of voice, video and data which is an indication that DVB-RCS is capable of supporting multimedia traffic sources.

2.5.5 DVB-RCS Capacity Request Strategies

The DVB-RCS standard defines five strategies which RCSTs may use for requesting capacity for the different classes of traffic they support. These strategies are introduced for efficient allocation and utilization of the finite network resources. They are listed in the following.

- Continuous Rate Assignment (CRA)
- Rate Based Dynamic Capacity (RBDC)
- Volume Based Dynamic Capacity (VBDC)
- Absolute Volume Based Dynamic Capacity (AVBDC) and
- Free Capacity Assignment (FCA)

These capacity request strategies distinguish the different classes of network traffic and in recognition of this, the NCC prioritizes the allocation of capacity for each type of request. The priority takes the following order:

$$CRA > RBDC > VBDC/AVBDC > FCA \tag{2.1}$$

CRA has the strictest QoS requirements and is therefore prioritized over all other requests while while the least priority is assigned to FCA due to its non-stringent QoS requirements. In the following, the five capacity request strategies are discussed in detail.

2.5.5.1 Continuous Rate Assignment (CRA)

The CRA capacity allocation method is similar to the constant bit rate (CBR) allocation in ATM networks in which fixed capacity allocation is required to be assigned. CRA is a fixed rate capacity which shall be allocated in full every superframe for as long as the capacity is required. This capacity is granted after successful negotiations between the RCST and the NCC.

2.5.5.2 Rate Based Dynamic Capacity (RBDC)

The RBDC capacity request strategy is a rate capacity that shall be requested dynamically by the RCST and shall also be provided as a result of explicit capacity requests made by the RCST to the NCC. For an RCST requesting RBDC capacity, each new request submitted to the NCC shall override all previous requests but shall not exceed the maximum rate negotiated between the RCST and the NCC. Furthermore, it is possible to combine CRA and RBDC capacity requests in provision capacity for RCSTs. A typical scenario is where a minimum rate is to be guaranteed for the RCST and CRA is used to provision the minimum rate and RBDC used to request additional but dynamic capacity.

2.5.5.3 Volume Based Dynamic Capacity (VBDC)

Similar to RBDC capacity request strategy, VBDC is also used to request capacity dynamically from the NCC. However, VBDC is a volume capacity and shall be provided in response to explicit requests made by the RCST to the NCC with each request adding up to all previous ones made by the RCST. In order to prevent excessive capacity allocation, the cumulative total capacity is reduced by the number of VBDC capacity in the current superframe.

2.5.5.4 Absolute Volume Based Dynamic Capacity (AVBDC)

AVBDC is also a volume capacity that shall be requested dynamically by the RCST and is provided in response to explicit requests made by the RCST to the NCC with each new request overriding the previous ones from the RCST. An RCST may prefer an AVBDC capacity request strategy over VBDC in situations when it observes that there is the likelihood that the VBDC request might be lost.

2.5.5.5 Free Capacity Assignment (FCA)

The FCA is a volume capacity and is unique in that it does not require any request or signaling from the RCST to the NCC before it is provided. It can be referred to as bonus capacity, which is assigned from capacity that would have been unused. FCA may be used to reduce delay or jitters hence, it should not be mapped to any class of traffic.

It may be noted that both RBDC and VBDC share important characteristics; they differ in terms of the type of capacity requested. While RBDC requests capacity in the form of bitrate, VBDC on the other hand requests capacity in the form of packets. In addition, requests made by RBDC sources are absolute while those of VBDC are cumulative. But RBDC appears to be more complex to deal with than any other strategy. It requires an efficient method for the estimation of the bitrate requested by the RCST so that capacity may be accurately estimated. In the proposed system, we consider mainly the two classes that require QoS namely the CRA and RBDC. While CRA requires a constant bandwidth allocation for its QoS satisfaction, allocation of the variable bandwidth requirements of RBDC connections is required for the satisfaction of their QoS.

2.5.6 RCST Signaling Techniques

The RCST employs two signaling techniques in requesting capacity from the NCC. These are in-band signaling and out-of-band signaling [3].

2.5.6.1 In-band Signaling

With in-band signaling, RCST embeds capacity request messages in a Satellite Access Control (SAC) format and send them in SYNC bursts or normal MPEG2 data bursts using Data Unit Labeling Method (DULM) which is used to transmit management and control information to the NCC. The proposed system is assumed to employ in-band signaling technique for satellite access.

2.5.6.2 Out-of-Band Signaling

In out-of-band signaling, an RCST or a group of RCSTs are periodically assigned a set of minislots which may be used to transmit capacity requests in short bursts. The minislots are shorter than the traffic slots used for transmitting packets.

2.6 Conclusion

The chapter examines the fundamentals of interactive satellite communication and networking. There are different types of communication satellites. Their classification may be done based on the application, orbital position and the type of transponder in their payload. It has been explained that regenerative satellites are best for ensuring high reliability and efficiency in the transmission of signals over satellite networks. This is because they recover the original signal from the transmitted signal before they are retransmitted using transmission parameters that match the current condition of the satellite downlink channel. This feature of regenerative satellites fits our objectives, thus the system being proposed in this work is based on regenerative satellite architecture. In order to unify implementation and achieve inter-vendor operability, configurations of satellite networks are standardized by the ETSI. Common standards for satellite networking include DVB-S, DVB-S2, DVB-RCS, DVB-RCS2 and S-UMTS. These standards provide detailed specifications of the air-interface design, physical and data link layer as well as the procedure for implementing the transport layer. In our proposed system, the DVB-S2 standard is assumed to be implemented on the forward channel. This indicates that forward link transmissions employ AMC; the broadcasted signals on the forward link are therefore received with high reliability. The performance of the DVB-RCS return link is also enhanced by implementing AMC on the link. This increases the overall performance of the network.

CHAPTER THREE

CALL ADMISSION CONTROL IN SATELLITE NETWORKS

3.1 Introduction

Radio resource management (RRM) is an important aspect of satellite communication and networking. It plays an important role in the provision of quality of service (QoS) for the different classes of traffic generated by network connections. In fact, RRM in conjunction with proper network planning and design determines the QoS performance of both network and users. From the network's perspective, high utilization is desired as QoS while low blocking/dropping probability is required by network users. In the satellite network, RRM imposes controls on the allocation of network resources to connection requests in order to maximize network QoS metrics such as throughput, resource utilization and/or revenue. It also guarantees users' QoS requirements which may include call blocking probability, call dropping probability, packet losses or minimum signal to noise and interference ratio (SINR) [35]. Moreover, the task of provisioning QoS guarantees for connections in satellite networks is quite challenging. This is due to the limited network bandwidth (resources) and the time-varying nature of the satellite propagation channel. User mobility also introduces further challenges as a result of multipath and shadowing. In order to address these challenges, efficient RRM techniques must be implemented in the satellite network in order to guarantee QoS for any connection that will be accepted into the network. As noted in Chapter one, satellite RRM techniques may be aggregated into three classes [3]. The first class includes techniques for managing the allocation of frequency/time resources to network connections. The second class is constituted by power allocation and control (PAC) schemes and in the third class, we have call admission control (CAC) schemes. This chapter focuses on the basics of CAC in satellite communication networks. We present a review of different CAC design techniques and a classification of existing CAC policies after which a performance comparison of two popular CAC polices is done.

3.2 Definition of CAC

CAC is an important RRM function whose operation is crucial towards delivering QoS for different classes of connections in multimedia satellite networks. It comprises all the actions and processes that are invoked during connection setup to determine whether a new connection request should be accepted or rejected. The connection is accepted if the network's resources are sufficient to satisfy the QoS requirements of the new connection and those of already established ones. Otherwise, the connection is rejected [3]. In order to guarantee QoS for different classes of connections, CAC must be highly efficient in its decision by ensuring that connections that should be rejected are not accepted and those that should otherwise have been accepted are not rejected. Its efficiency depends largely on its ability to accurately estimate the amount of resources required to satisfy the QoS requirements of any connection. By accurately estimating connections' required capacity, their QoS is guaranteed and high utilization of resources can be achieved.

3.3 Reasons for CAC in Satellite Networks

There are many reasons that necessitate the implementation of CAC in satellite networks. Some important ones are discussed in the following subsections [35]:

3.3.1 Signal quality

In interference limited networks where increasing network load results in deteriorating signal quality, CAC may be implemented to guarantee signal quality for accepted user connections. Such CAC policy will accept users only if it can be guaranteed that their signal quality will not drop beyond a certain threshold. The condition for the acceptance of new connection may be the number of users, interference level or the level of power received by the satellite terminal.

3.3.2 Call blocking/dropping probability

Since bandwidth is a limited resource, call blocking and dropping may occur due to insufficient resources. To users, blocking of a new call is preferred to dropping of an ongoing call. Therefore, CAC can be used to control the call dropping rates by reserving resources for handoff. Such admission control policy may use as admission criteria the number of ongoing handoff and new calls, call dropping rate or the amount of available resources.

3.3.3 Packet level parameters

In packet-oriented networks, CAC can be used to prevent excessive packet loss, a common result of network overloading. In its decision, the CAC may use the number of users and/or available resources. It may also include packet level parameters such as average packet delay, delay jitter or throughput.

3.3.4 Transmission rate

CAC can also be used to guarantee transmission rate for data connections in satellite networks. The policy will ensure that the transmission rate for any data connection does not drop beyond a set minimum.

Other reasons for implementing CAC in the network that are non-QoS related include the following [35].

3.3.5 Revenue

Network operators are concerned about maximizing revenue for the various services they render. When a new call is accepted, revenue accrues to the operator. However, the acceptance of the new call may penalize ongoing connections through degraded QoS. CAC can be used to maximize the operator's revenue function considering the revenue and penalty for accepting a new call. Such CAC may use the number of users or an estimate of the probability that QoS will be degraded if the call is accepted as criteria for admission.

3.3.6 Service prioritization

In order to provide QoS satisfaction for connections in multiple-class networks, CAC is used. Each traffic class differs significantly in terms of bandwidth and QoS parameters hence their connections must be handled differently. This necessitates that the different traffic classes are prioritized to ensure that the connections with stringent QoS are served promptly. In such networks, CAC ensures that the different connections are served according to the priority assigned to them.

3.3.7 Fair allocation of resources

In multiple-class networks where priorities are assigned to different classes of connections, there is a tendency that connections with lower priority are penalized for those of higher priority. CAC can be implemented to introduce fairness in the allocation of resources among connections of the different traffic classes so that the system resources are not dominated by any particular class.

3.4 Mechanism for Call Admission Control

As stated previously, one of the reasons for implementing CAC is to ensure fairness in the allocation of resources among the different classes of service. For its decision, CAC considers that the various classes of service have different traffic profiles and QoS requirements. In fact, it considers specific QoS requirements (e.g. Bandwidth, delay, jitter and/or throughput) of each traffic class in estimating their required capacities before its decision to admit or reject their connection requests is made. For example, CAC must consider that low delay, jitter and packet loss rate (PLR) are QoS requirements that must be satisfied for a voice connection and should guarantee these requirements by allocating to it, a fixed capacity for its entire duration.

In order to access any of the services offered, the user initiates a call (request for connection) which is processed by the admission control module. This request is accompanied by information on the class of service, bandwidth and other QoS parameters relevant to the requested service. CAC then refers to the current air-interface configuration to obtain the current allocation of resources and determine if there is enough capacity available to accommodate the new call. Should there be adequate capacity, the call is accepted and the user allocated its required capacity based on the bandwidth requirement specified in the call request. Otherwise, the request is rejected. A block diagram of an admission control process is shown in Fig. 12.

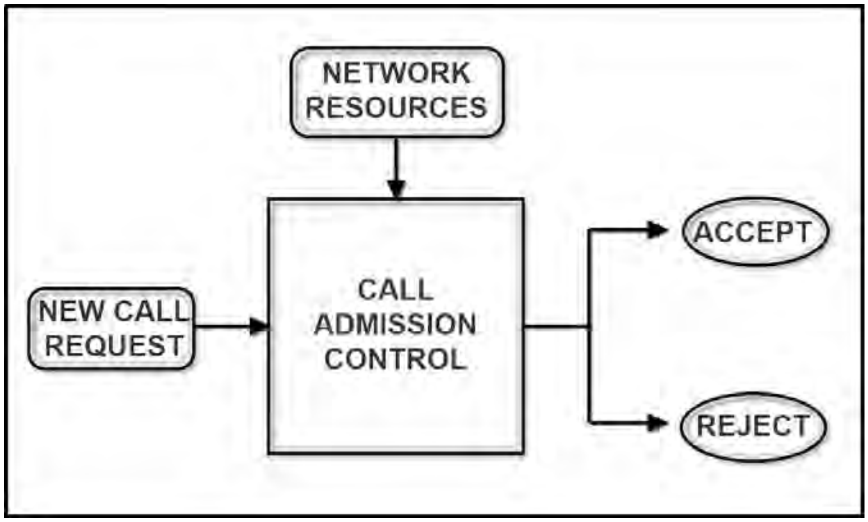

Figure 12: Call Admission Control

3.5 Classification of Call Admission Control Policies

The issue of admission control is a challenging one in wireless networks. Unlike in wired networks, admission control in wireless networks must consider sources' bandwidth requirements, network capacity and the impact of the time-varying atmosphere in its decision. The literature is replete with CAC schemes that are proposed for multimedia connections in satellite networks [21, 36, 37, 20, 38, 39]. The existing CAC schemes may be generally classified according to the following design choice based on the resource allocation policy employed by the policy, centralization of the decision-making entity, the number of traffic classes,the amount of information available to the admission control module, optimization strategy and the type of link [35] [3].

3.5.1 Resource Allocation

The most basic form of classification for CAC schemes is based on the method employed in the admission control scheme to allocate resources for connections. There are four different CAC approaches under this classification which are complete sharing (CS), complete partitioning (CP), trunk reservation (TR) and guaranteed minimum (GM) [3]. The first and simplest form of CAC based on resource allocation is the complete sharing (CS) policy. In a CS policy, a new connection is accepted only if there are sufficient resources available at the time such request is made. In other words, its decision to admit/reject a connection request is constrained by the overall capacity of the network. The advantage of this scheme is its simplicity; it does not consider the priority of any class of connection in its decision to accept or reject it. Its main limitation is that connections with smaller capacity requirements tend to be favoured for admission over ones with larger capacity requests.

The second approach to CAC classification based on resource allocation is the complete partitioning (CP) policy in which the overall system resources are partitioned into n sections where n is the number of traffic class in the system. The connections of each class can only be accepted if they can access resources allocated to the class to which they belong. In another approach known as Trunk Reservation (TR) [40], any connection belonging to class i will only be accepted if the available capacity is greater than r_i where r_i is the threshold for class i connections. In guaranteed minimum (GM) policy [41], each traffic class is allocated a portion of the overall system capacity while a shared portion of the overall resources is reserved. A connection may attempt to use resources from the shared portion only if the capacity allocated to its class has been completely utilized.

3.5.2 Centralization

CAC policies can be classified based on the logical location of the entity that makes the admission control decision. The design option may be centralized or distributed. In centralized CAC design, the decision to admit a connection is made by one entity such as the network control center in satellite networks (e.g. [16]) while in distributed systems, a decision is reached by involving all stations/nodes in the network (e.g. [42] [43]). Centralized CAC schemes are more efficient because they have a global perspective of the network, especially information on the current allocation of resources but they could be very complex to design.

3.5.3 Traffic Classes

CAC schemes may be further classified based on the number of traffic classes into single and multiple-class schemes. As the name implies, single-class CAC schemes are developed for systems where a single class of service is offered. They are common with first and second generation wireless networks where voice is the only service. However, contemporary networks are characterized by traffic of different types of multimedia services where voice, video and data services are simultaneously offered. To support these services and provide QoS guarantees for their connections, multiple-class CAC policies are developed e.g. [44] [45]

3.5.4 Information Scale

Based on the amount of information available to the admission control module, CAC schemes may be classified as global, semi-local or local.

- ***Global CAC Scheme*:** A CAC scheme is considered as global if the admission controller makes its decision based on information on the entire network. While the use of global network information helps to make good admission control decision, the implementation of the global CAC is complex [35]. An example of a global CAC is proposed in [37] [46].

- ***Semi-local Scheme*****:** In semi-local schemes, the admission control module uses information on the section from which a call originates as well as other sections close to the source of the call. (e.g. [42]).
- ***Local Scheme*****:** The admission controller in local CAC schemes only has information on the section of the network from which a call originates. It is the easiest to implement, however, it has the least efficiency [35].

3.5.5 Optimization

Optimization CAC policies are classified into optimal or near-optimal schemes.

- ***Optimal CAC Schemes***: Optimal CAC schemes define the admission control issue as an optimization problem. In [47], the authors developed a dynamic programming formulation to optimize satellite energy allocation. It is considered in this work that satellites often receive too many requests than they may be able to serve due to limited power onboard the satellite. The objective is therefore to optimize the service of connection requests such that the expected reward for such connection is maximized. Admission control is also addressed as an optimization problem in [48] to ensure fairness in the allocation of resources to connections of the different traffic classes. The utility function of users is used to indicate the fairness meted out to them by the network.
- ***Near-optimal*****:** These types of CAC schemes are also referred to as intelligent CAC schemes. They are developed because optimal CAC policies are very complicated to design and may not necessarily be attainable in reality. They employ heuristics and intelligent techniques such as genetic algorithm, fuzzy logic and neural network [36] [35].

Optimization based schemes are very complex in their implementation and thus are not popular with satellite networks. This complexity introduces further latency in addition to the round trip propagation delay that is inherent with satellite networks.

3.5.6 Link Type

Satellite CAC schemes can be classified according to the link for which they are designed as uplink or downlink schemes.

- ***Downlink schemes*****:** CAC for downlink are used to control and ensure QoS satisfaction as connection traffic are transmitted over the downlink (forward) channel. In interactive satellite networks, the downlink is broadcast-based. An admission control procedure for the satellite downlink channel is proposed in [49].

- ***Uplink schemes:*** Uplink CAC schemes designed to manage capacity and provide QoS for connection in the uplink (return) channel. In [50], an adaptive CAC policy is proposed to aggregate terrestrial flows into DVB flows for forwarding over the uplink satellite channel. Uplink CAC policies are designed in this research.

It is important to note that the capacity of the uplink and downlink are usually not symmetrical. In fact, the capacity of the downlink is usually very large compared to that of the uplink hence admission control is very important on the uplink channel. This avoids oversubscription and congestion of the link. Joint uplink and downlink admission control schemes are proposed to admit connections only when adequate bandwidth is guaranteed for connections in both uplink and downlink [36] [49] [37] [46]. However, these schemes are usually very complex in design due to the asymmetric capacities of both uplink and downlink. This thesis is focused on developing admission control for the return channel in a DVB-S2/DVB-RCS2 network. The problem is approached by assuming that every connection that is set up in the uplink will have enough capacity in the downlink.

3.6 Admission Control in Multimedia Satellite Networks

We have highlighted the need for CAC in maximizing the utilization of resources and provisioning QoS satisfaction to multimedia connections in satellite networks. Several CAC policies have been proposed in the literature and we present a review of some of the relvant existing policies. The CAC considered have been proposed for geostationary satellite networks. In [51], a joint resource allocation and CAC scheme is proposed for the return link of a satellite network that uses a geostationary satellite with onboard processing capability. The scheme is intended to provide minimum bandwidth guarantees for constant bitrate (CBR) and bursty data traffic. In order to achieve this and effectively manage the allocation of resources among the traffic classes, the frame of the TDMA return link is partitioned into three segments – the first is for CBR connections, the second for bursty data and the third part reserved as a common use by the traffic classes. The boundaries of each segment of the frame are made adjustable so that the amount of resources accessed by any class of connection can be varied. Thus the scheme is termed dynamic moveable boundary scheme (DMBS).

3.7 Gaussian CAC

The Gaussian CAC is based on statistical methods that are based on the Central Limit Theorem. The concept has been applied in aggregating connections of variable bitrate sources in terrestrial wireless and satellite networks [39] [52]. Consider a VBR source characterized by its mean bitrate, bitrate variance and peak data rate (PDR). An important characteristics of VBR sources is the long gap between their mean bitrates and PDR which makes the allocation of a capacity equal to their PDR inefficient (see

Figure 13). In order to efficiently utilize the bandwidth and satisfy their QoS requirements to a satisfactory degree, statistical multiplexing is done. Statistical multiplexing aggregates the bitrate generation process of multiplexed connections into a single stream so that a capacity equal to the aggregate bandwidth of the multiplexed sources is allocated. Thus, given N multiplexed VBR sources each of which has a mean M and standard deviation S, the aggregate mean M_{aggr} and standard deviation S_{aggr} is obtained as

$$M_{aggr} = \sum_{n=1}^{N} M_i \tag{3.1}$$

and

$$S_{aggr} = \sum_{n=1}^{N} S_i \tag{3.2}$$

where M_i and S_i are the mean bitrate and standard deviation of bitrate of the ith VBR source in the multiplex.

The aggregate bandwidth of the N multiplexed connection is then derived as follows

$$B_{aggr} = M_{aggr} + \alpha\, S_{aggr} \tag{3.3}$$

where α is a parameter related to the required QoS of the connections. It is usually referred to as the bandwidth expansion factor [39] [52].

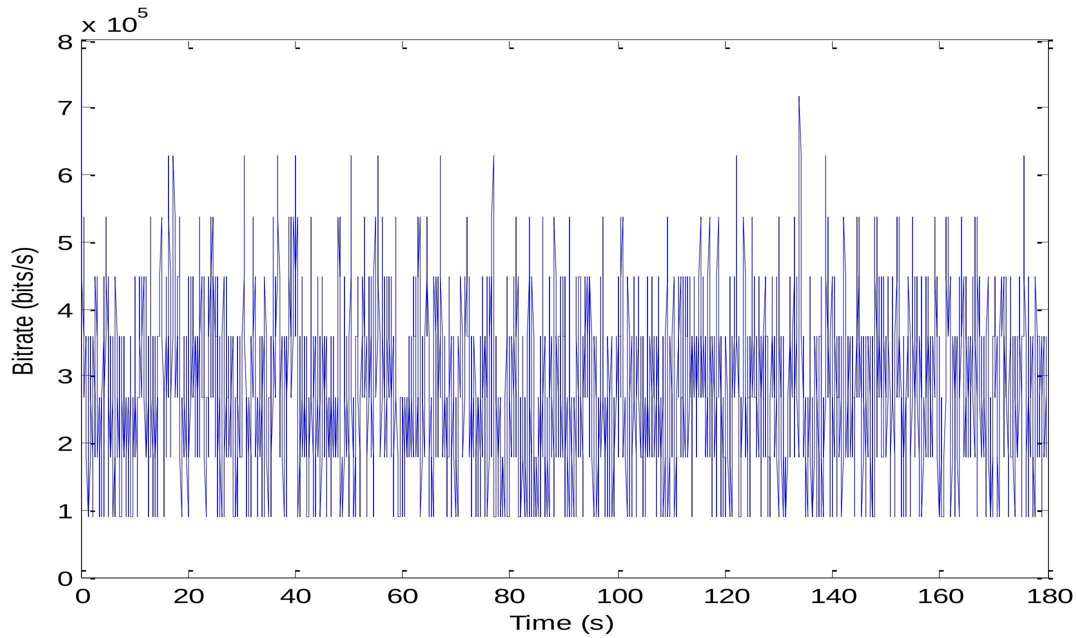

Figure 13: Bitrate Profile of a Typical Video Traffic Source

The efficiency of the Gaussian bandwidth aggregation technique can be best observed by comparing it with the PDR allocation policy. The PDR policy accepts VBR source and allocates resources to them based on the availability of resources that will satisfy their PDR capacity requirements. In order to compare both policies, we consider three classes of VBR connections whose bitrate parameters are as follows:

Source 1: $\{M$ = 96 Kbits/s, S = 32 Kbits/s, PDR = 202.667 Kbits/s$\}$

Source 2: $\{M$ = 320 Kbits/s, S = 64 Kbits/s, PDR = 448 Kbits/s$\}$

Source 3: $\{M$ = 544 Kbits/s, S = 32 Kbits/s, PDR = 576 Kbits/s$\}$

We developed a simulation software in C++ to estimate the aggregate bandwidth of multiplexed connections of VBR sources based on Gaussian and PDR policies. Under the Gaussian policy, the aggregate bandwidth is obtained using equations 3.1, 3.2 and 3.3 while aggregate bandwidth of sources under the PDR policy is obtained as a sum of PDRs of multiplexed sources. Figure 14 shows the aggregate bandwidth obtained based on the Gaussian approximation and PDR policies. From the graph, it can be observed that the aggregate bandwidth of multiplexed connections of the three VBR sources increases linearly as the number of connections in the multiplex. Also, one would notice that multiplexed connections of Source 1 and Source 2 require fewer bandwidth (or capacity) to be allocated to them than when PDR allocation is used. But the difference in the required capacity for Gaussian and PDR policies is higher for Source 1 multiplex than for Source 2 multiplex. An explanation for this is the higher PDR-to-

Mean bitrate ratio of Source 1 (2.1) compared to that of Source 2 (1.5). The high PDR-to-Mean ratio indicates high burstiness of the source which is a strong indication of the need to multiplex its connections in order achieve higher utility of resources. Unlike Sources 1 and 2, Source 3 requires higher bandwidth for its Gaussian multiplexed connections than with its PDR-based allocation. This is as a result of its low burstiness which is indicated by its PDR-to-Mean ratio of 1.06. Therefore, to utilize the bandwidth more efficiently, connections of sources like Source 3 are multiplexed with other VBR connections so that an aggregate bandwidth may be obtained for all the connections. This concept is also applied to the admission control policy proposed in chapter four of this work because better utilization is achieved through statistical multiplexing based on Gaussian approximation.

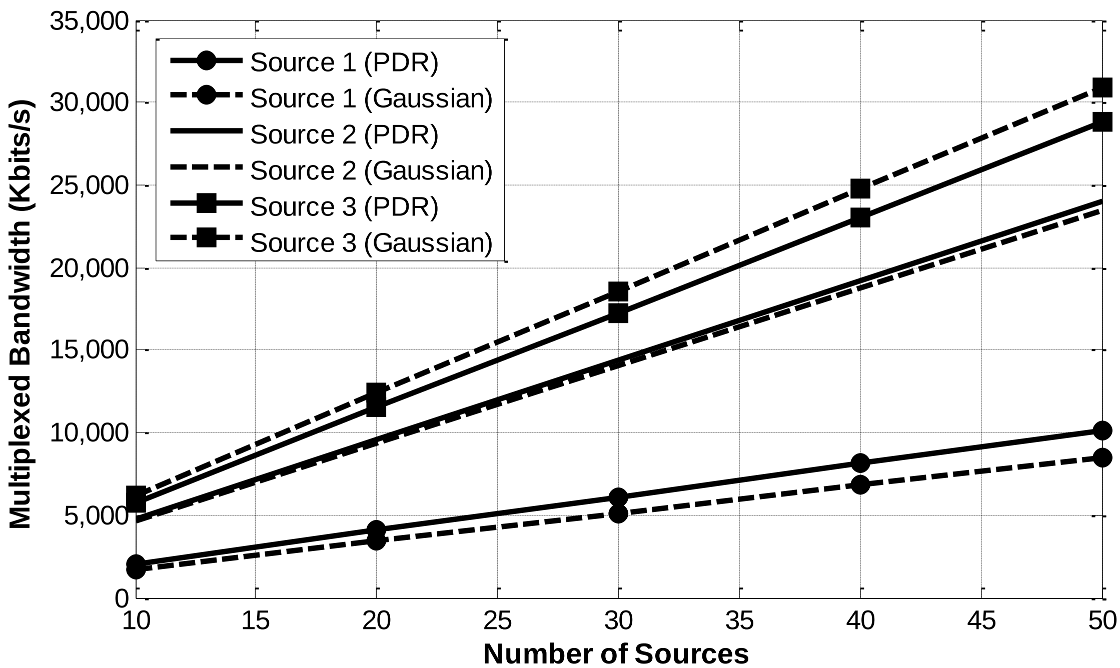

Figure 14: Gaussian Bandwidth and Peak Data Rate Allocation

3.8 Conclusion

CAC is an important RRM technique in interactive multimedia satellite networks. Its implementation may provide network connections some level of satisfaction of their QoS requirements. There are different types of CAC policies; they may be classified based on the resource allocation method, centralization of the decision making entity, traffic classes, information scale, optimization and the type of link. An important aspect of CAC's design which affects its efficiency is the accurate estimation of the capacity requirements of connection requests. This aspect is easy for constant bitrate sources which require static capacity assignment for their QoS satisfaction. However, it may be very challenging to accurately determine the capacity requirements of variable bitrate sources. An efficient solution is the adoption of Gaussian statistical multiplexing which allows for sources to be multiplexed into a single stream so that an aggregate capacity is allocated for the multiplexed stream. This technique prevents excessive or insufficient capacity allocation of resources to variable bitrate sources. However, some losses may be incurred but this must not exceed a specified threshold in order that QoS does not exceed beyond desirable levels.

CHAPTER FOUR

GAUSSIAN CALL ADMISSION CONTROL WITH LINK ADAPTATION

4.1 Introduction

As indicated in previous chapters, efficient RRM techniques are required to realize optimal performance of the satellite network. Call admission control (CAC) is an important RRM technique through which network performance may be optimized and QoS guaranteed for network connections. CAC seeks to achieve efficient utilization of limited network resources in addition to satisfying the different QoS requirements of the traffic generated by the different classes of services offered by the satellite network. Its control action on the acceptance of new connection requests further prevents the over-subscription of network resources thus preventing network congestion. However, like other wireless networks, the satellite propagation channel is liable to being affected by atmospheric effects of rain and other hydrometeors as well as environmental effects due to terminal mobility - multipath and shadowing [21] [22]. These factors influence the reliability of transmission as information/packet loss occurs due to outages caused by these factors. Furthermore, the nature of occurrence of these factors is time-varying thus, adaptive techniques such as adaptive power control, adaptive coding and adaptive modulation and coding (AMC) [53] are employed to mitigate their effects. AMC is well known for its efficient utilization of power because of its ability to adapt transmission parameters such as modulation format and coding rate to changing conditions of the satellite propagation channel. This capability ensures that information is transmitted with the highest possible spectral efficiency for all conditions of the propagation channel. From the foregoing, it is obvious, therefore, that a combined operation of CAC and AMC is important to realizing significantly improved performance of the satellite network. In this chapter, we propose a link adaptation-based call admission control policy. The performance of the satellite network in provisioning QoS satisfaction for different classes of users through efficient admission control and adaptive physical layer based on AMC is done. Since different spectral efficiencies will be employed for transmission, it is necessary to determine the resource requirements of connections for different transmission modes. Therefore, an approach for estimating the resources required to be allocated to connections as channel condition evolves is developed. The developed policy also considers the statistical multiplexing of user traffic based on Normal (Gaussian) distribution of their bitrate patterns in order to realize efficient allocation of resources.

4.2 Related Works

CAC has been studied as a tool for provisioning QoS satisfaction to multimedia connections in wireless networks. A detailed classification and survey of CAC strategies developed for wireless networks is presented in [54] and [35]. Most policies relate the different QoS requirements of network connections to the bandwidth that must be reserved in order that those requirements are met. In [55], a CAC policy that uses an excess demand probability (EDP) of multiplexed connections for its admission decision is proposed. A connection is accepted only if the EDP threshold for all traffic classes will not be exceeded when the new connection is multiplexed with on-going ones. In [39] and [52], connections are statistically multiplexed based on a Normal distribution and an aggregate bit rate is estimated to determine a bandwidth allocation for the multiplexed connections. The proposed CAC ensures that the EDP which is related to the cell loss ratio (CLR) is not exceeded. The authors in [56] propose a finite state Markov chain (FSMC) model in which states of the FSMC represent discrete bandwidth levels of the MPEG group of pictures (GoP) rates of variable bit rate (VBR) sources. With this approach, the aggregate bandwidth of all multiplexed connections is obtained as the aggregate state of the FMSCs. To satisfy QoS, the CAC ensures that the estimated aggregate state and bandwidth satisfy the packet loss rate requirement of the sources. While the CAC policies proposed in [55] [39] [52] [56] show plausible performance in terms of QoS satisfaction and utilization, it is important to note that their implementation is only idealistic. In reality, the QoS offered to connections may be affected by the dynamic condition of the propagation channel hence adaptive techniques must be employed.

In [38] [21] [42], the authors use adaptive forward error correction (FEC) in which the code rate is adapted to the rain attenuation experienced over the link. The idea is to allocate to each source an additional capacity over its required capacity to accommodate additional FEC information. The additional capacity is determined based on the coding rate required to overcome the current attenuation experienced during rain events. In [57], the authors also relying on forward error correction (FEC) propose the allocation of additional timeslots for transmission during rain events in order that established sources may maintain their required bandwidth. However, this approach results in under-utilization of network bandwidth when the additional capacity is overestimated. On the other hand, the QoS requirements of connections are violated when the additional resources are underestimated. In [16], adaptive closed-loop power control algorithm is proposed for guaranteeing QoS satisfaction for video traffic in a rain-faded satellite network. It is necessary to investigate the performance of satellite CAC policies when AMC is adopted for link adaptation over the return channel. A recent work in [58] proposes rain granularity and adaptive modulation and coding (AMC) for the return channel of the satellite network. The AMC scheme's operation is guided by the predicted rain attenuation value during transmission as well as the instantaneous values of rain attenuation measured along each link. While rain attenuation is a major concern when the satellite system is operated beyond 10GHz, signal deterioration also occurs as a result of environmental factors such as multipath and shadowing. We therefore deem it necessary to investigate the performance of the system when the variation in the condition of the propagation channel is the effect of these environmental factors.

The proposed CAC policy seeks to improve the utilization of the satellite resources while providing QoS satisfaction to connected users. The main contributions in this chapter are

- the introduction of a Markov model for the satellite channel and development of an AMC scheme to combat the effects of variation in channel conditions due to multipath and shadowing effects, and
- the development and investigation of an admission control policy for provisioning QoS guarantees for multimedia traffic connections in the return link in which AMC is employed.

4.3 System Model

This section presents a description of the system architecture, traffic classes, wireless channel model and the adaptive modulation and coding scheme.

4.3.1 System Architecture

The architecture of the network considered aligns with that of the Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) standard [23] typified in Figure 15. DVB-RCS is the de-facto standard for the return channel of an interactive satellite (IS) multimedia network. The network is comprised of a geostationary satellite with on-board processing capability operating in the Ka band, large number of user terminals known as return channel satellite terminals (RCSTs), a network control center (NCC) which is responsible for coordinating the interaction among components of the satellite network and the management of network resources. Our interest is in the return channel where the bandwidth is very small compared to that which is available on the forward channel. The bandwidth allocated for the return channel is segmented by multi-frequency time division multiple access (MF-TDMA) technique which divides the bandwidth into a number of carriers and each carrier is further divided in time domain. Therefore, resources are allocated as bandwidth-time units known as timeslots. In order to transmit, each RCST is allocated one or more contiguous timeslots within a carrier depending on the bandwidth required to satisfy its connections' QoS requirements. An adaptive physical layer based on AMC is adopted so that transmission parameters may be modified in consonance with variations in the quality of the signal received over the satellite channel. The AMC scheme will be described a subsequent subsection.

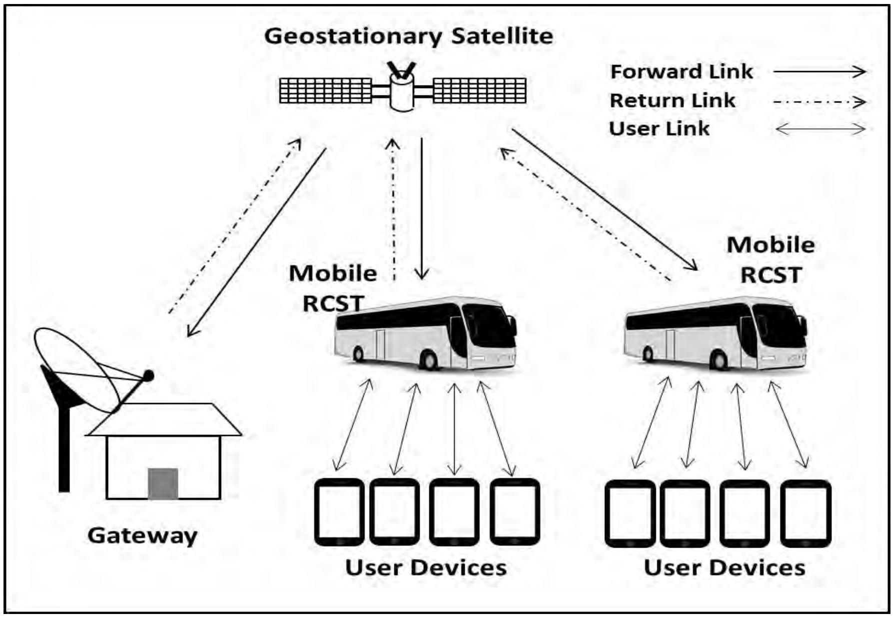

Figure 15: System Architecture

4.3.2 Traffic Classes

Network connections' traffic may generally be classified into real-time (RT) and non-real time (NRT) classes. The RT traffic class includes connections that have stringent QoS specifications which must not be preserved throughout their connection's lifetime. Such specifications include bitrate, delay and jitter. On the other hand, NRT traffic class refers to connections that do not have strict QoS specifications. They can tolerate large delays, jitters and low bit rates. The DVB-RCS standard defines five capacity request (CR) strategies which may also be used for classifying network traffic based on QoS requirements. These are Continuous Rate Allocation (CRA), Rate-Based Dynamic Capacity (RBDC), Volume-Based Dynamic Capacity (VBDC), Absolute Volume-Based Dynamic Capacity (AVBDC) and Free Capacity Assignment (FCA). CRA, RBDC, VBDC and AVBDC CR strategies define four different traffic classes with different requirements while FCA is used for allocating resources that have been previously allocated but not utilized. Both CRA and RBDC are of the RT traffic class and require efficient admission control policy in order to guarantee that their connections' QoS requirements will be satisfied. VBDC and AVBDC connections are best effort traffic (BE) types and do not require admission control for their connection. They are connected by utilizing unallocated (free) network resources. Our admission control considers QoS provisioning for the RT connections, i.e. CRA and RBDC connections. CRA connections are connections of constant bit rate (CBR) sources such as voice and high quality video communications while RBDC connections are generated by variable bit rate (VBR) sources. The behaviour of these traffic sources is implemented according to the traffic models in [10] [59].

4.3.3 Wireless Channel Model

The first order Markov process has been widely accepted for modeling the behaviour of the satellite propagation channel [22] [60] [61]. In this model, the channel is considered at any time to be in any one of M states and the probability of the channel being in a state only depends on the previous state. Generally, the state of the channel refers to any condition of the channel such as line-of-sight (LOS), non-line-of-sight (NLOS) and any conditions between LOS and NLOS. Based on these channel conditions, a three-state Markov model is considered for the return link. These states are:

State 1: Line of Sight (LOS), a state where the antenna of the RCST's antenna is in an unobstructed view of the satellite.

State 2: Non-Line-of-Sight (NLOS), a state where the RCST's antenna view of the satellite is partly obstructed. The received signal is majorly constituted by LOS components.

State 3: Deep shadowing (DS), a state where the received signal is majorly constituted by multipath and shadowing components. Usually, RCST's view of the satellite is obstructed by trees/ vegetation and/or buildings.

The transition between states of the Markov channel are determined by a transition probability matrix $\boldsymbol{P}$ while the overall probability of each of the states of the Markov model is expressed by a state probability matrix $\boldsymbol{W}$. $\boldsymbol{P}$ and $\boldsymbol{W}$ are defined in equations (4.1) and (4.2). The transition diagram of the three-state model is shown in Figure 16.

$$\boldsymbol{P} = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \tag{4.1}$$

$$\boldsymbol{W} = [W_1 \quad W_2 \quad W_3] \tag{4.2}$$

where P_{ij} $\{i = 1,2,3;\ j = 1,2\ 3\}$ denotes the probability of transition to state j given that the current state of the channel is i and $W_i\{i = 1,2,3\}$ denotes the steady state probability of the ith state of the Markov channel model. Parameters of our three-state model have been adopted from [22] where Markov chain model parameters are derived from comprehensive data obtained from experimental measurements in different environments and satellite elevation angles. The Markov chain models each state of the channel as different compositions of shadowing and multipath effects in the land mobile satellite (LMS) channel. The selected parameters are for Ka band frequency spectrum in urban, suburban and tree shadowed environment with an elevation angle of 45º and are given in Table 3.

Table 3: State and Transition Probability Matrices for the Markov Channel Model [22]

Environment	[W]	[P]		
Urban	P_1	P_{11}	P_{12}	P_{13}
	0.133	0.7081	0.0436	0.2483
	P_2	P_{21}	P_{22}	P_{23}
	0.1531	0.0509	0.9157	0.0334
	P_3	P_{31}	P_{32}	P_{33}
	0.7136	0.0436	0.0099	0.9465
Suburban	P_1	P_{11}	P_{12}	P_{13}
	0.8633	0.9412	0.0108	0.0480
	P_2	P_{21}	P_{22}	P_{23}
	0.0197	0.4736	0.2632	0.2632
	P_3	P_{31}	P_{32}	P_{33}
	0.1170	0.3540	0.0042	0.6018
Tree Area	P_1	P_{11}	P_{12}	P_{13}
	0.1055	0.6048	0.3684	0.0268
	P_2	P_{21}	P_{22}	P_{23}
	0.7741	0.0473	0.8630	0.0897
	P_3	P_{31}	P_{32}	P_{33}
	0.1204	0.0420	0.5579	0.4001

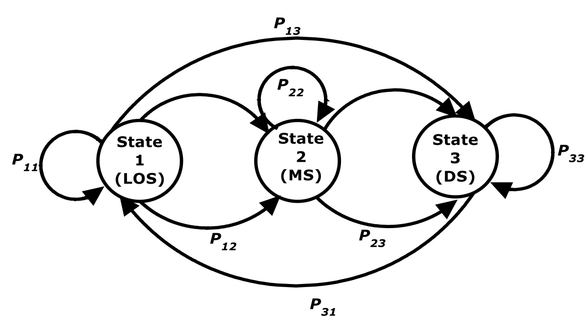

Figure 16: The 3-State Markov Model

4.3.4 Adaptive Modulation and Coding (AMC) Scheme for the Return Channel

The dynamic behaviour of the satellite propagation channel impacts negatively on the reliability of information transmission over the channel and violation of connections' QoS specifications during periods when the channel quality degrades. The degradation of the channel is the direct consequence of shadowing and multipath effects. We adopt adaptive modulation and coding (AMC) technique to mitigate the effect of this degradation. Our goal is to achieve reliable information transmission through the adaptation of modulation format and forward error correction (FEC) code rate (MODCOD) to variations in condition of the wireless channel.

Let δ_t denote the instantaneous signal-to-noise ratio (SNR) measured at the receiver at any time t and M the number of useable MODCODs, one of which an RCST employs for transmission at any given instant. Based on the number of channel states defined, the overall range of the received SNR is partitioned into M non-overlapping intervals with the upper boundary of each interval representing the SNR threshold for each state. Each useable MODCOD is then matched to a distinct channel state based on its spectral efficiency and the SNR threshold of the state. This matching is done by assigning the most spectrally efficient MODCOD to the state with the highest SNR while the least spectrally efficient MODCOD is assigned to be used in the state in which the SNR threshold is least. This form of adaptation affects the maximum bitrate that can be reached over the channel as a result of difference in spectral efficiency of each MODCOD. For each state m: $\{m = 1,2, \dots M\}$, the maximum bit rate R_m achievable is given by [19]

$$R_m = \begin{cases} 0; \quad if\ \delta_t < \delta_m \ : \ m = 1 \\ \eta_m R; \quad if\ \delta_m \le \delta_t < \delta_{m+1} \ : 1 \le m < M \\ \vdots \\ \eta_M R; \quad if\ \delta_t \ge \delta_m \ : m = M \end{cases} \tag{4.3}$$

where η_m is the spectral efficiency of the mth MODCOD, δ_m is the upper bound of the SNR threshold for mode m and R is the symbol rate which is fixed to ensure that the allocated bandwidth is not exceeded. In the present system, we consider a three-state Markov channel which requires three different AMC modes i.e. $M = 3$. The transmission parameters are presented in Table 4. They have been extrapolated from the MODCOD set derived for DVB-RCS in [53]. Each MODCOD in the set guarantees an upper bound for bit error rate (BER) not exceeding 10^{-5}.

Table 4: AMC Modes [53]

MODCOD			
Mode (m)	**Transmission Mode**	**Signal-to-Noise Ratio (SNR)**	**Spectral Efficiency (η_m)**
1	8PSK 2/3	9.6	3.00
2	8PSK ½	8.8	1.50
3	QPSK ½	5.5	1.00

4.4 Gaussian Call Admission Control with Link Adaptation (GCAC-LA)

We present our proposed admission control policy whose objectives are to maximize network bandwidth utilization and guarantee QoS satisfaction for connections despite the influence of the time-varying conditions of the channel. Considering that channel degradation is mitigated by AMC technique at link level, it considers the effect of such adaptation on QoS provisioning as well as resource utilization. We refer to this CAC policy as the Gaussian call admission control with link adaptation (GCAC-LA). The traffic considered are those of CRA and RBDC connections since only these two traffic classes require QoS guarantees. CRA connections require peak data rate (PDR) satisfaction as QoS requirement and RBDC connections require that a packet loss ratio (PLR) threshold should not be exceeded. In the following subsection, we discuss our approach for estimating the capacity requirements of both connection types before presenting the admission control policy.

4.4.1 Calculation of Required Capacity for CRA and RBDC Connections

An RCST is assigned capacity by allocating to it a number of timeslots that satisfies its requested bitrate. However, due to the channel adaptation, the number of timeslots required to satisfy the requested bitrate will vary as the AMC mode changes. Given a CRA connection whose PDR request is $\mathrm{BR_{CRA}}$Kbits/s, for every channel state m $\{m = 1,2, \dots M\}$, the number of timeslot $\mathrm{N_{CRA}}$ required to satisfy this bitrate request is obtained as

$$\mathrm{N_{CRA}} = \left\lceil \frac{\mathrm{BR_{CRA}}}{R_m} \right\rceil \tag{4.4}$$

The process for estimating capacity requirement for RBDC connections is different. Unlike CRA sources, an RBDC source is characterized by three bitrate parameters namely mean bitrate ($\bar{M}$), bitrate standard deviation ($\overline{SD}$) and peak data rate. A straightforward approach is to use the sources' PDR to estimate the required capacity but this would lead to bandwidth wastage resulting from high mean to peak bitrate ratio. Statistical multiplexing is employed so that an aggregate bandwidth may be obtained for all multiplexed RBDC connections. Given N active RBDC connections and assuming that N is large, then according to the Central Limit Theorem (CLT), we can obtain the aggregate bitrate for the multiplexed RBDC connections. If we assume that the bitrate process of each source is Normally distributed, then we can obtain an aggregate bitrate BR_{RBDC} which is also Normally distributed as

$$BR_{RBDC} = \bar{M}_{aggr} + \alpha.\overline{SD}_{aggr} \tag{4.5}$$

where α is a QoS parameter related to the maximum PLR that can be tolerated by each RBDC source; $\bar{M}_{aggr}$ and $\overline{SD}_{aggr}$ are the aggregate mean bitrate and bitrate standard deviation respectively. $\bar{M}_{aggr}$ and $\overline{SD}_{aggr}$ are estimated by

$$\bar{M}_{aggr} = \sum_{n=1}^{N} \bar{M}_n \tag{4.6}$$

$$\overline{SD}_{aggr} = \sum_{n=1}^{N} \overline{SD}_n \tag{4.7}$$

Where $\bar{M}_n$ is the mean bit rate of the nth RBDC source while $\overline{SD}_n$ denotes the standard deviation of the bit rate of the nth RBDC source. The number of timeslots N_{RBDC}^{k} that will be allocated to the kth RCST in order to support its N multiplexed RBDC connections in any state any channel state m $\{m = 1,2, \ldots M\}$ is given by

$$N_{RBDC}^{k} = \left\lceil \frac{BR_{RBDC}^{k}}{R_m} \right\rceil \tag{4.8}$$

Therefore, at any point in time, the total resource N_{RBDc} allocated for handling RBDC connections is

$$N_{RBDC} = \sum_{k=1}^{K} N_{RBDC}^{k} \tag{4.9}$$

where K is the number of RCSTs handling the RBDC connections.

4.4.2 GCAC-LA Algorithm

The admission control policy relies on information available on already allocated resources for its decision. Its operation is based on simple sums hence the decision on admission or rejection of connection requests will be quick. Given a generic connection request whose bandwidth request is B_R Kbits/s, the number of timeslots N_R required to satisfy its bandwidth requirement is first estimated as follows:

$$N_R = \left\lceil \frac{B_R}{R_m} \right\rceil; \quad m = 1 \tag{4.10}$$

We ensure that the bandwidth does not exceed available resources by estimating N_R based on the availability of resources required to support the new connection in the worst channel condition i.e. $m = 1$. If the total capacity of the network is N_T, the new connection request will be admitted only if

$$N_T - \sum_{k=1}^{K} N_{CRA} - N_{RBDC} \geq N_R \tag{4.11}$$

Otherwise it is rejected. The value of B_R for a new RBDC connection request is obtained by using equation (4.5).

4.4.3 GCAC

The GCAC [52] algorithm differs from the proposed GCAC-LA policy in that channel adaptation is lacking at the physical layer of the GCAC scheme. This is synonymous to admission control in systems that employ constant coding and modulation scheme. The major difference between both schemes is the frequency of estimating capacity allocation for connections. Whereas GCAC-LA re-estimates capacity allocation anytime a terminal experience a change in channel condition, GCAC estimates capacity for connection once at the admission control stage. Thus the operation of the GCAC-LA is adaptive while that of GCAC policy is fixed. The GCAC policy estimates the fixed number of timeslots required to support a generic connection request of B_R Kbits/s as follows:

$$N_R = \left\lceil \frac{B_R}{b} \right\rceil \tag{4.12}$$

where b is the fixed capacity of a timeslot (in Kbits/s). Still employing statistical multiplexing for RBDC connections, it estimates B_R for RBDC connections using equation (4.5).

4.5 Simulation and Results

The performance of the GCAC-LA has been investigated by simulation using an event-driven simulator which we developed in C#. Several simulation runs were performed to test the efficiency of the proposed scheme.

4.5.1 Performance Measures

The following performance metrics are investigated in the simulation:

- *Call blocking probability (CBP)*: This is the ratio of blocked calls to total generated calls for the period of the simulation;
- *Active Connections*: This is measured as the maximum number of connections of each traffic class that was simultaneously handled by the system throughout the simulation campaign.
- *Packet Loss Ratio (PLR)*: This is the ratio of the total number of packets generated to the total number of successfully transmitted packets. A packet is considered lost if it cannot be transmitted within the space of one frame duration.

4.5.2 Traffic Sources

A brief description of traffic models for voice and video sources implemented in investigating the performance of the GCAC-LA policy is presented in this subsection. The models are adopted from [10] [59] and are described in the following.

4.5.2.1 Voice Traffic Sources

The behaviour of a voice source may be described as a continuous alternation between two states, namely a talk-spurt (ON state) and a silent phase (OFF state) (see Figure 17). During the talk-spurt, the source generates traffic at a constant bitrate G while no traffic is generated in the silent phase. However, the duration of time spent in the talk-spurt and silent states follows an exponential distribution with mean $1/_{\Omega} = 1s$ and $1/_{\varsigma} = 1.35s$ respectively, where Ω and ς are the rate of transition from ON state to OFF state and the rate of transition from OFF to ON states respectively. The source activity factor A_V, which indicates the probability that the source will be in the ON state is derived as follows

$$prob\{ON\ State\} = \frac{1/_{\Omega}}{1/_{\Omega}+1/_{\varsigma}} = 0.425 \tag{4.13}$$

The burstiness β of the voice source which represents the maximum multiplexing gain achievable when several ON-OFF sources are multiplexed into a link of capacity *G* is given as the ratio of the peak bitrate and the average bitrate and is given by:

$$\beta = \frac{G}{A_V G} = \frac{1}{A_V} \tag{4.14}$$

For the voice source, the value of *G* is taken as 64 kbits/s which is the source's peak data rate. Traffic generated by the source in the talk-spurt are organized into MPEG packets and are sent within the timeslot allocated in the current frame. Each MPEG packet is made up of 1,504 bits (88 Bytes).

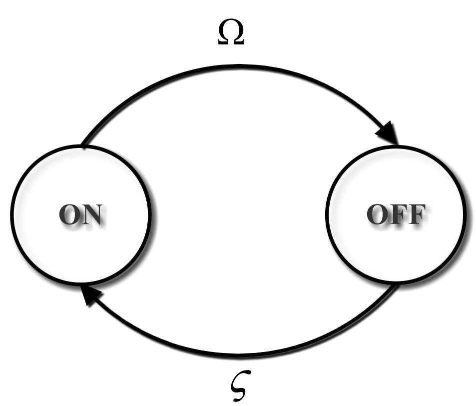

Figure 17: ON-OFF Voice Traffic Model

4.5.2.2 Video Traffic Sources

The video source described is one that is characterized by variable bit rate profile. Each source identified by its peak data rate (PDR), mean bit rate ($\overline{M}$)) and bitrate standard deviation ($\overline{SD}$). Traffic generated by the source is considered as the aggregated output of the bitrate generated by K independent mini-sources each of which continuously alternates between ON and OFF states. When in the ON state, a mini-source generates traffic at constant bitrate P Kbits/s but no traffic is generated when it is in the OFF state. Since the air-interface is based on MF-TDMA, the system evolves in timeslots T_s whose length is equal to an MPEG packet, the source's time is considered as multiples of T_s. The time spent by a mini-source in the ON and OFF state follows a geometric distribution with mean x and y respectively. The parameters x, y and P for a minisource is derived as follows:

$$P = \frac{\bar{M}}{K} + \frac{\overline{SD})^2}{\bar{M}} \text{ bits/s} \tag{4.15}$$

$$x = \frac{1}{aT_s}\left[1 + \frac{\overline{SD}^2}{K\bar{M}^2}\right] \tag{4.16}$$

$$y = \frac{1}{aT_s}\left[1 + \frac{K\bar{M}^2}{\overline{SD}^2}\right] \tag{4.17}$$

where a is the auto-covariance function of the bitrate generated by the video source; T_s is the time interval between successive bit rates generated by the source and is also equal to the duration of the timeslot. In order to prevent sudden variation in the generated bitrate, it is considered that only one mini-source makes a transition every T_s interval. At every timeslot, the bitrate of the video source is determined by the product kP where k is the number of mini-sources that are currently in the ON state.

In our implementation, T_s is set to $47ms$, and based on [10] [59], we take $a = 3.9s^{-1}$. We implemented three video sources which we christened as RBDC1, RBDC2 and RBDC3. The sources are differentiated by their mean bit rate, bitrate standard deviation and peak data rate which are given In Table 5. These parameters are used to implement the RBDC sources.

Table 5: RBDC Source Parameters

Video Source	**Mean ($\bar{M}$) Kits/s**	**Standard Deviation ($\overline{SD}$) Kbits/s**	**Peak Data Rate Kbits/s**
RBDC 1	96	32	202.667
RBDC 2	320	64	448
RBDC 3	544	32	562.824

In our simulation model, we segment the bandwidth in a MF-TDMA access format so that the capacity is evenly distributed among carriers of equal bandwidth. The capacity allocated for each carrier is then divided among its timeslots. In Table 6, important return link parameters that are considered in the simulation are presented.

Table 6: Simulation Parameters

Simulation Parameter	Values
Return Link Capacity	32 Mbits/s
Number of Carriers	16
Number of RCSTs	16
RCST Profile	Class D (2048
Slot rate	32,000 bits/s
Number of timeslots	1024
Average connection	600s (Exponential)
Packet Loss Ratio	1% (0.01)
Frame Length (Return	0.047 s
Normalized Load	0.5 – 4.0

We also implemented source traffic models to generate traffic for connections of CRA and RBDC sources. The bits generated by both sources are packetized according to the MPEG2-TS packet format with a payload of 88 Bytes per packet. We consider that each timeslot will transmit one packet per frame in the worst channel state. Higher spectral efficiency, reduces the transmission time so that more packets are transmitted per timeslot duration.

The CBP performance for RBDC connections under the GCAC and GCAC-LA algorithms are presented in Figure 18 as a function of normalized load. The GCAC policy of [52] is compared with the GCAC-LA policy. The results for the GCAC-LA policy in Figure 18 were obtained using the channel model for an urban environment. From the results, RBDC1 experienced the least CBP followed by RBDC2 and then RBDC3. Furthermore, the result also shows that all traffic classes experience lower CBP under the GCAC-LA policy compared to the GCAC policy. This can be explained as the result of adaptive allocation of resources to connections under the GCAC-LA policy. More connections are handled when channel state is good since fewer resources are required to support them in good channel states.

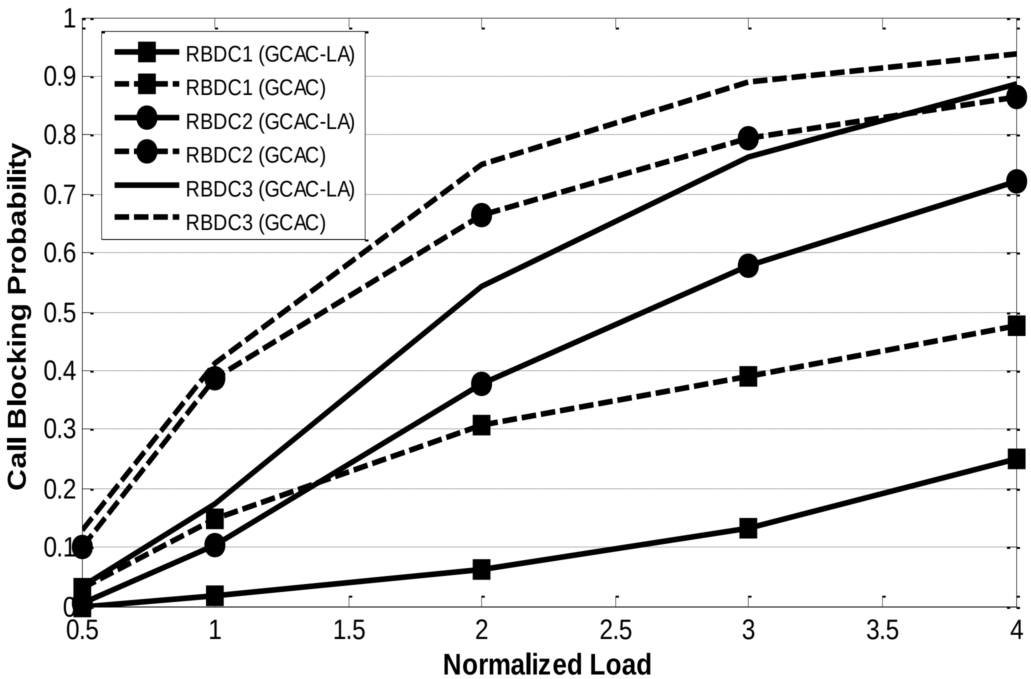

Figure 18: CBP for RBDC Connections (Urban)

The CBP performance for the GCAC-LA policy is also investigated for suburban and tree shadowed areas. This is in order to further validate the performance of the proposed scheme. Figures 19 shows the CBP performance of the three RBDC connections in a suburban environment. Like in an urban environment, the CBP for RBDC1 is the lowest, followed by RBDC 2 and then RBDC 3 connections.

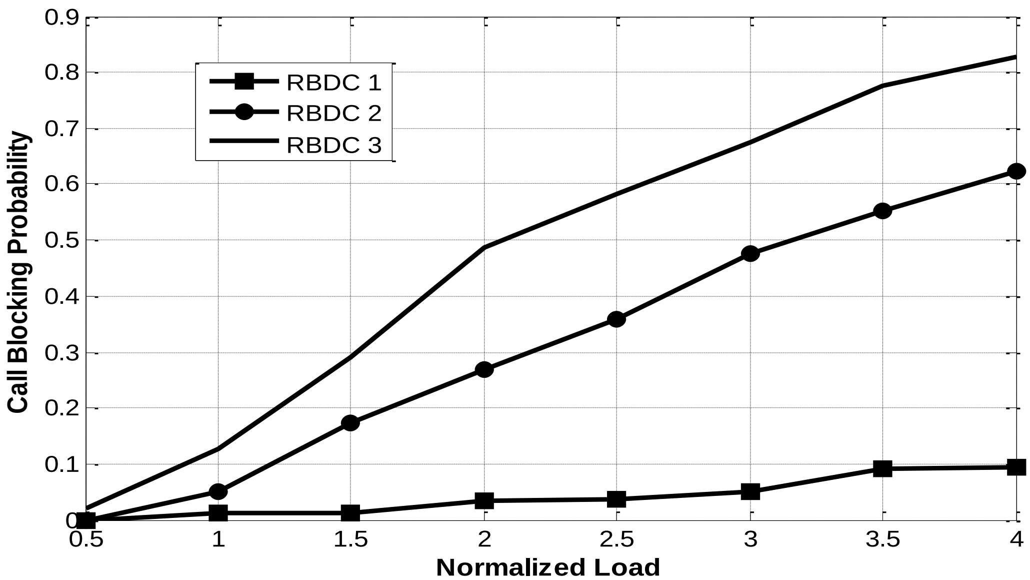

Figure 19: CBP for RBDC connections in suburban environment

Figure 20 shows the CBP performance for RBDC connections in a tree shadowed environment. It is also noticed that the RBDC1 connections have the lowest CBP, followed by RBDC2 then RBDC3.

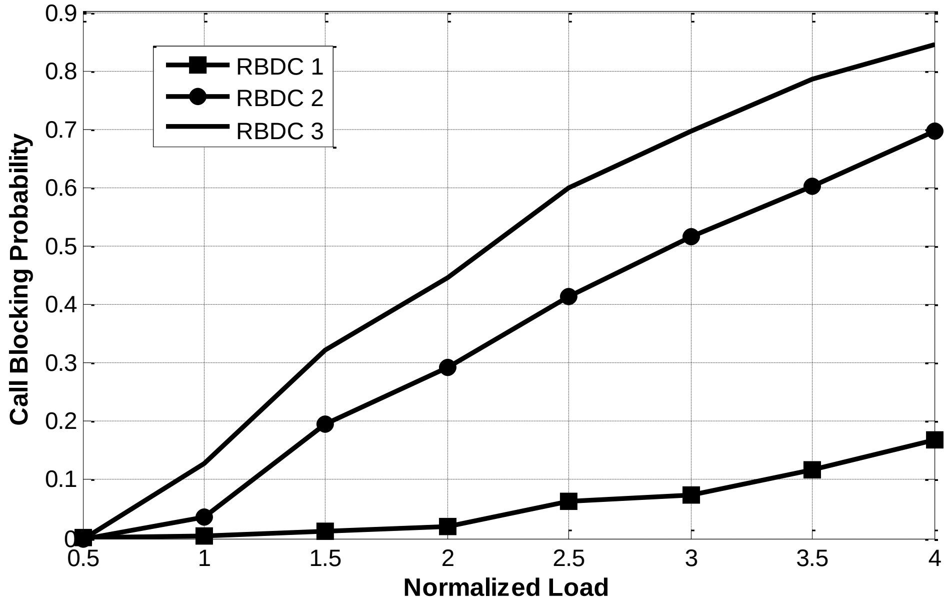

Figure 20: CBP for RBDC Connections in Tree shadowed Area

In Figure 21, we present results for the maximum number of each connection type that was handled by the network in an urban environment under the GCAC-LA policy. The result is presented as a function of the normalized load and is compared with the GCAC policy in [52]. The result shows that for all load values, the maximum number of active RBDC1 connection is greater than the maximum number of active RBDC2 and RBDC3 connections under both policies. Furthermore, for each load value, each traffic class have more connections admitted under the GCAC-LA policy than in the GCAC policy. However, the system is mostly populated by connections of RBDC1 under the GCAC-LA and GCAC policies. The same is also true for RBDC2 and RBDC 3 connections. The reason for the high number of active RBDC1 connections in the GCAC-LA policy is because when channel state is worse, more resources are required by all connections. But RBDC1 connections still require the least resources and thus are more favoured for admission than the other connection types.

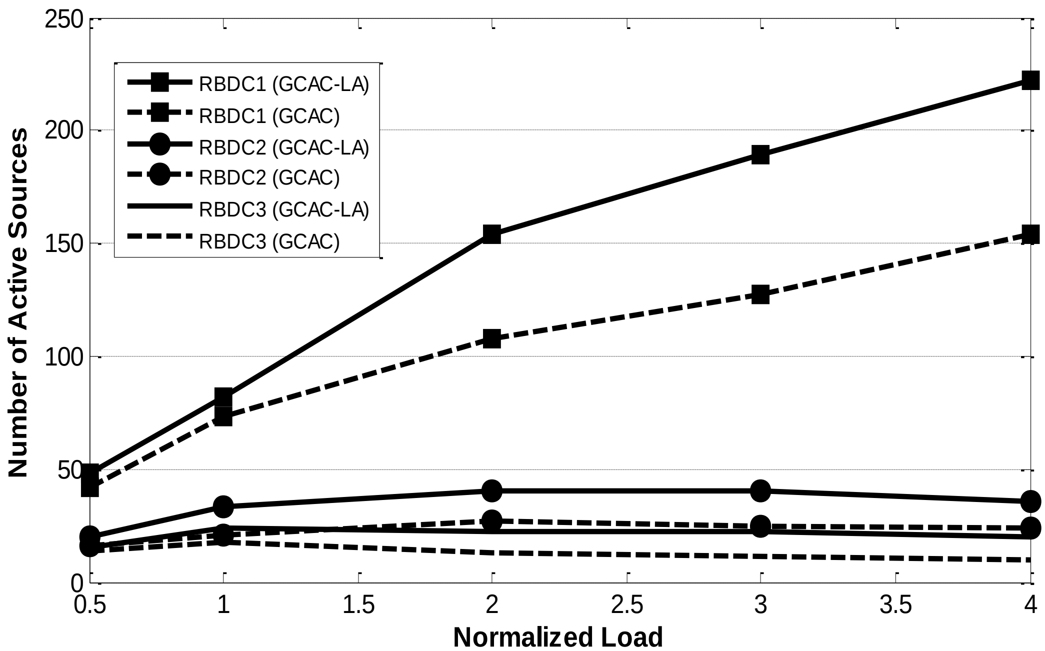

Figure 21: Maximum number of connected RBDC sources (Urban)

The maximum number of active sources in the three environments is also investigated and compared under the GCAC-LA policy. In Figure 22, the number of active RBDC1 connections is compared for urban, suburban and tree shadowed environments. From the result, the number of RBDC 1 connections is observed to increase as the normalized load. At low load values, the active sources in the network are similar for the three environments. However, as the load is increased, fewer number of RBDC1 connections are active in an urban environment. This is expected because the deep shadowing state dominates the link in an urban environment, thus fewer connections are handled. Also, the active sources in suburban and tree shadowed environments are similar as the load increases.

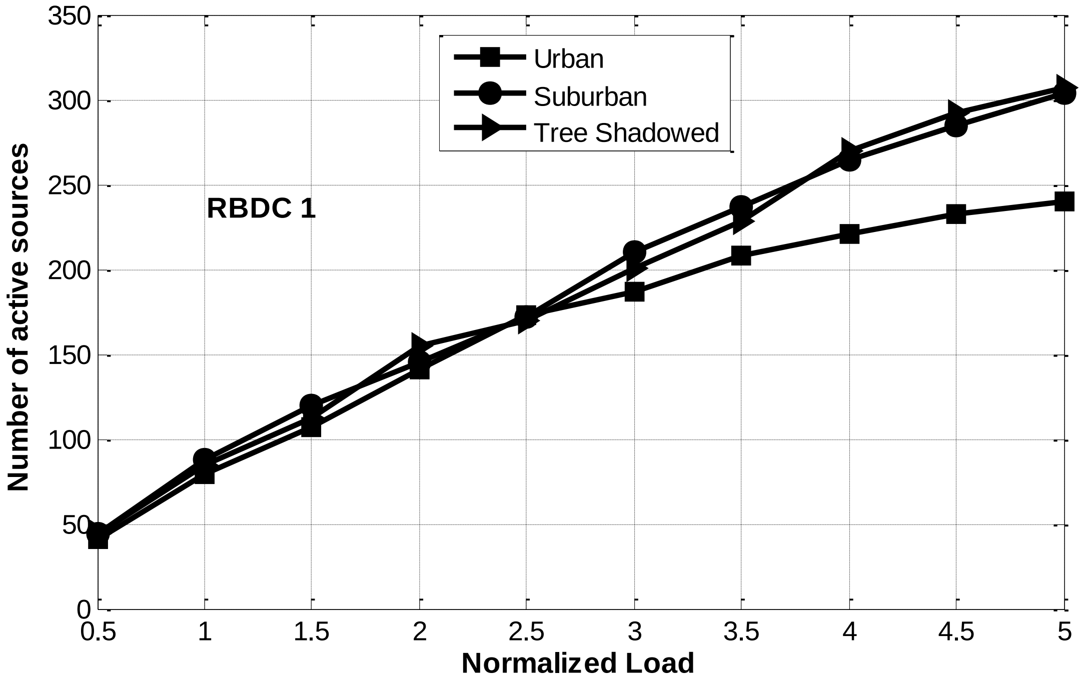

Figure 22: Maximum number of connected RBDC1 sources

In Figure 23, the number of active RBDC 2 connections varies for different load in different environments. In the urban environment, the active sources increase sharply for low load condition and then drop as the system load is increased. This behaviour is at variance with that which occurs in suburban and tree shadowed environments where a higher number of active sources is recorded as the load is increased. Lower number of active sources are recorded in the urban environment because it is dominated by the deep shadowing phenomenon and more capacity is required to support fewer connections. However, active sources for suburban and tree shadowed environments are similar. It should be noted also that in all environments, the number of active RBDC2 sources is fewer than those of RBDC1 sources.

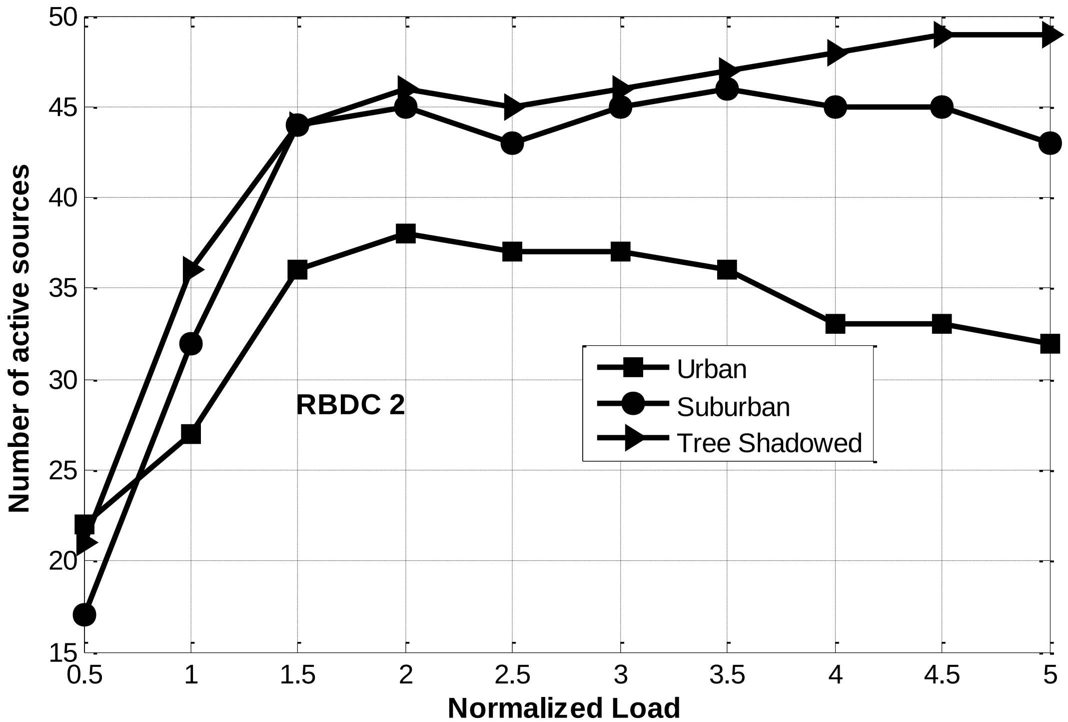

Figure 23: Maximum number of connected RBDC2 sources

The number of active RBDC3 sources is presented for different load and environments in Figure 24. As expected, a fewer number of RBDC3 sources are active in the urban environment. The result indicates that the total number of active RBDC 3 sources is less than those of active RBDC 1 and RBDC 2 sources in all three environments. This so because of the high aggregate bandwidth required to support multiplexed RBDC 3 sources. We also note a sharp drop in the number of active RBDC 3 sources in the tree shadowed state at high load values which can also be attributed to high aggregate capacity and the dominance of moderate shadowing state in tree environment. However, a steady increase in noticed for urban and suburban environments.

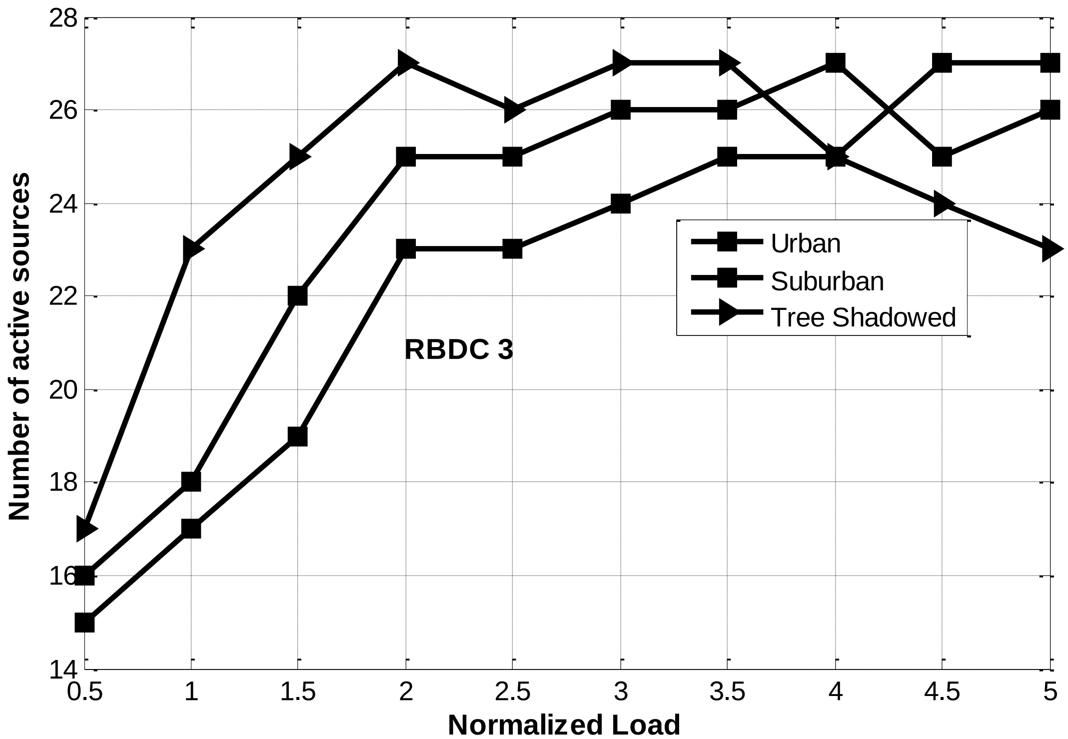

Figure 24: Maximum number of connected RBDC 3 sources

Lastly, we present results for the packet loss ratio (PLR) performance of the multiplexed connections as a function of normalized load (Figure 25) under the GCAC-LA and GCAC policies. It is required that the PLR does not exceed the PLR threshold so that the QoS of each connection in the multiplex is not violated. Using a threshold of 1% (0.01) with a corresponding value of 2.33 for QoS parameter (α), the results show that both policies satisfy this PLR requirement.

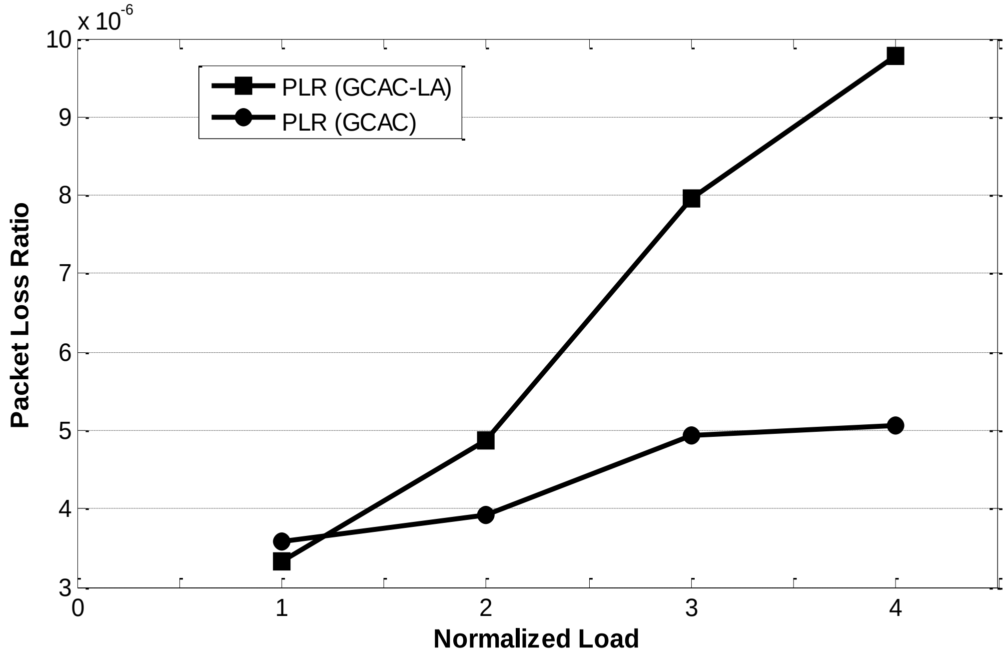

Figure 25: Packet Loss Ratio (PLR)

4.6 Conclusion

We have proposed a CAC policy (GCAC-LA) whose decision to admit/reject connection requests consider the dynamic behaviour of the propagation channel in which the source will be transmitting if admitted. We presented an approach for adaptive transmission with AMC as well as an approach to estimate required capacity for connections admitted under the proposed policy. The performance of the GCAC-LA is investigated under three environments, namely urban, suburban and tree shadowed areas and compared with the GCAC policy which does not incorporate link adaptation. From the simulation results, it is shown that link adaptation results in higher efficiency in the utilization of available network resources. For any given load, the GCAC-LA policy shows lower CBPs than the GCAC policy. Also, more connections are supported under the GCAC-LA policy than with the GCAC policy. It is also noteworthy to mention that the investigated CAC performs satisfactorily in that connections with the least aggregate capacity have the lowest CBP while the ones with the highest capacity requirement experience the highest CBP. Furthermore, by investigating the performance of the GCAC-LA performance under different environments, we have shown that the performance of CAC is also affected by the environment in which the satellite terminal is located. This is because the different environments have different proportions of the three channel states, namely LOS, MS and DS. Moreover, in all environments, the impact of channel adaptation is plausible as network capacity is significantly improved while the QoS requirements of connections are also satisfied.

CHAPTER FIVE

GAME THEORY BASED CALL ADMISSION CONTROL FOR MULTIMEDIA SATELLITE NETWORKS

5.1 Introduction

In the previous chapter, the GCAC-LA policy that considers the effect of link adaptation in its decision to admit or reject connection requests is proposed. The policy considers the variations experienced in channel conditions are the result of the mobility of the satellite users' terminals. In this chapter, we propose an alternative admission control policy which considers that variations in the conditions of the channel are the result of rain attenuation. Similar to the GCAC-LA policy, the effects of rain attenuation are mitigated through adaptive transmission in an AMC scheme. However, the admission control policy is designed using Game theory concepts to make decisions on the acceptance or rejection of connection requests. Thus the Game theory CAC scheme still fuses the operation of the CAC and AMC for optimal network performance through the satisfaction of QoS requirements of all accepted users' connections as well as efficiently utilizing network resources despite the time-varying effects of rain attenuation.

A number of policies that combine channel adaptation techniques with admission control have been proposed for multimedia connections handling in satellite networks. In [38], a CAC policy that considers adaptive coding for satellite users is proposed. The idea is to first estimate the capacity requirements for users in clear air and the capacity required for forward error correction (FEC) redundancy during rain fading. Admission is granted only if the sum of clear air and FEC redundancy capacity is less than or equal to available capacity. The concept is extended to multi-class traffic cases in [21] and a distributed CAC policy in [42]. In [43], a distributed CAC policy based on game theory concepts is proposed. By leveraging on adaptive FEC proposed in [38] [21] and [42], a bargaining game is developed for efficient bandwidth allocation and admission control for delay-sensitive services. The bargaining game is played for bandwidth allocation while admission control ensures that QoS for all accepted connections is guaranteed despite the time-varying influence of rain attenuation. The basis of these proposed CAC policies is the accurate estimation of the required resources for each connection. Furthermore, the estimation of the resources required to guarantee QoS for any connection is made based on accurate prediction of the rain attenuation experienced over the entire duration of such connection. However, it is notable that prediction of rain attenuation for a period as long as the duration of a connection (say video streaming service) is not optimal. This is because the rain fading statistics could vary significantly during the connection and there is the likelihood that the predicted attenuation is too high or too low causing either excessive or insufficient resources to be allocated. A model which predicts the rain attenuation for short periods within the connection's duration is therefore necessary. In this chapter, a Game theory based admission control policy which considers that AMC is employed to mitigate the dynamic effects of rain attenuation on the satellite link. The proposed game theory-based CAC differs from [43] in that it considers for its decision to accept/reject connection requests, the rain attenuation at periodic intervals during the connection as well as a bandwidth degradation strategy to extract channels towards the acceptance of RT connection requests. Our main contributions are as follows:

- Development of a framework for admission control in satellite networks based on game theory and rain attenuation prediction at short time intervals within a connection's duration,
- Development of an alternative admission control policy for handling traffic of connections of different classes.

5.2 System Model

In this section, we present the architecture of the proposed system, the traffic classes considered, channel model based on Markov chain. We also describe a prediction model which is used to predict channel states for different intervals within the duration of each call, which enables the selection of appropriate AMC modes for signal transmission within each interval.

5.2.1 System Architecture

The architecture of the considered system conforms to the Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) standard [23]. It comprises a geostationary satellite with on-board processing capability, multiple return channel satellite terminals (RCSTs) and a gateway which provides connectivity to external networks such as the internet. The assigned spectrum is segmented based on multiple frequency time division multiple access (MF-TDMA) technique so that capacity assignment to RCSTs is made by allocating to each of them, one or more bandwidth-time units (BTUs) (also known as timeslots) within a carrier according to the bit rate requirements of connections handled by the RCST and the current state of its channel.

5.2.2 Traffic Classes

Based on QoS requirements, network connections may be broadly classified into real time (RT) and non-real time (NRT) traffic classes. The RT traffic class refers to connections with stringent QoS requirements while the NRT class refers to connections with non-stringent QoS requirements, i.e. best effort services. Traffic of voice and high-quality video connections constitutes the RT traffic class. NRT traffic class on the other hand includes data services such as email and file transfer. The QoS requirements of each service classes differ and so the amount of resources that will be allocated to connections in each service classes differ. According to the DVB-RCS standard, the RT and NRT services respectively use the continuous rate assignment (CRA) and rate based dynamic capacity (RBDC) capacity request strategies respectively.

5.2.3 Prediction of Channel Conditions

Since rain attenuation is the predominant factor responsible for signal attenuation in the considered system, we model the satellite channel by variations in rain rate at the location of the satellite terminal. When the rain rate is predicted, AMC is then employed to mitigate the resulting attenuation. In [43], rain attenuation at the end of a connection is predicted and the probability that the attenuation at the end of the connection will be greater than at its beginning is considered in allocation of resources for such connection. However, rain attenuation over short periods during the connection is required in order that variations in channel conditions are observed and mitigated leading to better efficiency in the QoS served to connections. As in [62], the prediction of rain rate R is based on an M-state Markov chain (MC) model. A four-state MC [63] that captures the variations between clear air conditions and different types of rain events is employed. State 1 of the MC indicates clear air in which the rain rate is 0mm/hour. In State 2, stratiform clouds that produce rain rate between 0 and 25mm/hour are present. In the third state (State 3), there is convective cloud that yields rain rate greater than 25mm/hour but less than 120mm/hour. In State 4, the rain rate exceeds 120mm/hour while lightning and thunder are produced. The Markov model is shown in Figure 26. The MC prediction is defined by the state probability (S) and transition probability (P) matrices given in equations (5.1) and (5.2) both of which are adopted from [63]. The matrix S gives the overall probability of states of the MC while the matrix P expresses the probability of transitions among the states of the MC.

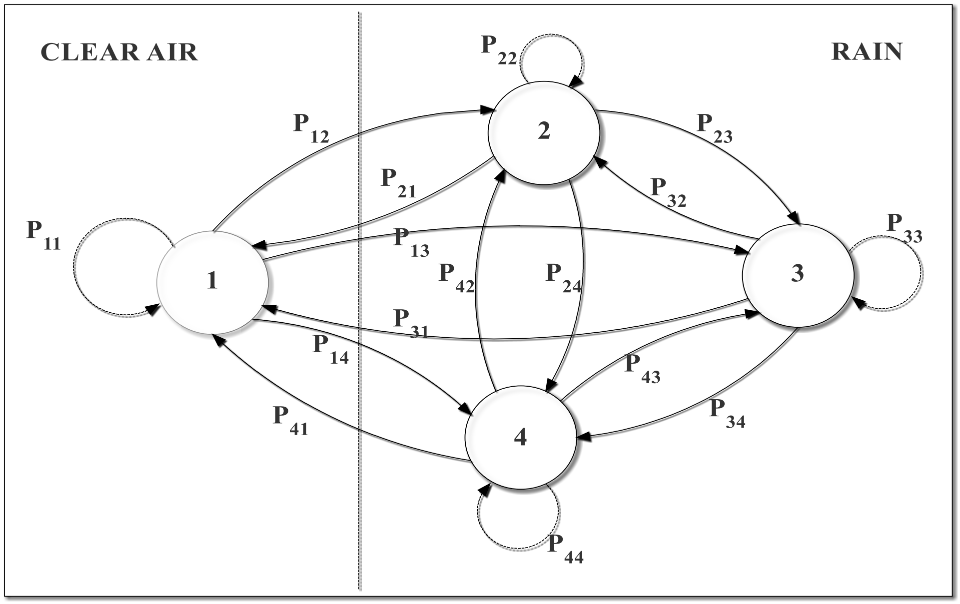

Figure 26: Four-State Markov Channel

$$S = [0.974682280319535 \quad 0.0235793391430646 \quad 0.00164760348583878 \quad 9.07770515613653e-05] \qquad (5.1)$$

$$P = \begin{bmatrix} 0.999813729096912 & 0.000107105769275546 & 7.91651338123600e-05 & 0 \\ 0.00654475457170356 & 0.986333012512031 & 0.00692974013474495 & 0.000192492781520693 \\ 0.0165289256198347 & 0.132231404958678 & 0.84848484848449 & 0.00275482093663912 \\ 0 & 0 & 0.100000000000000 & 0.900000000000000 \end{bmatrix} \qquad (5.2)$$

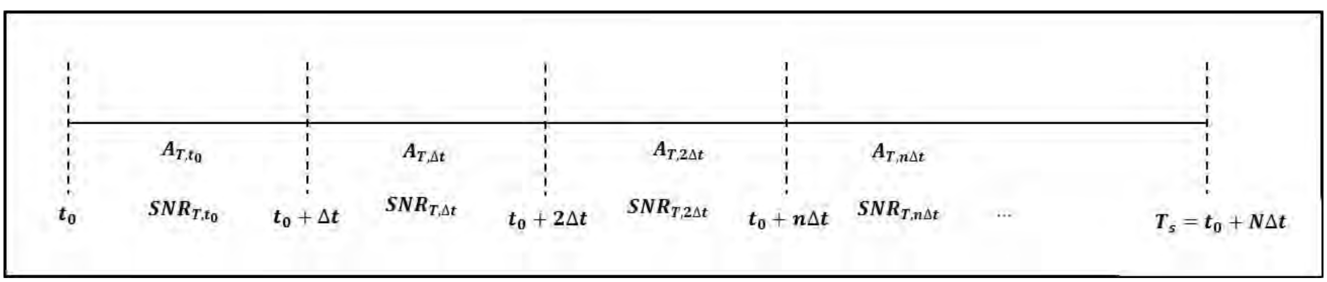

Figure 27: Rain Attenuation Prediction Model

Assuming that the duration (T_S) of each connection is known *a priori*, the rain attenuation prediction is made by first partitioning T_S into N finite periods of duration Δt each (Figure 27). The state of each period $n\ (n = 1,2, \dots N)$ is then predicted by the MC. However, the maximum rain rate $R_{max,n\Delta t}$ in that state may be generated by a lognormal distribution [43]. Based on other parameters such as frequency, elevation angle, polarization and effective path length, the rain attenuation $A_{R,n\Delta t}$ for the nth period is estimated using the relation [64]

$$A_{R,n\Delta t} = k(R_{max,n\Delta t})^{\alpha}.L_E \tag{5.3}$$

where k and α are frequency dependent coefficients and L_E is the effective path length between satellite and the antenna at the receiver. Free space loss A_{FS} is also a major source of attenuation and is estimated as $A_{FS} = (4\pi d/\lambda)^2$ where d is the distance between the antenna and the satellite and λ the wavelength. Thus, the total attenuation $A_{T,n\Delta t}$ within any period n of the call is obtained as the sum of the attenuation due to rain and free space loss, i.e.

$$A_{T,n\Delta t} = A_{R,n\Delta t} + A_{FS} \quad dB \tag{5.4}$$

5.2.4 Selection of Transmission Modes and Dynamic Resource Calculation

An accurate prediction of the attenuation along the link is plausible towards realizing efficient resource allocation and QoS satisfaction. The resource allocation therefore depends on the predicted state of the channel. At the receiver, the quality of the channel is indicated by the received signal-to-noise ratio (SNR) which relates the signal strength to the attenuation and noise. The $SNR_{n\Delta t}$ for the nth period is calculated from

$$SNR_{n\Delta t} = P_T + G_T - A_{T,n\Delta t} + G_R - T - K - R_S \quad dB \tag{5.5}$$

where P_T is the transmit power, G_T and $G_R$are the antenna gain at the transmitter and receiver respectively, T is the effective noise temperature, K is the Boltzmann constant and R_S is the symbol transmission rate. Furthermore, according to the number of channel states, M transmission modes are defined. Each mode $m\,\{m = 1,2,..M\}$ comprises the modulation format and coding rate (MODCOD) that optimizes spectral efficiency for a specific channel state. Also, the spectral efficiency of the mode employed determines the maximum achievable bitrate for that state. For the nth period, the maximum bitrate $b_{m,n\Delta t}$ achievable is given by

$$b_{m,n\Delta t} = \begin{cases} \eta_1 R_S, & if\ \Gamma_{min} \le SNR_{n\Delta t} < \Gamma_1 \\ \eta_2 R_S, & if\ \Gamma_1 \le SNR_{n\Delta t} < \Gamma_2 \\ & \vdots \\ \eta_M R_S\,, & if\ \Gamma_{M-1} \le SNR_{n\Delta t} < \Gamma_{max} \end{cases} \tag{5.6}$$

where η_m indicates the spectral efficiency of the mth mode and $\Gamma_m$indicates the SNR thresholds for each mode of the AMC scheme.

For the purpose of admission control, the capacity required for a connection to be admitted is estimated based on the 75th percentile of the N states predicted for the duration T_S of the connection. The total attenuation ($A^{75\%}_{T,n\Delta t}$) and SNR ($SNR^{75\%}_{T,n\Delta t}$) of the selected state are obtained using equation (5.4) and (5.5) before the maximum achievable bitrate $b^{75\%}_{m,n\Delta t}$is obtained from (5.6). The capacity $C_{R,m}$ (number of timeslots) required to satisfy a connection's bandwidth request of $B_R\ Kbits/s$, when the channel is in state m is given by

$$C_{R,m} = \left\lceil \frac{B_R}{b_{m,n\Delta t}^{75\%}} \right\rceil \tag{5.7}$$

The $\lceil x \rceil$ operator indicates the largest integer greater or equal to x. Table 7 below lists the AMC modes for each of the state of the channel.

Table 7: AMC Modes for the four-state Markov channel [53]

Transmission Mode	**MODCOD**	**SNR (dB)**	**Spectral Efficiency (bits/s/Hz)**
4	QPSK 1/2	5.5	1.0
3	QPSK 3/4	6.8	1.5
2	8PSK 1/2	8.8	2.0
1	8PSK 6/7	12.6	2.57

5.3 Game Theoretic Admission Control Scheme

In this section, we formulate a two-person non-cooperative game theoretic framework for admission control for multiclass services in satellite network. The proposed game is described as a triple $G = [N, S, U]$, where N denotes the players involved in the game, S denotes the set of actions or strategies that may be taken by players of the game and U the utility or satisfaction enjoyed by the players based on the strategy employed by them. Players of the game are the on-going RT and NRT connections in the satellite network and the new connection requesting to be served. Basically, the admission control algorithm takes on a simple algorithm as follows:

Given: a connection with capacity request C_R arrives

if $C_T - C_{RT} - C_{NRT} \geq C_R$

accept connection,

else

if (connection is NRT type)

reject

else

initiate Game process.

where C_T indicates the total available system resource; C_{RT} and C_{NRT} are the resources already allocated to existing RT and NRT connections. As depicted by the algorithm, the game is initiated when the available resources are insufficient to support the capacity requested by a new RT connection. The goal is to determine if additional capacity can be made available by degrading a number of NRT connections without violating their minimum requirements. However, the admission of NRT connections is based on the availability of their maximum capacity requirement. In the following, the bandwidth degradation process of the game is highlighted. A similar degradation model can be found in [45].

5.3.1 Utility Function

The degree of satisfaction of users' QoS is described using the concept of utility function. The utility function is a universal sigmoid function [65] whose parameters are unique for the RT and NRT traffic classes. For both RT and NRT connections, the domain of the utility function is [0, 1]. If the capacity requirement for any RT and NRT connection in any state m is C_{RT}^{m} and C_{NRT}^{m} respectively, the utility of the connection is a function of the allocated resources C and is expressed as:

$$U(C,m) = \begin{cases} \frac{1}{1+e^{-G_{RT}(C-C_{RT}^{m})}}; & RT \\ \frac{1}{1+Be^{-G_{NRT} \cdot C_{NRT}^{m}}} + D; & NRT \end{cases} \tag{5.8}$$

where C is the actual amount of resources allocated to the connection. The parameters G_{RT} and G_{NRT} both define the steepness of the utility curve around r while B and D are constants taken as 1.5 and -0.4 respectively [65]. The QoS requirement for RT connections is to satisfy their peak data rates (PDR), i.e. $C = C_{RT}^{m} = PDR$. Therefore, the utility of all accepted RT connections must always equal to unity for their QoS satisfaction – equation 5.8.

5.3.2 Game Strategies

The goal of the game is to find NRT connections that may be degraded in order that RT connections might be accepted. However, the degradation process is guided by utility of players. Different strategies are employed by the payers of the game. For the new connections, the strategy set S_{NC} is defined as $S_{NC} = \{B_A, B_R\}$ where actions B_A and B_R indicate acceptance and rejection respectively. However, for the network, the strategy set S_{NET} is based on the capacity that may be extracted by degrading certain numbers of ongoing NRT connections without violating their minimum capacity requirements. The set of network strategies S_{NET} is defined as $S_{NET} = \{b_0, b_1, \dots, b_{Q-1}, b_Q\}$; where each strategy b_q $\{q = 1,2, \dots Q\}$ indicates the action in which q resources are extracted from ongoing NRT connections. The maximum resource that can be extracted from NRT connections is Q.

5.3.3 Payoffs

The payoff refers to the utility of players after an action is taken. We express the payoff for the game as a matrix U whose elements $P_{b_q,}P_B$ indicate the utility for the network and the new connection. The payoff matrix U for the strategies is given by:

$$\boldsymbol{U} = \begin{bmatrix} U_{b_1,}U_A & U_{b_1,}U_R \\ U_{b_2,}U_A & U_{b_2,}U_R \\ U_{b_3,}U_A & U_{b_3,}U_R \\ & \vdots & \\ U_{b_Q,}U_A & U_{b_Q,}U_R \end{bmatrix} \tag{5.9}$$

In (5.9), U_{b_q} denotes the payoff for the network when b_q resources are extracted from its ongoing NRT connections. If the resources allocated to NRT connections is C_{NRT}, U_{b_q} is estimated from (5.8) as

$$U\left(C_{NRT}^{m} - b_q\right) = \frac{1}{1+Be^{-G_{NRT}\cdot(C_{NRT}^{m}-b_q)}} + D \tag{5.10}$$

On the other hand, $U_B = \{U_A, U_R\}$ denotes the payoff for the new connection if it accepts or rejects and is given by

$$U_B = \begin{cases} U_A = 1; & if\ accepted \\ U_R = 0; & otherwise \end{cases} \tag{5.11}$$

5.4 Results and Discussion

The performance of the developed CAC policy is investigated using an event-driven simulator developed in C#. In the simulation, the arrival of connections of each traffic class follows an exponential distribution. However, system loads is altered by increasing or decreasing the service inter-arrival times for each traffic class. Regarding bandwidth requirement and QoS, both service classes require a maximum bandwidth of 384Kbits/s. While RT connections require that this bandwidth be provisioned in full at all times for their QoS satisfaction, NRT connections tolerate service degradation albeit, such degradation must not exceed 192 Kbits/s. Simulation parameters are summarized in Table 8.

Table 8: Simulation parameters

Parameters	Value
System Capacity	32Mbits/s
Air Interface	MF-TDMA
Number of Timeslots	1000
System Load	10, 20, 30, 40, 50
Call Duration (Exponential)	600s
Simulation Time	10,000s

5.4.1 Performance of the Admission Control

The following metrics are used to investigate the performance of the proposed CAC policy.

Call blocking probability: For each service type, the CBP is the ratio of total requests accepted to the total number of generated requests.

Maximum active sources: This is the maximum number of each class of connections that were simultaneously handled. This expresses the utilization of the link.

Number of admitted sources: This is the average maximum number of sources admitted during each simulation campaign.

In the following, we benchmark our results by comparing the obtained call blocking probability (CBP) with those of a non-real time limitation (NRTL) CAC policy found in [66]. The results are obtained for real time (RT) and non-real time (NRT) connections. We set the system capacity to 78 timeslots with a maximum degradeable capacity of the NRT connections set at 50 timeslots. The system is run by predicting four (4) intervals within each connection duration.

In Figure 28, we present the CBP performance of RT connections under the Game CAC and NRTL policy as a function of system load. The form of the CBP curve of the Game CAC shows similarity to that of the NRTL CAC. While the Game CAC shows high CBP performance during low load conditions, the CBP almost the same as the system load increases.

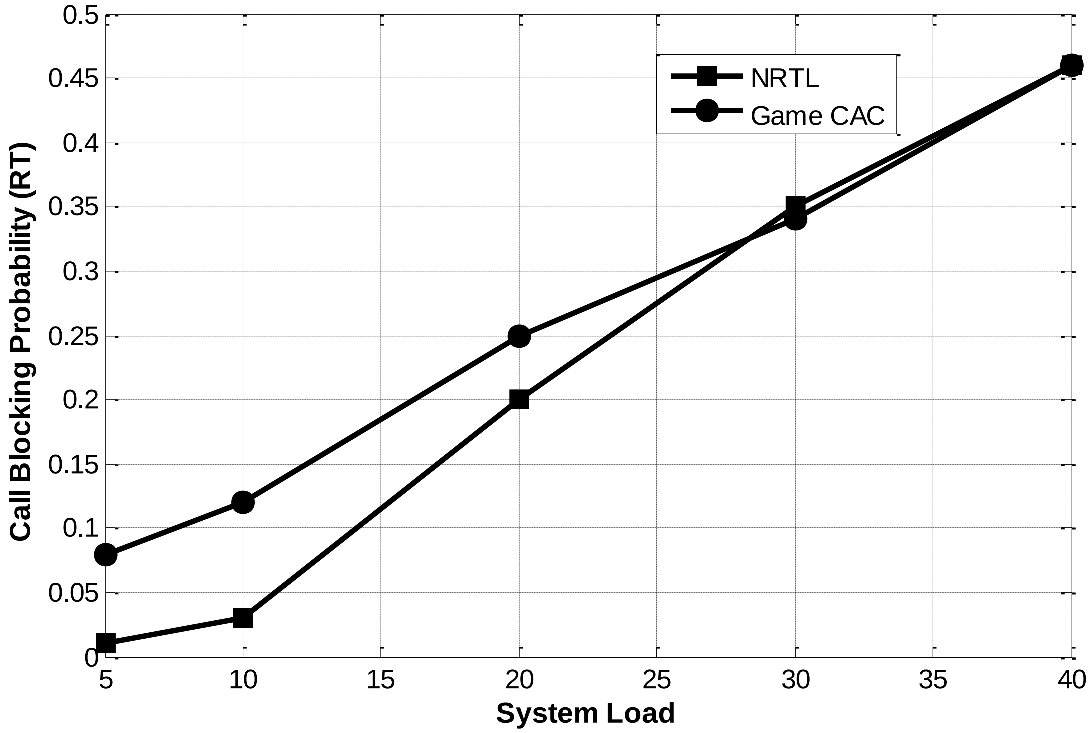

Figure 28: Call Blocking Probability for Real Time (RT) Connections (NRTL vs Game CAC)

In Figure 29, the obtained CBP curve for NRT connections under the NRTL CAC and Game CAC policies are compared. Although the CBP for the Game CAC is a little higher than that of the NRTL policy, their curves show great similarities in their outlook.

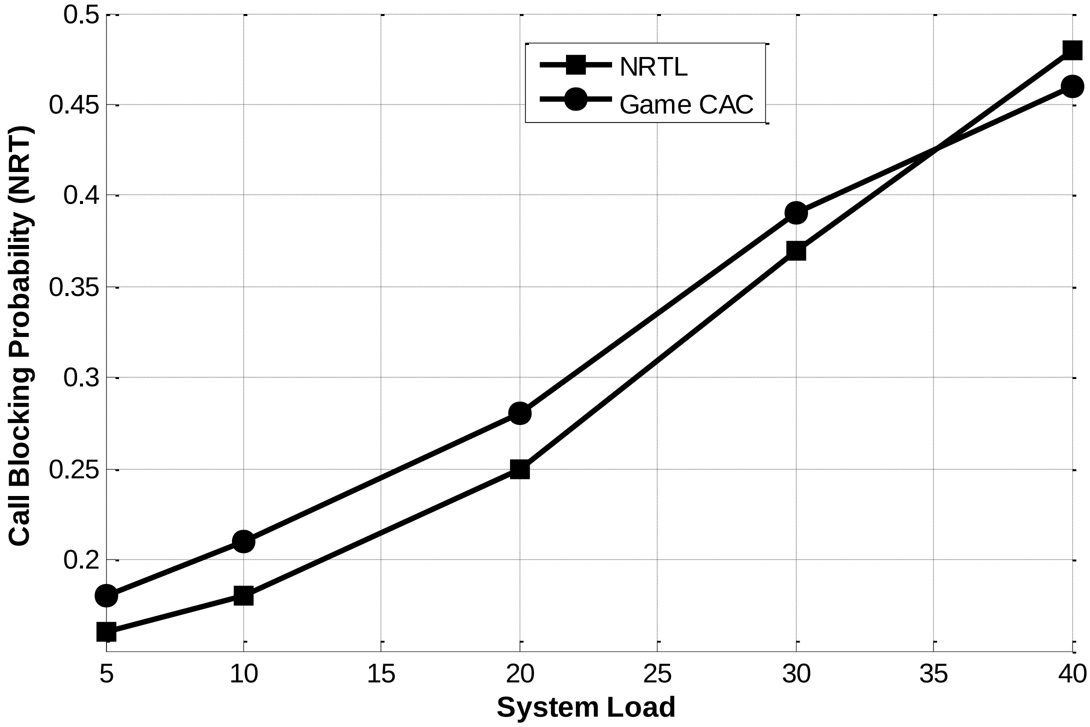

Figure 29: Call Blocking Probability for Real Time (NRT) Connections (NRTL vs Game CAC)

Next, we investigate the performance of the Game CAC policy in three different prediction intervals – 10, 7 and 4 intervals. We first present the results of the 10-period prediction scheme and then compare the results obtained with the 7 and 4 period prediction scheme.

Figure 30 shows the CBP performance for RT and NRT connections in the 10-period prediction scheme as a function of system load. The CBP for both traffic classes increases with the system load. However, the CBP for NRT traffic class was higher than those of RT traffic class. This can be explained as the consequence of degradation policy in which resources are extracted from NRT connections in order that RT connections might be served.

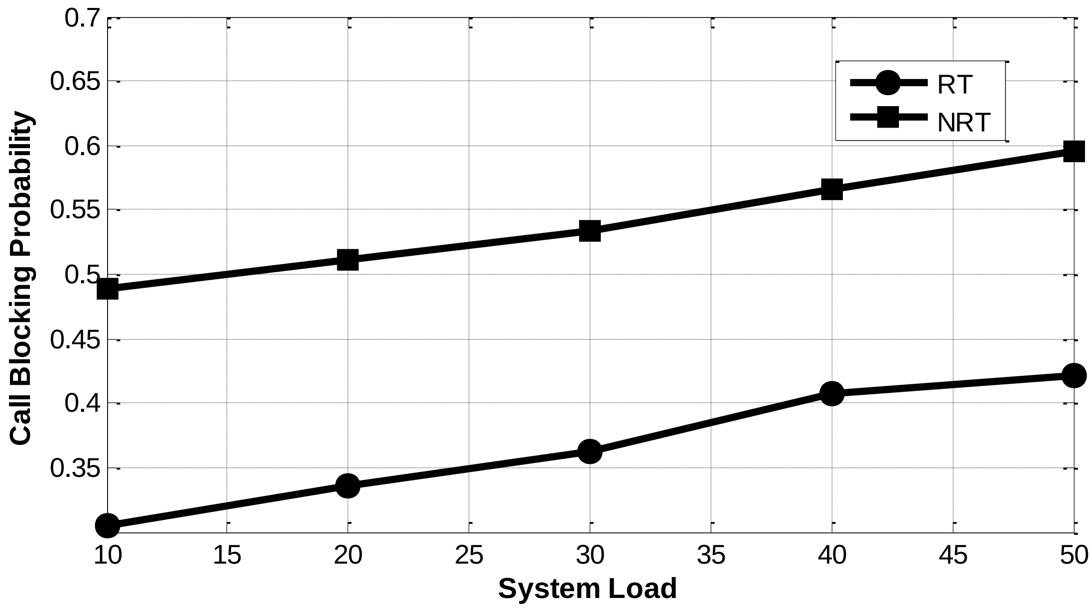

Figure 30: Call Blocking Probability in 10-Period Scheme

In Figure 31, the number of sources of each traffic class that were simultaneously connected in the system as a function of system load. Again, the number of connections handled is observed to increase with the system load. However, for each load value, there are more RT connections in the system than the NRT connections.

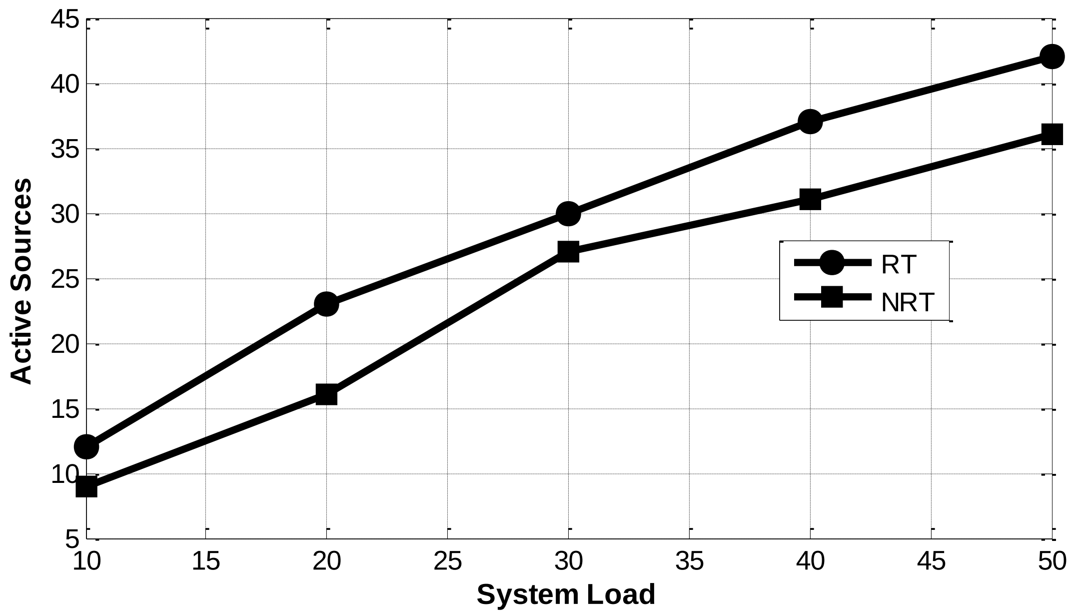

Figure 31: Number of Active Sources in 10-Period Scheme

The number of sources admitted during each simulation campaign is presented in Figure 32 as a function of the system load. It can be observed from the result that the number of admitted sources increases as the system load. For each load value, more RT connections are admitted into the system than there are NRT connections.

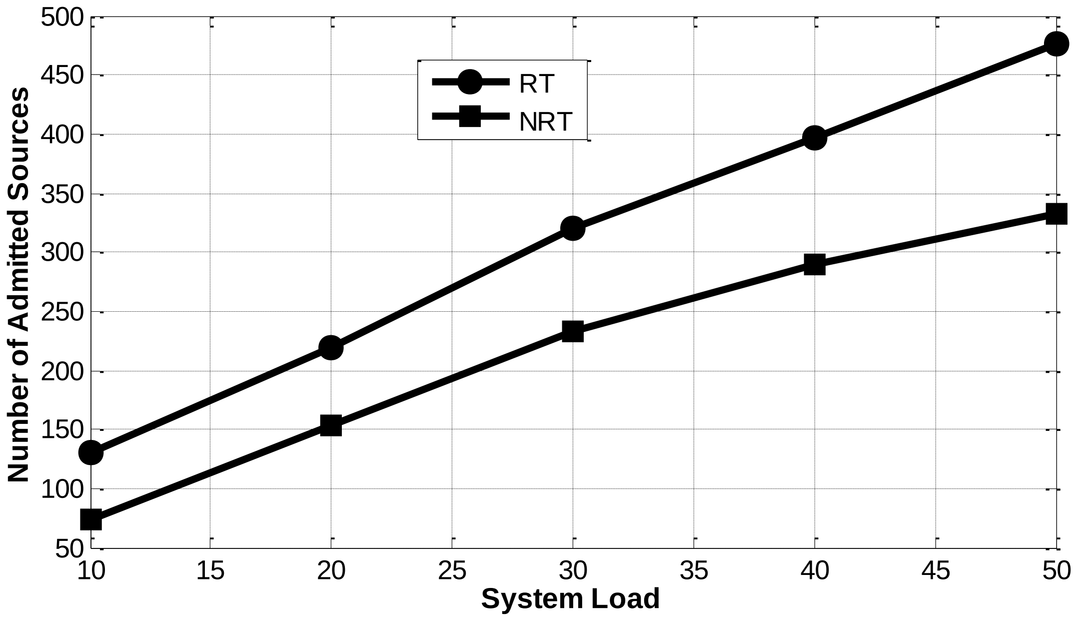

Figure 32: Number of Admitted Sources

It can be summarized that the results in Figures 30-32 present good performances of the GTCAC-LA policy since better performances are observed for the RT traffic class. The results were investigated under a channel state prediction scheme which predicts the state of the channel for 10 periods within the duration of the call. It is necessary to investigate the performance when the channel state is predicted for shorter intervals in order to justify the number of intervals for which the channel state should be predicted.

In Figure 33, the CBP for NRT connections in three different channel state prediction schemes are compared. From the result, the lowest CBP for NRT connections occurs when 4 periods are predicted. This is followed by the 7-period scheme and then the 10 period scheme. The graph also shows close CBP performance between the 7-period and 10-period schemes while there is a wider dfference between the 7-period and 4-period schemes.

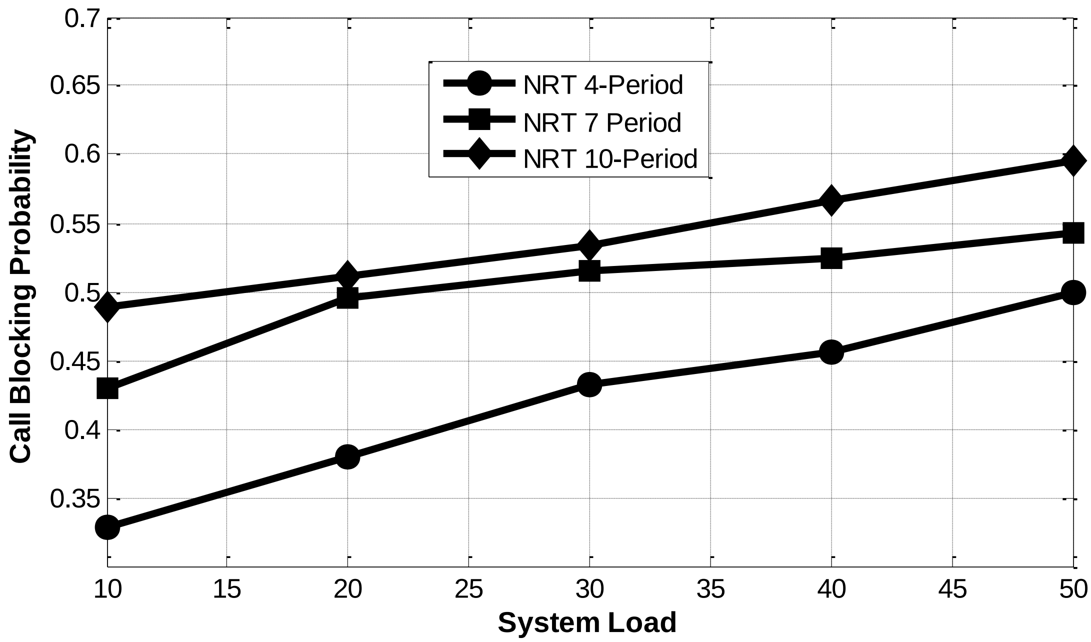

Figure 33: Comparison between CBP for NRT Connections in Different Prediction Schemes

In Figure 34, the number of active RT sources is investigated for the three prediction schemes. One would notice from the result that during low loads, the least number of connections that were simultaneously active for the 10 period prediction scheme. While the 4 and 7 period exhibits a higher number of connections compared to the 10 period scheme, both still had fewer connection simultaneously connected. However, as the load increases, a sharp increase in the number of connected calls is noticed for the 4 period scheme while almost similar number of connections are connected for the 7 and 10 period schemes at high loads.

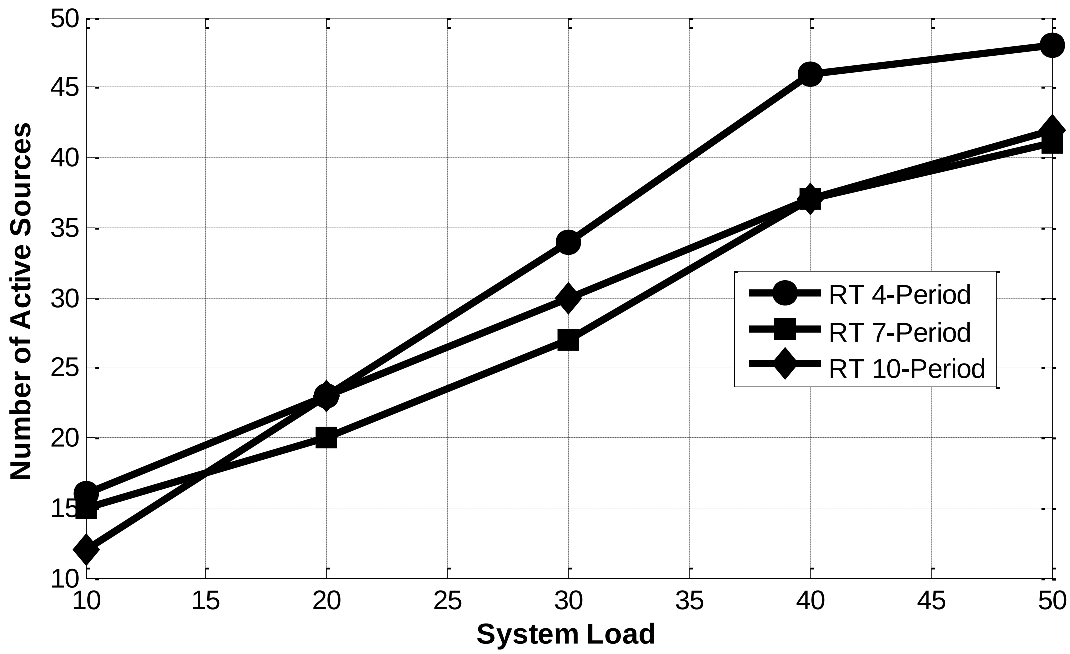

Figure 34: Comparison between Active RT Connections in Different Prediction Schemes

5.5 Conclusion

We have proposed a game theory based CAC policy for admission of multimedia connections in satellite networks. The network traffic is grouped into two classes, namely real time (RT) and non-real time (NRT). The RT connections are prioritized over the NRT ones which tolerate a significant amount of degradation in allocated bandwidth without losing connectivity. This allows for more connections of the RT traffic class to be admitted. In the admission control policy, a connection is accepted if there is enough capacity to support its connection upon its arrival. The connection is rejected if there is insufficient capacity available to support its connection. If the call requested is made for a RT connection, the connection may not be rejected out-rightly without first investigating the possibility of extracting resources from the existing connections NRT connections. In order to extract capacity from the existing NRT connections, a game is played between the network (existing connections) and the new connection. The new connection is accepted only if the extractable capacity is capable of supporting the new connection. The proposed policy considers the physical state of the channel in its operation. It relies on a channel state prediction scheme that predicts the rain attenuation in the channel and based on the predicted states, estimates the required capacity for each connection. The required capacity is estimated as the capacity required for the 75th percentile of the predicted states. The performance of the CAC policy was investigated with metrics CBP, maximum number of active source and the number of admitted sources. These metrics are compared in three different channel state prediction schemes. The result shows that the CAC guarantees connectivity for RT connections and that with fewer prediction intervals, better performance can be achieved.

CHAPTER SIX

CONCLUSION AND FUTURE WORK

This thesis investigates the performance of two CAC polices proposed for multimedia satellite networks. The first CAC policy is based on Gaussian approximation and link adaptation while the second is based on Game theory concepts also with link adaptation. Adaptive modulation and coding (AMC) is considered as link adaptation technique for both CAC policies.

In chapter one, we present a general introduction to the thesis. We presented an introduction to satellite networks and the various components that make up a satellite network. The various advantages of satellite communication were also highlighted. In addition, we discussed the challenges of satellite communications with emphasis on environmental and atmospheric effects as factors that affect the overall performance of the network. In systems operated at frequencies beyond 10 GHz, rain attenuation is the major factor responsible for signal degradation while multipath and shadowing are factors that cause attenuation when the terminal is mobile. In order to overcome the effect of these factors, different categories of FMT are used. FMT s may be categorized into power control, diversity and adaptive transmission techniques. Of these three, adaptive transmission techniques are best suited for the satellite channel. One such technique is AMC which dynamically adjusts the transmission parameters in accordance with variations in the conditions of the satellite channel. RRM functions are also highlighted as crucial to realizing optimal performance of the network. We therefore proposed CAC as a tool to improve the performance of the network. However, the proposed CAC policies integrate with AMC in order to ensure that adequate resource allocation for all connections with full consideration of the condition of channel.

Chapter two provides a general background to interactive satellite multimedia networks. It presents the system and reference models for interactive communication via satellite. Subsequent sections discussed the various DVB standards for satellite networks with emphasis on the DVB-RCS which is the approved standard for the return channel of interactive satellite networks. Details on the air-interface specification for DVB-RCS were also highlighted. These include return link segmentation based on MF-TDMA multiple access which structures the allocated bandwidth into timeslots, frames and superframes in order to efficiently management the resources. The different capacity requesting strategies which are used to request connections for different classes of traffic are also highlighted.

In chapter three, we presented a review of the different techniques for CAC in satellite networks. A discussion on the CAC mechanism and the various reasons for implementing CAC in satellite networks was done. Also, we noted that the existing CAC policies may be classified in different ways. A basic classification for CAC one that is based on the resource allocation employed in the admission control policy. A second classification is based on design approach of the CAC policy. When considering the design approach, CAC may be classified based on the centralization of the decision making entity, the number of traffic classes and the amount of information available to the admission control module. They may also be classified based on optimization and the type of link on which the admission control policy will be implemented. We also investigated the gains of statistical multiplexing for variable bitrate traffic sources by comparing Gaussian allocation with a PDR allocation policy. It was shown that the Gaussian admission control policy is highly efficient and guarantees QoS of VBR source.

In Chapter Four, we present the Gaussian CAC based on link adaptation (GCAC-LA) policy proposed for providing QoS for RBDC connections. We introduced a method for estimating the capacity requirements of connections under different transmission schemes whose parameters are selected based on the current channel state. A three-state Markov channel model was adopted for the satellite channel model. In evaluating the performance of the proposed GCAC-LA policy, we compared CBP, number of active sources and PLR for urban, suburban and tree shadowed environments. Firstly, the result shows that while statistical multiplexing provides high utilization of available bandwidth, the implementation of an adaptive transmission scheme such as AMC results in much higher utilization of network resources. The results confirm that when multiple connections of different capacity requirements are served in a network, the connections with the least bandwidth enjoy low CBP compared to those that require larger capacity. Given any class of traffic, the results show that performance metrics such as CBP and number of active sources are different for different environments, but the best performance is observed for the environment whose condition is as close as possible to the line-of-sight state.

Lastly, in Chapter Five presents the game theory based CAC policy for multimedia satellite networks. The scheme classifies connections into real time (RT) and non-real time (NRT) based on their tolerance for service degradation. The RT connections are prioritized over the NRT ones which may be degraded to increase bandwidth availability to support more RT connections. The game played is aimed at ensuring that adequate bandwidth can be extracted from existing connections before the extraction process can commence. However, the bandwidth extraction process is based on the utility of existing connections which is a function of their required and allocated capacity. The scheme also incorporates a channel state prediction scheme which predicts the rain attenuation on a satellite link at regular periods within the duration of a connection. The results obtained by simulation indicate good performance of the proposed CAC policy and that fewer prediction periods must be used to obtain better performance.

Recommendations for Future Work

The performance of the proposed admission control policies has been investigated by computer simulation and the results shows good performance of the proposed policies. It is recommended that analytical approach to evaluating the performance of the proposed policies be undertaken. The basic Gaussian CAC should first be analyzed before attempting an analysis of a scheme that integrates the Gaussian CAC with link adaptation. A comparison of the performance of the Gaussian CAC and the Game theory based CAC should also be done.

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