

**JOINT CALL ADMISSION CONTROL INCORPORATING PRICING FOR  
CONGESTION CONTROL TO ENHANCE QoS AND ENSURE REVENUE  
FOR NETWORK OPERATORS IN NEXT GENERATION WIRELESS  
NETWORKS**

**Sarah Kabahuma**



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of  
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As the candidate's supervisor, I have approved this dissertation for submission.

Name: Dr. Olabisi E. Falowo

Signed:

Date: 22<sup>nd</sup> November 2010

University of Cape Town

## DECLARATION

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This work is being submitted in partial fulfilment of the requirements for the Master of Science Degree in Electrical Engineering at the University of Cape Town. It has not been submitted to any other university for any other degree or examination.

Name: Sarah Kabahuma

Signed by candidate

Sign: Signature Removed

Date: 22<sup>nd</sup> November 2010

To my parents, Dr and Mrs Kasangaki

University of Cape Town

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## **ABSTRACT**

Next Generation Wireless Networks (NGWNs) are envisaged to be heterogeneous. They will integrate multiple Radio Access Technologies (RATs) on the same platform where the RATs are expected to work together in a coordinated fashion. Radio resources will therefore be jointly managed. Joint Call Admission Control (JCAC) approach has been adopted to jointly allocate or handle the radio resources amongst the different RATs in an NGWN. A number of JCAC algorithms have been proposed in the literature with the objective of enabling efficient utilisation of the radio resources and ensuring that required QoS requirements are met. However, studies in JCAC have not typically considered the revenue obtained by network operators in NGWNs.

With the implementation of NGWNs, user demand for network services is expected to significantly increase. Consequently, one of the challenges envisaged in the NGWNs for network operators is a large decoupling between users' traffic and the revenue obtained. Therefore, it is important to analyse the network operators' revenue in NGWNs and devise means to ensure that sufficient revenue is obtained.

This research analyses network operators' revenue in a heterogeneous network environment while maintaining QoS by incorporating pricing in JCAC. An analytical model based on a multi-dimensional Markov decision process is used to model JCAC algorithm in an NGWN. The JCAC algorithm used is load-based whereby calls arriving in the network are admitted to the least loaded RATs. The performance of the algorithm is evaluated using MATLAB.

The analysed NGWN consists of two RATs and two service classes. QoS performance is measured with connection-level QoS metrics namely call blocking probability and call dropping probability. Other investigated performance metrics are average number of calls in the systems, user utility and revenue obtained.

Performance of the NGWN is carried out with a dynamic pricing scheme incorporated in JCAC. A discount approach is applied to determine new price under the dynamic pricing scheme. User behaviour with price variation is impacted by change of call arrival rate and average call duration. Simulations are also carried out with flat pricing for comparison purposes. The results obtained show that better system performance and high revenue for network operators are obtained with the dynamic pricing scheme.

Furthermore, a hybrid pricing model is proposed whereby flat and dynamic pricing schemes are integrated, giving users flexibility of choosing an appropriate pricing scheme. The analysis is conducted with different percentages of users opting for either dynamic or flat pricing schemes. Simulation results show that higher user utility and improved QoS performance are obtained with the hybrid pricing model. Additionally, reasonable operators' revenue is guaranteed with the hybrid pricing model.

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## LIST OF ACRONYMS

1G	First Generation
2G	Second Generation
3G	Third Generation
AJCAC	Adaptive bandwidth management and Joint Call Admission Control
BBU	Basic Bandwidth Units
BWAS	Broadband Wireless Access Systems
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CRRM	Common Radio Resource Management
HJCAC	Hierarchical Joint Call Admission Control
HSPA	High Speed Packet Access
JCAC	Joint Call Admission Control
JPS	Joint Packet Scheduling
GSM	Global System for Mobile Communication
GPRS	General Radio Packet Service
LTE	Long Term Evolution
MADM	Multiple Attribute Decision Making
MCDM	Multi Criteria Decision Making
NGWN	Next Generation Wireless Network
OJSAC	Optimal Joint Session Admission Control
PCS	Personal Communication Systems

PPF	Proportional Fairness Pricing
PMP	Paris-Metro Pricing
PSF	Price Sensitivity Factor
PSM	Price Sensitivity Meter
QoS	Quality of Service
RAT	Radio Access Technology
RRM	Radio Resource Management
UMTS	Universal Mobile Telecommunication System
WIMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WTP	Willingness to Pay

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# 1. INTRODUCTION

## 1.1 BACKGROUND

The advancement of telecommunication technology has resulted into vast benefits in diverse spheres such as in military, health, education, business, and social sectors. One of the driving forces for the advancement is the increasing demand for network services from the users. Users expect to send and receive multimedia messages, have access to internet TV, tele-presence application and mobile commerce, to mention but a few, while maintaining mobility [1]. These services require high data rates, efficient use of the spectrum resources and infrastructure, sophisticated switching mechanisms and effective billing techniques. Next Generation Wireless Networks (NGWNs) are expected to meet these requirements.

Existing networks such as Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunication System (UMTS), Wireless Local Area Network (WLAN) and so forth are homogeneous in nature; i.e. they operate independent of each other. NGWNs are expected to be heterogeneous whereby different Radio Access Technologies (RATs) will be accessed on the same platform and radio resources will be jointly managed. This situation will result in efficient use of network resources. Moreover, NGWN are aimed at providing high bandwidth access anytime, anywhere [2] [3] and satisfy users' expectations. Therefore, NGWNs will facilitate high-speed wireless internet access and seamless mobility for users [4].

In spite of the expected benefits of NGWNs, there are a set of new challenges presented especially in the presences of high QoS requirements [5]. The heterogeneous network complexity of NGWNs substantiates the challenges. Some of the challenges in NGWNs fall under the following categories: security, accounting and billing, QoS provisioning, traffic and revenue challenge, mobility management, radio resource management (RRM), etc. The challenges create areas for research in NGWNs.

Joint Call Admission Control (JCAC) has been used to address part of QoS provisioning and RRM challenges in NGWNs. JCAC ensures effective allocation of radio resources with the aim of meeting the QoS requirements of users. A pricing aspect can be incorporated in JCAC to enhance network performance, as well as increase revenue for network operators.

## **1.2 RADIO RESOURCE MANAGEMENT AND CALL ADMISSION CONTROL**

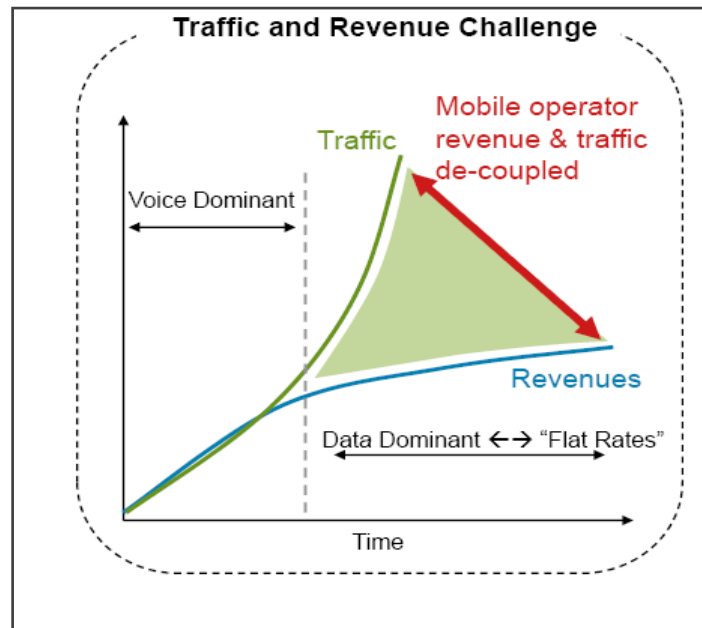
RRM is a vital technique in wireless networks for ensuring efficient utilisation of radio resources [6]. Scarcity of radio resources, user mobility and physical properties of radio channels increases the complexity of RRM in wireless networks [7]. Effective radio resource management techniques improve system throughput and satisfy user expectations [7].

Call Admission Control (CAC) is one of the techniques of RRM. CAC algorithms determine whether a call request should be accepted or rejected based on the available resources in the network. CAC ascertains QoS requirements of the new users and ensures that the QoS of existing users is maintained [8]. A lot of research has been conducted on CAC in homogeneous wireless networks. However, CAC in NGWNs is more challenging than in the homogeneous wireless networks. Therefore, CAC algorithms for NGWNs have to consider some of the following issues; precision and accuracy taking into account the increased complexity of the networks, bandwidth requirements and different QoS requirements [9].

Given that NGWNs will integrate different RATs on the same platform, a joint approach has been adopted for RRM namely Common Radio Resource Management (CRRM). CRRM is intended to achieve efficient utilisation of radio resources in a heterogeneous network environment [10]. Consequently, JCAC has been adopted to deal with admission control requirements in NGWNs. Diverse algorithms have been proposed for JCAC aimed at ensuring efficiency in admission of calls into NGWNs.

## **1.3 TRAFFIC AND REVENUE CHALLENGE IN NEXT GENERATION WIRELESS NETWORKS**

One of the key challenges envisaged in NGWNs is with regard to revenue obtained by network operators. There is an increasing demand for broadband services in NGWNs. Future projections for NGWNs show that with the high increase in the users' demand, there will be a high divergence between network operators' revenue and traffic. Figure 1.1 illustrates this traffic and revenue challenge envisaged for NGWNs.



**Figure 1.1: Traffic and Revenue Challenge in NGWNs [11]**

Demand for data services will dominate over voice service demand in NGWNs. Voice traffic revenue is volume based and thus linearly dependent on utilisation. Data services on the other hand are flat fee based i.e. the norm for charging data service is the use of flat rate pricing where users are given their desired capacity at a fixed charge. Revenue in NGWNs is therefore expected to be decoupled from user traffic. With the continual use of flat rate pricing and continual increase in user traffic, it is envisaged that the revenue obtained by network operators will not match traffic volumes being carried in NGWNs. Network operators will not obtain sufficient revenue from the traffic that they will be carrying.

Solutions are needed to ensure that network operators are able to get reasonable return on investment in NGWNs. Appropriate pricing schemes can motivate users to alter their behaviour as they access network services. Therefore, the user traffic demand function can be altered to have a positive impact on the revenue obtained in NGWNs.

## **1.4 RESEARCH PROBLEM**

Increase in users' demand for network services especially high bandwidth-consuming services and increase in mobile service penetration are envisioned in NGWNs. With independent users' demands, these factors will possibly lead to congestion in NGWNs. High levels of congestion will in turn lead to poor QoS, especially during peak periods.

To mitigate the problem of congestion in NGWNs, some JCAC algorithms integrated with pricing schemes have been proposed for NGWNs. The proposed schemes reduce congestion by varying the service price based on users' demands for network services in the network. However, variation in service prices directly affects operators' revenue in NGWNs. Existing JCAC algorithm incorporating pricing do not consider the effect of price changes on revenue obtained by network operators. Therefore, there is need to investigate the revenue obtained by network operators when a pricing scheme is integrated with JCAC for congestion control in NGWNs.

## **1.5 RESEARCH OBJECTIVES**

The main objectives of this work are:

1. Investigate the effect of incorporating pricing in JCAC algorithm on network operators' revenue while meeting users' QoS requirements in NGWNs.
2. Propose a hybrid pricing model incorporated with JCAC for meeting users QoS requirements and ensuring operators' revenue in NGWNs. The hybrid pricing model is intended to give users flexibility of determining the pricing scheme of their choice.

The specific objectives are:

- Determine user behaviour based on variation in arrival rate in the network as well as average call duration with price variations.
- Compare system performance between dynamic pricing and flat pricing schemes in NGWNs.
- Propose a discount policy for determining new price when dynamic pricing is applied.

## **1.6 METHODOLOGY**

This work focuses on integration of pricing with JCAC in order to investigate the revenue obtained by network operators in an NGWN. A numerical approach is used to simulate a JCAC algorithm in an NGWN using MATLAB.

The numerical approach is based on a multi-dimensional Markov decision process and it is used to model the JCAC algorithm in an NGWN. The performance of the system is evaluated using metrics namely call blocking probability, call dropping probability, average number of calls, user utility, and network operators' revenue derived from the Markov chain model.

Network operators' revenue is analysed using a dynamic pricing scheme. For comparison purposes, simulations are also carried out with flat rate pricing integrated in the NGWN. A traffic distribution over a 24-hour period from recent studies is used for the flat pricing scheme and from this distribution the user demand due to dynamic pricing is obtained. System performance parameters over a 24-hour period are determined in the NGWN for both the dynamic pricing and flat pricing schemes.

Furthermore, a hybrid pricing model is proposed whereby flat and dynamic pricing schemes are integrated to give users flexibility of choosing an appropriate pricing scheme. The analysis is conducted with different percentages of users opting for either dynamic or flat pricing schemes.

## **1.7 SCOPE AND LIMITATIONS**

This study considers JCAC algorithms integrated with pricing in NGWNs. The JCAC algorithm applied is load-based. The pricing mechanism investigated are limited to flat pricing and dynamic pricing based on a 24-hour period.

The NGWN analysed consists of multiple RATs as well as multiple service classes. The number of RATs and service classes in the NGWN are limited to two. Connection-level QoS metrics namely call blocking probability and call dropping probability are used to determine the QoS performance of the network.

A number of factors such as price variation, user mobility, desired QoS, price elasticity of demand etc can affect the way users behave as they access network resources. This analysis is limited to price variation as the variable that affects user behaviour in NGWNs.

Furthermore, the analysis follows a generic architecture for NGWNs. The specifics and dynamics of the NGWN are not considered.

## **1.8 CONTRIBUTION**

This research studies the JCAC functions in NGWNs while focusing on the network operators. It is important for network operators to offer services with good QoS so as to satisfy the users' requirements and at the same time obtain revenue from the services being offered. This research focuses on the effect of pricing on operators' revenue while ensuring QoS requirements of users are maintained.

The major contributions of this work are twofold. First is the evaluation of price variation and its effect on user behaviour and network operators' revenue using dynamic pricing incorporated with JCAC in NGWNs. Secondly, a hybrid pricing model is proposed for NGWNs which integrates flat and dynamic pricing to give users flexibility in determining an appropriate pricing scheme.

Part of the contribution of this work is contained in the author's publication stated below:

**S. Kabahuma** and O.E. Falowo, "Analysis of Network Operators' Revenue with a Dynamic Pricing Model Based on User Behaviour in NGWN Using JCAC," proceedings of Southern African Telecommunication Networks and Applications Conference (SATNAC), Spier Estate, South Africa, September 5-8, 2010.

## **1.9 OUTLINE OF THESIS**

The remainder of this thesis is organised as follows.

Chapter 2 presents background information on NGWNs, JCAC and pricing in wireless networks. A review of related work on pricing integrated with CAC in wireless networks is presented. Finally, a review of related work is made of network operators' revenue in wireless networks.

Chapter 3 describes the analytical approach used in this study. A load-based JCAC algorithm adopted in this research is presented in this chapter. Furthermore, a brief description of Markov decision process focusing on the multi-dimensional aspect is given. Lastly, the performance metrics used in this work are discussed.

Chapter 4 evaluates and analyses a dynamic pricing scheme for NGWNs with a load-based JCAC algorithm. An analysis of users' behaviour with price variation in an NGWN based on average call duration and arrival rate is presented. System performance comparisons are made between the dynamic pricing scheme and flat pricing scheme over a 24-hour period.

Chapter 5 proposes a hybrid pricing model for NGWNs whereby both flat and dynamic pricing are integrated. Analysis of the hybrid pricing model is made when different percentages of users opt for either dynamic pricing or flat pricing.

Finally, chapter 6 concludes the thesis and recommends areas for future work.

## 2. BACKGROUND INFORMATION AND LITERATURE REVIEW

### 2.1 NEXT GENERATION WIRELESS NETWORKS

Wireless networks have evolved rapidly over the past three decades. The first generation (1G) of wireless networks were analog in nature and the second generation (2G) were designed to handle digital technology and circuit switching. There was a growing need for wide range of services as well as higher data rates. The third generation (3G) of wireless networks were designed to meet these requirements. Beside the technologies that belong to the different generations, such as Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS) and 3G, other wireless technologies have been evolving. These technologies include Personal Communication Systems (PCS), Satellite, WLAN and WiMAX. However, the requirements of high data rates have not been achieved and it is envisioned that the NGWNs will meet these requirements

NGWNs are expected to be heterogeneous in nature. They will encompass multiple RATs such as satellite, GSM, GPRS, UMTS, WiMAX, etc, on the same platform. The architecture of NGWN will constitute these different RATs. Figure 2.1 shows an example of the architecture of NGWNs.

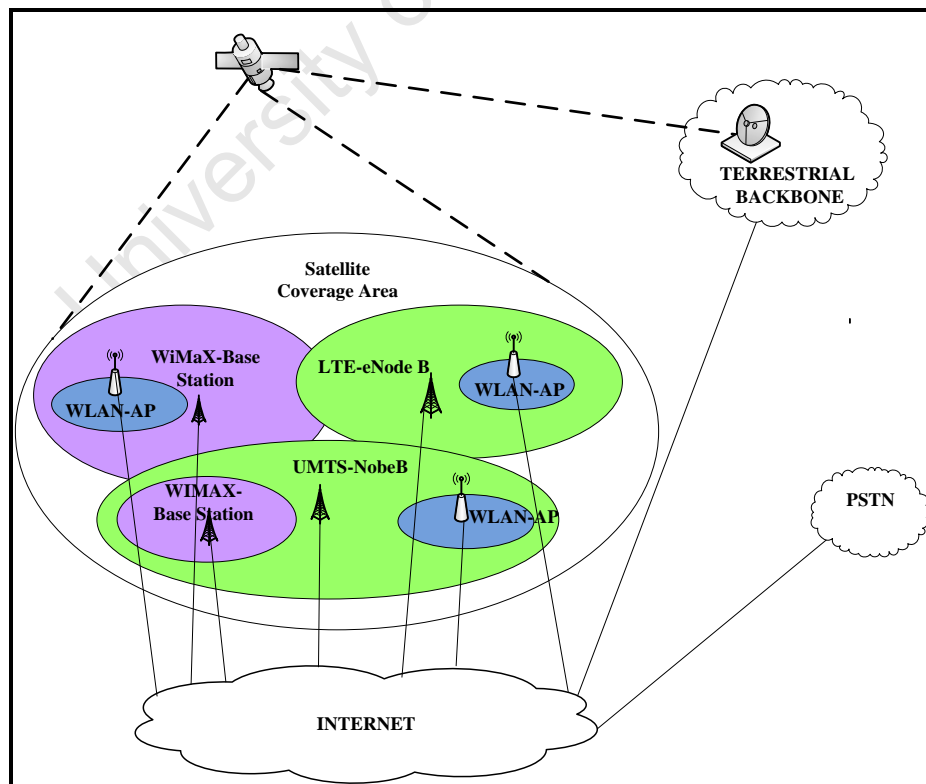


Figure 2.1: An Example of Next Generation Wireless Network Architecture

Migration is inevitable from existing homogeneous wireless networks towards the heterogeneous wireless environment of NGWNs. The motivations for NGWNs are identified as, cost reduction in the backbone, fast and new service creation, controlling QoS of services offered and central management of the whole network [12].

There is increasing user demand for network services, as well as increase in the use of high bandwidth consuming services [11]. NGWNs will be designed to meet the increasing demand for bandwidth. Therefore, NGWNs will be able to support services with high bandwidth requirements such as video calls, live streaming, etc. Additionally, the NGWNs will support multiple services classes and applications with specific QoS requirements [9].

User mobile terminals in NGWNs will have multi interface capabilities to be able to connect to the different access technologies. The mobile terminals will also be expected to support high bandwidth applications that will be offered by NGWN services [13].

NGWNs are intended to provide ubiquitous connectivity to users [7] [8]. Users will have access to network services at anytime from anywhere. Ubiquitous connectivity will result into increased coverage of wireless networks and thus increase users' level of satisfaction.

Ubiquitous connectivity will ensure that users maintain connectivity as they move. Seamless connections and global mobility will be a requirement in NGWNs. A call in one particular RAT must be able to roam and be handed over to another RAT transparently. This phenomenon is known as vertical handoff [9].

One of the requirements in NGWNs is effective RAT selection for the calls that arrive in the network. Selection of the RATs in the NGWNs can be based on service cost, utility function, service class, QoS specification, accessibility and availability of RATs [7] [14]. Users are will be served from the RAT that best suits the service requirements and terminal capabilities.

Packet-level QoS requirements are delay, jitter, data rate, and packet loss probability. Connection-level QoS requirements are new call blocking probability and handoff call dropping probability [14]. In designing NGWNs, the call dropping and call blocking probabilities, as well as the packet delay and packet dropping probabilities should be maintained at target levels [9] [14].

## **2.2 CHALLENGES OF NGWNS**

NGWNS present a number of challenges for designing and implementation [7] [9] [15] [16]. The challenges identified in the literature for NGWNS fall under the following categories:

### **2.2.1 INTERWORKING**

Interworking between different RATs is expected in NGWNS given that the RATs will exist on the same platform. Developing interworking techniques for the different RATs poses a challenge given that the different RATs have been operating independent of each other.

### **2.2.2 SECURITY**

The existing security schemes are designed for a specific service and technology and are therefore inappropriate for the heterogeneous environment of NGWNS [16]. Flexible security applications are required that can be interlinked to different RATs, different services and multimode user devices [16].

### **2.2.3 QoS PROVISIONING**

Given that NGWNS will support multiple services with different QoS requirements and different user QoS requirements, obtaining optimal QoS becomes intricate [9]. Moreover, QoS provisioning in NGWNS will present new problems in mobility management, such as location management for efficient access and timely service delivery, QoS negotiations during intersystem handoffs, etc [17].

### **2.2.4 TRAFFIC AND REVENUE DECOUPLING**

There is a drop in prices for applications which will constitute the services of NGWNS [15]. Nonetheless, user demand for services is envisaged to drastically increase. It is projected that the revenue obtained by network operators will not match the user traffic being carried. Innovative approaches are required to overcome this economic challenge and ensure that network operators are able to obtain sufficient revenue from services they offer in NGWNS. Details of the economic challenge in NGWNS are discussed in Section 1.3.

### **2.2.5 ACCOUNTING AND BILLING**

Multiple service and content providers will constitute NGWNS. Collecting, managing and storing users' account information from different service and content providers will be complex

in NGWNs. Flexible and simple billing and accounting frameworks are required for NGWNs [16].

## **2.2.6 MOBILITY MANAGEMENT**

Location and handoff management need to be done in a seamless fashion among the different RATs. Moreover, NGWNs need to support horizontal handoff, vertical handoff and roaming while ensuring that user QoS requirements are maintained.

## **2.2.7 USER TERMINALS**

The design of a single user terminal that is able to autonomously operate in heterogeneous network environment is one of the identified challenges of NGWNs. Cognitive radio technology will have to be incorporated in user terminals [17] and thus increasing the complexity of the user terminals.

## **2.2.8 RADIO RESOURCE MANAGEMENT**

NGWNs will handle radio resources from the different RATs in a joint manner. This challenge calls for new RRM algorithms operating from a common perspective. Therefore, CRRM algorithms need to be developed for NGWNs [10] [18]. One of the mechanisms that CRRM will have to handle effectively is RAT selection.

## **2.3 RADIO RESOURCE MANAGEMENT IN NGWNS**

RRM is an important factor in wireless networks which handles the scarce radio resources. RRM management ensures that required QoS levels are maintained in wireless networks. RRM is challenging in wireless networks due to user mobility, scarce radio resources and physical properties of radio channels [7].

### **2.3.1 RRM TECHNIQUES**

RRM comprises of the following techniques, handover, power control, call admission control and scheduling [19]:

### **2.3.1.1 Handover Control**

Handover control guarantees user connectivity during mobility. As a user moves from one coverage area to another, handover control ensures that a new connection is established in the new coverage area and the old connection discontinued.

### **2.3.1.2 Power Control**

Increasing power increases network capacity but increases interference which degrades the QoS. A trade-off has to be made between network capacity and interference. Effective power control algorithms ensure that interference is minimised and capacity is maximised [20].

### **2.3.1.3 Call Admission Control**

CAC determines whether there are sufficient network resources for a new call request without compromising the QoS of existing connections. Thus CAC algorithms should be able to predict the load of the network if a new call is admitted [19].

### **2.3.1.4 Scheduling**

Scheduling is needed to decide which packets need to be served since networks allow for packets to share resources such as buffers. Scheduling algorithms are required to prioritize users' traffic to meet various QoS requirements while fully utilising network resources [21].

## **2.4 COMMON RADIO RESOURCE MANAGEMENT**

Radio resources in NGWNS from the different RATs will be handled in pool. CRRM strategies are adopted to ensure efficient utilisation of radio resources in a heterogeneous network environment.

CRRM entity in NGWNS interacts with the RRM entity from the individual RATs. Figure 2.2 shows a representation of CRRM from a functional point of view. CRRM is characterised by two functionalities [22] [23]:

1. Information reporting

RRM entities from the different RATs report relevant information to their controlling CRRM entity. The reported and exchanged information includes static cell information such as cell relations, available QoS, maximum bit rate etc, and dynamic measurements such as received power level, interference measurements etc. The information reporting may also take place between different CRRM entities [22].

## 2. RRM decision support function

The RRM decision support functionality describes how the RRM and CRRM entities interact with each other to carry out decisions.

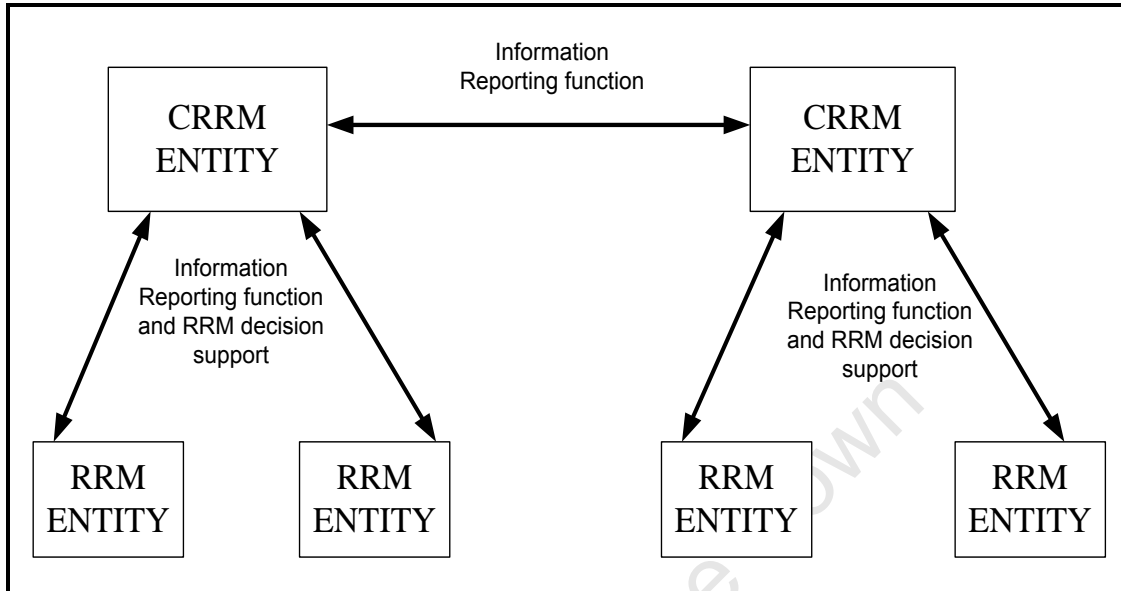


Figure 2.2: CRRM Functional Model [22]

### 2.4.1 ASPECTS OF CRRM

CRRM strategies comprise of two Key aspects namely Joint Call Admission Control and Joint Packet Scheduling (JPS). The two aspects are hereby defined:

#### 2.4.1.1 Joint Call Admission Control

JCAC handles admission control functionality in NGWNs from a common perspective. JCAC ensures that call requests in the NGWN are appropriately allocated without compromising QoS of existing users. Details of JCAC algorithms are discussed in Section 2.5.

#### 2.3.1.2 Joint Packet Scheduling

JPS distributes radio resources among different user sessions/connections. JPS in NGWNs ensures simultaneous traffic over multiple RATs. It is important that JPS algorithms achieve high throughput and fairness.

### 2.4.2 INVESTIGATIONS IN CRRM

Investigations and performance evaluation have been carried out on CRRM strategies for NGWNs. Some examples of research focusing on CRRM are identified below:

Delicado *et al.* proposed a CRRM initial RAT selection algorithm to provide and guarantee users with pre-established QoS satisfaction level based on their contract and service type [24].

Hasib *et al.* proposed an adaptive CRRM scheme using service type, service cost, user mobility, and location information parameters for heterogeneous wireless network [25]. The CRRM scheme minimises the rate of unnecessary vertical handoffs and therefore provides stable communication without degrading call blocking probabilities.

Abuhaija *et al.* proposed a CRRM algorithm to optimise available network resources in multi radio environment based on service requests. This study focused on an NGWN consisting of cellular technologies i.e. GSM, GPRS and 3G [26].

Wu *et al.* evaluated the performance of CRRM algorithms which took into account cell topology, user mobility, radio propagation loss, user traffic generation and admission control for an integrated GSM/UMTS network [27].

Lucas-Estan *et al.* used linear programming techniques to evaluate a CRRM policy that simultaneously assigns to each user an appropriate RAT and its corresponding radio resources [28].

## **2.5 JCAC IN WIRELESS NETWORKS**

JCAC is one of the fundamental techniques for CRRM used for QoS provisioning in wireless networks. It restricts access to the network based on resource availability in order to prevent network congestion and service degradation to already supported users [29]. A new call request is accepted if there are enough idle resources to meet the QoS requirements of the new call without violating the QoS requirements of already accepted calls [29].

JCAC in wireless network is challenging due to users' mobility and variable link quality [30]. In wireless systems, the network should be able to handover an ongoing user's connection from one cell to another when the user moves between cells [7]. Other factors that contribute to the complexity of JCAC in wireless networks are channel multiple interference, channel impairments and limited bandwidth [6].

JCAC algorithms need to be designed with accuracy and precision to minimise the following [31]:

1. False rejections which occur when the algorithm rejects a call although there is a RAT that can meet the call's requirements. In this case capacity is wasted and network operators' revenue is not optimised.
2. False admissions which occur when the algorithm accepts a call although it turns out that the network did not have available capacity for the call. In this case QoS requirements are not met, and user satisfaction is degraded.

The subject of admission control has been extensively studied in homogeneous wireless networks. Issues concerning CAC in homogeneous wireless networks are addressed in [6] [9] [29]. Various examples of CAC algorithms for homogeneous wireless networks have been proposed in the literature. Some of the algorithms are described below:

In [32], Ma *et al.* proposed an algorithm for CDMA cellular networks with the emphasis of reducing dropped calls. Priority is given to soft handoff calls by use of soft guard channels. The numerical results of the algorithm show that the call dropping probability can be reduced to zero; this is done at the expense of the blocking probability.

Fry *et al.* [33] acknowledged the increasing variety and complexity of mobile networks. They used CAC to meet the individual requirements and different traffic types. Predictions for usage for multiple services were made, and this was used to determine the average dropping probabilities for each service. Simulations were done in a CDMA network.

In [34], an admission-level bandwidth management scheme is proposed for broadband wireless networks. The management scheme consists of a CAC component and a pricing component.

Tewari *et al.* [35] presented a framework to explain an adaptive CAC for real-time traffic for wireless networks so as to improve system performance in terms of call blocking probabilities. A CAC algorithm was proposed for real-time traffic in a wired to wireless integrated network.

Ng *et al.* [36] proposed a CAC scheme based on reserve channels for a 3G mobile network using Markov chain. The proposed scheme provides improved channel utilisation and at the same time maintains an acceptable call blocking probability.

Unfortunately, the algorithms and approaches proposed for homogeneous wireless networks do not address the challenges and requirements for admission control in NGWNs [14]. Admission control algorithms and solutions specific to NGWNs are required. This section gives an

overview of JCAC in NGWNs as well as examples of JCAC algorithms that have been proposed in literature.

## **2.5.1 BENEFITS OF JCAC ALGORITHMS**

JCAC algorithms enable the coordination of radio resource allocation from different RATs of an NGWN in an optimised fashion [22]. The specific benefits of JCAC algorithms are identified in [6] [14] as:

### **2.5.1.1 Efficient Radio Resource Utilisation**

JCAC optimises the use of the scarce radio resources among different RATs while providing the required QoS to the users [14].

### **2.5.1.2 Consistent QoS Provisioning**

If a new call cannot be admitted to one RAT, or a handoff call to a target cell in its current RAT due to unavailable radio resources, it will be admitted to another RAT. In this way, JCAC algorithms improve connection-level QoS, by reducing the new call blocking probability and handoff call dropping probability [6] [14].

JCAC also improves packet-level QoS for ongoing calls. If the packet-level QoS requirements cannot be met by a particular RAT, JCAC algorithm will admit the call in another RAT which guarantees the QoS requirements.

### **2.5.1.3 Overall Network Stability**

JCAC algorithms are used to distribute load among the different RATs. If one RAT is overloaded, it may hand over some ongoing calls to another RAT that is not overloaded. In addition, new call requests can be admitted to RATs that are not overloaded. These mechanisms help achieve load balancing among the different RATs, and thus ensure overall network stability [14].

### **2.5.1.4 Enhancement of Users' Satisfaction**

User preferences may be taken into consideration when JCAC algorithms are used. A user may prefer one RAT to another for one reason or another for example service price, QoS offered, services supported, etc. In this case, JCAC algorithms may result into enhancing users' satisfaction [14].

#### **2.5.1.5 Guarantee Signal Quality**

JCAC is essential to guarantee the signal quality in interference limited wireless networks. In some wireless networks for example WCDMA, the more users the network admits, the more deteriorated is the signal quality. JCAC schemes will therefore admit a users only if it can maintain a minimum signal quality to the admitted users in the network [6].

#### **2.5.1.6 Minimise Transmission Rate**

JCAC schemes can be used to guarantee a minimum transmission rate in wireless networks for data services. Ensuring a minimum transmission rate is intricate in wireless networks because of limited bandwidth, user mobility and co-channel interference [6].

#### **2.5.1.7 Increase Network Operator's Revenue**

JCAC schemes can be used to increase the network operators' revenue based on rewarding and penalising admitted calls [6].

#### **2.5.1.8 Prioritisation of Service Classes**

JCAC schemes can be used to achieve prioritisation of specific services or classes. For example voice services are considered to have high priority than data services. CAC schemes will therefore ensure than higher priority is given to voice services than to data services [6].

#### **2.5.1.9 Ensure Fairness**

Fairness among different users in the same class and users of different classes can be achieved with JCAC. JCAC can be employed to admit or reject users based on the allocated resources such that no user class dominates the available resources [6].

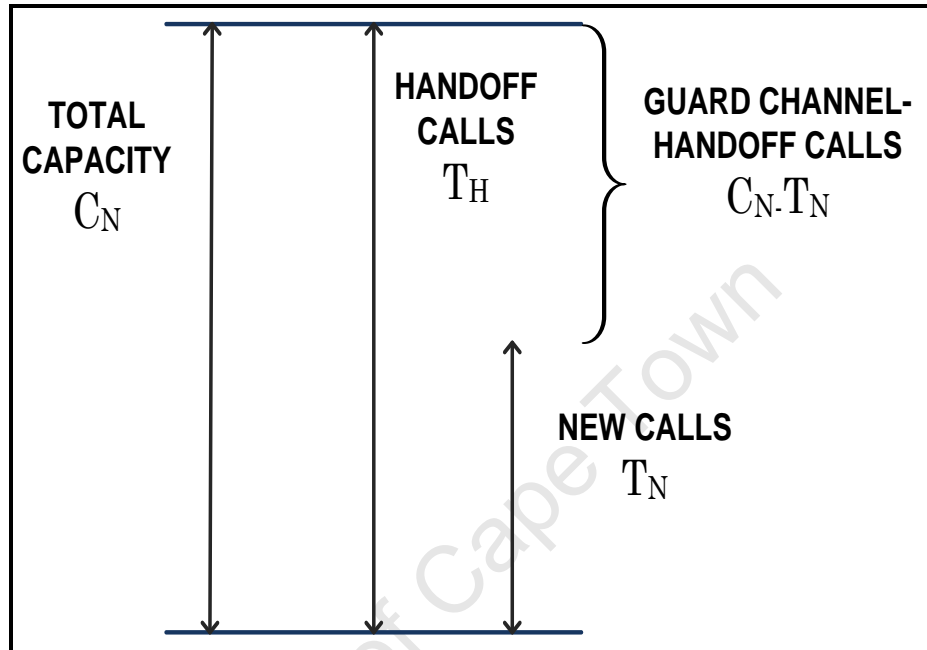
### **2.5.2 DESIGN APPROACHES FOR JCAC ALGORITHMS**

JCAC algorithms are designed based on different approaches. Niyato *et al* [9] points out some of the common approaches used when designing JCAC algorithms:

#### **2.5.2.1 Guard Channel Approach**

Prioritisation of calls may be required. To achieve this some channels (resources) are reserved for the higher priority calls. The reserved capacity is referred to as guard channels. For example handoff calls are considered to have a higher priority over handoff calls. It is more annoying to customers to have a call dropped than blocked [37].

Figure 2.3 illustrates the guard channel approach considering handoff and new calls. Given that the total number of channels is  $C_N$  and  $T_N$  is the threshold for low priority calls, and  $T_H$  is the threshold for high priority calls where  $C_N = T_H$ ; then the guard channels are  $(C_N - T_N)$ . A new call is accepted if the total channels utilised by existing calls is less than  $T_N$ , and handoff calls are accepted as long as there is available capacity.



**Figure 2.3: Bandwidth Reservation**

### 2.5.2.2 Collaborative Approach Based on Estimation

Information is exchanged among neighbouring cells for resource allocation and the admission call decision is made locally. Probability estimations are made for call dropping and call blocking. JCAC decisions are made based on the estimated probabilities.

### 2.5.2.3 Non-collaborative Approach Based on Prediction

Resource reservations are based on local information in a home cell, and this information is used to predict resources needed in the future. This approach is desirable in cells with high user mobility e.g. pico cells, and exchanging information among cells for resource reservation would incur significant control over head.

### 2.5.2.4 Mobility Based Approach

This approach exploits user mobility information for efficient admission control. User mobility information such as velocity, call holding time, current direction, etc, is used to predict/estimate future resource requirements. This approach is suitable for micro cells.

### **2.5.2.5 Pricing Based Approach**

A pricing scheme is required that will ensure that user satisfaction is met as well as maximize revenue for network operators. However, ensuring user satisfaction might not necessarily warrant maximum revenue for network operators. Therefore, price based JCAC algorithms should be designed to determine an optimal operation point. Dynamic pricing schemes have also been determined whereby service prices are increased or decreased depending on availability of network resources, purposely to ascertain QoS and efficient use of the resources.

## **2.5.3 REQUIREMENTS FOR JCAC ALGORITHMS**

It is important that JCAC algorithms meet certain requirements so as to perform effectively. The requirements for JCAC algorithms identified in the literature are simplicity, multi service, scalability, high execution speed stability and adaptivity:

### **2.5.3.1 Simplicity**

A simple JCAC algorithm will have a low computational overhead and thus will not incur additional delay [14]. However, a very simple JCAC algorithm may not achieve high radio resource utilisation [29] [14]. Therefore, a trade-off needs to be made between simplicity and effectiveness of the JCAC algorithms.

### **2.5.3.2 Multi service**

JCAC algorithms should be able to handle multiple service classes given that NGWNs will support multiple classes [14].

### **2.5.3.3 Efficiency**

JCAC algorithms are expected to be efficient to guarantee QoS requirements of accepted calls and achieve high system utilisation [14].

### **2.5.3.4 Scalability**

Growth is inevitable in telecommunications systems. Therefore, JCAC algorithms should be able to handle increase in network capacity and number of RATs in an NGWN. In addition, JCAC algorithms should minimise the amount of information being exchanged in spite of network expansions [14].

### **2.5.3.5 High-execution speed**

JCAC algorithms need to have a high execution speed given that admission control takes place in real time. High execution speed will overcome additional delays and thus enhance QoS in NGWNs [14].

### **2.5.3.6 Stability**

JCAC algorithms need to be insensitive to short term network traffic fluctuations [29]. JCAC algorithm reacting too fast to load changes may result into unstable conditions. Therefore, JCAC algorithms should ensure network stability. For example network instability may occur when certain RATs are over loaded whereas others are not. JCAC algorithms can overcome such a situation by achieving load balancing amongst the RATs [14].

### **2.5.3.8 Adaptivity**

JCAC algorithms are required to react to changes in network conditions. Adaptive JCAC algorithms result into effective radio resource utilisation [29].

## **2.5.4 CHALLENGES FOR JCAC ALGORITHM DESIGN**

Admission control algorithms for NGWNs are more complex than those for homogeneous wireless networks. Therefore, some challenges are faced in designing JCAC algorithms. The two key challenges in designing JCAC algorithms are identified as heterogeneous networking and support for multiple service classes.

### **2.5.4.1 Heterogeneous Networking**

Design of JCAC algorithm is complex because of the heterogeneous characteristic of NGWNs. JCAC algorithms are expected to perform admission control decisions to multiple RATs with varying features such as coverage air interface, cell size etc [8]. Moreover, JCAC algorithms are expected to handle vertical handover which does not exist in homogeneous wireless networks.

### **2.5.4.2 Support for Multiple Service Classes**

NGWNs will accommodate multiple service classes as well as users with different QoS requirements. JCAC algorithms should be designed to handle different service classes and meet different QoS requirements from different applications [9].

## **2.5.5 RAT SELECTION CRITERIA IN JCAC**

RAT selection strategies adopted by JCAC can be based on user preference or network operator preference.

NGWNs will consider user preferences when making JCAC decisions. User will indicate their preference for a particular RAT when they make a call request. Some of the factors that will determine user preference are least service cost, minimum delay, widest coverage, least battery power consumption, highest network security, maximum data rate etc [14].

RAT selection in JCAC approaches can be based on operators' preferences. Some of the operators' preferences are revenue maximisation, uniform load balancing, optimal network utilisation, and minimisation of call blocking and call dropping etc [14].

Multi Criteria Decision Making (MCDM) JCAC algorithms may take into consideration several factors from either the user preferences or network operator preference when making RAT selections. MCDM RAT selections are thorough and preferred over single criteria RAT selection which may be trivial [8]. However, MCDM RAT selection is complex.

JCAC algorithms have been categorised into the eight different groups based on RAT selection criteria. The different categorises of JCAC algorithms identified in [14] as load-based, random selection-based, service class-based, path loss-based, service cost-based, computational intelligence-based, utility/cost function-based and network layer-based.

### **2.5.5.1 Load-Based**

Load-based JCAC algorithms admit calls to the least loaded RAT in an NGWN, so that the load is almost the same for all the available RATs [14]. High network stability is achieved with the load-based algorithm. However, load-based JCAC algorithms may not meet users' satisfaction levels.

### **2.5.5.2 Random Selection-Based**

Under random selection, calls are admitted into any available RAT in an NGWN [14]. This approach is simple, but is ineffective because it results into high blocking and low network utilisation.

### **2.5.5.3 Service Class-Based**

Based on the fact that some RATs are optimised to support specific services, some JCAC algorithms maybe designed to be service class-based. Service class-based JCAC give high QoS. However, they are disadvantageous because they may result into highly unbalanced load [14].

### **2.5.5.4 Path loss-Based**

With the path loss based JCAC, calls are admitted to the required RAT based on path loss measurements. These JCAC algorithms result into low bit error rate and high throughput. However, high frequency of handover can be experienced with this algorithm.

### **2.5.5.5 Service Cost-Based**

In the service cost-based JCAC algorithm, calls are admitted to the least expensive RAT such that the users incur the least service cost in an NGWN [14]. Service-cost based JCAC are advantageous because they reduce overall service cost. However, they cause highly unbalanced load.

### **2.5.5.6 Computational Intelligence-Based**

Computational intelligence based JCAC algorithms apply a computational intelligent technique to determine the appropriate RAT in which to admit a call [14]. The commonly used intelligent techniques are fuzzy logic, fuzzy neural and generic fuzzy Multiple Attribute Decision Making (MADM) [8]. Despite being complex, these algorithms are highly efficient and result into high user satisfaction.

### **2.5.5.7 Utility /Cost Function-Based JCAC**

Incoming calls are admitted into a particular RAT based on a utility or cost function [14]. These algorithms are very efficient and they improve satisfaction. However, they are usually complex and incur into high computational overhead.

### **2.5.5.8 Network Layer-Based**

In overlaid networks, network layer-based JCAC algorithms admit calls into layers starting from upper layers. If the current layer is overloaded, JCAC algorithm will try the next lower layer. This algorithm is simple, but it can result into highly unbalanced load [14].

### **2.5.6 EXAMPLES OF JCAC ALGORITHMS**

A lot of research has been done to devise effective JCAC algorithms for NGWNs. Examples of JCAC algorithms that have been proposed in the literature are discussed below:

Yu *et al.* proposed an Optimal Joint Session Admission Control (OJSAC) algorithm [38]. This algorithm was aimed at maximising revenue while satisfying several QoS requirements in an integrated network of WLAN and CDMA (Code Division Multiple Access) access networks.

Jiajia *et al.* [39] proposed a Hierarchical Joint Call Admission Control (HJCAC) algorithm for multi service heterogeneous wireless networks. The results obtained showed that acceptance ratio was enhanced, and selection of the most appropriate network for incoming call was achieved.

Falowo *et al.* [40] proposed an Adaptive bandwidth management and Joint Call Admission Control (AJCAC) algorithm to enhance system utilisation and connection-level QoS in heterogeneous cellular networks supporting multiple classes of calls such as voice and video.

In [41], a dynamic guard margin algorithm was proposed for connection admission control for heterogeneous wireless networks. In this scheme, resources are effectively allocated by implementing dynamic resource reservation and rate adaptive CAC algorithm which results in a low connection dropping probability.

A threshold CAC system based on Markov decision process and sensitivity analysis is proposed for NGWNs by Chen *et al.* [42]. The Markov decision process is used to derive an optimal CAC policy for predetermined goals. The sensitivity analysis is used to reduce the effort of unnecessary re-computation of the CAC policy when traffic conditions vary.

Weidong *et al.* [43] proposed a JCAC algorithm based on inter-link load balance to overcome pseudo congestion and improve network performance in NGWNs. The algorithm aims to balance uplink and downlinks of NGWNs. Simulations were carried out for an integrated WLAN and High Speed Packet Access (HSPA) networks.

## **2.6 PRICING IN WIRELESS NETWORKS**

From an economic point of view, pricing plays an important role in trading any resource or service. The most important objective for trading is to provide benefits to both the buyers and

sellers. The price which maximises the revenue of the seller should be set, while the highest satisfaction of the buyers is assured [44].

Telecommunication services such as voice, video and data are considered as economic goods which need to be priced appropriately [45]. Pricing is a mechanism used by network operators to recover cost such as operational cost, infrastructure cost, etc, for the services offered to subscribers.

Pricing is not only used for cost recovery, but also for congestion control. Pricing schemes can be developed to take into account resource usage and thus control congestion levels in a network [46]. Pricing schemes can produce just the right incentives to ensure that customers do not waste important radio resources [45]. Therefore, pricing acts as a control mechanism to shape user demand [45].

Pricing can be used as a means of communication between the users and the network operators. The way that users respond to prices can indicate to the operator something about the users' preferences. For example, the users' choice of pricing profile can indicate to the network operator when users intend to overly use the network. This information can be used by the network operator to appropriately dimension network capacity and allocate resources when they are most needed [45].

## **2.6.1 FACTORS AFFECTING PRICE**

A number of factors will determine the price that network operators charge users. Some of these factors include cost of spectrum, cost of delivering service, competition and demand for a service.

### **2.6.1.1 Cost of Spectrum**

Spectrum regulators in each country charge operators a given amount for the frequency spectrum allocated to them, and in some cases this price is dependent on the deployment of the spectrum. Depending on the cost of the spectrum operators will add their mark-ups to operate at a profit.

### **2.6.1.2 Cost of Delivering a Service**

A number of costs are incurred before a service is availed to customers. For example, cost of equipment, taxes on calls, logistics, etc. These costs will contribute to the eventual price of a service.

### **2.6.1.3 Competition**

Competition is a major driving factor in determining the price that will be charged to customers. Users will usually opt for a provider who offers the highest satisfaction at the lowest price. A network provider might therefore reduce its prices to attract more users and gain higher revenue; this will have an impact on other providers who might also decide to reduce their prices [44].

### **2.6.1.4 Demand for Services**

If the demand of services is high, then the price of the services will increase. On the other hand if the demand is low, lower prices will be charged to attract users [44].

## **2.6.2 REQUIREMENTS OF PRICING SCHEMES**

Pricing in wireless networks is aided by different kinds of pricing schemes. Different criteria can be used by network operators to determine the effectiveness of a pricing scheme. These criteria are identified in [47] and include compliance with existing technologies, measurement requirements for accounting and billing, support for congestion control, provision of individual QoS guarantees, network efficiency, economic efficiency, and economic efficiency:

### **2.6.2.1 Compliance with Existing Technologies**

Pricing schemes that are compatible with existing technologies are easier to implement than those that are not. This requirement is vital for NGWNs whereby pricing schemes will need to be compatible with multiple RATs.

### **2.6.2.2 Measurement Requirements for Accounting and Billing**

This criterion indicates the complexity of a pricing scheme. Some pricing schemes do not require measurements, thus simplifying the accounting and billing processes. Other pricing schemes however, may require extensive measurements, and thus complicate the accounting and billing processes.

### **2.6.2.3 Support for Congestion Control**

Pricing schemes maybe designed to have the capability of influencing user behaviour and exploit the price sensitivity of users. In this way the pricing scheme will control network congestion.

### **2.6.2.4 Provision of Individual QoS Guarantees**

Pricing schemes may support QoS guarantees to individual users. Pricing schemes allow users to carry out personal QoS decisions [48].

#### **2.6.2.5 Network Efficiency**

A trade-off needs to be made between network utilisation and optimal QoS. High network utilisation may be a preference for network operators, but it degrades system performance. Pricing schemes can be designed to give an optimal level of network utilisation with adequate QoS.

#### **2.6.2.6 Economic Efficiency**

Users regard a service as being economically efficient if they obtain high satisfaction at a low cost. Pricing schemes may charge low prices so as to increase user satisfaction. The economic efficiency of a pricing scheme aims to achieve high user satisfaction levels.

#### **2.6.2.7 Social Fairness**

Pricing schemes should ensure that social fairness is achieved. For example a pricing scheme may be regarded as being unfair if it denies access to users who are unable to pay for the services.

#### **2.6.2.8 Pricing Time Frame**

Pricing schemes which support short time frames (minutes and seconds) increase flexibility because they are able to respond to varying network conditions and thus control congestion. However, short time frames may be undesirable from a user's point of view in regard to network efficiency. Long term frames on the other hand, do not enable pricing schemes to deal with congestion control.

### **2.6.3 CATEGORIES OF PRICING SCHEMES**

The different categories of existing pricing schemes identified in literature are flat pricing, dynamic pricing, priority pricing, paris-metro pricing, smart market pricing, edge pricing, expected capacity pricing, effective bandwidth pricing and proportional fairness pricing. These categories of pricing schemes are explicitly discussed below:

#### **2.6.3.1 Flat Pricing**

In flat pricing, as the name suggests, a constant price is used for services across the network regardless of traffic conditions. The price may be fixed for all periods or fixed at specific periods of the day or week [49]. For example, in time-of-day pricing where a fixed higher price is charged during working hours than at night. In day-of-the-week pricing, a fixed cheaper price is charged during the weekends.

Flat pricing has been found to be simple and convenient [44], and for this reason it is widely used in many networks [50]. Furthermore, flat pricing is appropriate for stimulating new services in the market [51].

However, flat pricing does not allow the network to influence the way users behave over short time frames (minutes or less) when congestion is most likely to occur [47]. Under flat pricing scheme users may request or utilise more network resources than what they actually need. Flat pricing therefore results into wastage of network resources.

### **2.6.3.2 Dynamic Pricing**

Dynamic pricing schemes change the price of services based on resource usage. Prices are changed over short periods of times i.e. in the range of minutes or less [49]. The price is increased with increase in demand. Increasing service price during peak hours (congestion periods) will discourage users from accessing the network or holding network resources for long periods [52].

Dynamic pricing is favourable given that it causes users to value the services being offered by the network operators and thus avoid wastage of resources [45]. Consequently, dynamic pricing can be used to alleviate network congestion and subsequently yield more revenue [53].

### **2.6.3.3 Priority Pricing**

Users are required to state the value of their traffic by selecting a priority level. Traffic belonging to high priority classes is charged higher than belonging to lower priority [50]. During periods of congestion, traffic is transmitted by priority level; low priority traffic is delayed or dropped [47].

### **2.6.3.4 Paris-Metro Pricing**

Paris-metro pricing (PMP) is similar to the flat pricing mechanism. Unlike in flat pricing where the network is looked at as a whole, in PMP the total network capacity is subdivided into sub networks with each sub network implementing flat pricing [47] [50].

The advantages of PMP are its simplicity, and ability to achieve traffic management through encouraging users to separate themselves into different classes. However, PMP results into instability. If one sub network is preferred over other sub networks, this will result in congestion in the preferred sub network and thus cause network instability [47].

### **2.6.3.5 Smart Market Pricing**

In addition to a fixed price to cover connection cost and a charge per packet to cover an incremental cost per packet, an additional cost is added known as usage charge when the network is congested [47]. This additional charge is determined through an auction. Smart marketing encourages network and economic efficiency. Bandwidth is allocated to users based on bids, and it is given to those users whose traffic is most socially valuable [47].

### **2.6.3.6 Edge Pricing**

In edge pricing, charges are computed based on congestion and routes. Basing the charge on the expected distance between source and destination, allows the charge to be applied at the edge of the network, either at the source or at the destination. Prices can be communicated from any place in the network [47].

### **2.6.3.7 Expected Capacity Pricing**

In this scheme, the user specifies their required capacity. The user is then charged based on the expected capacity that the network provisions and on actual usage. The network is expected to provision for a user's expected capacity using CAC schemes and to police traffic to ensure conformance.

Assuming that the network fulfils this function, all users can gain access to the network irrespective of their ability to pay, making this scheme socially fair.

### **2.6.3.8 Effective Bandwidth Pricing**

In effective bandwidth pricing, the users are charged based on the effective bandwidth they use; i.e. based on real time bandwidth with QoS constraints [47]

### **2.6.3.9 Proportional Fairness Pricing**

The proportional fairness pricing (PFP) incorporates the notion of fairness in allocation of network resources. Resource allocation is fair if it is proportional to the users' willingness to pay (WTP). Every user who is willing to pay is allocated some bandwidth, and charged based on this criterion. Billing and measurements are not required for this scheme since each user is charged based on the indicated WTP [47].

## 2.6.4 USER PRICE SENSITIVITY

Users of commodities and services are inherently sensitive to price. The law of demand states that a rise in price with no other change will cause a decrease in the quantity demanded [54]. A representation of the demand curve is shown in Figure 2.4.

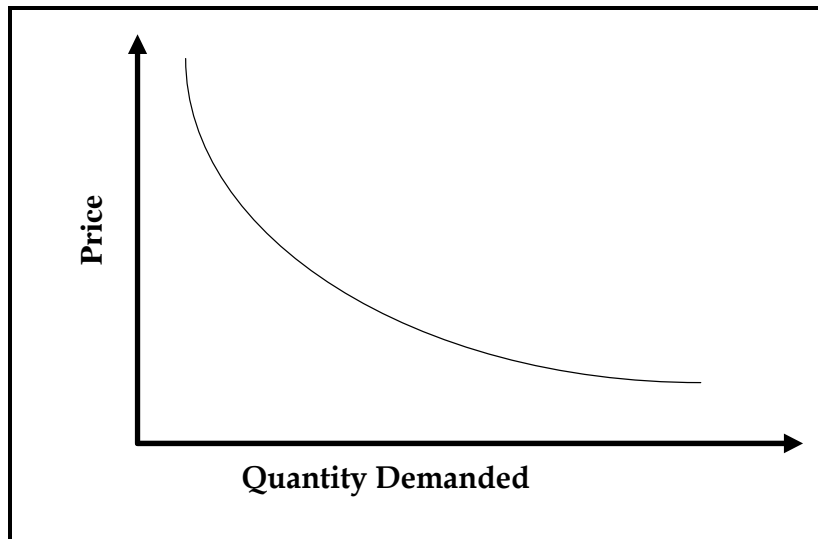


Figure 2.4: Demand Curve

Price elasticity of demand is the ratio of percentage change of the quantity demanded to percentage change of price. Price elasticity of demand is used to give the measure of user responsiveness of a change in the quantity demanded for goods or services due to a change in the price [54] [55] [58]. The greater the extent to which demand falls as price rises, the greater the price elasticity of demand [54] [55]. The concept of price elasticity of demand has been used to analyse user behaviour in telecommunications network. For example, Yamori *et al.* used price elasticity of demand to study user behaviour in IP broadcast services [55].

User demand functions have been used in literature to study and determine user behaviour with price variation. The demand functions express user demand as a function of price. The demand functions identified in the literature express user demand as a decreasing exponential function of price. Examples of demand functions appear in [53] [56] [57].

The measure of how sensitive users are to a given price will determine how they will respond to price variation. A Price Sensitivity Meter (PSM) was devised by van Westendorp in 1979 which states that there is an upper limit where users consider a commodity to be extremely expensive, and a lower limit where they question its quality [58] [59] [60]. The PSM indicates that there is a range of prices that users in a given market are willing to pay. PSM has been

found valuable in estimating market demand [58]. Furthermore, the PSM can be used to determine user responsiveness to variation in price for services and products.

## **2.7 PRICING INTEGRATED WITH CALL ADMISSION CONTROL**

CAC can guarantee that the packet-level QoS requirements are not degraded as a result of new incoming calls [34]. CAC is efficient in maintaining packet-level QoS especially during periods of congestion. However, it is not efficient in improving connection-level QoS. During periods of congestion, the new call blocking probabilities and handoff call dropping probabilities escalate to high values.

CAC algorithms functioning independently do not offer incentives to users to use the radio resources in a rational and efficient manner [34]. Monetary incentives are used so as to affect the way users access the limited radio resources. In this way, CAC is used with pricing so that effective utilisation of the resources is achieved.

Furthermore, integrating pricing with CAC can result into improved QoS by lowering call blocking and call dropping probabilities during peak periods. The principle of dynamic pricing can promote rational and efficient use of network resources by influencing users' behaviour. Pricing can discourage users from using the network when it is congested when a high price is used for services, and increase the user-demand when the network is underutilised. Pricing can help relieve the problem of congestion and provide efficient resource management [34].

Al-manthari *et al.* carried out a study on CAC using dynamic pricing in a Broadband Wireless Access System (BWAS), characterised by multiple QoS classes with multiple bandwidth requirements [34]. Dynamic pricing is employed during all network conditions. In this way, the scheme is able to maximise the utilisation when the network is underutilised as well as prevent congestion when they are over utilised. This work is limited to a homogeneous network environment and does not take handoff calls into consideration.

Viterbo *et al.* used dynamic pricing for connection-oriented services in wireless communication systems [51]. They modeled the user demand and call duration as function of service price and employed an optimal linear pricing scheme. The results they obtained showed that by varying prices with network usage, better use of available bandwidth is achieved, as well as greater revenue to the network operators and improved QoS to users. Despite modeling a user demand

function, user demand pattern is not considered and therefore overall revenue obtained in the network over a given period is not ascertained.

E.D Fitkov-Norris proposed a dynamic pricing algorithm which he uses in a GSM network [61]. Dynamic pricing was implemented over a period of 27 hours. There was a reduction obtained in the percentage of blocked calls during peak hours and network usage was shifted towards off-peak hours. The simulations in this work were limited to the GSM network considering only voice calls.

Falowo *et al.* used dynamic pricing to achieve load balancing across the different RATs in a heterogeneous wireless network with JCAC [62]. The results obtained showed that better performance was achieved, as well as lower new call blocking probabilities and handoff call dropping probabilities were attained. This work does not examine revenue obtained by network operators.

Due to the limitations in the studies made on CAC integrating pricing, there is need for further investigations especially for NGWNs. Most of the work that has been done is under homogeneous wireless networks and is inappropriate for NGWNs. Moreover, the analyses identified on pricing incorporated in JCAC for NGWNs do not take into account the revenue obtained by network operators.

## **2.8 OPERATORS' REVENUE**

Obtaining high revenue is one of the key objectives for network operators. It is vital that as network operators offer services to users they are able obtain profits to guarantee their sustainability. Investigations and evaluations have been carried to ensure that network operators maximise revenue in wireless networks.

Yilmaz *et al.* utilise admission control algorithms designed for revenue optimisation with QoS guarantees [63]. An optimal price that will yield the required maximum system revenue is derived. The determined optimal price remains static allowing users to be charged with the same rate while roaming. A given set of parameters such as arrival rate, departure rate, network load etc are used to determine the optimal price. This work disregards dynamic pricing and instead opts for purely static pricing. This approach may be unfair to users given that it aims at obtaining the maximum possible revenue. This analysis is limited to a homogeneous cellular network that supports multiple service classes.

In [30], an investigation is made in a homogeneous network on the revenue obtained by operators. The pricing scheme applied aims at maximising the revenue obtained and the scheme can be designed to always generate maximum possible revenue for any network load.

The schemes discussed above aim at obtaining maximum revenue in wireless networks. However, obtaining maximum revenue may be done at the expense of users, whereby users are exploited with high charges. It is important for pricing schemes to offer reasonable revenues to network operators while exhibiting fairness to the users.

Limited work has been done in determining and optimising network operators' revenue in NGWNs. There is need to ensure that network operator obtain required revenue in NGWNs while ensuring that QoS requirements are met.

## **2.9 CHAPTER SUMMARY**

This chapter has given a brief discussion of characteristics and the challenges of NGWNs. An overview was presented on RRM in wireless networks as well as CRRM strategies for NGWNs. JCAC a key aspect of CRRM was also discussed highlighting its benefits, challenges, design approaches, requirements and RAT selection criterion. The subject of pricing in wireless networks was presented. It was identified from the literature that pricing has been incorporated with CAC to enhance QoS. However, most of the related work on pricing integrated with CAC was identified for homogeneous wireless networks. Therefore, studies made on network operators' revenue in NGWNs are limited. Moreover, the work done with pricing incorporated in JCAC for NGWN does not determine the revenue obtained by network operators. This thesis will investigate the effect of pricing and JCAC in NGWNs on network operators' revenue while maintaining connection-level QoS.

### 3. ANALYTICAL MODEL

This chapter discusses the analytical model applied in this work and the different performance parameters used to study JCAC integrated with a pricing component in NGWNs. A numerical approach based on Markov decision process is used to evaluate the system performance with a load-based JCAC algorithm.

#### 3.1 HETEROGENEOUS NETWORK ENVIRONMENT

It has been noted that NGWNs will be heterogeneous in nature. As illustrated in Figure 3.1, a given coverage area will therefore contains multiple RATs. A RAT in a given coverage area denoted by  $RAT_j$  where  $j=1, 2, 3, \dots, Y$  and  $Y$  represents the total number of RATs in the NGWN in a given coverage area.

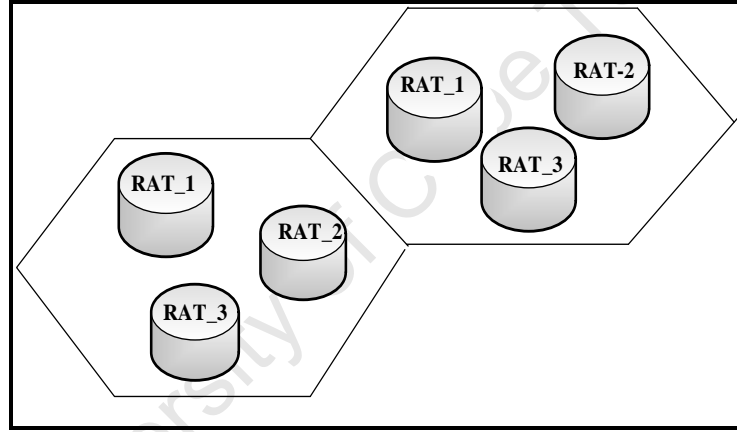


Figure 3.1: Coverage Area in NGWN

Each RAT has a maximum amount of radio resources that it can offer, which represents the available capacity of the RAT. In practice, radio resources can be offered in terms of timeslots, code sequence or frequency channels. In this analysis, the capacity offered is considered in terms of basic bandwidth units (bbu) [64] where each RAT has a maximum amount of bbu that it can offer represented by  $C_j$ . The total capacity of the system,  $C_{total}$ , is the summation of the available capacity in each RAT. Therefore:

$$\begin{aligned} C_{total} &= C_1 + C_2 + C_3 + \dots + C_j \\ &= \sum_{j=1}^Y C_j \end{aligned} \quad (3.1)$$

Next generation wireless networks will be able to support multiple service classes such as voice, video, data etc to meet different users' requirements. The service classes are denoted by class\_  $i$ , where  $i=1, 2, 3, \dots, X$  and  $X$  is the total number of service classes that can be supported by the NGWN.

Bandwidth requirements are dependent on the type of service as well as the QoS being offered. Therefore, bandwidth requirements will vary from one service class to another. It is assumed that a call in a given class\_  $i$  will require a given amount of bbu represented by  $b_i$ .

### 3.2 LOAD-BASED JCAC ALGORITHM

In [65], three JCAC algorithms namely service-based, random-based and load-based were analysed and compared. The results showed that the load-based algorithm out performs the other two algorithms. A load-based JCAC algorithm is therefore used in this work.

The load-based JCAC algorithm admits calls to the least loaded RAT in an NGWN [65]. The load-based JCAC algorithm distributes calls to the respective RATs based on call arrival rate and the capacity of individual RATs.

Given that  $\lambda_i$  represents the arrival rate of class\_  $i$  into the network, and  $\lambda_{ij}$  represents the arrival rate of class\_  $i$  calls into the respective RATs of the NGWN, Figure 3.2 shows a representation of a load-based JCAC algorithm.

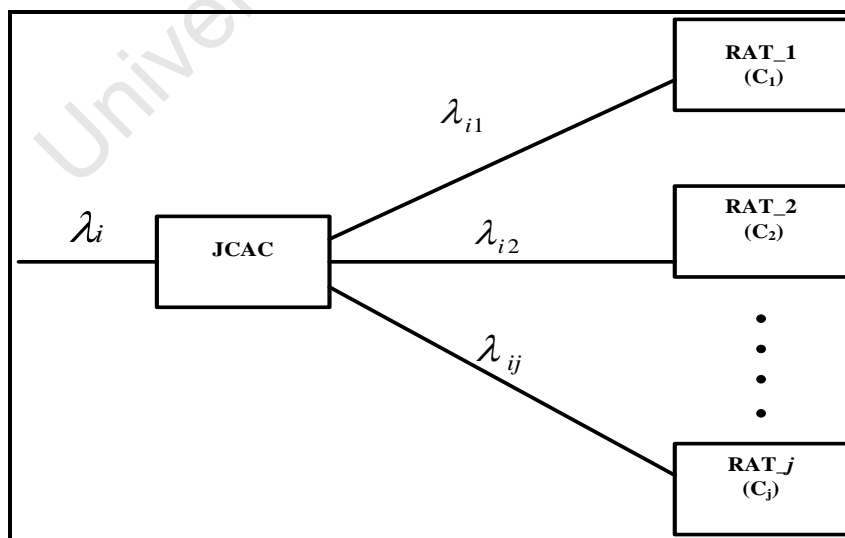


Figure 3.2: JCAC Algorithm

### 3.2.1 CALL ARRIVAL RATE IN LOAD-BASED JCAC ALGORITHM

Call arrival rate of different classes of calls indicates users' demand for network resources; if the arrival rate is high, the demand is equally high. It is assumed that the arrival rate follows a Poisson distribution [29] [64] [36].

The arrival of calls in the network is distributed to the different RATs based on the load that each RAT can handle. The calls arriving in the network are categorised as either new calls or handoff calls. Let  $\lambda n_i$  denote the arrival rate for new class\_  $i$  calls in the system and  $\lambda h_i$  denote the arrival rate of handoff class\_  $i$  calls in the system.  $\lambda n_{ij}$  denotes the arrival rate for new calls in class\_  $i$  in RAT\_  $j$  and  $\lambda h_{ij}$  denotes the arrival rate of handoff calls in class\_  $i$  in RAT\_  $j$ .  $\lambda n_{ij}$  is computed as follows:

$$\lambda n_{ij} = \left( \frac{C_j}{\sum_1^j C_j} \right) \times \lambda n_i \quad (3.2)$$

Similarly, for handoff calls,

$$\lambda h_{ij} = \left( \frac{C_j}{\sum_1^j C_j} \right) \times \lambda h_i \quad (3.3)$$

### 3.3 BANDWIDTH RESERVATION POLICY

In order to meet QoS requirements and cater for higher priority calls, a bandwidth reservation policy is applied. The bandwidth reservation policy follows after the guard channel approach discussed in Section 2.5.2.

In view of the fact that customers are more sensitive to call dropping than to call blocking, handoff calls are given higher priority over new calls. Therefore, more bandwidth is reserved for handoff calls than for new calls [7] [37].

Some call classes are given more priority over others depending on the type of service being offered. For example delay-sensitive services require higher priority over non delay-sensitive services. It therefore necessitates more capacity to be reserved for the higher priority type of calls.

From the total capacity,  $C_j$ , of a given RAT thresholds are set for both new and handoff calls belonging to different service classes. Let  $Tn_{ij}$  denote the threshold for rejecting new calls in class  $i$  in RAT  $_j$ , and  $Th_{i,j}$  denote the threshold for rejecting handoff calls in class  $i$  in RAT  $_j$ . Figure 3.3 gives a representation of how the bandwidth reservation policy applied in NGWNs.

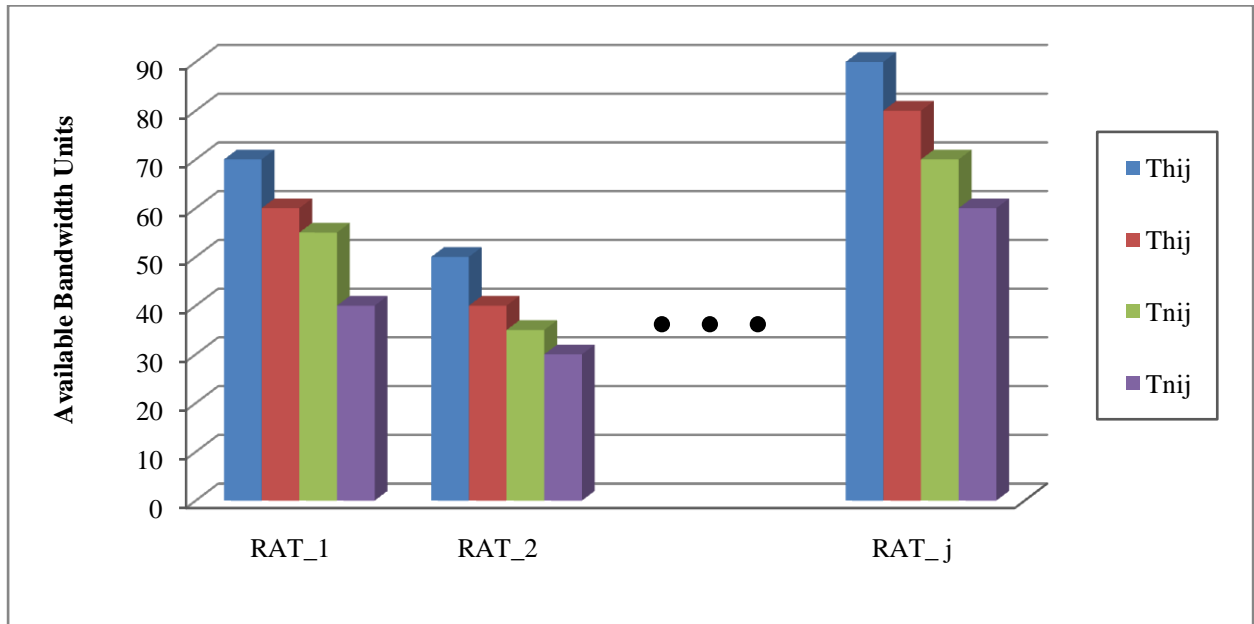


Figure 3.3: Bandwidth Reservation in an NGWN

### 3.4 MARKOV DECISION PROCESS

Markov decision process offer analytical models for performance evaluation and reliability analysis. The Markov decision process is used to design analytical models that are state space [67]. A Markov chain therefore consists of a set of states and labelled transitions between the states [67].

The following sections discuss the attributes of the Markov decision process that that applied in modelling the JCAC algorithm in an NGWN.

#### 3.4.1 AVERAGE SERVICE TIME AND TRAFFIC INTENSITY

Average service time and traffic intensity are parameters applied in Markov chain models. The average service time for a call is described as the channel holding time or channel occupancy and is assumed to follows an exponential distribution [29] [36] [64]. In this analysis it is assumed that channel holding time relates to the duration of a call. Let  $D_i$  and  $\mu_i$  denote the

mean call duration and the mean service rate respectively for class\_  $i$  calls. The service time for a class\_  $i$  call is expressed with mean  $1/\mu_i$  as follows:

$$D_i = \frac{1}{\mu_i} \quad (3.4)$$

The traffic intensity  $\rho$ , is defined as the ratio of mean arrival rate to mean service rate. Traffic intensity for new calls in class\_  $i$  in RAT\_  $j$  is denoted by  $\rho n_{ij}$ . Similarly the traffic intensity of handoff calls in class\_  $i$  in RAT\_  $j$  is denoted by  $\rho h_{ij}$ .  $\rho n_{ij}$  and  $\rho h_{ij}$  are defined below:

$$\rho n_{ij} = \frac{\lambda n_{ij}}{\mu_i} \quad (3.5)$$

$$\rho h_{ij} = \frac{\lambda h_{ij}}{\mu_i} \quad (3.6)$$

### 3.4.2 M/M/m/m QUEUEING MODEL

The  $M/M/m/m$  queueing model is used to define call arrival distribution in telecommunication systems [66] [68] [69].  $M/M/m/m$  queueing systems assume that arrival rate follows a Poisson distribution and service rate follows an exponential distribution.

In the  $M/M/m/m$  queueing model there are a limited number of resources available in the system and there are a maximum number of calls that the system can support. Calls arriving into the system in excess of the maximum capacity are rejected.

Figure 3.4 shows the state transition diagram of one-dimensional  $M/M/m/m$  queueing model, with  $\lambda$  representing arrival rate and  $\mu$  the service rate.

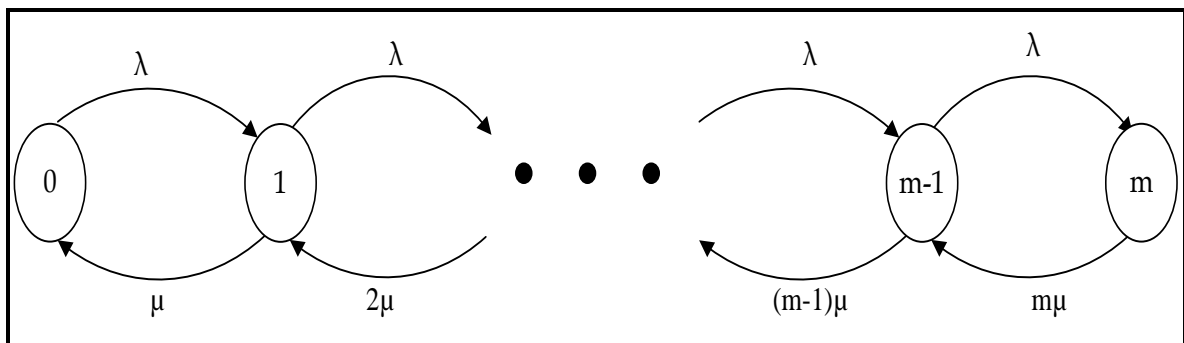


Figure 3.4: One-Dimensional  $M/M/m/m$  State Transition Diagram

Let  $C$  represent the total capacity on the system and  $R$  the capacity reserved for handoff calls. With  $\lambda_n$  and  $\lambda_h$  representing the arrival rate of new calls and handoff call respectively, and  $\mu_c$  the service rate for both new calls and handoff calls, the steady state transition diagram for the  $M/M/m/m$  taking bandwidth reservation into consideration appears as shown in Figure 3.5.

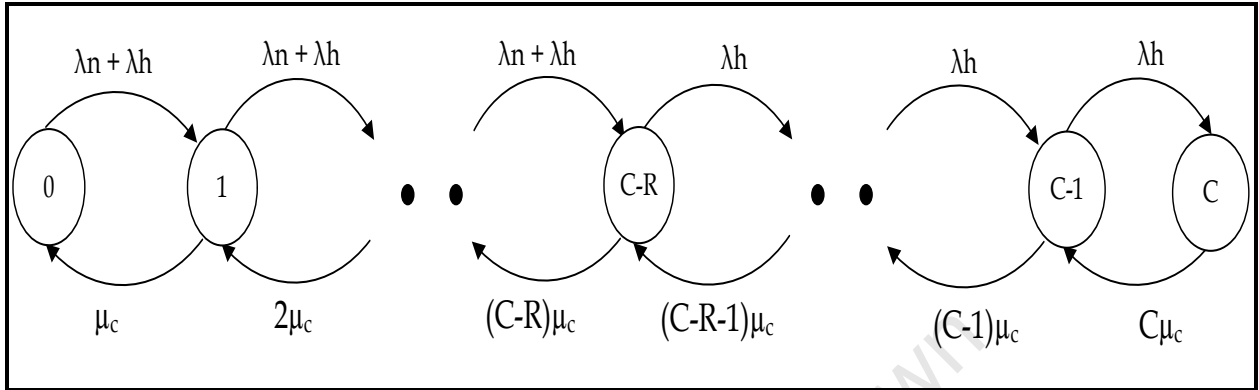
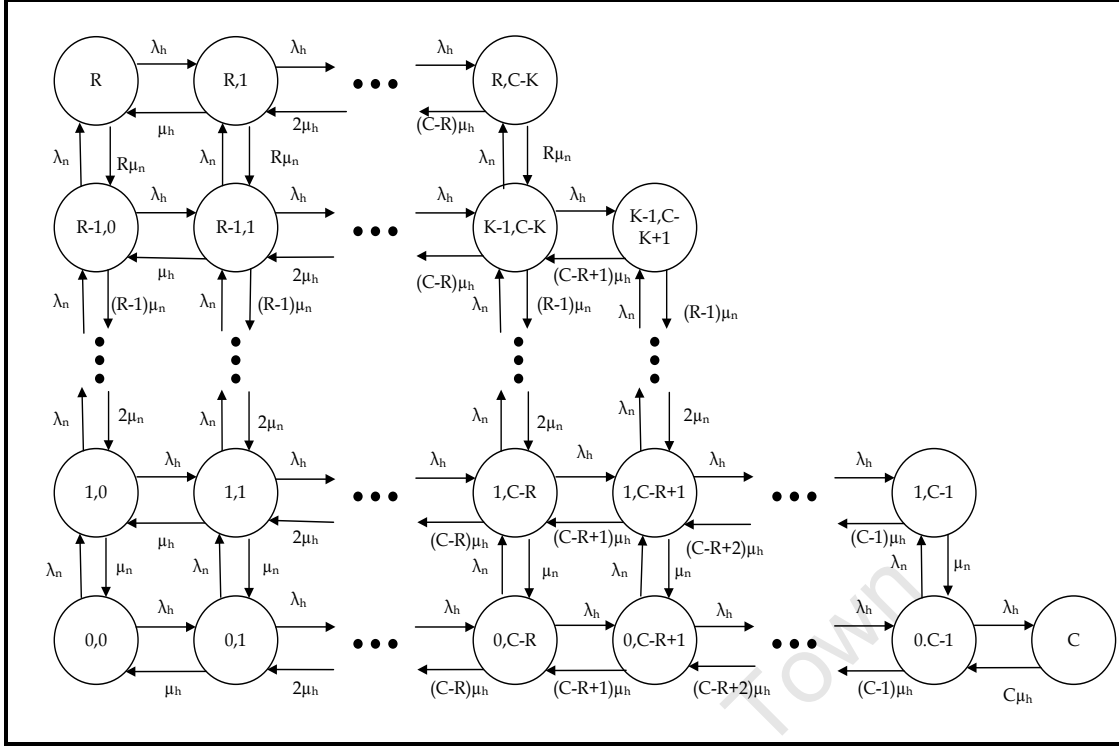


Figure 3.5:  $M/M/m/m$  Transition State Diagram with Bandwidth Reservation

### 3.4.3 MULTI-DIMENSIONAL MARKOV MODEL

In order to evaluate the JCAC in an NGWN, a multi-dimensional Markov model is found desirable. Zeng *et al.* specified that a multi-dimensional Markov model is preferred to the one-dimensional model [66]. The multi-dimensional model is able to employ different channel holding times for new calls and handoff calls; which is not the case in the one-dimensional model.

Let  $C$  represent the total capacity on the system and  $R$  the capacity reserved for handoff calls. With  $\lambda_n$  and  $\lambda_h$  representing the arrival rate of new calls and handoff call respectively, and  $\mu_n$  and  $\mu_h$  the service rate for both new calls and handoff calls respectively, the state diagram for a two-dimensional Markov model is represented in Figure 3.6.



**Figure 3.6: Two-Dimensional Markov Chain Model [70]**

A multi-dimensional Markov chain model based on the  $M/M/m/m$  queueing system is applied in this research that takes into consideration multiple service classes, multiple RATs and both handoff and new calls.

Let  $n_{ij}$  and  $h_{ij}$  represent the number of ongoing new calls and handoff calls respectively of class  $i$  and RAT  $j$ . The state space, which is the set of possible values or states that can be taken [68], is denoted by vector  $k$  [62] [71]:

$$k = (n_{ij}, h_{ij} : i = 1, 2, \dots, X; j = 1, 2, 3, \dots, Y) \quad (3.7)$$

The set of all possible states,  $A$ , is given by:

$$A = \left\{ k \mid \sum_{i=1}^X \sum_{j=1}^Y (b_i \times n_{ij}) \leq Tn_{ij} \wedge \sum_{i=1}^X \sum_{j=1}^Y (b_i \times h_{ij}) \leq Th_{ij} \right. \\ \left. \wedge \sum_{i=1}^X \sum_{j=1}^Y ((b_i \times n_{ij}) + (b_i \times h_{ij})) \leq C_j \right\} \quad (3.8)$$

Let  $P_k$  denote the steady state probability that the system is in state  $k$ .  $P_k$  is expressed by:

$$P_k = \prod_{i=1}^X \prod_{j=1}^Y \frac{(\rho h_{i,j})^{h_{ij}}}{h_{ij}!} \frac{(\rho n_{i,j})^{n_{ij}}}{n_{ij}!} \times P_0 \quad k \in A \quad (3.9)$$

$P_0$  is given as:

$$P_0 = \left[ \sum_{k \in A} \prod_{i=1}^X \prod_{j=1}^Y \frac{(\rho h_{i,j})^{h_{ij}}}{h_{ij}!} \frac{(\rho n_{i,j})^{n_{ij}}}{n_{ij}!} \right]^{-1} \quad (3.10)$$

### 3.5 PERFORMANCE METRICS

From the Markov chain model, performance metrics for the JCAC algorithm in an NGWN are determined. The performance metrics include; call blocking probability, call dropping probability, mean number of calls, user utility and revenue. A discussion of each of these metrics follows.

#### 3.5.1 CALL BLOCKING PROBABILITY

Blocking of a new class\_  $i$  call request occurs when there is no more capacity in a given coverage area to take on the new call request. This occurs when the maximum capacity of the coverage area is exceeded and is described with the following condition:

$$b_i + \sum_{i=1}^X ((b_i \times n_{ij}) + (b_i \times h_{ij})) > C_j \quad (3.11)$$

A threshold is set for the maximum capacity that can be occupied by new calls. Call blocking will also take place when this threshold is exceeded and is described by the constraint below:

$$b_i + \sum_{i=1}^X (b_i \times n_{ij}) > Tn_{ij} \quad (3.12)$$

Let  $A_{bi}$  denote the set of states for which a new call in class\_  $i$  is blocked. Therefore,  $A_{bi}$  is expressed as:

$$A_{bi} = \left\{ k \in A \mid b_i + \sum_{i=1}^X (b_i \times n_{ij}) > Tn_{ij} \vee b_i + \sum_{i=1}^X ((b_i \times n_{ij}) + (b_i \times h_{ij})) > C_j \right\} \quad (3.13)$$

Let  $PB_{n_{ij}}$  denote the call blocking probability of new calls in class\_  $i$  in RAT\_  $j$ . The call blocking probability is computed as:

$$PB_{n_{ij}} = \sum_{k \in A_{bi}} P_k \quad (3.14)$$

### 3.5.2 CALL DROPPING PROBABILITY

Dropping of a handoff class\_  $i$  calls occurs when there is no more capacity in a given coverage area to take on the handoff call. This occurs when the maximum capacity of the coverage area is exceeded and is described with the following condition:

$$b_i + \sum_{i=1}^X ((b_i \times n_{ij}) + (b_i \times h_{ij})) > C_j \quad (3.15)$$

Dropping of handoff calls will also occur when the set threshold capacity for handoff calls is exceeded and is described by the constraint below:

$$b_i + \sum_{i=1}^X (b_i \times h_{ij}) > Th_{ij} \quad (3.16)$$

Let  $A_{di}$  denote the set of states for which a new call in class\_  $i$  is blocked. Therefore,  $A_{di}$  is expressed as:

$$A_{di} = \left\{ k \in A \mid b_i + \sum_{i=1}^X (b_i \times h_{ij}) > Th_{ij} \vee b_i + \sum_{i=1}^X ((b_i \times n_{ij}) + (b_i \times h_{ij})) > C_j \right\} \quad (3.17)$$

The dropping probability of class\_  $i$  calls in RAT\_  $j$  is denoted as  $PD_{h_{ij}}$  and computed as follows:

$$PD_{h_{ij}} = \sum_{k \in A_{di}} P_k \quad (3.18)$$

### 3.5.3 USER UTILITY FUNCTION

Utility functions are used to describe the users' levels of satisfaction [72] [73]. Utility is a decreasing function of call blocking and call dropping probabilities [8] [30]. The utility for class\_  $i$  calls is denoted by  $U_i$  is derived from [73] and computed as follows:

$$U_i = \sum_{i=0}^X e^{-P_i} \quad \forall j \quad (3.19)$$

$P_i$  is a QoS metric for class\_  $i$  calls that incorporates both call blocking and call dropping probabilities and is given as:

$$P_i = \theta PB_{n_{ij}} + \beta PD_{h_{ij}} \quad (3.20)$$

$$(\beta > \theta \text{ and } \beta + \theta = 1).$$

$\theta$  and  $\beta$  are constants that represent the penalty associated with blocking a new call or dropping a handoff call respectively.

The average user utility in the system, denoted by  $U_{avg}$ , over a given period  $T$  from  $t_1$  to  $t_2$  is computed as follows:

$$U_{avg} = \frac{1}{T} \left( \int_{t_1}^{t_2} f(U_i) dt \right) \quad (3.21)$$

The utility values range from 0 to 1, where 1 represents the highest user satisfaction and 0 represents lowest user satisfaction.

### 3.5.4 MEAN NUMBER OF CALLS

Let  $N$  denote the mean number of calls in the NGWN; it is obtained from the expression below [74]:

$$N = \sum_{i=1}^X \sum_{j=1}^Y (n_{i,j}) (h_{i,j}) P_k \quad \forall k \in A \quad (3.22)$$

Let  $N_i$  denote the average number of calls in class\_  $i$ .  $N_i$  for all admissible calls ( $k \in A$ ) is obtained as follows:

$$N_i = \sum_{k \in A} \sum_{j=1}^Y (n_{i,j}) (h_{i,j}) P_k \quad (3.23)$$

The total number of calls class\_ $i$ , denoted by  $NT_i$ , over a given period from  $t_1$  to  $t_2$ , is computed as follows:

$$NT_i = \int_{t_1}^{t_2} N_i dt \quad (3.24)$$

### 3.5.5 REVENUE

Total duration of calls in a given class can be determined from the average number of calls from that class and the mean service rate. The total duration of class\_ $i$  denoted by  $D_i$ , calls is given by:

$$D_i = N_i \times \frac{1}{\mu_i} \quad (3.25)$$

Let  $Px_i$  denote the unit price for class\_ $i$  calls. Therefore, the Revenue  $R_i$  obtained from class\_ $i$  calls is deduced as follows:

$$R_i = \sum_{k \in A} (Px_i \times D_i) \quad \forall j \quad (3.26)$$

The total revenue denoted as  $R_T$ , obtained from all RATs is a summation of individual revenues from all the service classes from all the RATs. Therefore,  $R_T$  is computed as follows:

$$R_T = \sum_{k \in A} \sum_{i=1}^X R_i \quad \forall j \quad (3.27)$$

The total revenue obtained over a given period from  $t_1$  to  $t_2$ , denoted by  $R$  is obtained as follows:

$$R = \int_{t_1}^{t_2} f(R_T) dt \quad (3.28)$$

## 3.6 CHAPTER SUMMARY

This chapter has given an overview of the analytical approach highlighting the load-based JCAC, bandwidth reservation policy and multi-dimensional Markov chain model. It has also discussed the system performance metrics that will be used throughout this work based on the

multi-dimensional Markov model. In chapter 4 the analytical model is applied to study dynamic pricing in NGWNs, and in chapter 5 it is applied to propose a hybrid pricing model for NGWNs.

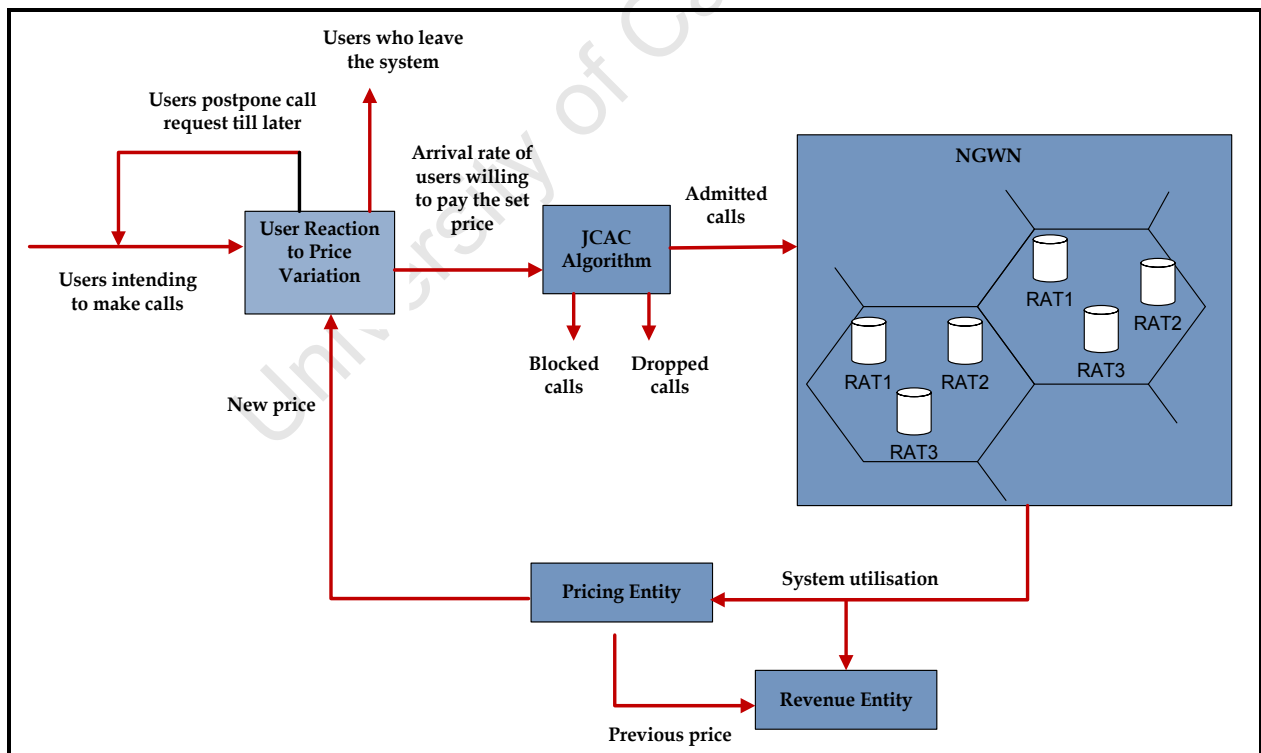
University of Cape Town

## 4. ANALYSIS OF NETWORK OPERATORS' REVENUE WITH A DYNAMIC PRICING SCHEME BASED ON USERS' BEHAVIOUR

This chapter analyses and evaluates a dynamic pricing scheme based on a discount policy to determine the new price charged to users arriving into the network. A study is carried out of users' behaviour with price variation based on user price sensitivity when dynamic pricing is applied to an NGWN. A stochastic analysis of network operators' revenue is analysed based on a 24-hour period.

### 4.1 DYNAMIC PRICING SCHEME

A feedback system is used to represent the dynamic pricing model. Figure 4.1 shows the dynamic pricing model. It consists of five major components i.e. user reaction to price, JCAC algorithm, NGWN, pricing entity and a revenue entity.



**Figure 4.1: Diagram of Dynamic Pricing Scheme**

Users intending to access the network will be presented with the price to be charged for a given service class. Given that users are price sensitive, they will react to the price in the following three ways:

- The users who find the new price set by the pricing entity acceptable will proceed to request for network resources to access their required service.
- Some users will find the price unacceptable and will desist from requesting for network resources.
- Other users who find the price unacceptable will try again at a later time, hoping to find a price that will be acceptable to them.

The JCAC algorithm will allocate call requests from users who find the price appropriate into the respective RATs of the NGWN. The JCAC algorithm will block and drop new calls and handoff calls respectively, if there are no resources to take on the call requests. The utilisation of the NGWN, depending on the admitted calls, is fed into the pricing entity. The pricing entity incorporates system utilisation and determines the new price to charge for different service classes. The new price from the pricing entity is then presented to the users and the cycle continues.

The components of the dynamic pricing scheme shown in Figure 4.1 are discussed below.

#### **4.1.1 PRICING ENTITY**

The pricing entity will determine the new price that will be charged for services based on the existing system utilisation. To ensure that QoS is obtained, the pricing entity will increase the price when the network load is high so as to discourage users from accessing the network. The pricing entity will decrease the price when the network load is low, so as to encourage users to request for network services.

#### **4.1.2 USER REACTION TO PRICE VARIATION**

The price set by the pricing entity will determine the response of the users. Depending on the price, users will either increase or decrease their demand for network services. Users' demand for the network services will increase with lower prices. Conversely, for higher prices the users' demand for the network services will decrease.

### **4.1.3 JCAC ALGORITHM**

The JCAC ensures that effective allocation of calls is done without compromising the QoS of existing calls. Depending on the network conditions in the RATs and the arrival rate of calls in the NGWN, the JCAC algorithm will admit some calls, and block or drop other calls. The conditions for the occurrence of call blocking and call dropping are discussed in Sections 3.6.1 and 3.6.2 respectively.

### **4.1.4 NGWN**

In this work, system utilisation is based on the total number of calls in the NGWN. The obtained system utilisation in the NGWN at a given instant in time is then fed into the pricing entity.

### **4.1.5 REVENUE ENTITY**

The revenue entity computes the revenue obtained in the NGWN by using inputs from the pricing entity and from the NGWN. The pricing entity provides the previous computed price to the revenue entity, and the NGWN provides the system utilisation. System utilisation and the previous price are used to determine the revenue obtained by network operators.

## **4.2 DISCOUNT POLICY**

A discount approach is used to determine the new price in the network. Users are given a discount depending on the network utilisation such that if the utilisation is low the discount offered will be high and vice versa. The discount policy is aimed at encouraging users to access the network when network utilisation is low and conversely, to discourage them under high load conditions. The new price is computed based on the previous traffic intensity of the NGWN as utilisation is proportional to traffic intensity.

The NGWN is designed to support a maximum amount of traffic. Users are charged a maximum price when the planned upper limit of the system capacity is reached. The maximum price per unit time for class  $i$  calls is represented by  $P_{max_i}$ . This acts as a means to discourage users from accessing the network when it is congested, and encourage them to access it when it is underutilised, because the price charged in the latter case is low.

A scaling factor  $\alpha$  is used to give the level of the discount. The value of  $\alpha$  is predetermined by network operators depending on how much discount they are willing to offer their subscribers. The value of  $\alpha$  can also be determined based on by market forces.

Let  $DT_i$  denote the discount offered for class\_  $i$  calls.  $DT_i$  is computed as follows:

$$DT_i = \alpha \left( \left( 1 - \left( \frac{\sum_{j=1}^Y (\rho n_{ij} + \rho h_{ij})}{\max(\sum_{i=1}^X (\rho n_{ij} + \rho h_{ij}) \forall j)} \right) \right) \times P_{max_i} \right), \quad \alpha > 0 \quad (4.1)$$

The new price to be used in the system for class\_  $i$  calls, denoted as  $NPx_i$ , is computed as follows:

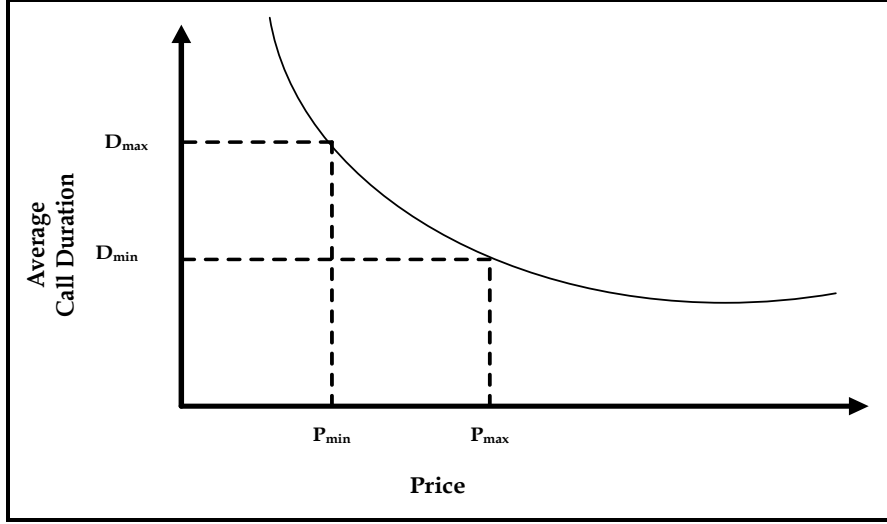
$$NPx_i = P_{max_i} - DT_i \quad (4.2)$$

### 4.3 DETERMINING USER BEHAVIOUR

Users intending to access the system will alter or adjust their behaviour based on the price of the services. In this work, it is assumed that user behaviour is affected in two aspects; average call duration and arrival rate. Users can reduce the duration of their calls or reduce the arrival rate into the network when a higher price is charged, and vice versa.

#### 4.3.1 CALL DURATION WITH PRICE VARIATION

The relationship for price and average call duration follows a decreasing function [51] [61] [75]. This relationship is represented in Figure 4.2 below.



**Figure 4.2: Variation of Call Duration with Service Price**

A minimum average call duration and maximum average call duration are considered. The minimum average call duration for class\_  $i$  calls is denoted as  $D_{min_i}$ , and the maximum average call duration for class\_  $i$  calls is denoted by  $D_{max_i}$ . Therefore:

$$\{ \text{average call duration} \mid D_{min_i} \leq \text{average call duration} \leq D_{max_i} \} \quad (4.3)$$

The service price charged by the network operator ranges from the minimum price to a maximum price. The minimum price for class\_  $i$  calls is denoted as  $P_{min_i}$ , and the maximum price for class\_  $i$  calls is denoted by  $P_{max_i}$ . Therefore:

$$\{ \text{service Price} \mid P_{min_i} \leq \text{service price} \leq P_{max_i} \} \quad (4.4)$$

Call duration is modelled as a decreasing exponential function of service price as follows:

$$\text{Duration} = A e^{-k \text{ Price}} \quad (4.5)$$

where  $A$  and  $k$  are constants.

A maximum price is charged when average call duration is at minimum level, and a minimum price is charged when the average call duration is at a maximum level [51]. Therefore, the relation between  $D_{min_i}$  and  $P_{max_i}$  is described as follows:

$$D_{min_i} = A e^{-k P_{max_i}} \quad (4.6)$$

Similarly, the relation between  $D_{max_i}$  and  $P_{min_i}$  is described as follows:

$$D_{max_i} = A e^{-k P_{min_i}} \quad (4.7)$$

By solving for equations 4.6 and 4.7,  $A$  and  $k$  are obtained as follows:

$$A = \frac{D_{max_i}}{e^{-kP_{min_i}}} \quad (4.8)$$

$$k = \frac{\ln\left(\frac{D_{max_i}}{D_{min_i}}\right)}{(P_{max_i} - P_{min_i})} \quad (4.9)$$

### 4.3.2 ARRIVAL RATE WITH PRICE VARIATION

Users do not consider a single price but rather a set of prices that are acceptable to pay [76]. Following the concept from the van Westendorp PSM, users consider a range of prices bounded by a maximum and minimum within which they are willing to pay [58] [59] [60].

For a given range of price values the users will have a specific perception i.e. very expensive, expensive, moderate, cheap, and very cheap. To represent user perception a price sensitivity model is devised in this work. In the price sensitivity model, a specific user perception correlates to a given parameter known as Price Sensitivity Factor (PSF). Numerical values are used to represent PSF. Different values are chosen for PSF with 'Very Cheap' having the highest PSF value and 'Very Expensive' having the lowest PSF value. PSF values will vary in different regions and with different products/services. It is assumed that the users will have the same demand if the service price falls within a specific range, as they have the same PSF.

The price sensitivity model is demonstrated in Table 4.1 and it describes the relationship between price range, user perception and selected PSF values; where  $P_x$  denotes the price charged.

**Table 4.1: Price Sensitivity Model**

Price Range	User Perception	PSF
$0 \leq P_x \leq 0.3$	Very Cheap	5
$0.3 < P_x \leq 0.6$	Cheap	2.5
$0.6 < P_x \leq 0.9$	Moderate	1.25
$0.9 < P_x \leq 1.2$	Expensive	0.625
$1.2 < P_x \leq 1.5$	Very Expensive	0.3125

Let  $\lambda_{ij}(\text{new})$  denote the new arrival rate for class\_  $i$  calls in RAT\_  $j$  after users react to price variation. Let  $\lambda_{ij}(\text{old})$  denote the arrival rate for class\_  $i$  calls in RAT\_  $j$  without dynamic pricing. The new arrival rate in the system is obtained as follows:

$$\lambda_{ij}(\text{new}) = \lambda_{ij}(\text{old}) \times (PSF) \quad (4.10)$$

#### 4.4 SYSTEM MODEL

The NGWN applied in the simulations consists of two RATs, therefore  $Y=2$ . The coverage area of the NGWN is fully overlapped with the two RATs.

The NGWN considered supports two service classes, therefore  $X=2$ . Class\_  $1$  calls represent services with low bandwidth requirements while class\_  $2$  calls represent services that have high bandwidth requirements. The bu assigned to class\_  $2$  calls are therefore more than those assigned to class\_  $1$  calls.

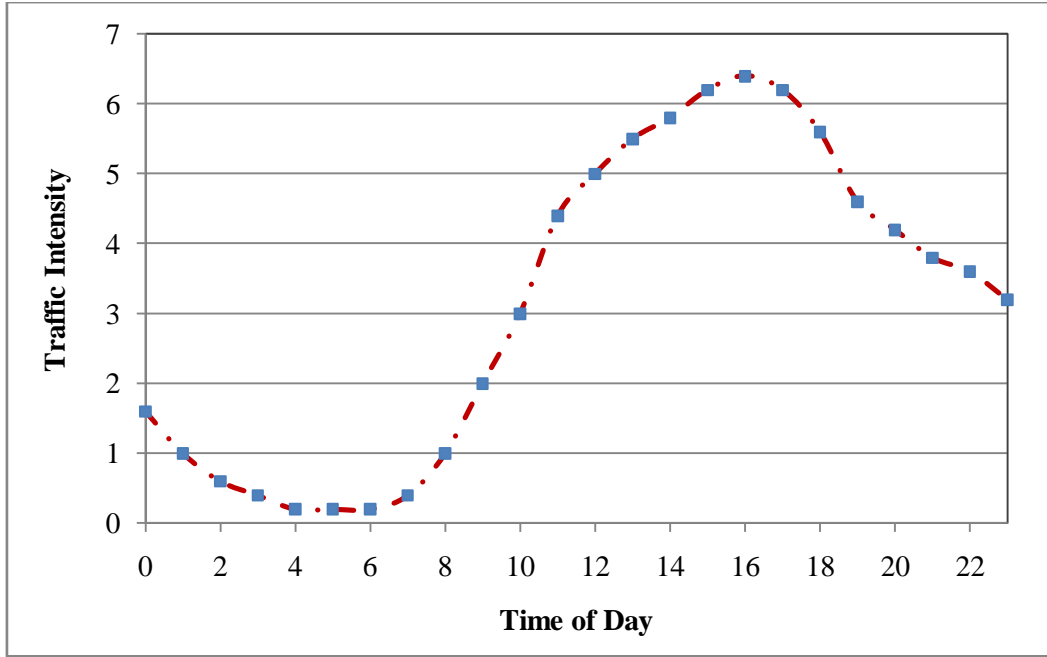
Lower priority is given to class\_  $1$  calls than to class\_  $2$  calls, and this is catered for in the bandwidth reservation policy where the threshold set for rejecting class\_  $1$  calls is lower than that for rejecting class\_  $2$  calls.

The calls arriving in the system are either handoff calls or new calls. Higher priority is given to handoff calls than to new calls and this is reflected in the reservation policy. The threshold set for rejecting handoff calls is higher than the threshold set for rejecting new calls.

Users who intend to make calls will decide if the price being charged is appropriate. Users who find the price appropriate will make a call request. The load-based JCAC algorithm will distribute calls to either RAT\_  $1$  or RAT\_  $2$  depending on the load in either RAT. Call blocking and dropping will occur when the set threshold for new calls and handoff calls are exceeded.

#### 4.5 PERFORMANCE EVALUATION

In this section, the performance of the proposed dynamic pricing scheme is evaluated through simulations and compared with when flat pricing is applied in the NGWN. Figure 4.3 shows the demand distribution upon which the flat pricing analysis is based. It represents mobile telephony traffic in [77]. This demand distribution was determined in 2005 and it depicts a recent finding on user behaviour characteristics. From this demand distribution, user demand due to dynamic pricing is derived from the simulations.



**Figure 4.3: User Demand for Mobile Telephony Based Services [77]**

The system parameters used are:

$$C_1, = 50, C_2, = 35, b_1 = 2, b_2 = 5, Tn_{11} = 15, Tn_{21} = 20, Tn_{12} = 10, Tn_{22} = 15, Th_{11} = 45, Th_{21} = 50, Th_{12} = 25, Th_{22} = 35, \mu_1 = 1, \mu_2 = 1, (\lambda_{ij}) = \max(\lambda_{ij}) = 7, \theta = \frac{1}{3}, \beta = \frac{2}{3}.$$

The parameters used for dynamic pricing are as follows:

$$P_{min_1} = P_{min_2} = 0, P_{max_1} = P_{max_2} = 2.5.$$

The values used for the price sensitivity model are shown in Table 4.2.

**Table 4.2: Price Sensitivity Model Parameters**

Price Range	User Perception	PSF
$0 \leq P_x \leq 0.5$	Very Cheap	2.000
$0.5 < P_x \leq 1.0$	Cheap	1.500
$1.0 < P_x \leq 1.5$	Moderate	1.125
$1.5 < P_x \leq 2.0$	Expensive	0.844
$1.5 < P_x \leq 2.5$	Very Expensive	0.633

Two scenarios of user behaviour with price variations are considered in this section, namely:

1. Variation in call arrival rate with change in price
2. Variation in average call duration and arrival rate with change in price.

### 4.5.1 VARIATION IN CALL ARRIVAL RATE WITH CHANGE IN PRICE

Users vary arrival rate in the NGWN with change in price. The user behaviour is determined based on the price sensitivity model discussed in Section 4.3.2. In this analysis average service rate is assumed to be constant and it takes on the following values:  $\mu_1 = \mu_2 = 1$ .

Figure 4.4 shows the traffic demand with respect to dynamic pricing and flat pricing. During the low load conditions, users' demand under dynamic pricing is greater than that of flat pricing. Users' demand under the dynamic pricing scheme decreases during high load conditions of the flat pricing scheme. The decrease is experienced between 10:00 am and 8:00 pm. A decrease in demand also exists at some instances between 7:00 pm and 10:00 pm. During these periods, the prices charged are considered to be expensive by some users who desist from accessing the network or try later and thus there is a decrease in the traffic intensity. Nevertheless, there are some users who are willing to pay the high penalty.

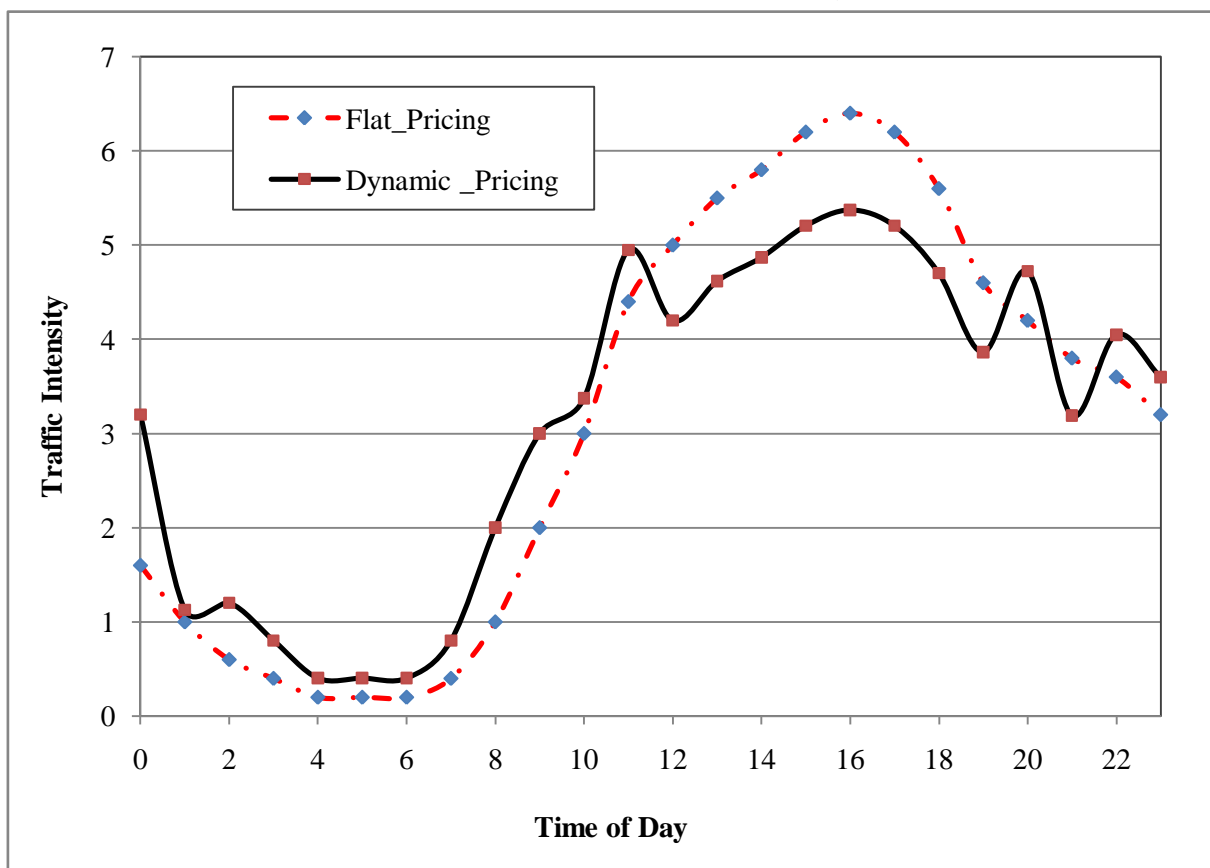
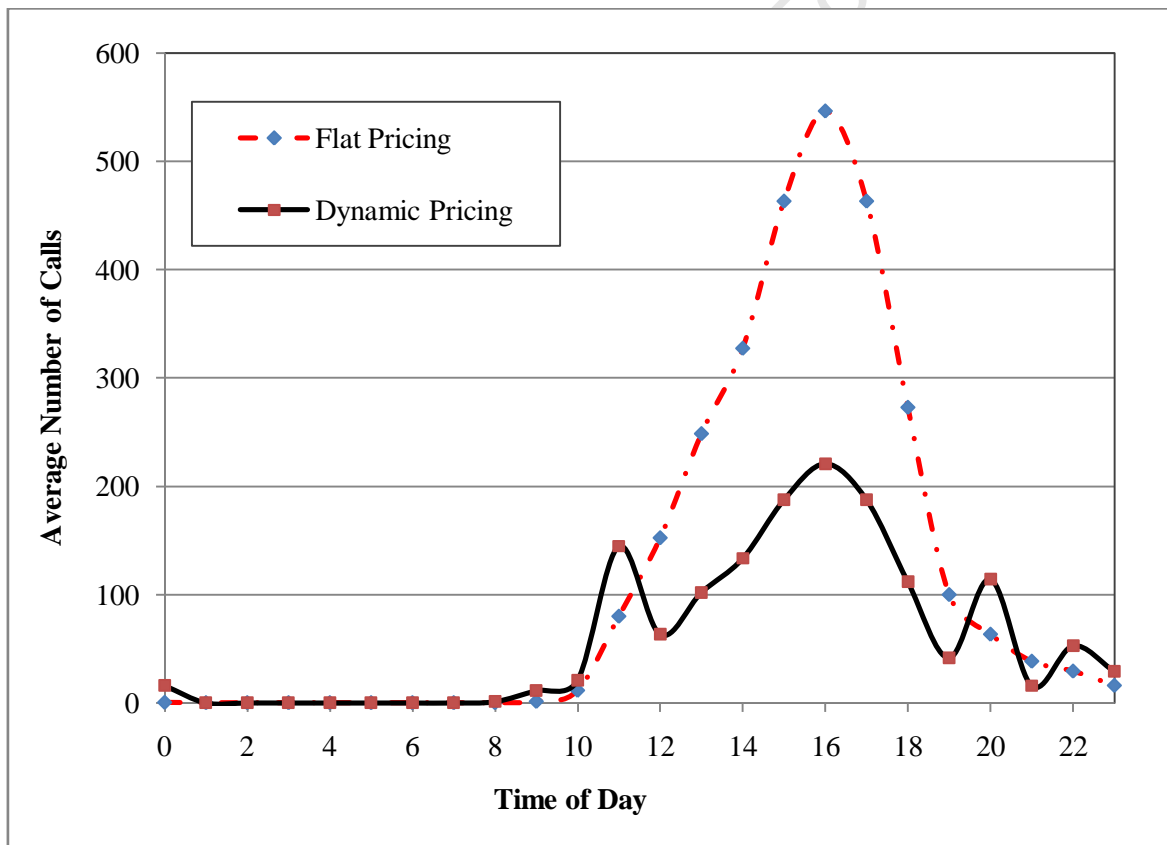


Figure 4.4: Traffic Demand Distribution

Figure 4.5 shows the average number of calls in the system over a 24-hour period in the dynamic and the flat pricing schemes. The average number of calls increases under dynamic

pricing during low load network conditions. The increase in the average number of calls is experienced from 12:00 am to 10:00 am, and during some instances between 7:00 pm and 11:00 pm. However, the average numbers of users start to decrease during the high load network conditions; this is experienced between 10:00 am and 8:00 pm. Given that higher prices are charged during periods of high load conditions, it acts as a deterrent to users.

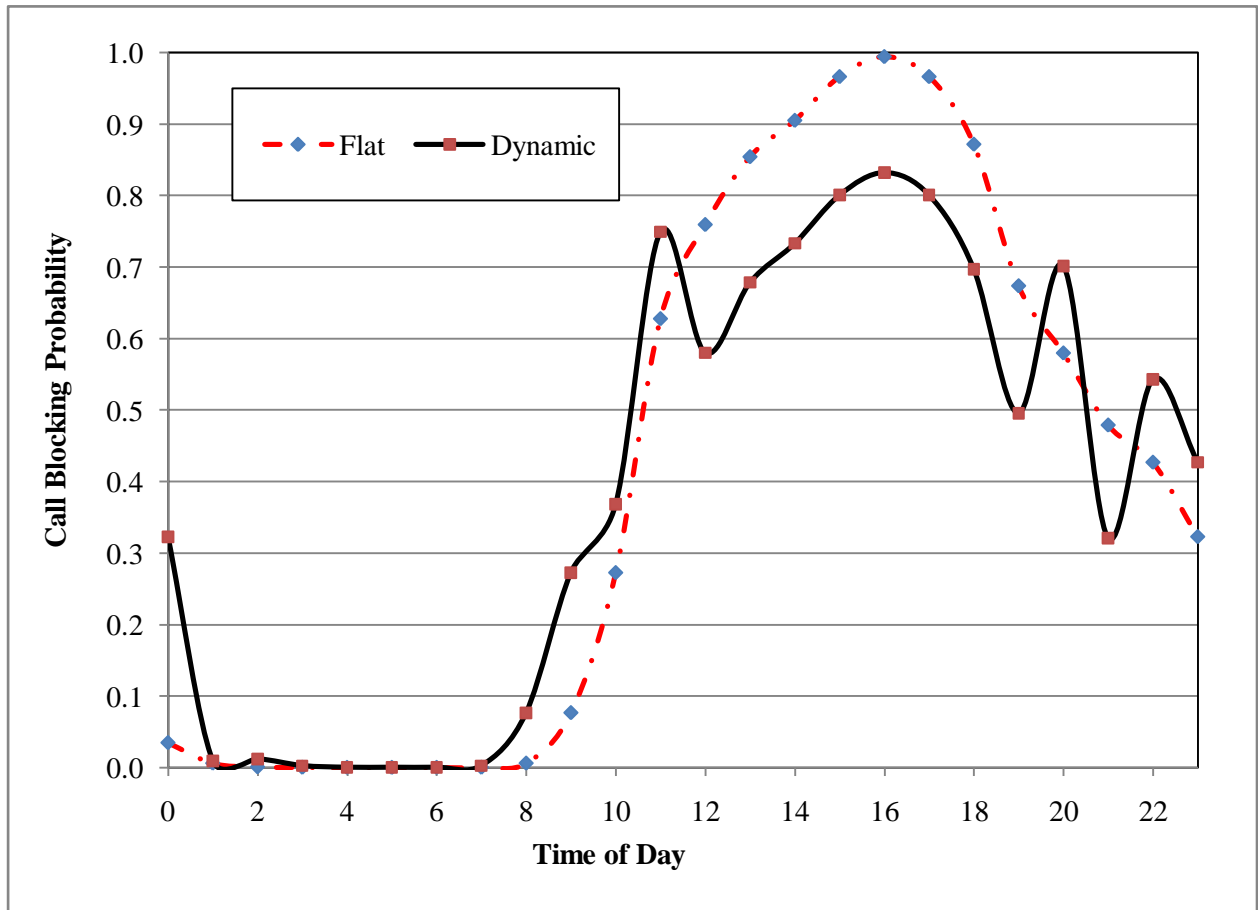
Over the 24-hour period, the overall average number of calls in the NGWN under the dynamic pricing scheme is 1,454, and 2,812 with the flat pricing approach. It is noted that there are more users in the flat pricing scheme than in dynamic pricing scheme. From this outcome, it is assumed that network resources are accessed by those who value them and wastage of network resource is minimised when dynamic pricing is applied. Therefore, users act rationally as they access network resources under dynamic pricing.



**Figure 4.5: Average Number of Calls over a 24-hour Period**

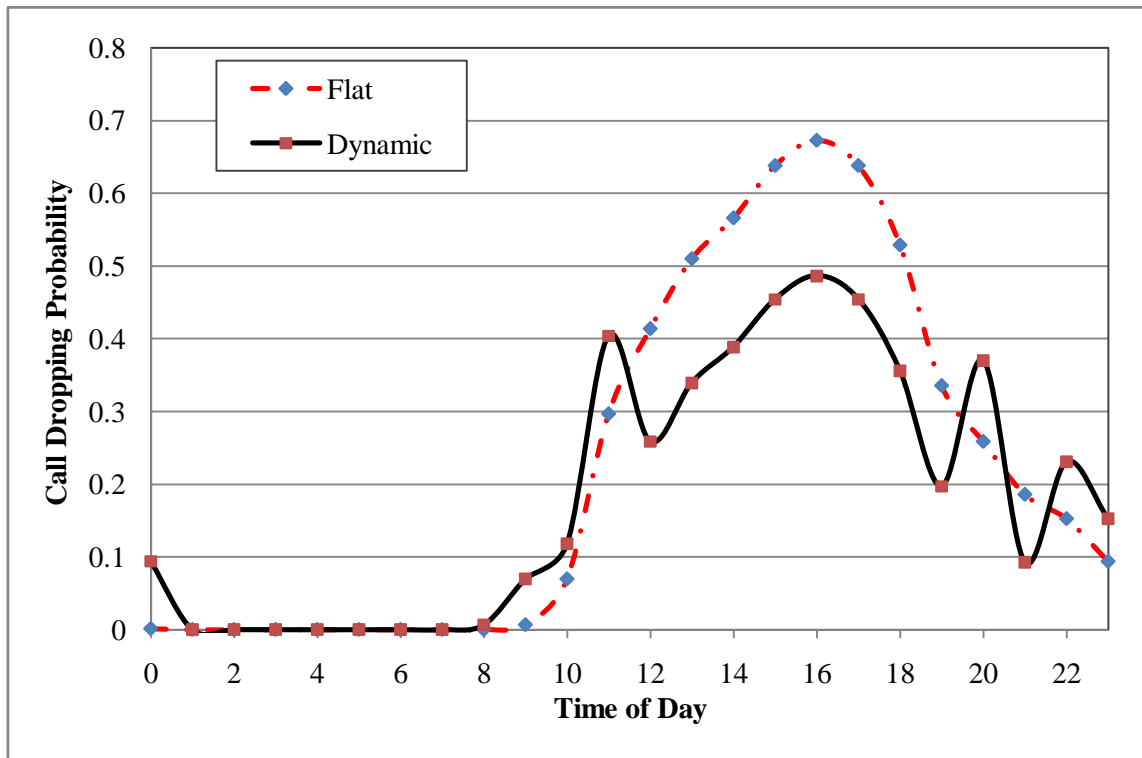
Call blocking probability is represented in Figure 4.6. During the peak period, between 10:00 am and 8:00 pm, call blocking probabilities under the dynamic pricing scheme are lower than under the flat pricing scheme. The dynamic pricing scheme therefore overcomes network congestion during high load network conditions by reducing call blocking probabilities. During

low load conditions, the call blocking probabilities under dynamic pricing are higher than for flat pricing, but are not high enough to negatively affect QoS of the NGWN. The dynamic pricing scheme maintains the overall call blocking probability below 0.83, while the flat pricing scheme maintains the overall call blocking probability below 0.99. Generally, the dynamic pricing scheme offers improved performance with regard to call blocking probability.



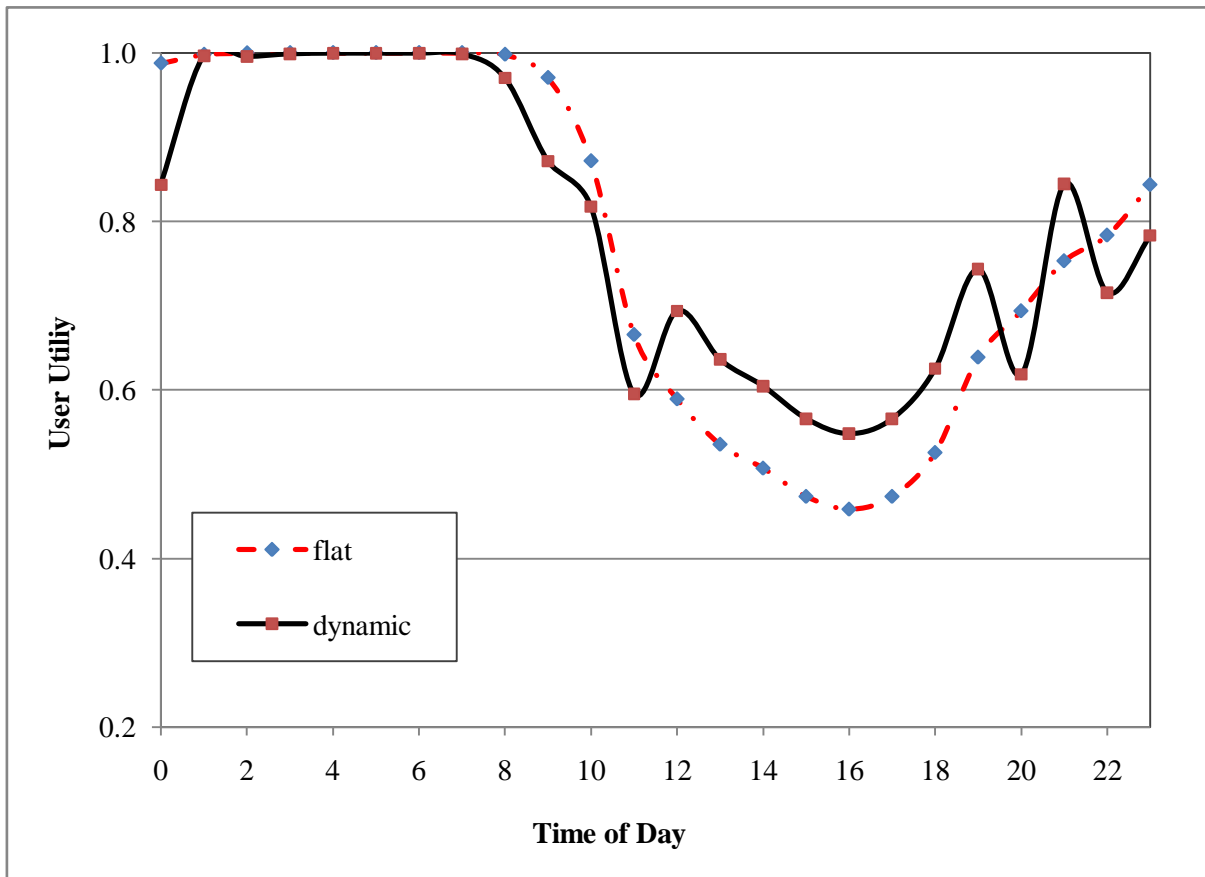
**Figure 4.6: Call Blocking Probability over a 24-hour Period**

The performance of call dropping probability is similar to call blocking probability except for the lower probabilities values obtained at any given instance for call dropping than call blocking. The lower call dropping probability values are due to the fact that higher priority is given to handoff calls than new calls in the bandwidth reservation policy. Figure 4.7 represents call dropping probability obtained over a 24-hour period. The overall call dropping probabilities are maintained below 0.49 in the dynamic pricing scheme unlike the flat pricing scheme where call dropping probabilities as high as 0.67 are obtained.



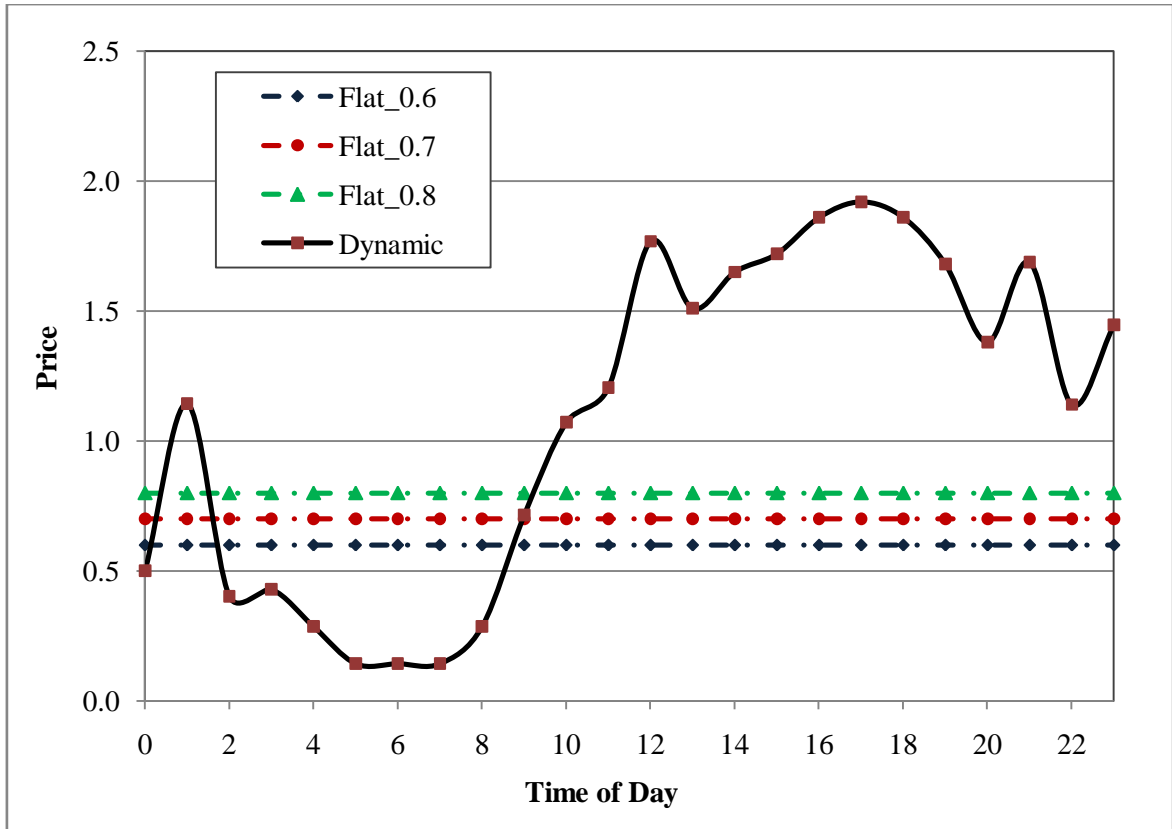
**Figure 4.7: Call Dropping Probability over 24-hour Period**

The user utility over a 24-hour period is shown in Figure 4.8. The average user utility in the dynamic pricing scheme is obtained as 0.76 whereas in the flat pricing scheme it is 0.74. The average user utility is higher in the dynamic pricing scheme than in the flat pricing. Moreover, in the dynamic pricing scheme higher utility is obtained during the peak periods between 10:00 am and 8:00 pm. Therefore, the dynamic pricing guarantees high user satisfaction.



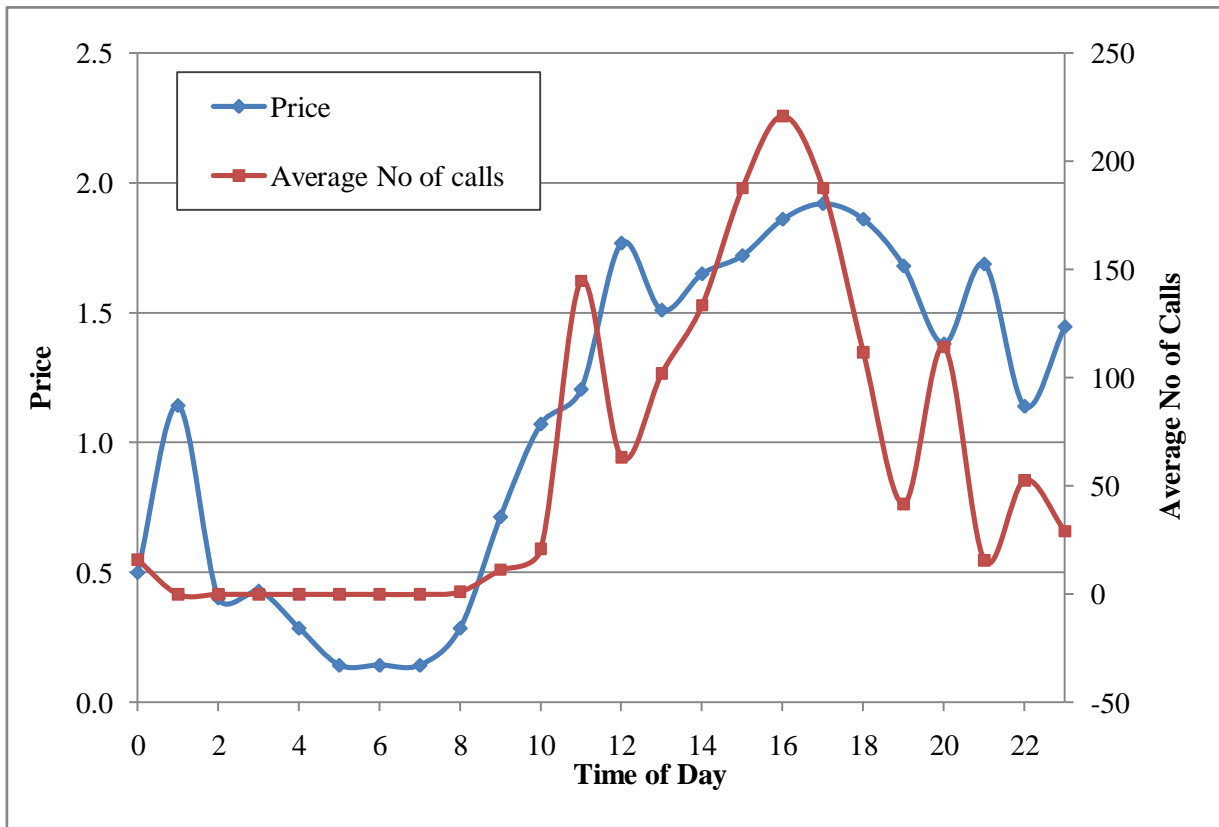
**Figure 4.8: User Utility over 24-hour Period**

The price applied in the flat pricing scheme is assumed to fall under the price range that users consider cheap in the price sensitivity model. Therefore three price values in this range are considered in the simulations when determining revenue obtained. Figure 4.9 shows how the prices charged change over time for the dynamic and flat pricing schemes. The price for the flat pricing scheme remains constant while that for dynamic pricing changes over time.



**Figure 4.9: Price Variation over 24-hour Period**

Figure 4.10 illustrates how the price changes for the dynamic pricing scheme with the average number of calls. A higher penalty is charged to users when the average numbers of calls in the system increases and vice versa. Therefore, the average number of calls and the price will keep changing with time.

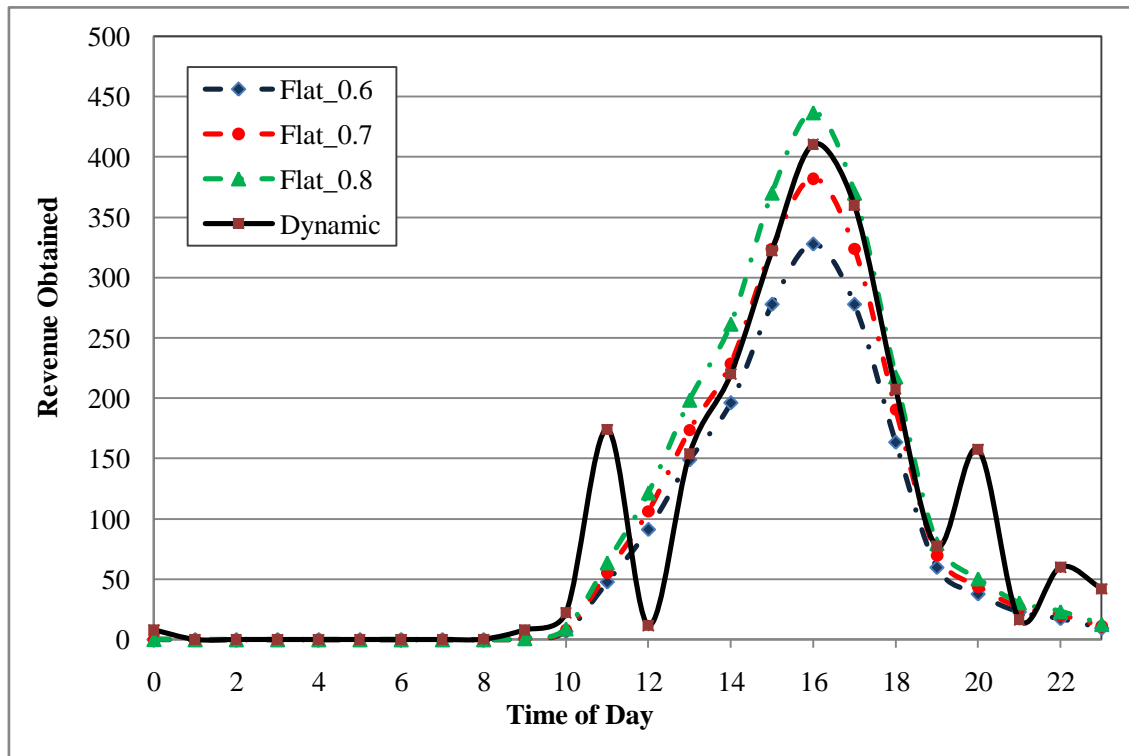


**Figure 4.10: Price Variation with Average Number of Calls under Dynamic Pricing Scheme**

The results obtained for the overall revenue in the NGWN are shown in Table 4.3 and represented in Figure 4.11. Lower values for price used in the flat pricing scheme avail lower revenue for the NGWN. As the values for flat pricing are increased they guarantee higher revenue. However, it would be unjust to charge a high price for the flat pricing scheme especially during low network conditions. Typically, the price values for flat pricing are low and increasing them to obtain more revenue is unfair and may be considered manipulative. Dynamic pricing on the other hand, guarantees high revenue for network operators through varying the price charged with network usage.

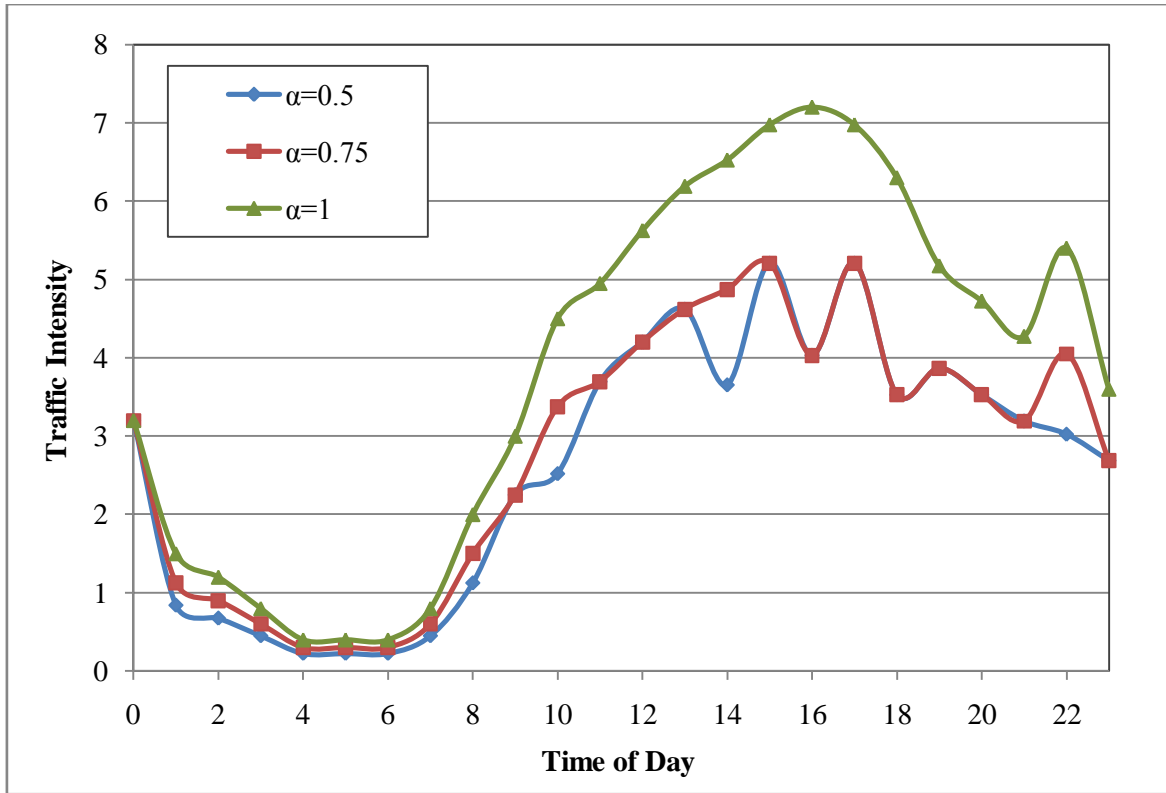
**Table 4.3: Overall Revenue Obtained**

Pricing Scheme	Dynamic Pricing	Flat Pricing		
		0.6	0.7	0.8
Prices charged	Variable	0.6	0.7	0.8
Revenue Obtained	2,233.68	1,683.70	1963.46	2,243.71



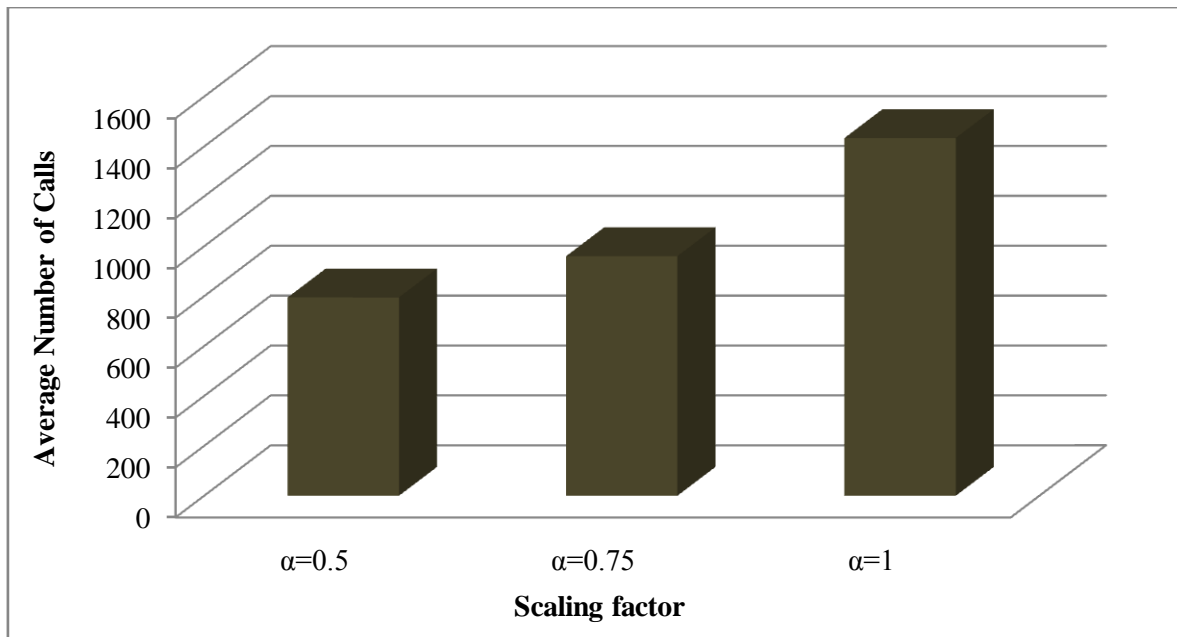
**Figure 4.11: Revenue Obtained**

Scaling factor  $\alpha$ , in the discount policy applied enables network operators to regulate the discount they offer to users. Figure 4.12 shows the traffic intensity obtained with different values of  $\alpha$ . Generally, lower values of  $\alpha$  result into lower traffic intensity. The high traffic intensity obtained with higher values of  $\alpha$  is due to the fact that higher discounts are given and they attract users to access the network.



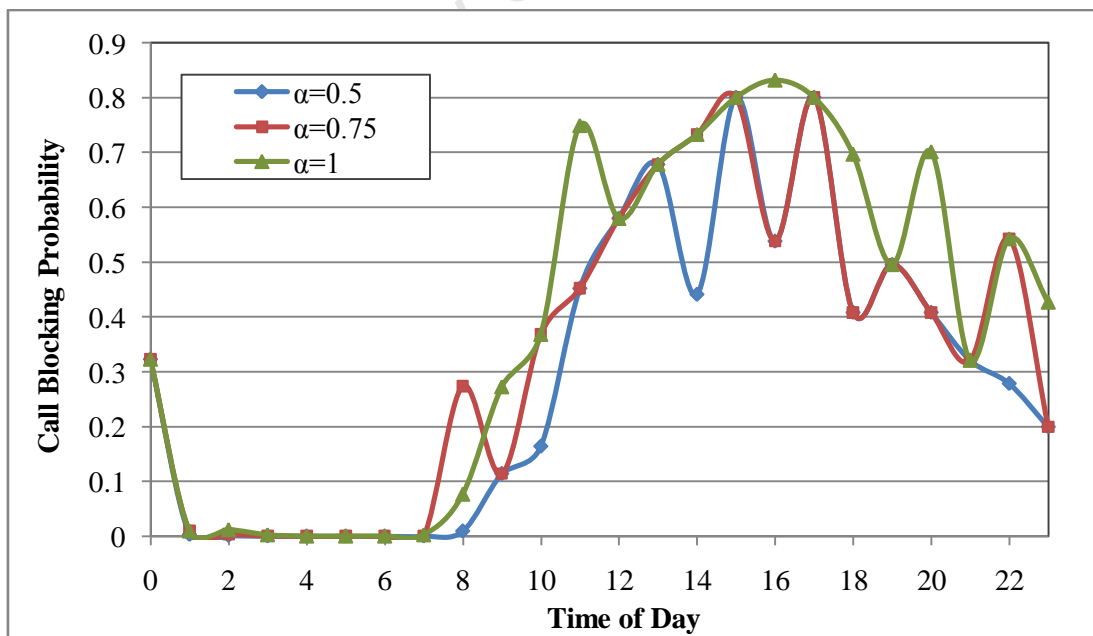
**Figure 4.12: Traffic Intensity with Different Scaling Factors**

Figure 4.13 shows the total average number of calls in the NGWN with different scaling factors. The average number of calls in the network increases with increase in the value of  $\alpha$ . Higher values of  $\alpha$  offer higher discounts and therefore encourages more users to request for network resources. Similarly, lower values of  $\alpha$  offer lower discounts to users and thus attract fewer users to the network.



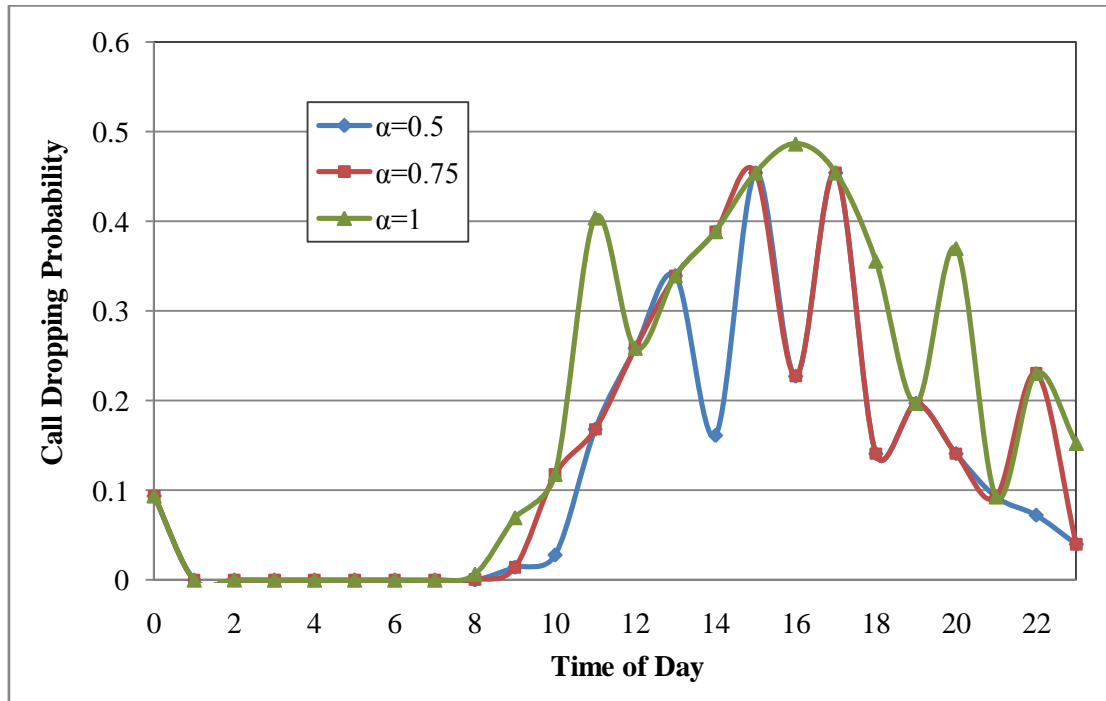
**Figure 4.13: Average of Calls in the NGWN with Different Scaling Factors**

Figure 4.14 shows call blocking probabilities obtained for different scaling factors over a period of 24-hours. High scaling factors result into high call blocking probabilities during peak periods between 10:00 pm and 7:00 pm. Therefore, lower values of  $\alpha$  guarantee better QoS than higher values of  $\alpha$ .



**Figure 4.14: Call blocking Probability with Different Scaling Factors**

Figure 4.15 shows the results obtained for call dropping probabilities for different values of  $\alpha$ . The results for call dropping probability are similar to those of call blocking probability, whereby high values of  $\alpha$  result into high call dropping probabilities during the peak period.



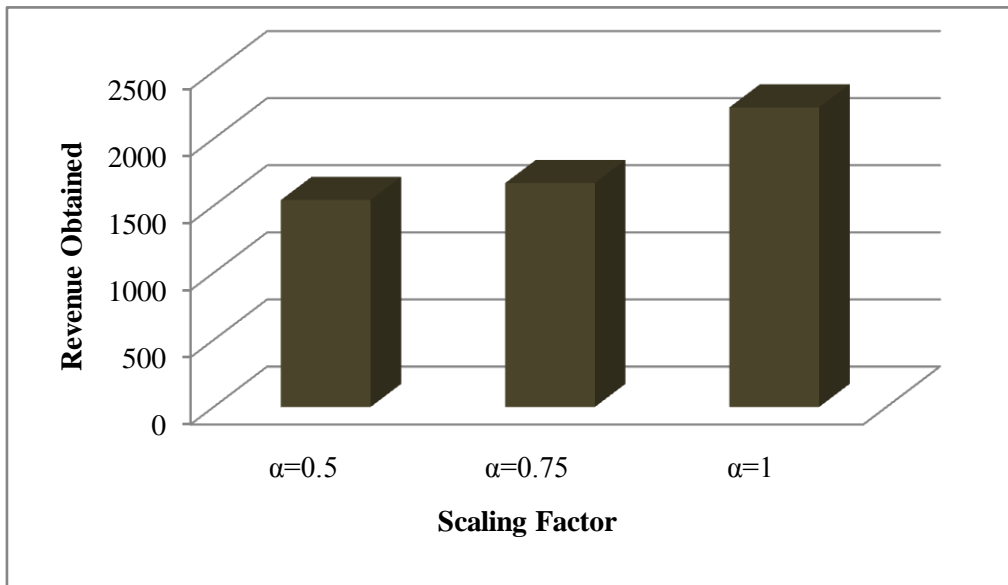
**Figure 4.15: Call Dropping Probability with Different Scaling Factors**

Scaling factor  $\alpha$ , in the discount policy applied enables network operators to regulate the discount they offer to users. Table 4.4 gives the overall revenue obtained over a period of 24-hours with different values of  $\alpha$  in the dynamic pricing scheme.

**Table 4.4: Overall Revenue in Dynamic Pricing Scheme Considering Different Scaling Factors**

Scaling Factor	$\alpha=0.5$	$\alpha=0.75$	$\alpha=1$
Overall Revenue	1,543.07	1,669.07	2,233.68

Figure 4.16 shows a graphical representation of the overall revenue. Lower revenue is obtained with lower values of  $\alpha$  while higher values of  $\alpha$  guarantee high revenue.



**Figure 4.16: Graphical Representation of Overall Revenue Obtained with Different Scaling Factors**

Higher values of  $\alpha$  offer higher discounts and therefore they attract more users to request for network services. Consequently, high values of  $\alpha$  will guarantee higher revenue for network operators. However, this can be detrimental to the QoS offered in NGWNs during peak periods. The results obtained show that high call blocking probabilities and call dropping probabilities are obtained with high values of  $\alpha$  during peak periods. Therefore, a compromise has to be made when determining the values for  $\alpha$ . Network operators have to select appropriate values for  $\alpha$  that guarantee high revenue and satisfactory QoS levels.

#### **4.5.2 VARIATION IN AVERAGE CALL DURATION AND CALL ARRIVAL RATE WITH CHANGE IN PRICE**

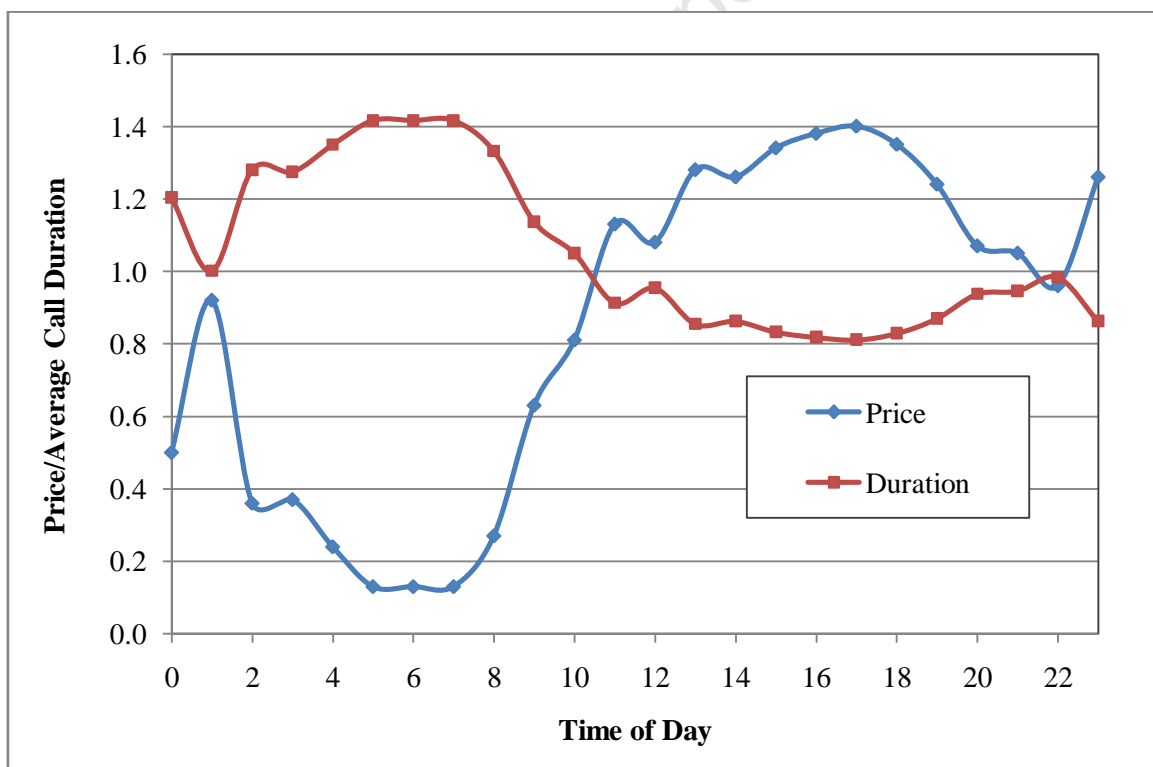
Dynamic pricing not only affects the call generation rate in a network but also affects call duration [61]. Users will regulate the duration of the calls based on the price set in the pricing entity of the dynamic pricing scheme. This section discusses the results obtained on analysing call duration variation as well as variation in call arrival rate with changes in price. Comparisons are carried out between dynamic pricing and with flat pricing implemented in the NGWN. Simulations in the flat pricing scheme consider different average call duration values.

The parameters values used for average call duration are as follows:  $D_{min_1} = D_{min_2} = 0.5$ ,  $D_{max_1} = D_{max_2} = 1.5$  and  $\alpha = 1$ .

The call duration for customers who pay flat rate is usually longer than for customers who pay based on utilisation [51]. Percentages greater than 50% of the maximum average call duration under dynamic pricing are considered for the flat rate pricing. Therefore, simulations are carried out for 60%, 70% and 80% of the maximum average call duration for dynamic pricing for the flat pricing scheme. 60% relates to average call duration of 0.9 units of time, 70 % to 1.05 units of time and 80% to 1.2 units of time. The average call duration for the flat pricing is denoted by  $D$ , and it is assumed to be the same across different service classes.

The price values for the dynamic pricing scheme appear in Table 4.2. The price charged for flat pricing service is taken as 0.75 units. It falls under the price range considered cheap in the price sensitivity model of Table 4.2.

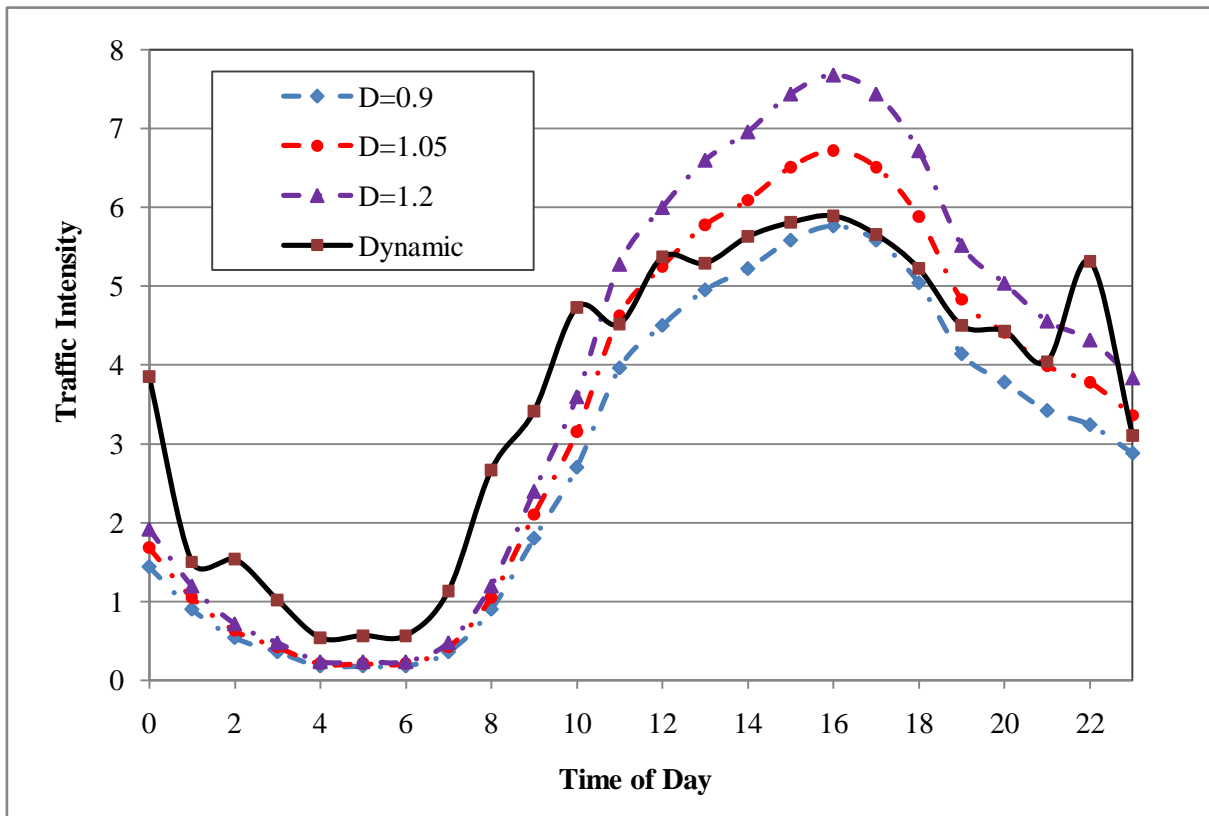
Figure 4.17 shows how the average call duration varies with price over a 24-hour period. The graph shows that as price increases, the average call duration decreases. Similarly, as the price decreases the average call duration increases.



**Figure 4.17: Variation of Average Call Duration with Price in Dynamic Pricing Scheme**

Figure 4.18 shows the traffic intensity for dynamic and flat pricing schemes with the different average call duration values. Between 12:00 midnight and 11:00 am, the traffic intensity with dynamic pricing is higher than for flat pricing for all the considered average call duration

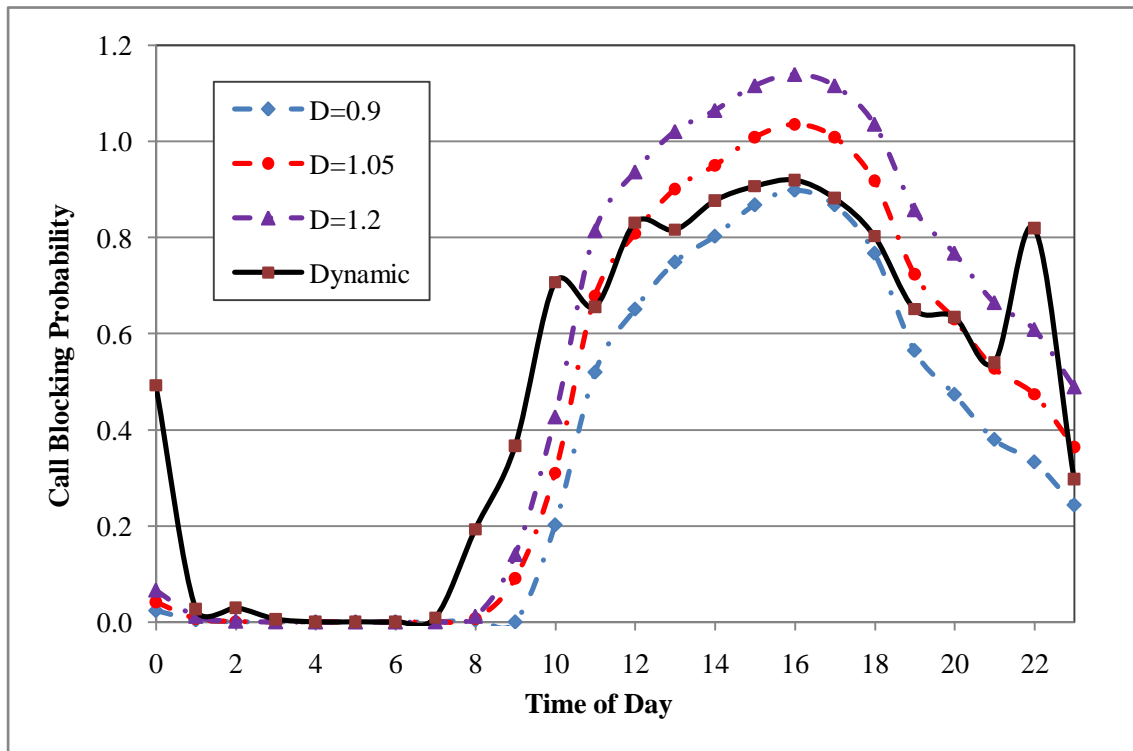
values. During this period, the dynamic pricing offers users pricing incentives to access the network; lower prices are charged to encourage users to request for network resources. Between 10:00 am and 10:00 pm, the traffic intensity is greater for higher average call duration values of flat pricing scheme than for the dynamic pricing scheme. During this period, user demand for network services is high and therefore the dynamic pricing scheme charges higher prices to discourage users from accessing the network. It is noted that lower values of average call duration for flat pricing give lower traffic intensity.



**Figure 4.18: Traffic Intensity for Dynamic and Flat Pricing Schemes**

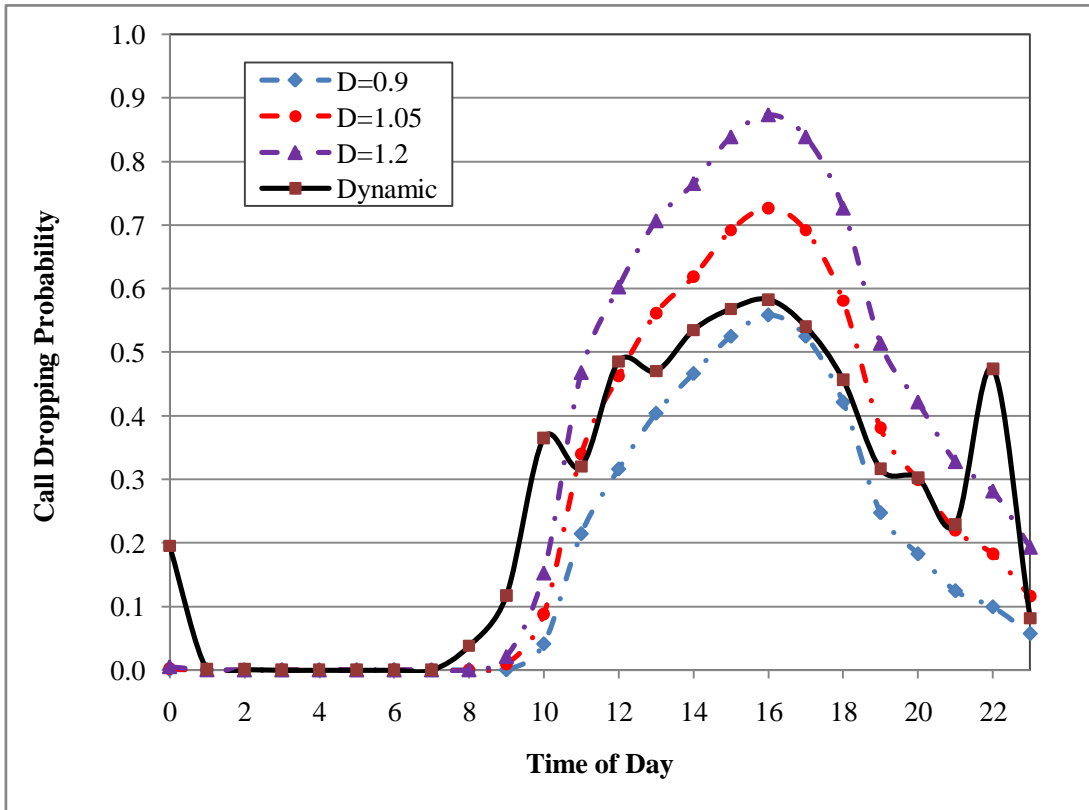
Figure 4.19 shows the results for call blocking probability. During the low load conditions, between 12:00 midnight and 11:00 am and for some instances between 9:00 pm and 11:00 pm, the call blocking probabilities for the dynamic pricing scheme are higher than for the average call durations considered for flat pricing. However, the high call blocking probabilities obtained with dynamic pricing during this period do not have an intense negative effect on QoS. During the peak period, the call blocking probabilities for dynamic pricing are lower than for the higher values of average call duration considered for flat pricing scheme. This is due to the fact that some users are discouraged from accessing the network due to high prices being charged in the dynamic pricing scheme. However, for lower call durations the call blocking

probabilities are generally lower than those obtained for dynamic periods throughout the whole 24-hour duration.



**Figure 4.19: Call Blocking Probability Obtained from Varying Average Call Duration and Arrival Rate**

Figure 4.20 shows the obtained results of call dropping probability. The outcome of call dropping probability is similar to that of call blocking probability. Higher values of average call duration for flat pricing have high call blocking probability during the peak period between 10:00 am and 8:00 pm. Dynamic pricing on the hand, gives lower call dropping probability during this period. However, low average call duration values of flat pricing give lower call dropping probabilities than dynamic pricing for most of the time.



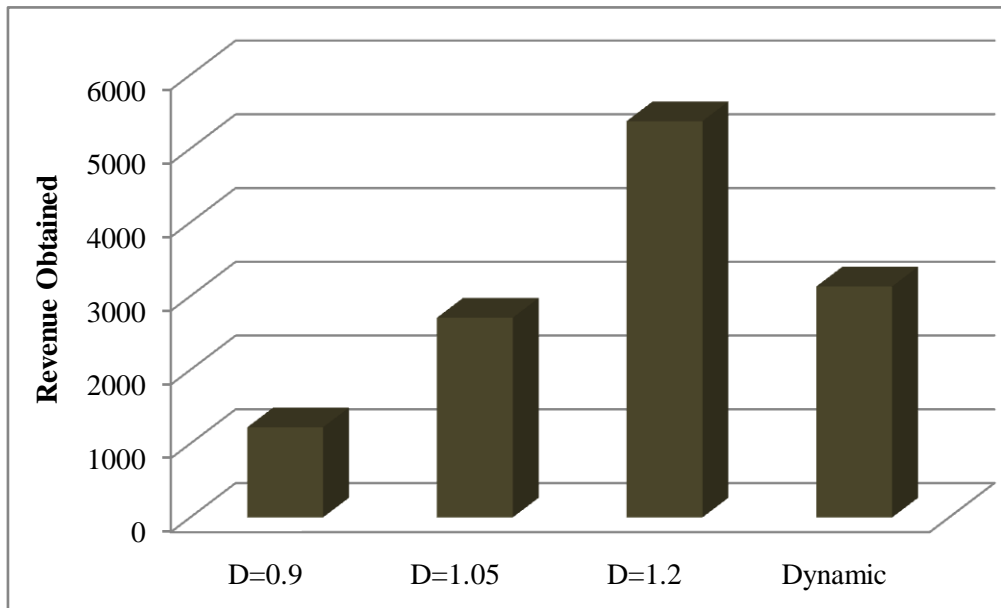
**Figure 4.20: Call Dropping Probability Obtained from Varying Average Call Duration and Arrival Rate**

Table 4.5 shows the values of the overall revenue obtained in the NGWN for the dynamic pricing schemes and for the different average call duration values in the flat pricing scheme. Figure 4.21 gives a graphical representation of the results showed in Table 4.5

The overall revenue obtained in the dynamic pricing scheme is greater than that obtained for lower call duration values of the flat pricing scheme. For the high average duration value of 1.2, the revenue obtained with the dynamic pricing scheme is less.

**Table 4.5: Summary of Overall Revenue Obtained**

Pricing Scheme	Dynamic	Flat		
		D=0.9	D=1.05	D=1.2
Average Call Duration	$D_{min} = 0.5, D_{max} = 1.5$	D=0.9	D=1.05	D=1.2
Revenue Obtained	3131.58	1,221.35	2,707.62	5373.03



**Figure 4.21: Overall Revenue Obtained with Variation in Average Call Duration and Average Arrival Rate**

Despite offering high revenue, the high average call durations for flat pricing are inappropriate because they result in increased congestion during the peak periods. Similarly, lower average call durations of the flat pricing scheme are also inappropriate because they offer low revenue despite giving improved QoS. However, dynamic pricing offers improved QoS by reducing congestion during the peak periods and guarantees reasonably high revenue for network operators.

## 4.6 DISCUSSION OF RESULTS

From the analyses made in Sections 4.5.1 and 4.5.2, the following can be deduced about dynamic pricing scheme:

- It offers better system performance, by offering lower blocking and dropping probability during periods of network overload. Therefore, the QoS offered is enhanced for NGWNs with dynamic pricing.
- It provides appropriate distribution of traffic by encouraging users to access the network when the network is underutilised and discouraging them when it is over utilised; hence optimising network resources.
- Higher overall revenue is obtained by network operators when dynamic pricing is incorporated in JCAC in NGWNs. Although there will be cases when revenue increase will not be achieved with dynamic pricing, improved system performance is obtained.

For example high values of flat pricing and high average call duration offer higher revenue than dynamic pricing, but offer poor QoS.

- An increase is noted in overall user utility and there is increased user utility during period of high network load. Therefore, dynamic pricing increases user satisfaction levels.

## **4.7 CHAPTER SUMMARY**

A dynamic pricing scheme has been analysed and evaluated for NGWNs integrated with JCAC. The dynamic pricing scheme causes rational use of resources whereby users are encouraged to use network resources during low-load conditions and discouraged from trying to access the network when the network is overloaded. The dynamic pricing scheme proposed applies a discount policy method whereby a discount is offered to users based on the system utilisation. When the utilisation increases the discount reduces and vice versa. Two analyses of user behaviour with dynamic pricing have been studied in this chapter namely variation in call arrival rate with change in price and variation in both average call duration and arrival rate with change in price. In both studies, comparisons were made with the flat pricing scheme. It was found that dynamic pricing outperforms flat pricing by offering lower call blocking and dropping probabilities during peak periods, improved user utility and ensuring that reasonable revenue is obtained by operators.

# 5. HYBRID PRICING MODEL

## 5.1 INTRODUCTION

Network users are characterised as having different requirements, and NGWNs are expected to satisfy these different requirements. One of the major considerations of users as they access telecommunications services is a friendly pricing scheme. In this chapter a hybrid pricing model is proposed for NGWNs. The hybrid pricing scheme caters for different user profiles i.e. flat pricing profile and dynamic pricing profile. The hybrid pricing model provides flexibility to the users to decide an appropriate pricing scheme.

## 5.2 HYBRID PRICING MODEL

The network operator is assumed to avail two pricing schemes; flat pricing and dynamic pricing. Figure 5.1 illustrates the hybrid pricing model.

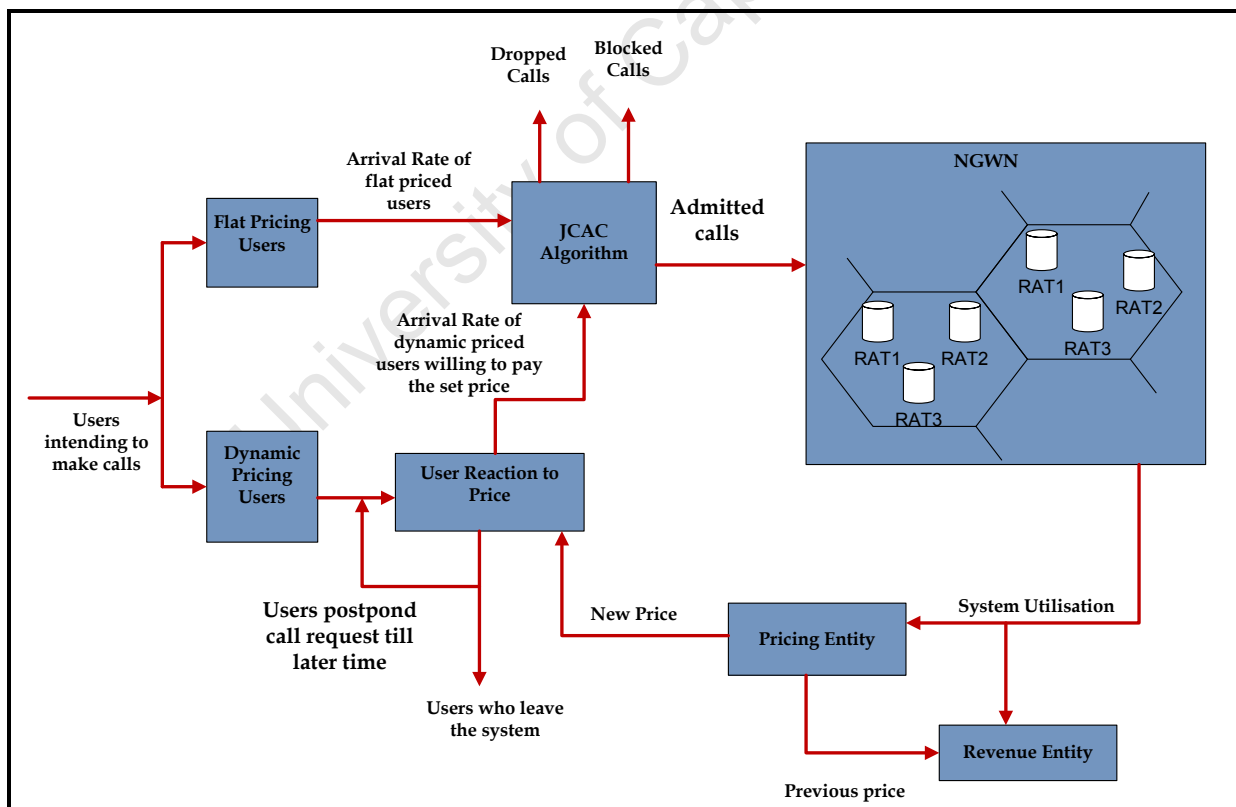


Figure 5.1: Hybrid Pricing Model

Users arriving in the network will determine the pricing scheme they prefer; either the flat pricing or the dynamic pricing. As the price charged under the flat pricing is constant

regardless of utilisation, the users who choose this scheme will not change their behaviour as they access the network. However, the users who choose the dynamic pricing scheme will alter their behaviour because the price charged will constantly keep changing with change in network utilisation. The dynamic priced users who find the price set by the pricing entity appropriate will go on to request for network services while those who find the price inappropriate will either try again later or forfeit requesting for services.

The JCAC algorithm will admit calls from the flat priced and the dynamic priced users to the appropriate RATs of the NGWN. The JCAC algorithm will admit calls if the requested capacity is available and drop handoff calls or block new calls if the requested capacity is unavailable.

The network utilisation is computed by the NGWN and feed into the pricing entity. The pricing entity determines the new price that needs to be used for the dynamic pricing scheme based on the system utilisation.

The revenue entity determines the revenue obtained in the system by using inputs from the pricing entity and from the NGWN. The NGWN will specify what portion of the utilisation is from the dynamic priced users and what portion is from the flat priced users. The price entity avails the price computed to charge the dynamic priced user. Since the price charged to the flat users is constant, the revenue entity will have records of it.

### **5.3 DISCOUNT POLICY**

The pricing entity shown in the hybrid pricing model in Figure 5.1 determines the new price applied in the dynamic pricing scheme. The pricing entity determines the new price to encourage users to use the network during low load conditions, and discourage them during high load conditions.

A discount policy is adopted to determine the new price. Users are given a discount based on the utilisation such that if the utilisation is high a low discount is given, and if the utilisation is low a higher discount is given.

Let  $DT_i$  denote the discount offered for class\_  $i$  calls.  $DT_i$  is given as:

$$DT_i = \alpha \left( \left( 1 - \left( \frac{\sum_{j=1}^Y (\rho n_{ij} + \rho h_{ij})}{\max(\sum_{i=1}^X (\rho n_{ij} + \rho h_{ij}) \forall j)} \right) \right) \times P_{max_i} \right), \alpha > 0 \quad (5.1)$$

The new price to be used in the system for class\_1 calls denoted as  $NPx_i$  is computed as follows:

$$NPx_i = P_{max_i} - DT_i \quad (5.2)$$

## 5.4 SYSTEM MODEL

The NGWN considered supports two classes of calls; class\_1 and class\_2. Class\_1 calls are considered to have a lower priority than class\_2 calls. Higher threshold are therefore set for rejecting class\_2 calls than for rejecting class\_1 calls.

The bandwidth requirement for class\_2 calls is considered to be higher than for class\_1 calls. For example class\_2 calls may represent services that require high bandwidth as well high level of performance such as live streaming video whereas class\_1 will represent services that have low bandwidth requirement and low priority such as email services.

Calls arriving in the system will be admitted for the flat pricing scheme or the dynamic pricing scheme depending on the users' preferences. The flat pricing users will be charged a flat price regardless of the network utilisation or the time of the day. While the users under dynamic pricing have a high penalty when the network utilisation is high and a lower penalty when the utilisation is low. There will be instances when the users under dynamic pricing are charged a lower price than the one being charged to the users under flat pricing, and vice versa.

The effective arrival rate into the NGWN comprises of the arrival rate of calls from dynamic priced users as well as calls from flat priced users. Let  $\lambda n_{i_{flat}}$  denote the arrival rate of new calls of class\_1 from users under flat the pricing scheme. Let  $\lambda n_{i_{dyn}}$  denote the arrival rate of new calls of class\_1 from users under dynamic the pricing scheme. Let  $\lambda n_i$  denote the arrival rate of new calls of class\_1 is the JCAC algorithm.  $\lambda n_i$  is computed as follows:

$$\lambda n_i = \lambda n_{i_{flat}} + \lambda n_{i_{dyn}} \quad (5.3)$$

Similarly, for handoff calls let  $\lambda h_{i_{flat}}$  denote the arrival rate of handoff calls of class  $i$  under the flat pricing scheme and  $\lambda h_{i_{dyn}}$  denote the arrival rate of handoff calls of class  $i$  under dynamic the pricing scheme.  $\lambda h_i$ , the arrival rate of new calls of class  $i$  is determined as follows:

$$\lambda h_i = \lambda h_{i_{flat}} + \lambda h_{i_{dyn}} \quad (5.4)$$

With  $n_{i,j}$  and  $h_{i,j}$  representing the ongoing new calls and handoff respectively, as was shown in Chapter 3, the total number of calls in class  $i$  made in the NGWN is given as:

$$N_i = \sum_{k \in A} \sum_{j=1}^Y (n_{ij}) (h_{ij}) P_k \quad (5.5)$$

where  $A$  is the set of all possible admissible calls described as:

$$A = \left\{ k = (n_{ij}, h_{ij} : i = 1, 2, \dots, X; j = 1, 2, 3, \dots, Y) \right. \\ \left. \begin{aligned} &| \sum_{i=1}^X \sum_{j=1}^Y (b_i \times n_{ij}) \leq T n_{ij} \wedge \sum_{i=1}^X \sum_{j=1}^Y (b_i \times h_{ij}) \leq T h_{ij} \\ &\wedge \sum_{i=1}^X \sum_{j=1}^Y ((b_i \times n_{ij}) + (b_i \times h_{ij})) \leq C_j \end{aligned} \right\} \quad (5.6)$$

$P_k$  is defined in chapter 3 as the steady state probability that the system is in state  $k$  and it is expressed as follows:

$$P_k = \prod_{i=1}^X \prod_{j=1}^Y \frac{(\rho h_{i,j})^{h_{ij}}}{h_{ij}!} \frac{(\rho n_{i,j})^{n_{ij}}}{n_{ij}!} \times P_0 \quad k \in A \quad (5.7)$$

$P_0$  is given as:

$$P_0 = \left[ \sum_{k \in A} \prod_{i=1}^X \prod_{j=1}^Y \frac{(\rho h_{i,j})^{h_{ij}}}{h_{ij}} \frac{(\rho n_{i,j})^{n_{ij}}}{n_{ij}} \right]^{-1} \quad (5.8)$$

Let  $N_{i_{flat}}$  denote the average number of calls in class  $i$  in the system from users who opt to be charged through the flat pricing policy.  $N_{i_{flat}}$  is computed as follows:

$$N_{i_{flat}} = \left\{ \left( \frac{\lambda n_{i_{flat}} + \lambda h_{i_{flat}}}{\lambda n_i + \lambda h_i} \right) \times N_i \right\} \quad \forall j \quad (5.9)$$

Similarly for dynamic pricing, the total number of calls in the systems due to users under the dynamic pricing scheme denoted as  $N_{dynamic}$ , is given as:

$$N_{i_{dyn}} = \left\{ \left( \frac{\lambda n_{i_{dyn}} + \lambda h_{i_{dyn}}}{\lambda n_i + \lambda h_i} \right) \times N_i \right\} \quad \forall j \quad (5.10)$$

Let  $D_{i_{flat}}$  denote the total duration of calls in class\_  $i$  made by users in the flat pricing scheme.

$D_{i_{flat}}$  is given as follows:

$$D_{i_{flat}} = N_{i_{flat}} \times \frac{1}{\mu_i} \quad (5.11)$$

Similarly, let  $D_{i_{dyn}}$  denote the total duration of calls in class\_  $i$  made by users in the dynamic pricing scheme.  $D_{i_{dyn}}$  is given as follows:

$$D_{i_{dyn}} = N_{i_{dyn}} \times \frac{1}{\mu_i} \quad (5.12)$$

Let  $Px_{i_{flat}}$  and  $Px_{i_{dyn}}$  denote the unit price for flat rate pricing scheme and the dynamic pricing scheme respectively for class\_  $i$  calls. The revenue obtained from dynamic pricing denoted by  $R_{i_{dyn}}$ , is derived as follows:

$$R_{i_{dyn}} = \sum_{k \in A} (Px_{i_{dyn}} \times D_{i_{dyn}}) \quad \forall j \quad (5.13)$$

Correspondingly, the revenue obtained from flat pricing denoted  $R_{i_{flat}}$  is derived as follows:

$$R_{i_{flat}} = \sum_{k \in A} (Px_{i_{flat}} \times D_{i_{flat}}) \quad \forall j \quad (5.14)$$

Therefore, the total revenue  $R_T$  in the system is deduced as follows:

$$R_T = \sum_{i=1}^X (R_{i_{dyn}} + R_{i_{flat}}) \quad \forall j \quad (5.15)$$

## 5.6 PERFORMANCE EVALUATION

This section gives the results obtained with having a hybrid pricing scheme in an NGWN. The analysis is made when 0%, 25%, 50%, 75% and 100% of the users choose dynamic

pricing which is analogous to when 100%, 75%, 50%, 25% and 0% respectively, of the users choose the flat pricing scheme.

Figure 5.2 shows the user demand distribution for when 100% of the users opt for flat pricing scheme. It is from this demand distribution, that user demand due to dynamic pricing is computed. This demand distribution was determined in 2005 and it depicts a recent finding on user behaviour characteristics.

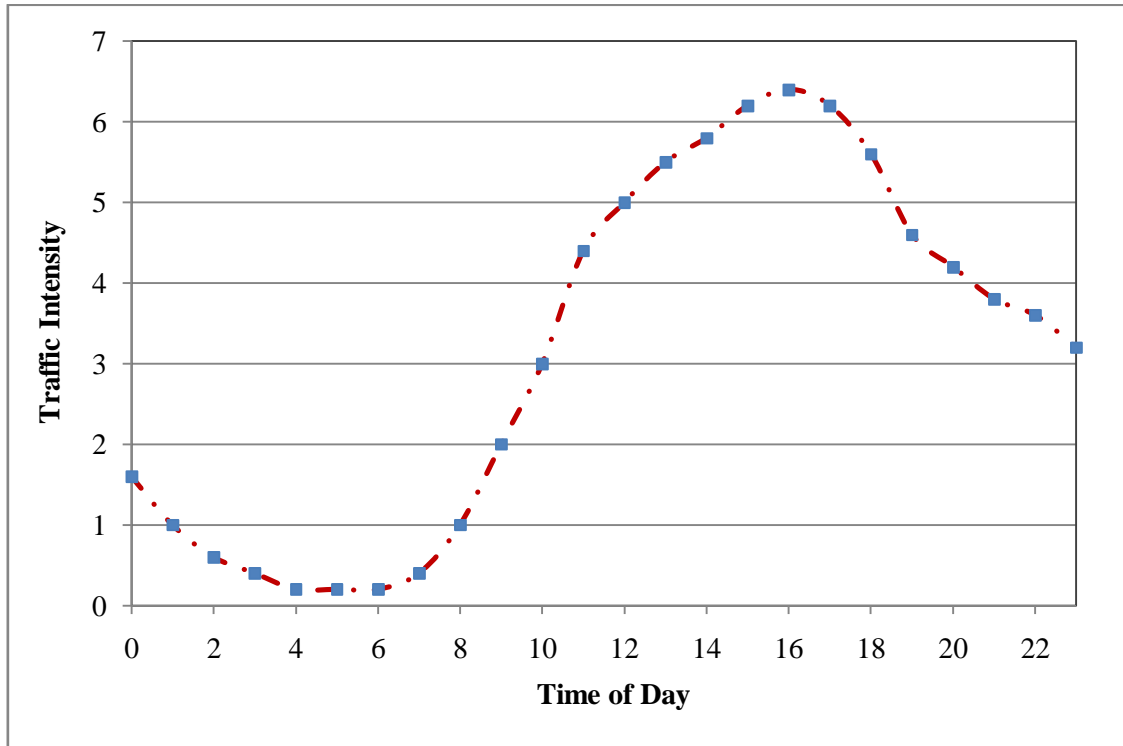


Figure 5.2: Traffic Demand Applied for Flat Pricing [77]

In this analysis, user reaction due to price variation is computed based on the price sensitivity model described in Section 4.3.2. PSF values are chosen to represent user perception with ‘Very cheap’ having the highest value and ‘Very Expensive’ having the lowest value. Table 5.1 shows the parameters used for the price sensitivity model

Table 5.1: Price Sensitivity Parameters used for the Hybrid Pricing Model

Price Range	User Perception	PSF
$0 \leq P_x < 0.4$	Very Cheap	2.000
$0.5 < P_x \leq 0.8$	Cheap	1.500
$1.0 < P_x \leq 1.2$	Moderate	1.125
$1.5 < P_x \leq 1.6$	Expensive	0.844

$1.5 < P_x \leq 2.0$	Very Expensive	0.633
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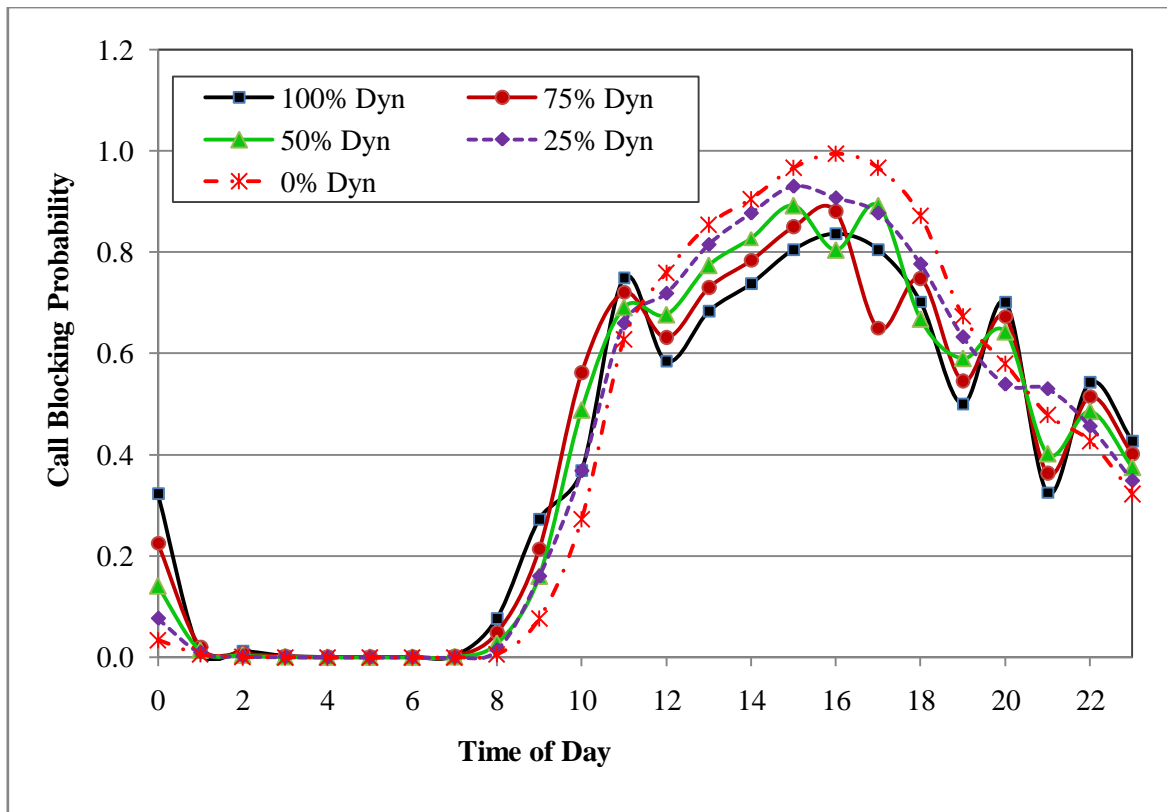
The system parameters used are as follow:

$$C_1 = 50, C_2 = 35, b_1 = 2, b_2 = 5, Tn_{11} = 15, Tn_{21} = 20, Tn_{12} = 10, Tn_{22} = 15, Th_{11} = 45, Th_{21} = 50, Th_{12} = 2, Th_{22} = 35, \mu_1 = 1, \mu_2 = 1, \alpha = 1, \max(\lambda n_{ij}) = \max(\lambda h_{ij}) = 7, P_{min_1} = P_{min_2} = 0, P_{max_1} = P_{max_2} = 2, \theta = \frac{1}{4}, \beta = \frac{3}{4}.$$

### 5.6.1 SYSTEM PERFORMANCE

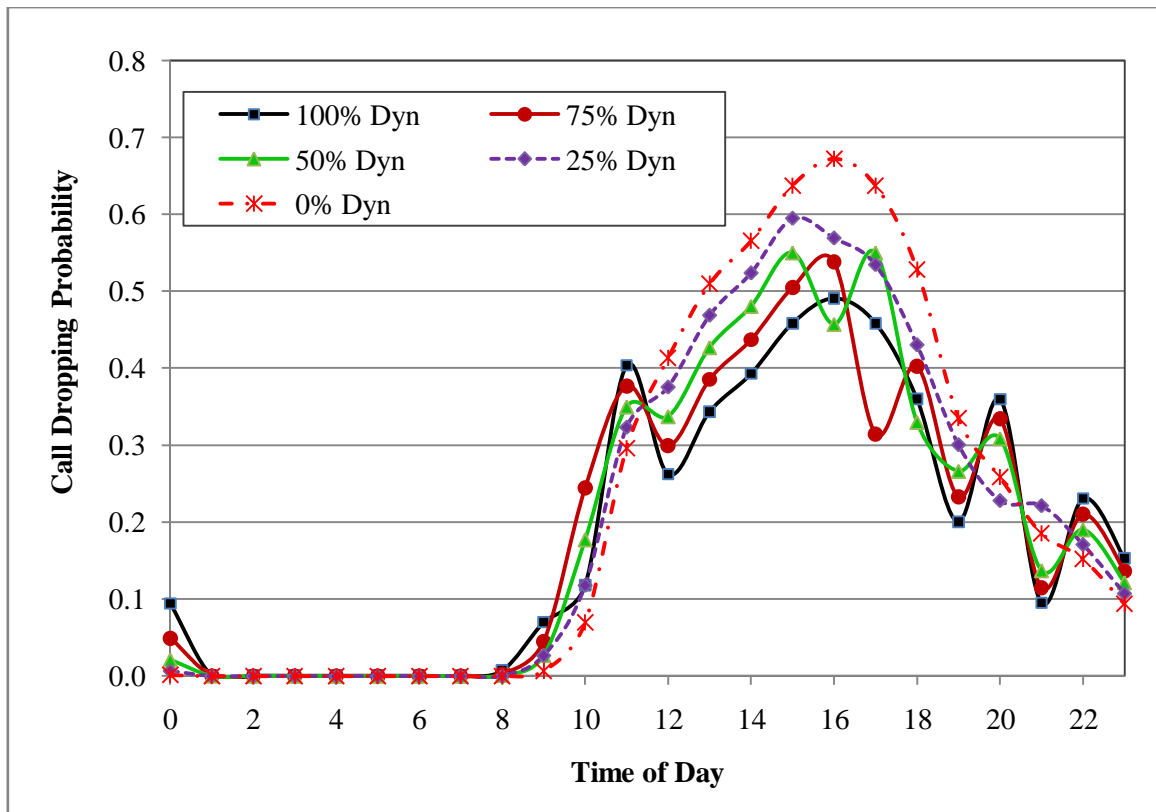
Figure 5.3 shows the call blocking probability over a 24-hour period when 0%, 25%, 50% 75% and 100% of the users choose the dynamic pricing scheme, which is equivalent to 100%, 75%, 50% 25% and 0% respectively, of the users choosing flat pricing scheme.

During off peak periods, call blocking probabilities are generally low. However, as the percentage of users under the dynamic pricing scheme increase, the call blocking probabilities during the peak period (12:00 pm - 7:00 pm) go down. Therefore, blocking of calls is reduced in the hybrid pricing model during peak periods as there will always be a certain percentage of users who will opt for dynamic pricing.



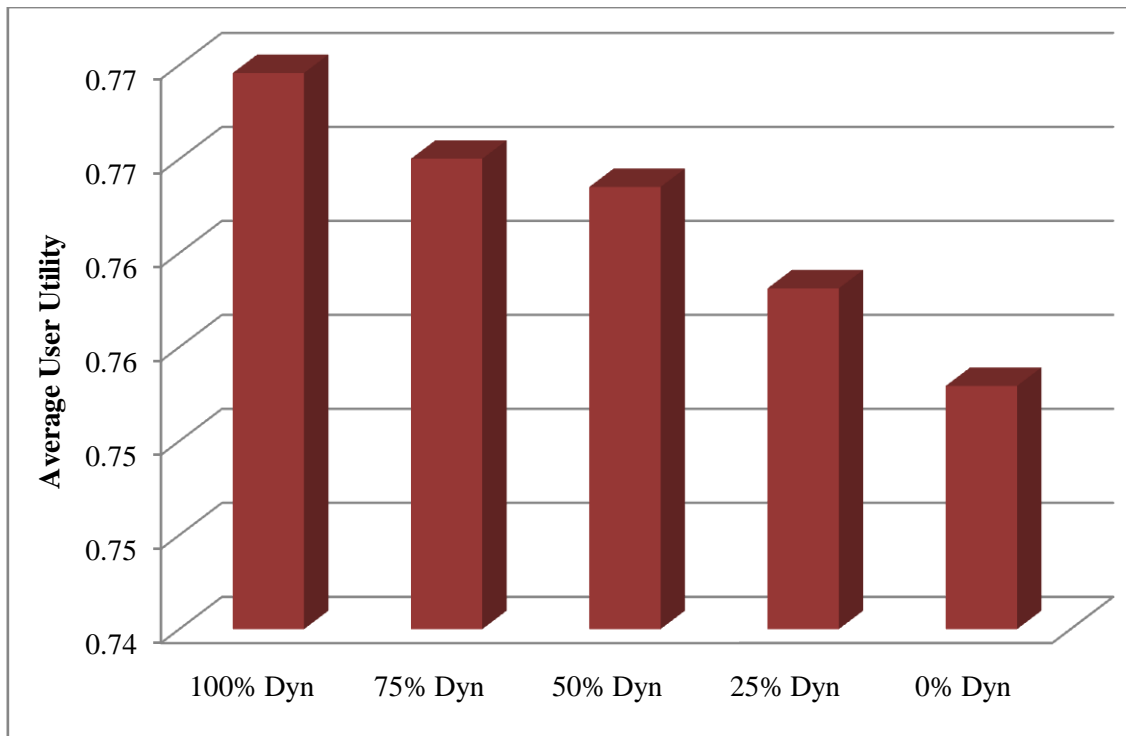
**Figure 5.3: Call Blocking Probability in the Hybrid Pricing Model**

Figure 5.4 shows the call dropping probabilities obtained over a 24-hour period. Evidently, the call dropping probabilities are lower than call blocking probabilities due to the fact that higher thresholds are set for rejecting handoff calls. The behaviour of call dropping probability is similar to that of the call blocking probability; when the numbers of users who choose the dynamic pricing scheme increases, lower call dropping probabilities are experienced during the peak periods.



**Figure 5.4: Call Dropping Probability in the Hybrid Pricing Model**

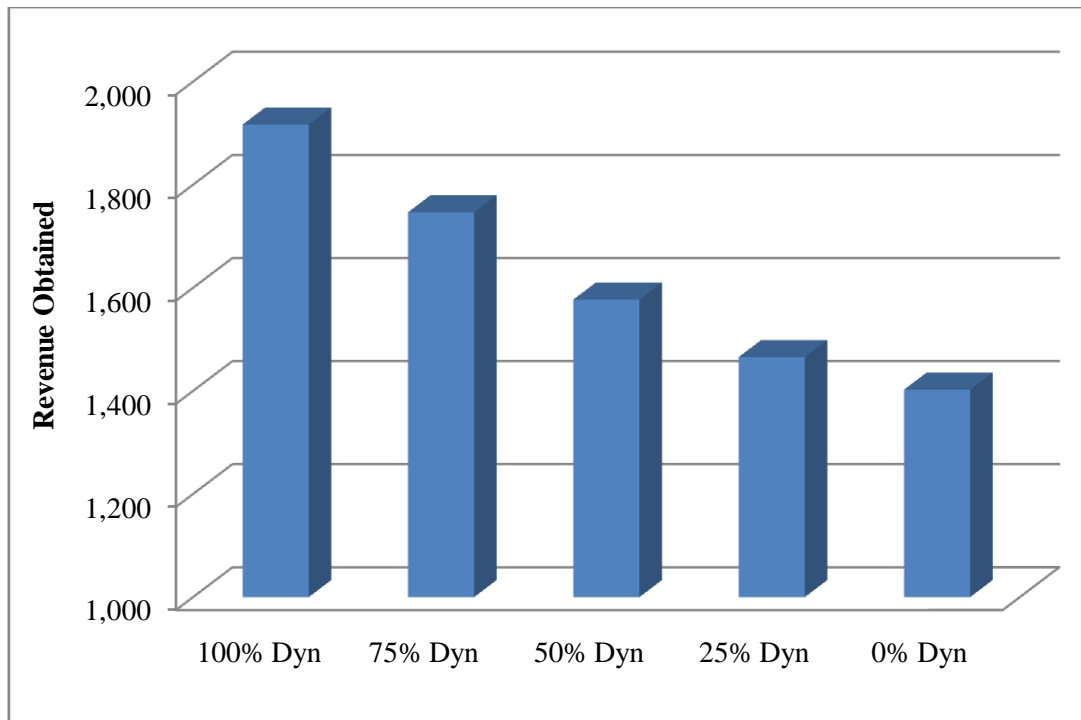
Figure 5.5 shows the average user utility values obtained for the different percentages over a 24-hour period. User utility is highest when 100% of the users are under the dynamic pricing scheme and it is lowest when 100% are under the flat pricing scheme. The hybrid pricing model will therefore result into increased user satisfaction.



**Figure 5.5: Average User Utility in the Hybrid Pricing Model**

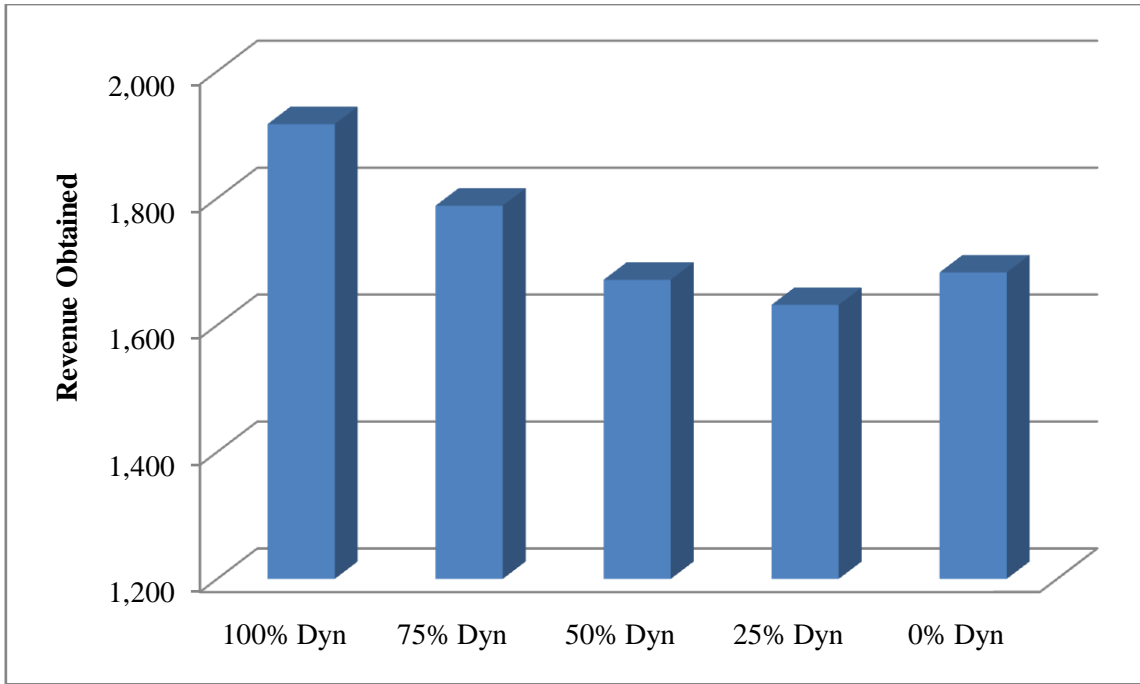
The prices applied to the flat pricing scheme fall under the price range that users perceive as cheap in the price sensitivity model. For comparison purposes, three price values are considered for users under the flat pricing scheme; these values are 0.5, 0.6 and 0.7 units.

Figure 5.6 shows the overall revenue obtained in the system over a period of 24-hours in the hybrid pricing model with the flat pricing users charged at 0.5 units. Higher revenue is obtained in the NGWN as more users choose the dynamic pricing scheme increase. The lowest revenue is obtained when 100% of the users opt for the flat pricing scheme.



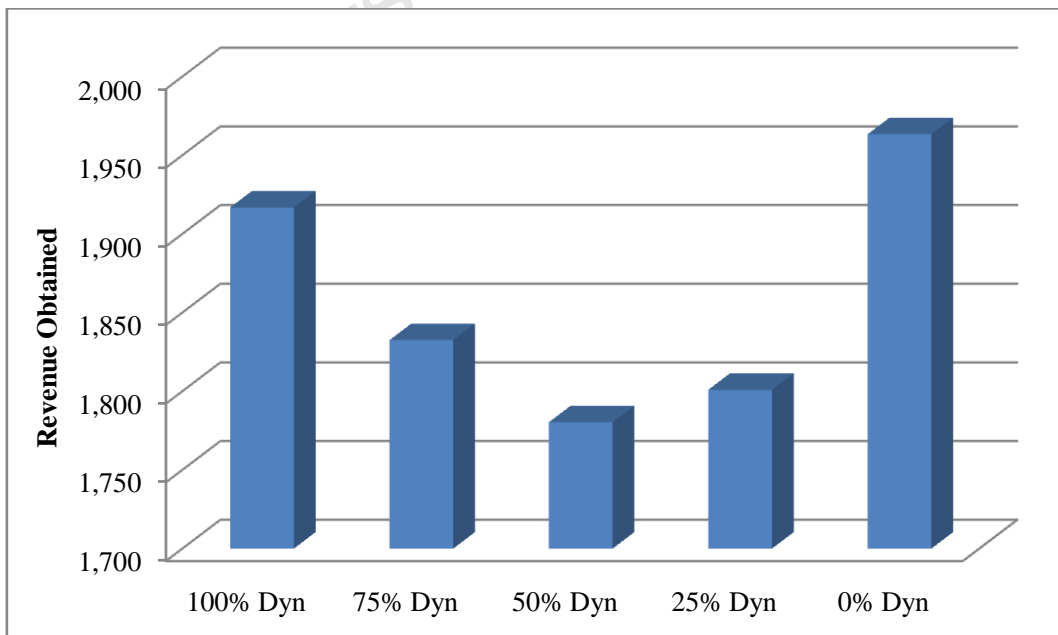
**Figure 5.6: Revenue Obtained in Hybrid Pricing Model over a 24-Hour Period with Flat Pricing Charged at 0.5 Units**

Figure 5.7 shows the revenue obtained in the NGWN when the flat pricing charge is increased to 0.6. The highest revenue is obtained when 100% of the users choose the dynamic pricing scheme. The lowest revenue, however, is not obtained when 100% of the users choose flat pricing. It is noted that when fewer number of users opt for the dynamic pricing scheme the revenue obtained is low. For example when 25% of the users choose dynamic pricing and 75% choose flat pricing, the revenue obtained is lower than when 100% of the users choose the flat pricing scheme.



**Figure 5.7: Revenue Obtained in Hybrid Pricing Model over a 24-Hour Period with Flat Pricing Charged at 0.6 Units**

When the flat pricing charge is further increased to 0.7 units, higher revenue is obtained when fewer users opt for dynamic pricing. Figure 5.8 gives a representation of the revenue obtained when the unit charge for flat pricing is 0.7. The highest revenue obtained in the system is when 100% of the users choose flat pricing.



**Figure 5.8: Revenue Obtained in Hybrid Pricing Model over a 24-Hour Period with Flat Pricing Charged at 0.7 Units**

When the price charged for flat pricing increases, more revenue is obtained when 100 % of the users opt for flat pricing scheme. However, having a purely flat priced network compromises system performance. The performance results showed that call blocking and call blocking probabilities are reduced when more users in the network choose dynamic pricing. Given that users are price sensitive, there will always be a percentage of users who will choose dynamic pricing.

## **5.7 CHAPTER SUMMARY**

To improve flexibility in charging and pricing mechanisms, a hybrid pricing model has been proposed in this chapter for NGWNs. The hybrid pricing model offers both flat pricing and dynamic pricing schemes to users. This gives users the freedom to decide the pricing mechanism that best suits them. Having an entity of dynamic pricing incorporated in the hybrid pricing model results into improved system performance by reducing call blocking and call dropping probabilities during peak periods. Given that users are price sensitive, there will be a given percentage of users that will choose dynamic pricing over flat pricing, and this will result into improved QoS. Not only does incorporating dynamic pricing improve QoS, it also results into increased revenue benefits for network operators and improved user utility. A hybrid pricing model is therefore favourable both to the users and to the network operators.

## 6. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

### 6.1 CONCLUDING REMARKS

This thesis has presented an analysis of JCAC incorporated with pricing in NGWNs. Given that network users are inherently price sensitive, variation in price affects their behaviour as they access network resource. This phenomenon was adopted to perform an analysis of network operators' revenue in heterogeneous wireless network environment using a multi-dimensional Markov decision process.

Evaluation of user behaviour has been performed with a dynamic pricing scheme and JCAC in NGWNs. Pricing incentives and disincentives are used to affect the behaviour of users as they access network resources. The analytical results obtained show that under dynamic pricing lower call blocking and call dropping probabilities are experienced during peak periods. Consequently, the dynamic pricing scheme offers effective traffic distribution whereby users are encouraged to access the network during low load conditions and overcomes network overload during peak periods. Average user utility is found to be higher under the dynamic pricing scheme. Moreover, the dynamic pricing scheme guarantees higher revenue with improved QoS for NGWNs. A discount policy which comprises of a scaling factor is proposed for determining new price in the dynamic pricing scheme. Higher values of the scaling factor offer higher discount to users encouraging more users to access the network, and thus ensuring that higher revenue is obtained by the network operators. However, higher scaling factors offer high call blocking and call dropping probabilities during peak periods. Therefore, network operators have to make a compromise on revenue and QoS when determining an appropriate scaling factor value.

Furthermore, a hybrid pricing model is proposed for NGWNs whereby flat pricing and dynamic pricing are integrated. Users are given the flexibility of choosing the pricing scheme that suits them. It is expected that under the hybrid pricing model, at all times, there will always be some users who will be interested in the dynamic pricing scheme. With some percentage of users opting for dynamic pricing scheme, the results obtained show improved QoS, as well as increased revenue for network operators.

This thesis has shown that integrating pricing with JCAC in NGWNs will result in enhanced system performance of the network benefiting both the network users and service providers.

## **6.2 RECOMMENDATIONS FOR FUTURE WORK**

Areas for future work are hereby discussed.

This thesis assumes that the RATs in the NGWN belong to the same operators. Competition between network operators affects the user behaviour in wireless network environment. Network operators' revenue can be analysed in a multiple operator environment while examining churning effects that an operator faces due to alterations made by the competition.

The RATs in the NGWN considered in this work are assumed to be fully overlapped, whereby all the RATs offer full coverage and at any given moment users have access to any of the available RATs. In reality this is not the case. To extend this work, RATs for an NGWN can be considered that do not overlap and when they partially overlap.

The JCAC algorithm used in this analysis was limited to the load-based algorithm. However a number of JCAC algorithms have been proposed in the literature. Therefore, to extend this work, pricing should be incorporated in other JCAC algorithms such as the service class-based, random-based, path loss-based, service cost-based, etc.

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