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Agent Based Resource Management in 3G Wireless Networks

by

Rajeev Babbar

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Agent Based Resource Management in 3G Wireless Networks" submitted by Rajeev Babbar in partial fulfillment of the requirements for the degree of Master of Science.

Supervisor, Dr. A. O. Fapojuwo,
Dept. of Electrical and Computer Engineering

Co-Supervisor, Dr. B. H. Far,
Dept. of Electrical and Computer Engineering

Dr. D. Krishnamurthy,
Dept. of Electrical and Computer Engineering

Dr. A. Mahanti,
Dept. of Computer Science

April 12, 2005
Date

Abstract

Wireless networks are no more used for transfer of only voice but now also support data, video and multimedia. Due to large number of customers and the resources being limited, Radio Resource Management (RRM) becomes much more important and complicated in wireless networks. Thus the resource management in such circumstances requires network to be intelligent and adaptive which can be implemented through the use of agent technology branch of Artificial Intelligence (AI). The use of agent technology for RRM in 3G (Universal Mobile Telecommunication System (UMTS)) wireless networks is presented in this thesis. The proposed scheme is based on collaborating agents and Open Agent Architecture (OAA).

The effectiveness of the proposed agent based scheme was demonstrated by simulation technique. The agent based scheme provided reduced call blocking and call dropping rates which would benefit both users and network providers in terms of high quality service and increased network capacity, respectively.

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List of Notations

AC_{ij}	Average of number of calls from class j per hour of past 15 weeks for any hour i
BRH	Total bandwidth required in a network cell for handoff calls
BW_{IU}	Total bandwidth in use by handoff calls in a network cell
$(BW_{OPER})_j$	Operating bandwidth, if sufficient is not available
$(BW_{OPER})_j$	Minimum bandwidth, if sufficient is available
E_b/N_o	Required ratio of energy per user bit with noise spectral density of a user
I_{total}	Total interference received from N users in the cell
I	Other cell interference ratio
MBR_i	Bandwidth required in a network cell for any hour i
N_{DL}	Downlink Load Factor
P_T	Transmitted Power
P_D	Power received by mobile station at radial distance D from base station
R_j	Bit rate of user j
SNR	Signal to Noise Ratio
S_{HO}	SNR value at which handoff is executed
S_{RSV}	SNR value at which channel reservation request is made by mobile station
v_j	Activity factor of user j
W	Chip rate
α	Orthogonality factor

Abbreviations and Acrnonyms

ACR	Adaptive Channel Reservation
ACL	Agent Communication Language
ABRM	Agent Based Resource Management
BSC	Base Station Controller
BS	Base Station
CDMA	Code Division Multiple Access
CBR	Constant Bit Rate
DCA	Dynamic Channel Allocation
FCA	Fixed Channel Allocation
FTP	File Transfer Protocol
GUI	Graphical User Interface
HCA	Hybrid Channel Allocation
MS	Mobile Station
QoS	Quality of Service
RNC	Radio Network Controller
SNR	Signal to Noise Ratio
THD	Traffic History Database
VBR	Variable Bit Rate
UBR	Unspecified Bit Rate
UPD	User Profile Database
UMTS	Universal Mobile Telecommunications Systems
WCDMA	Wideband CDMA

CHAPTER ONE

Introduction

1.1 Overview of Wireless Communications

The introduction of wireless communications completely redefined the term "communication" by giving subscribers the liberty to talk anytime and most importantly anywhere. In 1901, Guglielmo Marconi sent telegraphic signals through wireless technology from England to Canada that allowed two ends to communicate in alpha numeric characters encoded in analog signals. Now, a hundred years later it is possible to send almost any kind of information on wireless networks. Wireless communication currently focuses primarily on wireless networking, cellular telephony and satellite communications.

Wireless networking has gained a great deal of attention from both academic and industrial research. Wide Area Networks (WANs), Local Area Networks (LANs) and Personal Area Networks (PANs) are capable of providing users with high speed data transfer with flexibility to move from place to place. With the advent of wireless networking, the market for Personal Digital Assistants (PDAs) and notebook computers has witnessed significant growth. The major breakthrough for wireless community was to establish cellular communication networks which not only provide two-way communication in voice and data, but also allow global roaming. Satellite communication plays vital role in connecting the entire world by carrying voice traffic and television signals across continents.

Wireless communications have gradually moved from analog to digital which has opened doors to several new features, increasing number of users due to reduced hardware costs as well as support for more users. With introduction of wireless Internet, several new types of portable devices that are capable of supporting both voice and data applications have been introduced. At the same time, wireless systems are achieving higher data rates to support internet and other data-related applications. A summary of different generations of wireless networks is presented in the following sections.

1.1.1 First-Generation Wireless Networks

First generation cellular and cordless telephone networks are based on analog technology and digital control channels. All first generation cellular systems use Frequency Modulation (FM) with digital control channels using Frequency Shift Keying (FSK) [1]. Figure 1.1 shows the first generation cellular radio network architecture having network elements such as mobile terminals, base stations, and mobile switching centre (MSC).

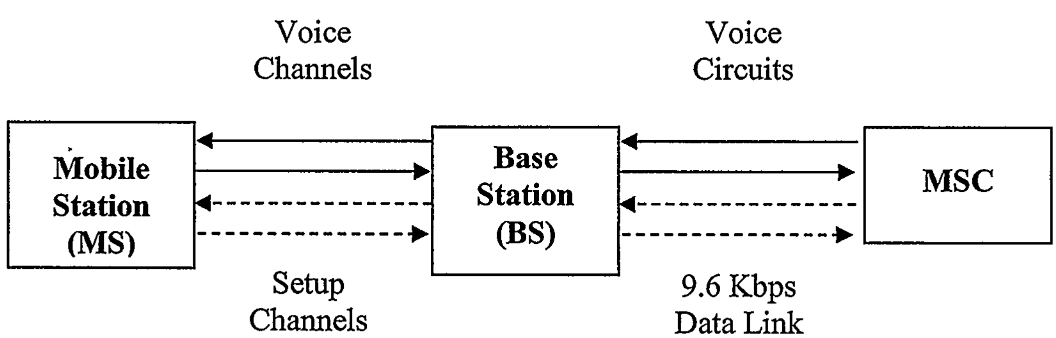


Figure 1.1 First Generation (1G) Wireless Network Architecture [1]

In first generation cellular networks, MSC maintains all mobile related information and controls each mobile handoff. In 1G wireless networks, MSC also performed all network management functions such as call handling, billing, et cetera. One MSC is connected with the other MSCs through dedicated signaling channels [1].

Analog systems include Advanced Mobile Phone Services (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communications System (TACS). In 1979, the first commercial analog cellular system was set up by NTT in Japan. During the same time AMPS was being tested in North America and was later introduced in the United States in 1983. Two years later in 1985, TACS was rolled out into United Kingdom cellular market. US cellular customers had to register manually each time they entered a new wireless network during roaming. In the early 1990s, the IS-41 network protocol standard was adopted by US cellular carriers which made it possible for different cellular systems to automatically accommodate roaming subscribers. This was achieved by allowing different MSCs to exchange information about their roaming subscribers, as and when required [1].

The first generation of systems for mobile telephony was analog, circuit switched, and it only carried voice traffic. The major problem with the first generation wireless networks was support for only voice calls and low data rates. The analog phones used in 1G cellular networks were less secure and prone to interference where the signal was weak [1] [2].

1.1.2 Second-Generation Wireless Networks

First generation wireless networks were becoming obsolete due to low data rates, voice only support, et cetera and were replaced with second generation wireless networks (2G) which had digital modulation and advanced call processing capabilities. This not only provided the subscribers with a better quality of service but also reduced the costs significantly. Digital systems provided more capacity in terms of the number of users due to efficient use of available spectrum. Some examples of second-generation wireless systems are Global System for Mobile Communications (GSM), North American Digital Cellular and Code Division Multiple Access (CDMA) systems pioneered by QUALCOMM [1]. Second-generation wireless networks introduced a new network element called a Base Station Controller (BSC) which was inserted between the base stations (BTS) and the mobile station controller. Introduction of BSC not only reduced the computational burden of the MSC but also allowed data interfaces between the base station controller and MSC to be standardized [1]. The network architecture of second-generation wireless system is shown in Figure 1.2.

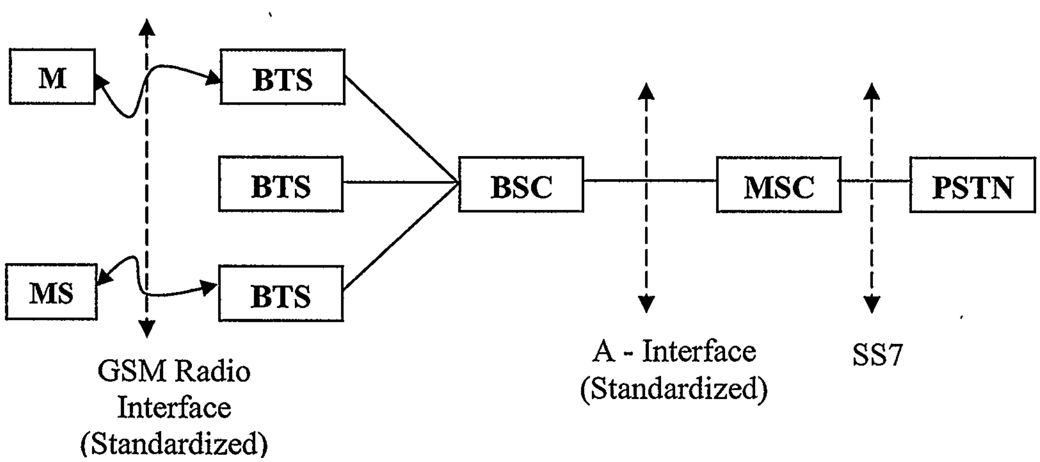


Figure 1.2 Second Generation (2G) GSM Network Architecture [1]

Unlike 1G, 2G wireless networks provided support for data services such as fax and high data rate applications (up to 64 kbps). 2G also provided features like enhanced mobility, security through encryption and short text messaging. The maximum data rate supported in 2G networks was approximately 64 kbps. In order to achieve higher data rates, a new standard called 2.5G was introduced. This was capable of providing much better data rates as compared to 2G and was made possible through General Packet Radio Service (GPRS) and Enhanced Data for Global Evolution (EDGE) technologies. GPRS can achieve up to 170 kbps and EDGE can even exceed data rate of 384 kbps [3].

But second generation cellular networks had few shortcomings which served as a driving force for development of third generation (3G) networks. 2G suffered from limited capacity and lower data rates when supporting high end applications. Although 2G was better than 1G, it had limited roaming capabilities. 2G networks had no support for multimedia and limited support for packet data [1][3].

1.1.3 Third Generation (3G) Wireless Networks

The primary focus of third generation wireless networks will be to evolve second generation systems that will provide high-speed data services in order to support multimedia applications which were not supported in 2G. International Telecommunications Union (ITU) has received several proposals towards 3G networks. In 1997 the Association for Radio Industry and Business (ARIB) in Japan played an important role behind a third-generation radio transmission technology known as wideband CDMA (WCDMA). European Telecommunications Standards Institute (ETSI)

Special Mobile Group (SMG) technical subcommittee has responsibility for UMTS standardization [4]. The need for third generation wireless networks was felt because there was a need:

1) For voice quality comparable to Public Switched Telephone Network (PSTN) as in landline phones.
2) To support data rates up to 2 Mbps or greater depending upon the environment
3) For high spectral capacity
4) To support multimedia services
5) For packet data network and IP mobility
6) For true global roaming
7) For virtual home environment
8) For better quality of service
9) For interoperability with 2G networks

The general architecture of 3G wireless networks is shown in Figure 1.3.

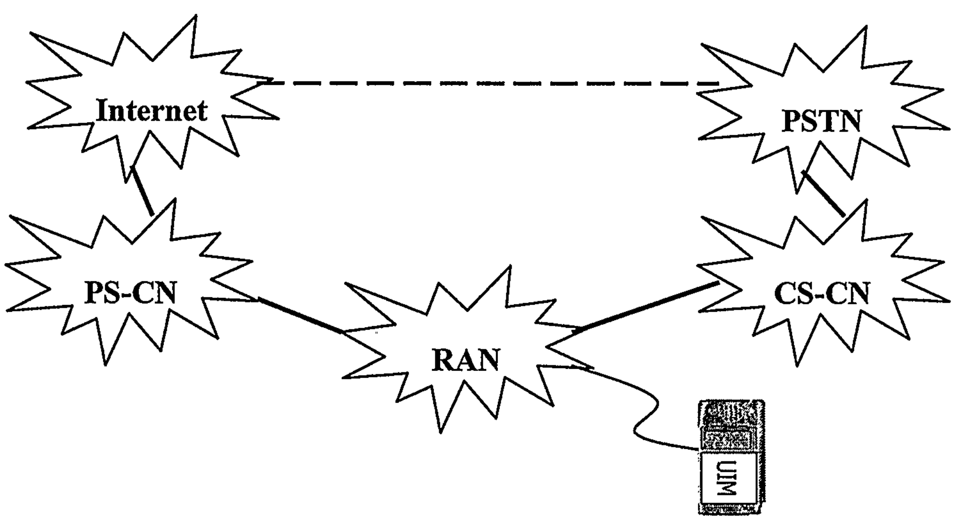


Figure 1.3 Typical 3G Network Architecture [3]

The 3G architecture consists of three parts: Radio Access Network (RAN), Core Network (CN) and external network. Core network can be either Circuit-Switched (CS-CN) or Packet-Switched (PS-CN) which is connected to external network such as the Internet or Public Switched Telecommunications Network (PSTN) respectively. Both the base stations (Node-Bs) and Radio Network Controller (RNC) reside inside the RAN layer. The MS's are connected to the network through their respective Node-Bs. In order to facilitate specifying the 3G wireless network as a global, multimedia-enabled network, a 3rd Generation Partnership Project (3GPP) was formed which aimed to specify a set of standards that would provide multimedia services as well as enable an interoperable worldwide network in the near future. Ultimately 3GPP aims to create an all-IP wireless infrastructure [5].

1.1.4 Future Wireless Networks

A currently debated technology which is supposed to roll into the market in a decade is the fourth generation wireless networks also called 4G. It is in the process of being defined with plans for extensive studies in various organizations [5]. 4G cellular networks will be deployed in an environment where wired and wireless infrastructure is already established. Thus, it will support the current generation and will complement and enhance these systems. 4G will have benefits such as low cost products from cellular companies, readily available personal information, enhanced pocket computing, possible tele-presence for video and audio conversations, communication between machines and appliances, highly secured systems, transparent and seamless internetworking, et cetera [6].

Future wireless systems will be highly user oriented where the user will be able to run any required service, anywhere, anytime without being hindered by the limitations of the wireless system. The user will always be connected to the most efficient access network in terms of network resource usage. The biggest advantage will be the opportunities for equipment manufacturers providing IP enabled components and systems as the wireless infrastructure evolves [5].

1.1.5 Challenges in Future Wireless Networks

Some of the challenges, such as providing enough bandwidth for multimedia applications, will be solved over time as experience has shown that demand will increase as more and varied types of communications seek to go wireless. This can be seen from the fact that cellular telephony has moved from voice only to multimedia. As video becomes more widespread in wireless communications, the bandwidth demand is sure to increase requiring guaranteed quality for real time traffic. Support of video and high data rate traffic means more data flow through the wireless link, this may require a lot of redesigning of wireless systems [7].

With more and more applications going wireless, security will be one of the greatest challenges for the wireless industry. There will be a strong need for mechanisms to block intruders which might cause heavy losses to both users and service providers. Another concern for wireless companies will be to reduce infrastructure costs in order to provide low cost services that will encourage more people and companies to shift to wireless technology. Global roaming will require a very mature and strong understanding between various carriers and a highly sophisticated integration between various technologies like WLAN, 2G, 3G or 4G wireless networks, internet, Bluetooth, et cetera. Power consumption can also impose a challenge for wireless portable devices. People who are always on the move and dependent on wireless devices will likely not appreciate the service until the devices have the capability to work longer on mobile power source (e.g., batteries). Resource management will be a huge challenge in itself because of the high number of subscribers and most of the applications being run on wireless technology.

1.2 Overview of Radio Resource Management

1.2.1 Importance of Radio Resource Management (RRM)

Wireless networks have seen tremendous growth in terms of the number of users in the past few years. They are not just used for voice communication now but also support new applications such as data, video and multimedia. With such advancement in mobile applications, the need for higher data rate, more network capacity and continuous mobility becomes obvious [8 - 10]. There has been some improvement in network capacity with the introduction of 3G networks but it still remains a challenge with the increasing number of subscribers and high data rate applications. Inefficient allocation of these resources may incur heavy losses to the service providers as well as poor user experience. Due to a large number of customers, the resources on the network are in high demand and users compete for them. Furthermore, the requirements for resources in a wireless network keep changing with varying network loads and radio channel conditions. Therefore there is a need for a dynamic resource management system that can maximize network resource utilization. Under the circumstances of capacity becoming a bottleneck, using available resources efficiently becomes very important thus, radio resource management has always been an open and important area of research for wireless engineers.

1.2.2 Radio Resource Management Issues in Wireless Networks

Under the circumstances of limited resources, increasing number of users and growing demand for high data rates, efficient resource management becomes very important. Resource management is a broad area with focuses on several resources such as power, bandwidth, et cetera. The most common RRM issue faced by network operators is channel allocation and channel reuse methods. Various techniques like fixed channel allocation, dynamic channel allocation and hybrid channel allocation have been introduced but have only provided partial solutions to the resource management problem [11].

Mobility management is another issue faced by network operators. Firstly, tracking the current location of mobile users moving at high speeds is very complex and difficult. This problem is termed as location management. Secondly, handoff management for mobile users requires sophisticated and effective procedures in order to reduce call dropping rates. As most of the solutions to the handoff management problem are now based on predicting a user's speed and direction, thus accuracy of location management is very important. 4G is expected to support data rates up to 150 Mbps. This means that some of the supported application will be real-time and will require guaranteed quality of service from network providers. Under limited resources and capacity, this would be another critical resource management issue for wireless networks.

These issues will require wireless networks to be intelligent in nature and be able to adapt to the varying traffic conditions. This is an open research area and has not been addressed to the extent of providing any solutions in spite of numerous amounts of research currently being conducted on it.

1.3 Research Motivation and Goals

1.3.1 Motivation and Problem Statement

The research is inspired to address the present and future issues of radio resource management discussed in section 1.2.2. The research is geared to building self-adaptable intelligent wireless networks capable of providing better and efficient radio resource management. Fixed channel allocation causes under-usage of the available channels, while dynamic channel allocation is less efficient during heavy traffic loads [12]. Due to constantly varying user distribution in the network, none of the channel assignment techniques are self–sufficient enough to provide optimal solutions alone and thus a mix-and-match approach of these schemes is required.

Handoff calls have higher priorities over new calls; therefore a certain number of channels are reserved exclusively in each cell to execute handoffs. Fixed channel reservation can either cause under-usage of the reserved channels during low traffic mobility or the number of reserved channels may not be enough to accommodate handoff calls during high traffic mobility. Therefore adaptive reservation techniques are required which reserve channels based on previous traffic load history in the cell and also approximate the volume of inflowing traffic from the neighboring cells.

The proposed agent based radio resource management scheme intends to improve the efficient utilization of available radio channels and distribute traffic load evenly in the network. The scheme primarily aims to reduce call blocking rate, reduce call dropping rate and evenly distribute load in the network to increase resource (channel) utilization. This adaptive reservation requires handoff prediction which further requires built-in intelligence in the network. Multi-agent technology is capable of building intelligent networks by means of distributed intelligent entities called software agents.

The proposed scheme is based on the 3G network architecture. 3G networks support applications such as conversational (voice), streaming (e.g. video-on demand), interactive (e.g. email and web browsing) and background (e.g. FTP or downloading). Conversational and streaming classes have strict resource (bandwidth) requirements as they are delay-sensitive services while interactive and background classes have loose resource (bandwidth) requirements as they are delay-tolerant services. Each cell can provide a data rate of a maximum 2 Mbps and each channel is assumed to provide different bandwidths.

1.3.2 Research Goals

The proposed agent based scheme aims to

a) Reduce call blocking rate

b) Reduce call dropping rate

c) Evenly distribute the load in the network to increase resource utilization

Multi-agent technology will be used to realize the concept where each base station and mobile station acts as an independent intelligent entity and these entities work in co-operative ways to achieve the desired goals. This concept also encourages intelligent load balancing where each mobile station can be used as a low power computational entity.

The proposed agent based scheme uses hybrid channel allocation where the frequency channels will be assigned to each participating cell from a central pool of channels, based on its traffic load history. This central pool of channels will be located at the RNC. The unassigned channels will be used to balance the traffic load and user distribution in the network as and when required. These unassigned channels will be accessible to all cells supported by the RNC. Adaptive channel reservation scheme will be adopted to reserve channels (from the number of channels allocated to the individual base station) for handoff calls. Both traffic load and mobility keeps changing during different times of the day so it becomes important to vary the channel allocation and channel reservation policies accordingly.

Considering future traffic loads in neighboring cells for channel borrowing (i.e., borrowing channels from the least busy cell in the future) will not only reduce call dropping rate in both cells but also distribute the traffic load evenly in all cells. Based on the mobility prediction, user data can be passed to the destination network in advance in order to speed up new connection establishment.

A user's mobility and traffic profile is an important factor to be considered while allocating the channel. The profile will be based on a user's roaming history, which predicts its future path at some given time and a user's call duration history that approximates the resource usage time. This profile also facilitates the resource reservation in the cells where the user is expected to relocate. Call duration history gives an idea of how long the resources will be held by the user and such knowledge becomes very useful for resource reservation and allocation during peak traffic conditions.

Users, who are allocated minimum resources due to an insufficient number of available channels can re-negotiate with the base station for more resources during the call duration. Under high traffic load conditions, internal calls on the cell boundary can be forced to execute handoff with the neighboring cells in order to accommodate incoming traffic and to balance the network load evenly. A call queuing concept would be considered to further improve the results in terms of reduced call blocking and dropping rates.

1.3.3 Thesis Contributions

The main contribution of this thesis is the proposal of agent based resource management scheme for 3G wireless networks (WCDMA for UMTS). The proposed scheme will benefit both users and network providers. Specific contributions made in the thesis include:

- The proposal of an agent based resource management scheme for 3G wireless network such as the UMTS standards.
- Application of multi agent technology for radio resource management in wireless networks.
- Simulation analysis of the proposed scheme to evaluate its performance in a realistic network environment.
- Development of mathematical expressions for resource management in the proposed agent-based scheme.

1.4 Thesis Outline

The remainder of this thesis is organized as follows: Chapter 2 talks about multi agent systems and radio resource management principles. Chapter 3 presents the system architecture of the simulation. Simulation modeling of Agent Based Resource Management (ABRM) simulator is discussed in chapter 4. Chapter 5 takes a closer look at simulation results and comparison with existing techniques. Finally, Chapter 6 presents the conclusions of this research and provides suggestions for future work.

CHAPTER TWO

Multi – Agent Systems and Radio Resource Management

2.1 Introduction

Agent programming has emerged as a flexible and complementary technology to manage resources of distributed systems due to the increased flexibility to handle dynamically changing requirements. A very interesting application would be managing radio resources in wireless networks [13]. Efficient use of resources has always been stuck in a bottleneck in wireless networks, however agent technology promises to reduce this through the coordination of different cooperating software entities.

2.2 Introduction to Multi – Agent Systems

The research project is an application based on Multi-Agent Systems (MAS). Foundation for Intelligent Physical Agents (FIPA) defines an agent as "an entity that resides in environments where it interprets "sensor" data that reflects events in the environment and executes "motor" commands that produce effects in the environment" [14]. Wooldridge defines an agent as an object (as in object oriented programming) with attributes like autonomy, pro-activeness, reactivity and social ability [15].

2.2.1 Multi-Agent Systems and Artificial Intelligence

Agent and MAS are a new software development paradigm geared towards solving more complex problems than those achieved by more conventional algorithmic programming.

A MAS is a network of agents that interact to solve larger problems that are beyond an individual agent's capabilities. This interaction involves collaboration and communication between the agents [16].

Distributed Artificial Intelligence (DAI) systems can be defined as cooperative systems where a set of agents act together to solve a given problem [13]. These agents are often heterogeneous. Further, intelligence in DAI is based upon the social behavior of co-operating agents. Wireless networks have been seen as a natural domain for the investigation and application of intelligent agent technology. One such area for its application is Radio Resource Management (RRM) in wireless networks.

2.2.2 Attributes of Software Agents

An agent is a small, efficient, and autonomous software robot that works on behalf of a user to solve computing problems. It will generally consist of state information, behavioral routines, an autonomous nature and social ability. Autonomy and Social ability are primary characteristics in this definition.

Autonomy allows an object to act independently without human interaction based on the information collected from its environment. Artificial intelligence techniques (like multi-agent systems) are used to provide autonomous behaviors. Some applications like supply chain management and ubiquitous computing cannot be realized without accepting autonomy as a key feature [15].

Social ability gives rise to MAS. In a MAS environment, several agents work together to achieve some desired goals. This involves aspects of coordination, communication and hypothetical reasoning. It is a highly desirable characteristic in systems that require concurrent processing [15].

There are some disadvantages associated with multi-agent technology. If the autonomy is not designed properly, the objects may go out of control and the system will not perform as expected. As agents have the ability to communicate and take decisions based on this communication, it becomes very important to define and implement the communication accurately otherwise it may lead to system collapse.

2.3 Overview of Resource Management Techniques

2.3.1 Overview of Channel Allocation Techniques

In FCA, the total coverage area is divided into a certain number of cells and, based on reuse pattern, a certain number of channels, are assigned to each cell. There have been several resource management schemes [17 - 19] proposed based on FCA in the last few years but they do not tend to provide an optimal solution because of constantly changing traffic conditions and varying user distribution. This drawback has been overcome by DCA based schemes [17], [20 - 22] in which all channels are placed in a pool and the assignment to each cell is made according to traffic characteristics. However, under high traffic load, DCA schemes are less efficient [17] and a combination of both schemes (i.e., hybrid channel allocation) [17], [23 - 24] is often used. There have been several analysis conducted [17], [25 - 28] to compare the performance of both FCA and DCA. A comprehensive survey of channel assignment strategies has been presented in [17].

2.3.2 Overview of Channel Reservation Techniques

Channel reservation for handoff calls can be made in two different ways, namely fixed channel reservation (FCR) and variable channel reservation (VCR) (also known as dynamic or adaptive channel reservation). In FCR, a fixed number of channels, called guard channels, are reserved for handoff calls. There have been several schemes [29 - 31] proposed for resource management based on FCR, and although these schemes have reduced call dropping rates, they suffer from two major disadvantages. In the case of low traffic mobility, reserved channels are under used and in the case of high mobility they may not be enough to accommodate inflowing traffic from neighboring cells.

FCR schemes were not able to provide very convincing results due to the major drawbacks mentioned above which were later addressed by VCR schemes. Variable channel reservation promised better results in terms of reduced call blocking and dropping rates as compared to FCR techniques. Unlike FCR, VCR considers the mobility trend of the user and reserves the channels for handoff calls based on the past, current or future traffic load in the cell.

Agent programming technology has emerged as a flexible and complementary way to manage resources of distributed systems due to the increased flexibility in adapting to the dynamically changing requirements of such systems. Being autonomous, knowledgeable and pro-active, agents have the ability to estimate the results of any action beforehand and thus react accordingly. Employing an agent to monitor the network and make changes to resource configuration leads to an efficient use of resources. There has been a significant use of agents for resource management in wireless networks [32 - 50].

Extensive research has been done on VCR [12], [32 – 47], [51 – 59], [61 – 63] in the last few years using various approaches which are discussed in the following sections.

2.3.2.1 Channel Reservation without Handover Prediction

VCR based schemes presented in [32 - 40], [61 – 63] reserve handoff channels based on the history of network traffic. These schemes provide better results as compared to FCR schemes but ignore user mobility in terms of expected traffic load in the cell. It is not wise to estimate future traffic characteristics based on traffic history (static traffic load data) in the cell, and there should be some dynamic handover prediction for better management of radio resources. Some of these schemes [32 - 40] use multi–agent technology to make the network more intelligent but do not consider the mobility of users.

Another drawback associated with some of these schemes [32][39] is not considering user's roaming profile and calling history which is very helpful in making decisions about radio resource allocation during handoffs.

2.3.2.2 Channel Reservation with Handover Prediction

The allocation of radio resources based on handover prediction has two advantages. Firstly, it reduces the under-usage of radio channels by suggesting the number of channels required to admit future handoff calls. Secondly, it helps to manage traffic in the neighboring cells. Several schemes [12], [41 – 47], [51-59] have been proposed in the past where resource management was done based on handover prediction. Some of these schemes [52-53], [55] predict handoff based on the current or future handoff rate in the cell, but the continuously changing handoff rate challenges the accuracy of the results.

This drawback was addressed by schemes employing multi-agent technology [41 - 47] to predict future traffic characteristics in the cell based on the user mobility pattern. After continuous time intervals, the base station approximates the number of users moving towards it and reserves the channels accordingly.

Many of these schemes [12], [51 - 52], [55 - 59] do not consider the user's roaming profile and call duration history that are important factors while allocating resources. Schemes [41 - 45], [51], [53 – 55], [59]which address these issues, tend to overlook other factors such as future traffic characteristics in neighboring cells for borrowing channels, re-negotiation for more resources during call duration, call queuing and justification of use of mobile agents.

2.3.3 Other Agent Based Research on Resource Management

Some of the presented schemes [47][54] are oriented more towards management issues of resources at a business level rather than at resource management level. Their primary focus is to address issues like information transfer from base station to base station or network to network along with the mobile user, collecting resource usage data, monitoring the network to verify that all entities are working correctly, et cetera.

Some of the schemes [48 - 50], [47] use multi-agent technology to balance the load in the network through smart antennas. In case of heavy traffic load in one cell, the shape and size of that and neighboring cells can be changed. To compensate the coverage loss due to this re-direction, neighboring cells may change their antenna direction. A few schemes [34 - 38] present an architecture which allows customers to negotiate with a service provider for resources at lower costs and the service provider then negotiates with a network provider.

2.4 Similarity and Differences with Existing Work

The proposed scheme is based on adaptive channel reservation with handoff prediction. There has been enormous work done based on adaptive channel reservation [12][32 – 47][61 – 63][51 – 59] Conceptually, the proposed work is similar to previous schemes based on adaptive channel reservation with handoff prediction [12][41 – 47][51 – 59]. Many of the schemes have already addressed the issues such as user mobility, user profile and channel borrowing. However, there exists no scheme that provides a comprehensive solution for resource management during handover in context to parameters such as considering a user's call history and roaming profile, user mobility, future traffic conditions in neighboring cells, channel borrowing, call queuing and re-negotiation for resources during call duration.

The proposed scheme aims at efficient management of radio channels and evenly distributed traffic load in the network unlike schemes which focus simply on load balancing [48 - 50]. Some schemes [47], [54] focus on upper-level resource management issues like monitoring traffic load, management of hardware resources, collecting performance data of network elements, et cetera which is very different from the objective of the proposed work. The schemes presented in [34 - 38] focus primarily on the customer, service provider and network provider negotiations for providing better resources to customers at a lower cost which completely falls out of scope of the proposed scheme.

The use of agent technology in adaptive channel reservation makes the work different from several schemes [12], [51 – 59], [61 - 63] that are implemented without multi – agents. The proposed work which is based on dynamic channel allocation and variable channel reservation is different from schemes based on FCA [17 - 19] and FCR [29 - 31].

2.5 Significance of Proposed Work

With the ever increasing number of users and demand for higher bandwidth, there are only two possible solutions to accommodate these users, either by increasing the capacity of the network or using available resources in the best possible manner. The former solution has a few limitations such as high infrastructure cost, limited technology and government regulations. Hence, efficient use of available resources is a more feasible and cost effective solution. Combined with the differences and advantages over the previously completed works listed in previous sections, the proposed scheme becomes a significant step towards research done on resource management in wireless networks.

2.6 Summary

Several schemes were investigated as a comprehensive literature survey to get familiarized with research done on resource management in wireless networks. The survey shows the increasing popularity of agent technology in wireless networks and results provided from these schemes justify its use. The presented schemes tend to provide solutions either to one or multiple problems in radio resource management. In this chapter an overview of multi agent technology and attributes of software agents have been provided. A brief survey of various channel allocation and channel reservation techniques has also been presented. Other agent-based research done on resource management which includes mechanisms proposed for information transfer from base station to base station or network to network, efficient load balancing techniques, network monitoring techniques, et cetera was also discussed.

CHAPTER THREE

System Architecture

3.1 Introduction

Multi-agent technology is capable of building intelligent networks by means of distributed intelligent entities called software agents. Software agents will be used to realize the concept where each base station (Node B), radio network controller and mobile station acts as an independent intelligent entity and these entities work in a co-operative way to achieve the desired goals.

3.2 3G Network Architecture

3.2.1 3G Network Architecture of Simulator

The simulator is based on the UMTS standard. The architecture for UMTS is illustrated in Figure 3.1. Base station and base station controller functionality has been replaced by Node B and RNC (Radio Network Controller), respectively. Each RNC governs several Node B's and each Node B provides services to several mobile users.

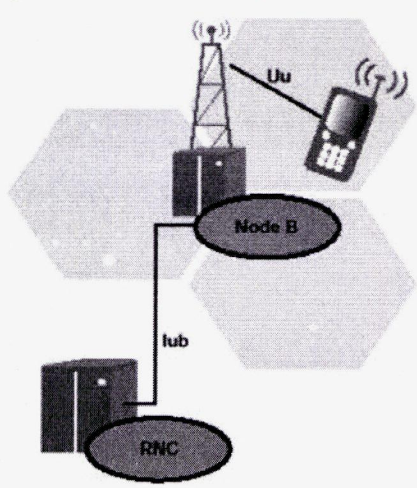


Figure 3.1 3G Network Architecture [64]

3.2.2 Modeled Network Elements

The network elements that will be modeled are User Equipment (UE) or MS, Node B and Radio Network Controller (RNC) as shown in Figure 3.2.

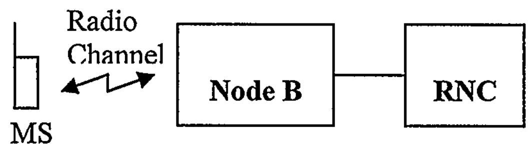


Figure 3.2 Modeled Network Elements in ABRM Simulator

3.2.3 Cellular Structure and Partitioning

Fig. 3.3 shows the cellular layout of the simulation. There are a total of 19 hexagonal network cells, each having a 2 Km radius, with the innermost cell surrounded by two rings of network cells. These 19 cells are divided into three different regions of mobility and Node B's are placed in the centre of each cell while mobile stations are uniformly distributed. Users can be mobile and hop from one network cell to another cell. The three types of network cells considered are:

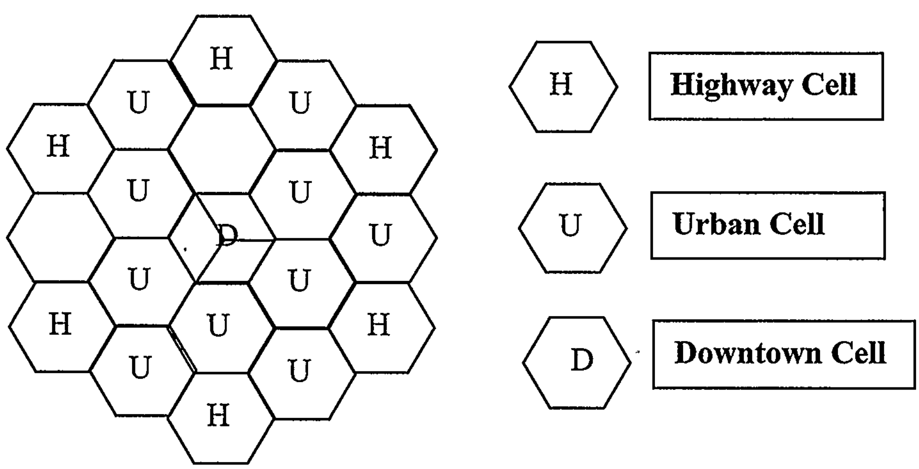


Figure 3.3 ABRM Simulator cellular Layout

Network Cell Type:

1) *Downtown (D) Cell:* - represents the downtown region. The traffic in this cell will be dominated by low speed users. Downtown cell is expected to have less handoff calls as compared to other cells.

2) *Urban (U) Cells:* - represent the urban area within the city other than downtown region. This area will have an equal balance of low and high speed users. The number of handoff calls in this region is expected to be higher than that of downtown cell but less than those for highway cells.

3) *Highway (H) Cells:* - represent highway cells with traffic being dominated by high speed users. The number of handoff calls in this region is expected to be the highest.

3.3 Multi-Agent Architecture

3.3.1 Open Agent Architecture

Multi-agent technology is capable of building intelligent networks by means of distributed intelligent entities called software agents. Software agents will be used to realize the concept where each Node B, radio network controller and mobile station acts as an independent intelligent entity and these entities work in co-operative way to achieve the desired goals. The multi-agent architecture adopted for the simulation is based on the Open Agent Architecture (OAA) proposal shown in Fig. 3.4. OAA has advantages over other famous available agent architectures such as Cougaar Agent Architecture and KAoS (Knowledgeable Agent-oriented System) in terms of enhanced distributedness, fined grained co-operation, simple communication procedures and, above all, ease of adding and deleting agents from the architecture.

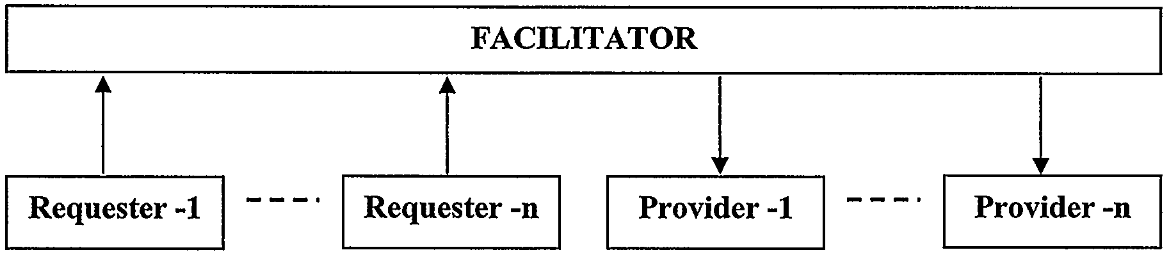


Figure 3.4 Open Agent Architecture [64]

Requester agents request for resources or services from provider agents. The facilitator agent acts as a controller, coordinates their efforts and provides directory service in some cases [65].

3.3.2 Multi-Agent Architecture of ABRM Simulator

Fig. 3.5 shows the architecture for the resource management problem being investigated

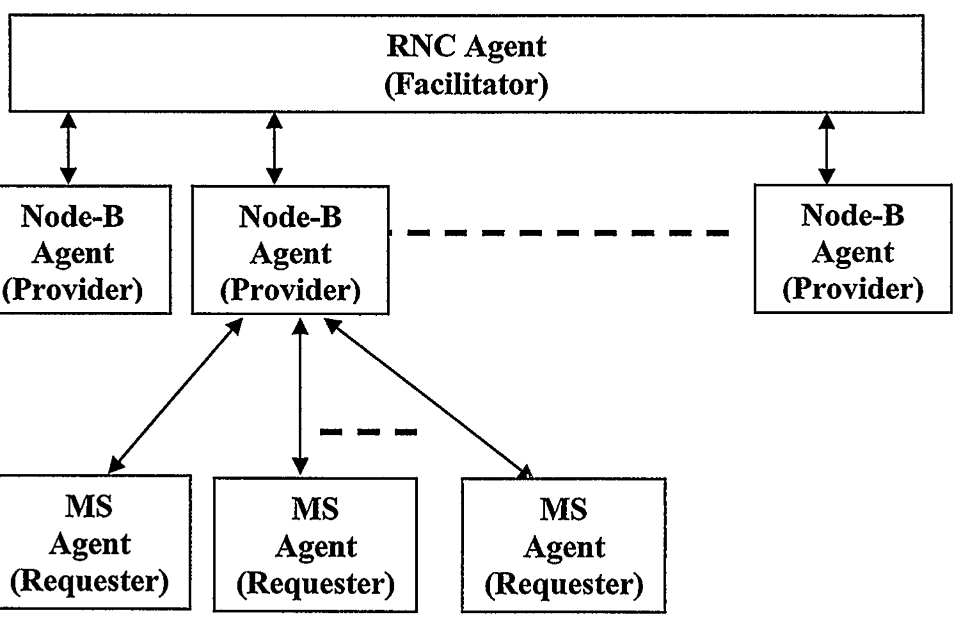


Figure 3.5 Multi Agent Architecture of ABRM Simulator

Each Node B, mobile station and Radio Network controller (RNC) will be equipped with a software agent. The RNC agent acts as facilitator agent and provides services to Node-B agents which further provide services to MS agents. Node-B and MS agents represent provider and requester agents in OAA, respectively. The agent's internal structure is illustrated in Fig. 3.6

3.3.3 Agent's Internal Structure

Layered approach is adopted to design a software agent because it is very easy to troubleshoot in case of malfunctioning or system errors.

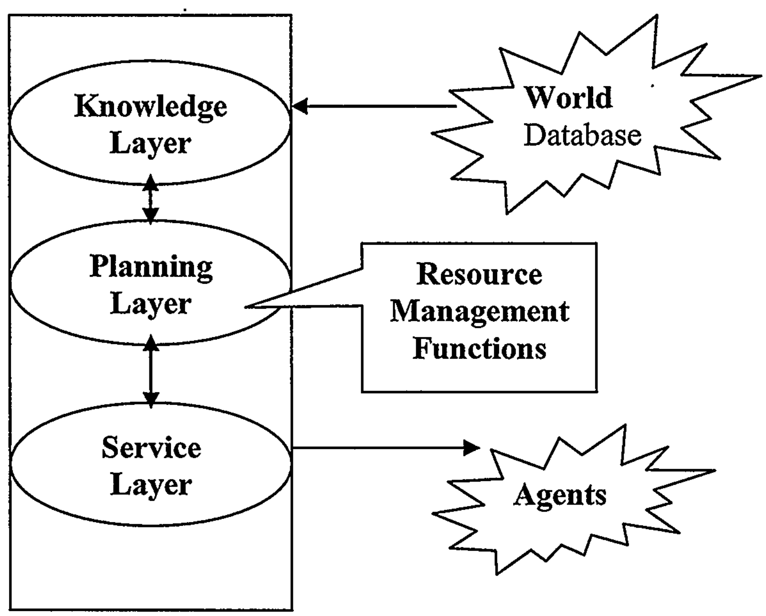


Figure 3.6 Agent's Internal Structure

Knowledge Layer: stores the knowledge base of an agent. Knowledge is obtained from the world or sensors or databases. RNC and Node-B agents obtain this knowledge from

Traffic History Database (THD) and the MS agent obtains this knowledge from a signal strength calculation module in the device.

Planning Layer: encapsulates the agent's reasoning mechanism based on the resource management functions or equations.

Service Layer: this layer provides services to other agents as requested. For instance these services can be Node-B agents providing call admission service to MS agents, MS agents providing signal strength data to Node-B agents, RNC agent providing information about the least busy cell to Node-B agents, channel borrowing, resource negotiation, recording traffic patterns and load balancing operation.

3.3.4 Agent Roles and Responsibilities

Each Node B, mobile station and RNC will be equipped with a software agent. The roles and responsibilities of these agents are discussed in the following sections.

3.3.4.1 Node B Agent

Channel reservation is done by the Node B agent of the individual cell, based on the THD. The Node B agent performs the following operations:

1) Reserves channels for handoff calls based on the THD.
2) Performs channel borrowing with neighboring cells.
3) Maintains a call queue for new and handoff calls.

4) Performs load balancing operations by forcing internal calls to execute handoff with neighboring cells.

5) On request, provides traffic load characteristics to the neighboring Node B agents.

6) Estimates the incoming traffic from neighboring cells.

7) Provides the services of a registry agent.

3.3.4.2 Radio Network Controller (RNC) Agent

All the channel allocation decisions would be taken by the RNC agent, based on the traffic history of the cell because the central pool of channels is located at RNC. The RNC software agent is responsible for:

1) Allocating channels to all individual network cells based on THD.

2) Generating user profile and traffic history databases.

3) Performing network monitoring for load balancing through a centralized pool of unassigned channels.

4) Generating UPD and THD and providing information to Node B agents as and when requested.

5) Serving as a directory agent for Node B agents in order to provide address or location services.

3.3.4.3 Mobile Station (MS) Agent

A mobile station agent is a low computational power entity and is responsible for:

1) Continuously measuring the received signal strength from the Node B's and initiating channel reservation requests in the destination cell when signal strength falls below a certain threshold value.

2) Initiating resource negotiation request for more resources.

3) Registering with a Node B station on creation.

3.4 Summary

This chapter presented the system architecture of the ABRM Simulator. 3G network architecture adopted for simulation was also presented in detail including modeled network elements and cellular structure. Also, multi-agent architecture of the simulator was discussed. Three types of agents were discussed and their roles and responsibilities were highlighted. The agent's internal structure which describes its 3 layered working mechanism was also presented.

CHAPTER FOUR

Simulation Modeling of ABRM Simulator

4.1. Introduction

The ABRM network simulator supports all 3G Quality of Service (QoS) classes namely: conversational, streaming, interactive and background. The ABRM network simulator implements the agent facilitated call admission control and load balancing operations of 3G networks. This chapter provides a pseudo-code level description of the ABRM simulator including algorithmic details of the processes and procedure for computing system variables. The algorithms have been represented as flow charts and the procedures for computing simulation variables have been illustrated in terms of mathematical equations.

4.2 Mobility Model

4.2.1 Speed and Direction Characteristics of Mobile Users

The users were divided into three categories based on their speed viz. stationary users (0 km/hr), low speed users (under 70 km/hr) and high speed users (above 70 km/hr). The direction of mobility will be randomly selected on call origin and will be changed after random time intervals (between 0 and 60 seconds).

The speed assigned to the user depends on the area of origin of call. The probability of user having high speed in a highway cell is much more than that of downtown cell. The probability distribution chart for assigning speed to a new call is shown in Table 4.1

Table 4.1 Probability distribution for assignment of speed based on network cell type

Network Cell Type	High Speed User Probability	Low Speed User Probability	Stationary User Probability
Highway Cell	80%	15%	5%
Urban Cell	30%	45%	25%
Downtown Cell	20%	45%	35%

Speed limits on highways are generally more than 80 km/hr thus the probability of user having high speed characteristics is very high. Low speed and stationary users will only be present in remote locations. In urban area, there is a good balance of users with different speeds. As speed limits in urban areas are normally less than 80 km/hr, the traffic is expected to be dominated by low speed users. The downtown area is very congested and user speed is usually very low and as it is usually the business capital of the city, the traffic pattern is expected to have users mainly from the pedestrian and stationary speed classes.

4.2.2 Data Rates Based On User Speed and Environment

The data rate received by the user depends on the user's speed and location significantly. The simulation will have the following constraints on data rate for users with different mobility speeds.

a) *High Speed Users (outdoor):* - maximum supported data rate of 144 kbps.

b) Low Speed Users (outdoor): - maximum supported data rate of 384 kbps.

c) *Stationary Users (indoor):* - maximum supported data rate of 2 Mbps.

4.2.3 Signal Strength Calculation

Signal strength, being a function of distance, can be measured easily with the knowledge of the user's radial distance from the base station. For simulation purposes, transmitted power (P_T) from the base station is assumed to be 500 mW hence the power received at any radial distance D from the base station can be calculated using equation (4.1):

$$P_D = \frac{P_T}{D^4} \tag{4.1}$$

where P_D is the received power at distance D from Node B and P_T is the transmitted power. Only distance dependant path loss is considered.

Thus, Signal to Interference Ratio (SIR) at any radial distance D from base station can be computed using equation (4.2) [1]:

$$SIR = 10\log_{10}\frac{P_D}{I_{total}} \tag{4.2}$$

where $I_{total} = \dfrac{P_N}{1-\eta_{DL}}$ (4.3)

Thermal Noise P_N = 1 mW [51]

And the downlink load factor η_{DL} is given by equation (4.4) [1]:

$$\eta_{DL} = \sum_{j=1}^{N} \frac{(E_b/N_o)}{W/R_j}.[(1-\overline{\alpha})+I] \tag{4.4}$$

where N is the number of users, I_{total} is the total interference received from N users in the cell, E_b/N_o is the required ratio of energy per user bit with noise spectral density of user j, v_j is the activity factor of user j, W is the chip rate, R_j is the bit rate of user j, α is the orthogonality factor and I is the other cell interference ratio.

The received SIR can be calculated using equations (4.2), (4.3) and (4.4). The values of all parameters are listed in section 4.6.

As shown in Fig. 4.1, user is currently being served by Node B1 (BS1) and then moves towards a neighboring Node B (BS2). When a user moves towards the neighboring Node B, the signal strength received from Node B providing the service (i.e., BS1) gradually decreases. The MS agent continuously calculates the signal received from Node B that is currently providing service to the mobile station. When this signal strength falls below the threshold value (S_{HO}), handoff with the neighboring Node B agent is executed. In the proposed scheme, another threshold (S_{RSV}) is used and as soon as signal strength falls below S_{RSV}, the mobile station agent sends a channel reservation request to the destination Node B agent. The S_{RSV} and S_{HO} values for different types of calls are shown in Table 4.2.

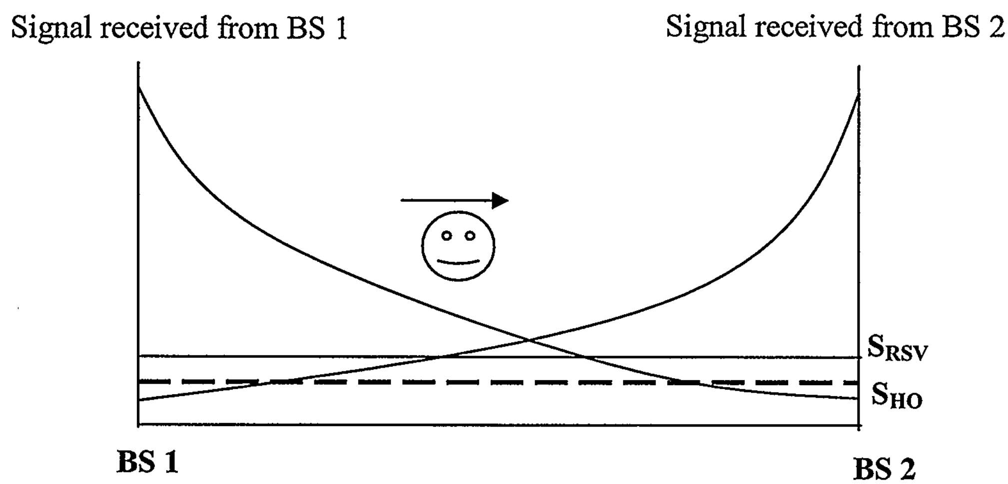


Figure 4.1 Channel Reservation Request Process

Table 4.2 S_{RSV} and S_{HO} values for different types of calls [3]

Call Type	S_{RSV}	S_{HO}
CBR	8 dB	5 dB
CBR	9 dB	7 dB
VBR (real-time)	9 dB	7 dB
VBR (non real-time)	9 dB	7 dB
UBR	9 dB	7 dB
UBR	9 dB	7 dB

In the proposed scheme, MS agent makes a channel reservation request before the received SIR falls below the required E_b/N_o (S_{HO}) value, thus S_{RSV} value is selected higher than S_{HO} to compensate the time consumed by channel reservation and channel borrowing processes.

4.2.4 Types of Traffic and Traffic Mix

Table 4.3 Resource requirements for applications supported in 3G wireless network with a maximum data rate of 2 Mbps per cell [1] [66].

Tra	Type of	Minimum	Desired	Average	Example of

ffic Cla ss	Traffic	Bandwidth	Bandwidth	Connection Duration	Applications
1	CBR	12.2 Kbps	12.2 Kbps	3 minutes	Voice
2	CBR	56 Kbps	64 Kbps	3 minutes	Video-phone and video-conference
3	VBR (real-time)	64 Kbps	128 Kbps	2 minutes	Interactive multimedia and video-on-demand
4	VBR (non real-time)	56 Kbps	128 Kbps	3 minutes	Telnet, WWW
5	UBR	5 Kbps	20 Kbps	30 seconds	SMS, E-mail, paging and fax
6	UBR	56 Kbps	384 Kbps	2 minutes	File transfer

Table 4.3 shows the different types of traffic classes and applications considered where class 1 represents voice and all other classes are data applications. It lists the resource requirements of each traffic class such as minimum bandwidth, desired bandwidth, average connection duration and example of applications of each class. Each cell supports a maximum data rate of 2 Mbps. The proposed scheme considers three types of Traffic Mix (TM); traffic mix with high volume of voice calls (TM1), traffic mix with low volume of voice calls (TM2) and traffic mix with equal balance of voice and data traffic (TM3) [66][67].

TM1	**TM2**	**TM3**
Traffic Class 1 = .9	Traffic Class 1 = .1	Traffic Class 1 = .5
Traffic Class 2 = .02	Traffic Class 2 = .3	Traffic Class 2 = .05
Traffic Class 3 = .03	Traffic Class 3 = .3	Traffic Class 3 = .1
Traffic Class 4 = .02	Traffic Class 4 = .2	Traffic Class 4 = .1
Traffic Class 5 = .01	Traffic Class 5 = .05	Traffic Class 5 = .2

Traffic Class 6 = .02 Traffic Class 6 = .05 Traffic Class 6 = .05

4.3 ABRM Simulator Class Structure

The simulation is built using the Microsoft Visual Studio. The implementation language selected is Visual C++. Visual C++ is selected over other languages like Java because of its features like Microsoft Foundation Classes (MFC) which are readymade class libraries that make the implementation easier, very easy GUI development, efficient debugging tools, fast execution and memory management functions through the use of pointers. Fig. 4.2 shows the abstract view of the ABRM simulator classes.

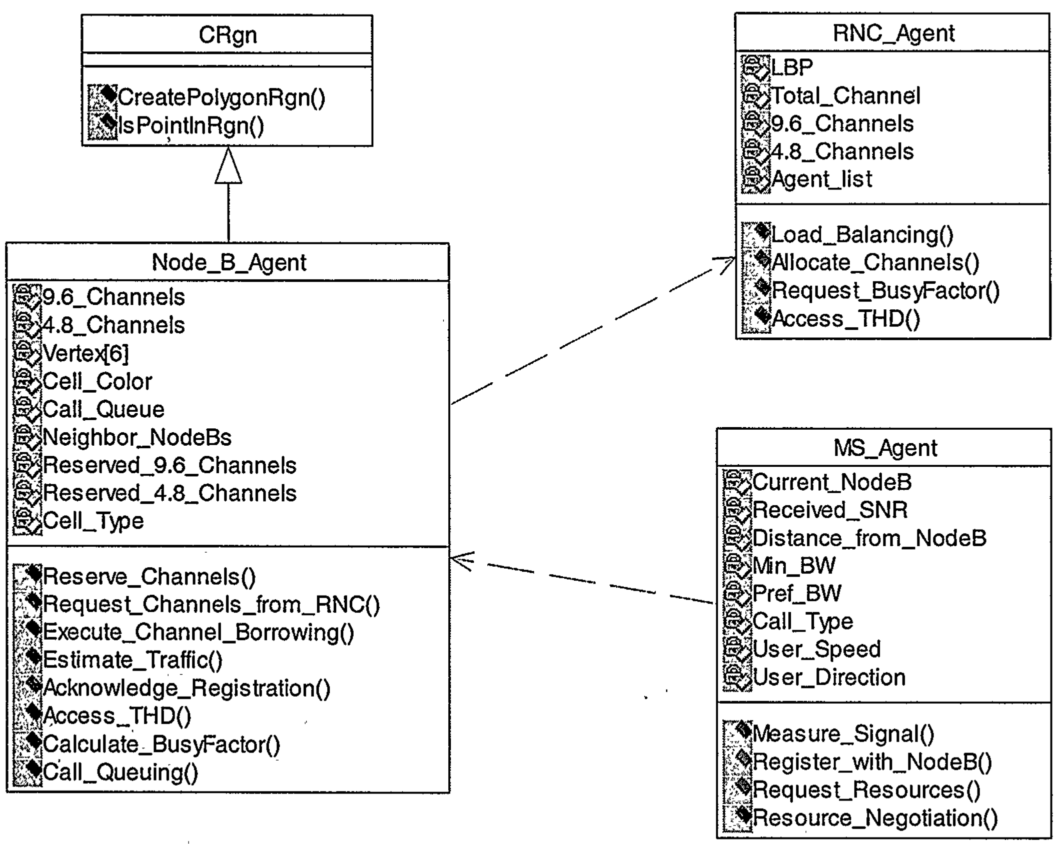


Figure 4.2 ABRM Simulator Class Diagram

4.3.1 RNC Agent Class: - RNC agent class is a generic C++ class. It has methods implementing resource management functions (e.g., channel allocation) and services provided to Node-B agents (finding least busy cell in the future).

4.3.2 Node-B Agent Class: - It is derived from CRgn. CRgn is one of the MFC libraries that facilitate the implementation of polygon regions. In ABRM simulator hexagonal cells (Node-B coverage area) are drawn with the help of CRgn class. Node-B agent class implements the functionality of Node-B agents. It consists of methods performing resource management functions (e.g., channel reservation) and services provided to MS agents (e.g., registration service).

4.3.3 *MS Agent Class:* - it is a generic C++ class that implements the behaviors of MS agents. It does not implement any resource management functions but encapsulates the functionality to calculate signal strength and play initiator's role in channel reservation process.

4.4 ABRM Simulator Databases

4.4.1 Traffic History Database (THD)

THD stores the day-to-day traffic information about each cell in the network such as traffic load in the cell, blocking rate and dropping rate. This knowledge about traffic characteristics will be stored on a per hour basis. This database is generated and maintained by RNC agent instead of individual Node Bs to reduce the signaling and querying cost.

4.4.2 User Profile Database (UPD)

Values for UPD such as expected call duration based on the users call history will be randomly generated during implementation because it requires a huge amount of time and size to develop a database consisting of thousands of users.

4.5 Simulation Outputs

The ABRM simulator will provide results in terms of:

1) Call Blocking Rate (CBR): a percentage of the number of new calls blocked in total number of calls arrived.

2) Call Dropping Rate (CDR): a percentage of the number of handoff calls blocked in the total number of handoff calls arrived.

3) Downlink Load Factor (η_{DL}) Deviation (ND): is the percentage difference between η_{DL} value of cell with minimum η_{DL} and average η_{DL} in the network.

4.6 Simulation Parameters

The values of all the parameters used in the simulation are listed in Table 4.4.

Table 4.4 Simulation parameters and their values

Parameter	Description	Value [1]
I_{total}	Total interference received from N users in the cell	Equation 4.3

η_{DL}	Downlink Load Factor	Equation 4.4
$(E_b/N_o)_j$	Required ratio of energy per user bit and noise power spectral density of user j	5 dB (data) 7dB (Voice)
v_j	Activity factor of user j	0.58 (Voice) 1 (data)
W	Chip rate	3.84 Mcps
R_j	Bit rate of user j	Table 4.3
A	Orthogonality factor	0.4
I	Other cell interference ratio	0.5

4.7 Simulation Algorithms

4.7.1 Multi-Agent Facilitated Channel Allocation Algorithm

ABRM simulator adopts HCA to allot channels to all 19 cells [60]. The channel allocation is done by RNC agent for one hour [60]. All the available channels reside at RNC itself. The unassigned channels are placed in Load Balancing Pool (LBP) at RNC for one hour and can be requested by overloaded cells to accommodate extra traffic.

Traffic History Database (THD) which has day-to-day traffic information about all cells, stores the information about the total number of calls received per hour for all 24 hours of a day. This information is very useful in estimating the traffic bandwidth (channel) requirement for any hour of the day.

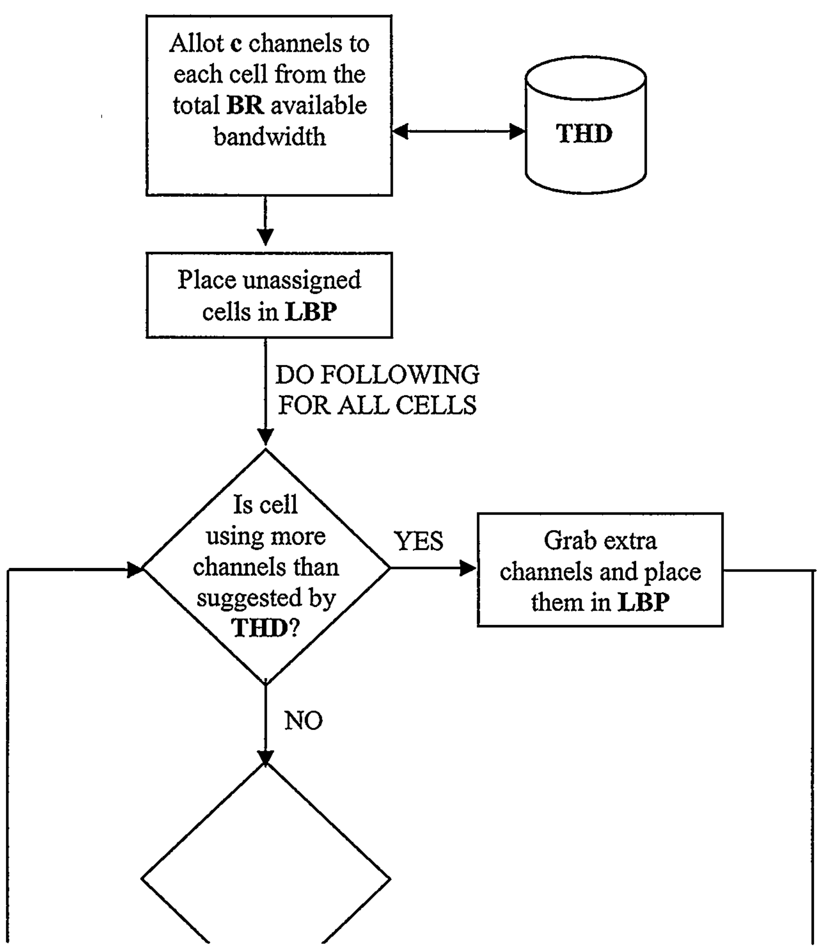
The formula for estimating minimum required bandwidth per minute for any given hour of the day is presented in equation 4.5. The formula implements adaptive channel allocation where number of channels to be allocated is based on the traffic history of previous 15 weeks [60].

$$Minimum\ Bandwidth\ Required\,(MBR_i) = \frac{\sum_{j=1}^{6} AC_{i,j} \times (BW_{min})_j}{60} \qquad (4.5)$$

where MBR_i is the bandwidth required in a network cell for any hour i, $AC_{i,j}$ is the average number of calls (from class j) per hour of past 15 weeks for any hour i and $(BW_{min})_j$ is the minimum bandwidth requirement for class j, $1 \le j \le 6$

Each cell can support a maximum data rate of 2 Mbps. Physical channel data rate for downlink as per UMTS standards [1], adopted for simulation, can be either 2.4 kbps or 4.8 Kbps or 9.6 Kbps. The calls demanding data rate more than 9.6 kbps would be assigned multiple channels to meet their requirements.

The channel allocation algorithm of the RNC agent is shown in Fig. 4.3



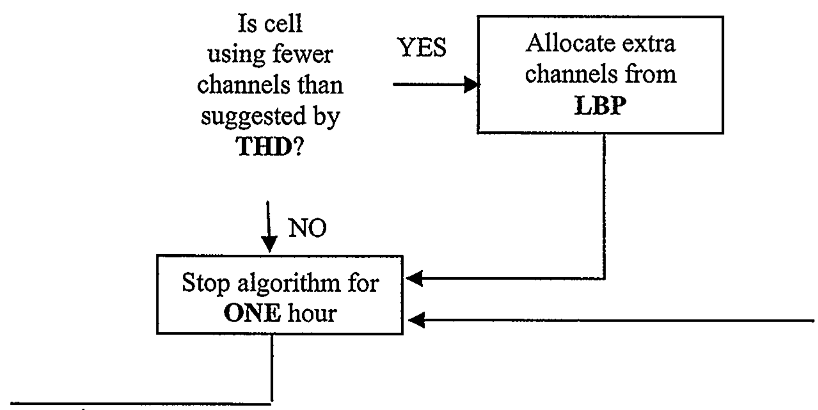


Figure 4.3 Channel allocation algorithm of RNC agent.

4.7.2 Multi-Agent Based Channel Reservation Process

Channel reservation being dependant on incoming traffic from neighboring cells needs to be adaptive and is performed by Node B agent based on the number of handoff requests received. The equation 4.6 estimates the bandwidth required for handoff calls.

$$BRH = BW_{IU} + \sum_{0}^{n} (BW_{OPER})_n \tag{4.6}$$

where BRH is the total bandwidth in a network cell for handoff calls, BW_{IU} is the total bandwidth in use by handoff calls in the network cell, BW_{OPER} is the operating bandwidth if sufficient bandwidth is available in destination cell else is minimum bandwidth if sufficient bandwidth is not available in destination cell and n is the number of approaching handoff calls.

Number of 9.6 kbps channels required for reservation can be computed by dividing BRH by 9.6. In order to obtain best results in terms of call blocking and call dropping rates, simulation will be run for different values of BRH.

4.7.3 Multi-Agent Algorithm for Channel Borrowing and Load Balancing

Because of high traffic load, calls cannot always be accommodated due to an insufficient number of available channels. In such a case, channels have to be borrowed from either the RNC agent (LBP) or neighboring cells through RNC. In the proposed scheme, a small number of channels called "Reserved Channels" are kept in a Load Balancing Pool (LBP) at RNC. These channels can be borrowed from the RNC as and when required. In case where load balancing pool is empty, the channels can be borrowed from the neighboring cells with the least busy factor, as explained later. Channel borrowing can reduce call blocking or dropping in one cell but can degrade these performance metrics in cells from where the channels have been borrowed. Therefore, channels will be borrowed from the least busy cell in the near future to reduce this problem. This also distributes the traffic load evenly in the network. For this, a new parameter called Busy Factor (bf) is introduced which is defined as follows:

$$\text{Busy Factor (bf)} = \text{array of } \eta_{DL} \text{ of all neighbor cells} \qquad (4.7)$$

The cell with the lowest (η_{DL} value) busy factor is selected for borrowing channels. Busy factor is computed every time channel borrowing is done. Although calculating busy factor each time increases the computation, it helps in spreading traffic load evenly across the network by selecting the least busy cell in the future for channel borrowing.

Channel borrowing is executed by the Node B agent that has insufficient bandwidth to accommodate approaching handoff calls. If the request for reserved channels fails due to lack of channels at RNC, the RNC agent asks all neighboring cells to compute and send their busy factors. The RNC agent then recommends the cell with the lowest busy factor to the heavily loaded cell and thereafter the channel borrowing process is carried out directly between the lender and borrower network cells. To make the system more reliable, RNC agent will provide a list of three least busy Node-Bs in case the least busy Node-B fails to respond. If there is only one available cell for lending channels, ongoing call(s) in that cell are forced to execute handoff. The algorithm for executing channel borrowing is presented in Fig. 4.4

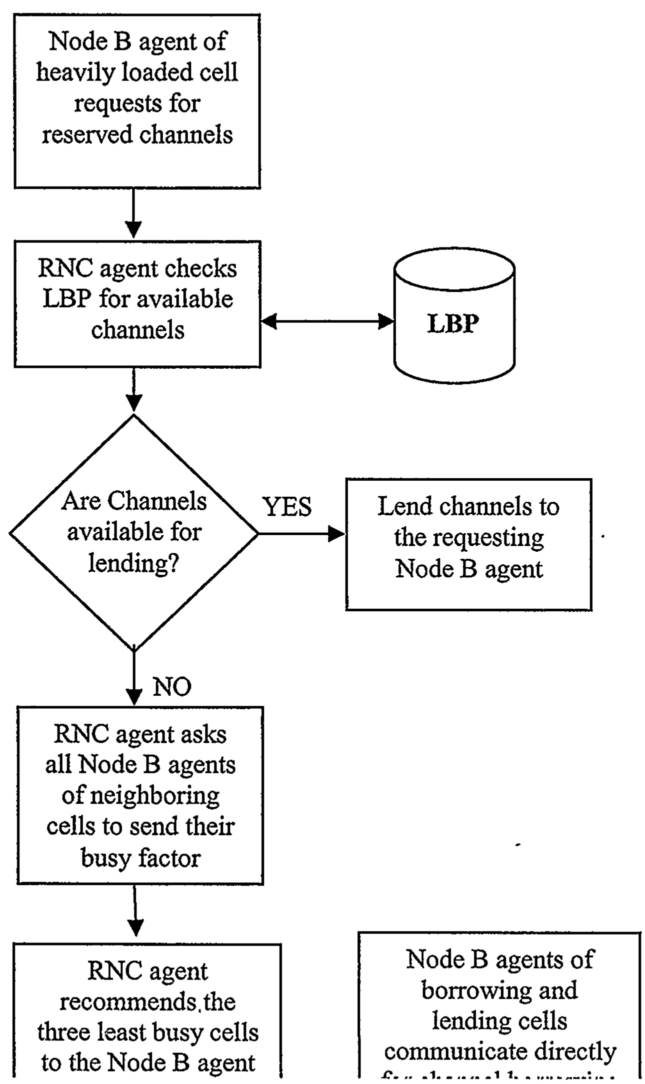


Figure 4.4 RNC and Node B agent algorithm for channel borrowing

4.7.4 Multi-Agent Driven Handoff Algorithm

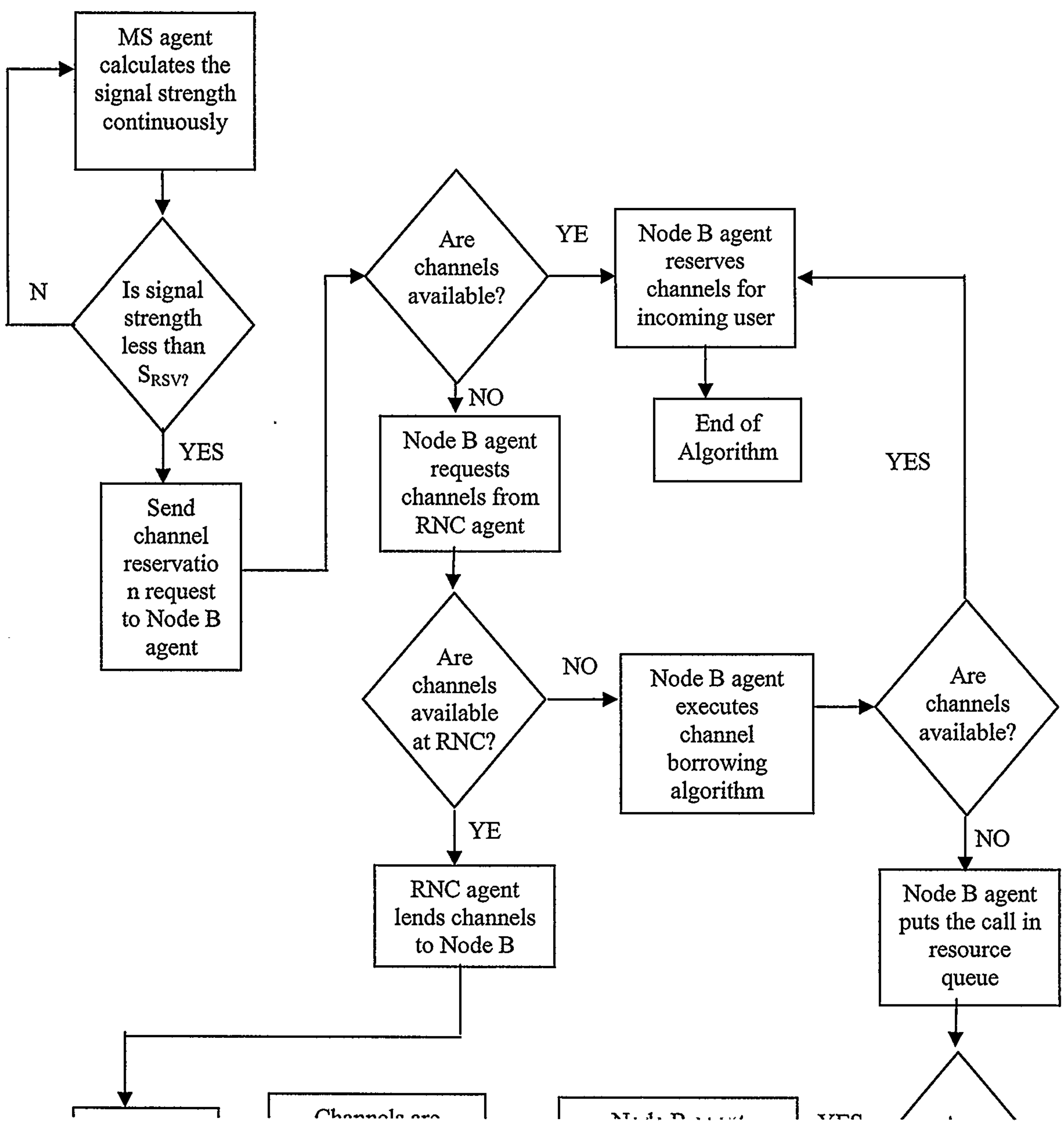


Figure 4.5 Multi-Agent Based Handover Algorithm

As shown in Fig. 4.5, MS agent continuously calculates the received SIR. As soon as the received SIR falls below the threshold value (S_{RSV}), MS agent sends a request to the destination Node B agent for channel reservation. If Node-B agent has sufficient channels for the approaching user, it reserves the channels, otherwise it sends a request to RNC agent to borrow channels from LBP at RNC. In this case, the call will be accepted at minimum bandwidth but the user can negotiate for more channels after the call is admitted.

RNC agent will send a request to all Node-B agents to send their respective busy factors in case there are no channels available in LBP. The address of the cell with least busy factor (out of the three suggested cells) is sent to the Node-B agent who requested for channels. Thus, the remaining aspects of channel borrowing process are executed directly between the borrowing and lending Node-B agents. If there are no channels available to accommodate the approaching user, it is placed in resource queue with a defined maximum waiting time. If the channels become available during this time and there is no other call with higher priority for resources, the call is admitted, otherwise it is dropped.

4.7.5 Resource Negotiation process between MS and Node-B agent

Users, who are allocated minimum resources due to the insufficient number of available channels, can re-negotiate with the Node B for more resources during the call duration. The call with allocated bandwidth less than the desired bandwidth can request for more channels after T seconds (T being generated randomly between 0 and 60) from Node B agent. Acceptance or denial of request will depend on the availability of channels.

4.7.6 Call Queuing

4.7.6.1 Call Queue and Waiting Time

A call queuing concept will be considered to further improve the results in terms of reduced call blocking and dropping rates. Instead of blocking or dropping new or handoff calls instantly, they can be put in a resource queue at Node-B. As soon as the resource(s) become available, it can be allocated to the waiting call. Each call is placed in a queue of length L and a maximum waiting time of K seconds. The best value of L and K will be determined based on some experiments.

4.7.6.2 Application Resource Priority Model

The priority queue data structure will be adopted for implementing the call queuing. As soon as the resources become available, they would be assigned first to the call with the highest priority or arrival sequence in case of a deadlock. All handoff calls have higher priority over new calls for resource allocation. The application resource priority has been shown in Table 4.5.

Table 4.5 Priority for resource allocation to each application on a scale of 10 where 10 is the highest priority level.

Application	Priority (on scale of 10)
Voice Calls	10
Video Telephony	9
Multimedia	8
Web Browsing	7
File Transfer	6
Text Messaging	5
Email Downloading	4

4.8 Verification of Simulation Software

Verification of the simulator was done by tracing the events during the simulation and constantly checking the simulation parameters and test values. These test values were special flags (programming variables) used to print specific values for simulation software testing purpose. The results were collected after the simulation was in steady-state region. The steady state region was identified when the outputs from simulation duration T_1 and T_2 are within +/- 10% which is good enough. All the simulation parameters were reset after T_2 to account for the transient period, T_R.

4.9 Validation of Simulation Outputs

A mixed approach of both averaging test results and analytical study was followed to validate simulation results. Each simulation was run at least 10 times with the same parameters (but using different random number seeds) to ensure that the results provided by the ABRM simulator follow the same trend. The results presented in chapter 5 are obtained by averaging the results of 10 simulation runs. This type of validation is important due to the use of several random values during execution. Analytical study was carried out to ensure that values generated by algorithms are correct, lies between +/- 10% confidence interval and distributions used in the simulation did not exceed boundary conditions for example η_{DL} does not exceed 1.0 and P_T remains between 0 and 500 mW. For manual checking, simulation was stopped at several instances and all the parameters values were printed. The values of these parameters were put in the equations to verify that the values obtained from simulation are equal to the values obtained by solving equations (4.4) to (4.6) manually.

4.10 Simulation Experiments

Experiment #1: Effect of varying channel reservation upper limit on call blocking and call dropping probabilities.

This experiment will be run for different call generation rates to find the best value for channel reservation percentage. The best value denotes a value after which the results obtained from the simulation stabilizes.

Experiment #2: Effect of varying call queue length on call blocking and call dropping probabilities.

This experiment will be run for different call generation rates to find the best value for call queue length.

Experiment #3: Effect of varying call waiting time in the queue on call blocking and call dropping probabilities.

This experiment will be run for different call generation rates to find the best value for call waiting time.

Experiment #4: Effect on call blocking and call dropping probabilities without agent intelligence.

This experiment will be run for different call generation rates with obtained best values for channel reservation percentage, call queue length and call waiting time to determine the reduction in call blocking and dropping probabilities when multi agent technology is used for radio resource management.

Experiment #5: Comparison with schemes based on FCA in terms of call blocking and call dropping probabilities with and without agents.

The aim of this experiment is compare and optimize the simulation if the results obtained from the proposed scheme are not better than the results obtained from FCA schemes.

Experiment #6: Comparison with schemes based on DCA in terms of call blocking and call dropping probabilities with and without agents.

The aim of this experiment is compare and optimize the simulation if the results obtained from the proposed scheme are not better than the results obtained from DCA schemes.

Experiment #7: Comparison with schemes based on FCR in terms of call blocking and call dropping probabilities with and without agents.

The aim of this experiment is compare and optimize the simulation if the results obtained from the proposed scheme are not better than the results obtained from FCR schemes.

Experiment #8: Comparison with schemes based on VCR in terms of call blocking and call dropping probabilities with and without agents.

The aim of this experiment is compare and optimize the simulation if the results obtained from the proposed scheme are not better than the results obtained from VCR schemes.

The results presented in chapter 5 (Fig. 5.8 to 5.14) were better than the results presented in the considered schemes so there was no need of further optimizing the simulation. Hence, experiment number 5, 6, 7 and 8 were not conducted.

4.11 Summary

3G networks support applications like conversational (voice), streaming (e.g. video-on demand), interactive (e.g. email and web browsing) and background (e.g. FTP or downloading). Each class of application has different bandwidth requirement. The simulation considers three types of cells namely; Downtown, Urban and Highway. Each cell has its own traffic mix and mobility pattern. In this chapter a complete discussion of traffic mobility pattern has been done. In order to develop a robust design each agent is implemented as a separate class of object oriented programming. The implementation of the simulation has been presented as algorithms in terms of flow charts. This chapter lists all the experiments to be conducted in order to obtain results. The procedure followed for verification of simulation software and validation of outputs was also discussed.

CHAPTER FIVE

Simulation Results and Comparison with Existing Techniques

5.1 Introduction

In chapter four, we presented the simulation model of the ABRM simulator and the algorithms of the proposed scheme. The benefits obtained through the use of the proposed algorithms will be evaluated through computer simulations in this chapter. The goal is to use typical 3G system specifications, UMTS in this case, and observe the advantages the proposed scheme have to offer for resource management in wireless networks. This chapter presents the results obtained from the simulation and its comparison with existing techniques.

5.2 Performance Metrics

The proposed scheme was evaluated based on three performance metrics namely, call blocking rate, call dropping rate and downlink load factor deviation where call blocking rate is the percentage of the number of new calls blocked in total number of calls arrived, call dropping rate is the percentage of the number of handoff calls blocked in the total number of handoff calls arrived and downlink load factor (η_{DL}) deviation is the percentage difference between η_{DL} value of cell with minimum η_{DL} and average η_{DL} in the network. The traffic model adopted for the simulation considered six different types of traffic classes and applications such as voice and data. The call channel reservation and queue length are simulation inputs. The values for these inputs are decided based on experiments number 1 and 2. Experiment number 3 suggests the best value for maximum waiting time for the simulation. The simulations were run from 0-20 Erlang traffic load because the call blocking rate exceeds 5% after 20 Erlangs (in each cell).

5.3 Simulation Results and Discussion

5.3.1 Experiment for Finding Best Channel Reservation Limit

The objective of this experiment was to find the best value for channel reservation percentage in terms of call blocking and call dropping probabilities. The simulation was run from 0 to 20 Erlangs and it was observed that call dropping is reduced by increasing the channel reservation percentage. However, increasing channel reservation more than 3% does not have any significant impact on call dropping as RNC agent distributes the load evenly across the network by forcing the calls (of the over-loaded cell) to execute handoff with neighboring cells. Thus the further experiments are run with channel reservation equal to 3%. The sample results obtained when the simulation is run at 20 Erlangs are shown in Fig. 5.1.

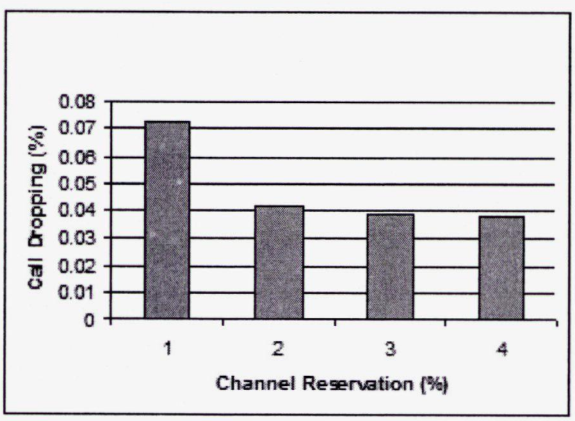


Fig 5.1 Call Dropping Versus Channel Reservation (voice and data calls)

5.3.2 Experiment for Finding Best Call Queue Length

The aim of this experiment was to find the best call queue length in terms of both call blocking and call dropping. The simulation was a run from 0 - 20 Erlangs and it was observed that by increasing the call queue length both call dropping and call blocking rates are reduced. Any increase in call queue length more than five does not reduce call blocking and dropping rates by much because of load balancing operation of RNC agent. Therefore further experiments were run with a call queue length equal to five. The sample results obtained when the simulation was run at 20 Erlangs are shown in Fig. 5.2 and Fig. 5.3.

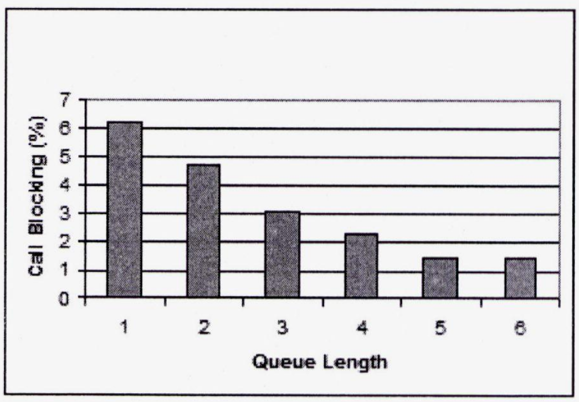


Fig 5.2 Effect of Queue Length on Call Blocking (voice and data)

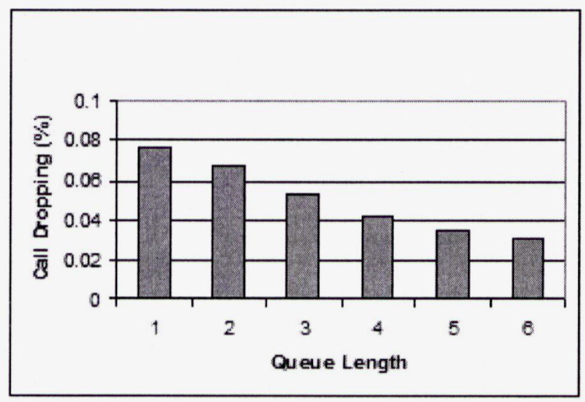


Fig 5.3 Effect of Queue Length on Call Dropping (voice and data)

5.3.3 Experiment for Finding Best Value for Maximum Waiting Time

The aim of this experiment was to find the best maximum waiting time in the queue in terms of both call blocking and call dropping. The results obtained from the simulation (at 20 Erlangs) are shown in Fig 5.4 and Fig. 5.5. The simulation was a run from 0-20 Erlangs with call queue length of five and it was observed that by increasing the maximum waiting time both call dropping and call blocking rates are reduced. Any increase in maximum waiting time more than 8 seconds does not reduce call blocking and dopping rates by much as RNC agents distributes the load evenly in all cells. Therefore further experiments were run with a waiting time equal to 8 seconds.

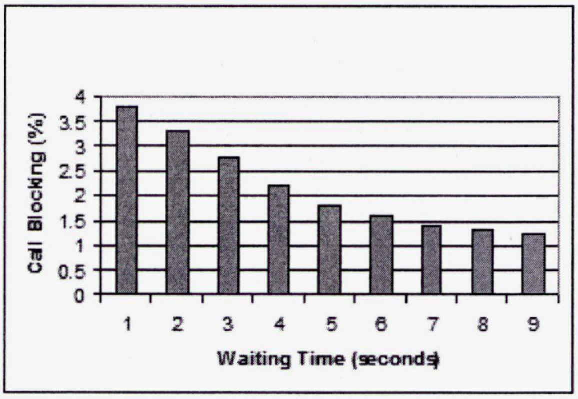


Fig 5.4 Effect of Waiting Time on Call Blocking (voice and data)

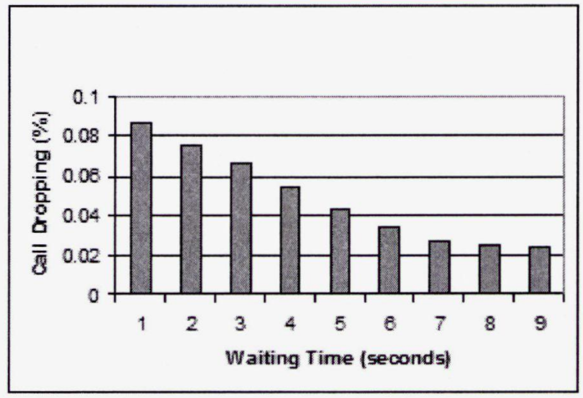


Fig 5.5 Effect of Waiting Time on Call Dropping (voice and data)

5.4 Impact of Traffic Load on Call Blocking and Dropping on Each Traffic Class

It was observed that all the results from each simulation run were in the +/- 10% confidence interval as shown in Figures 5.6 and 5.7.

Fig 5.6 Call Blocking Rate of Each Traffic Class with Increasing Load for Traffic Mix 1

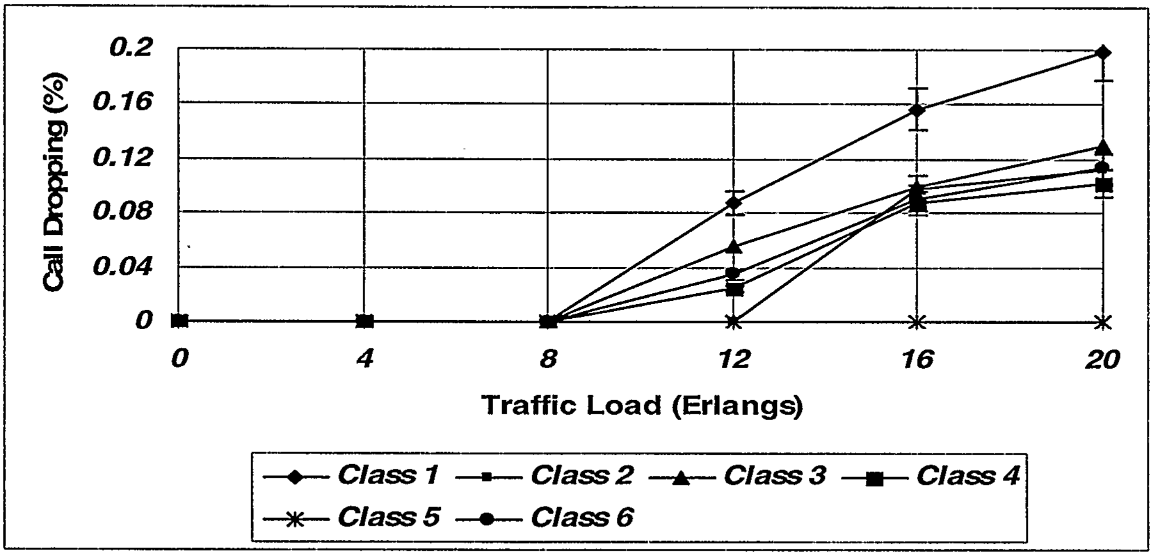


Fig 5.7 Call Dropping Rate of Each Traffic Class with Increasing Load for Traffic Mix 1

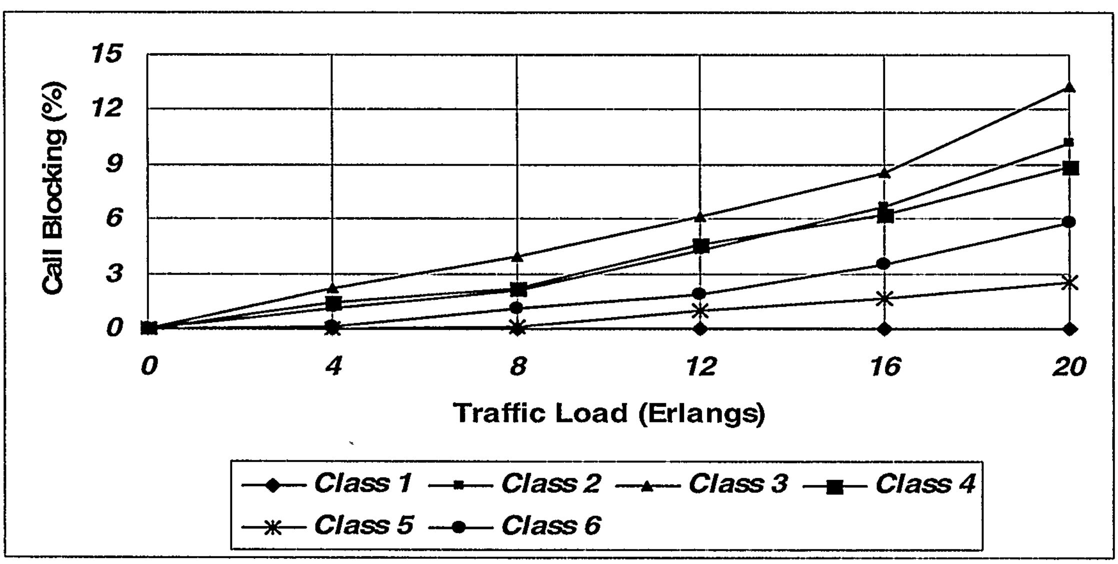


Fig 5.8 Call Blocking Rate of Each Traffic Class with Increasing Load for Traffic Mix 2

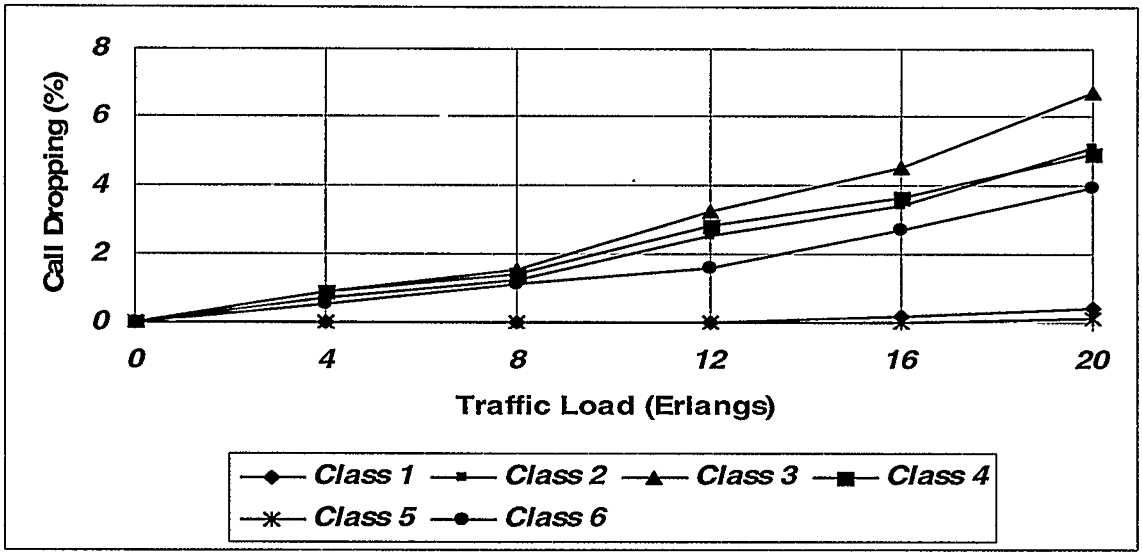


Fig 5.9 Call Dropping Rate of Each Traffic Class with Increasing Traffic Load for Traffic Mix 2

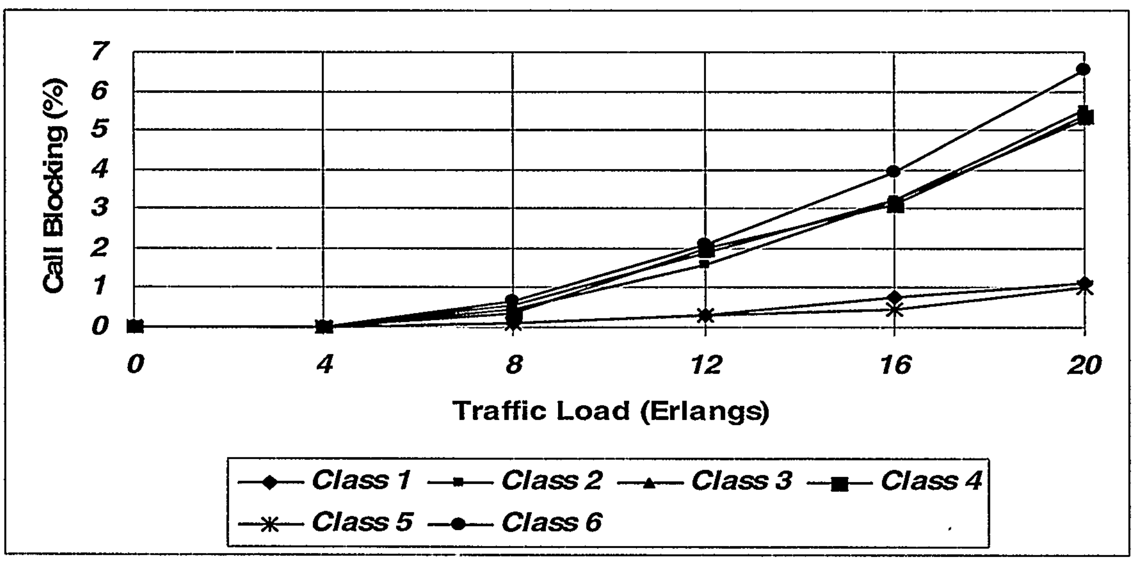


Fig 5.10 Call Blocking Rate of Each Traffic Class with Increasing Traffic Load for Traffic Mix 3

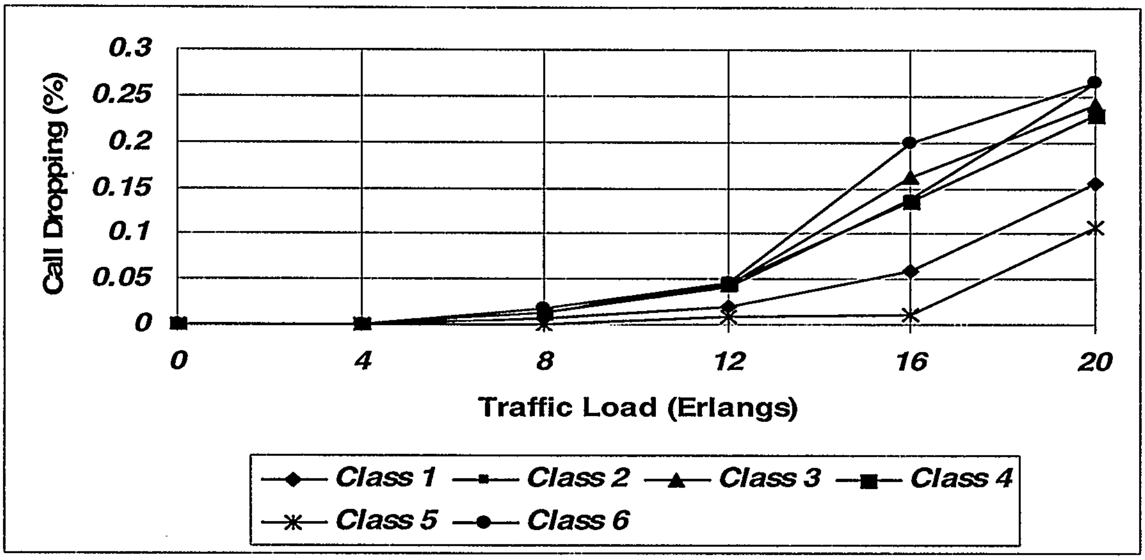


Fig 5.11 Call Dropping Rate of Each Traffic Class with Increasing Traffic Load for Traffic Mix 3

Figures 5.7 to 5.11 show the call blocking and call dropping trends of all six traffic classes considered in the proposed scheme. The call blocking and dropping rates increase as traffic load increases. Class 1 represents voice calls and all other classes represent data applications. Call blocking rates of class 1 and class 5 (which represent UBR, SMS application) are much less than all other classes. A similar trend is observed in call dropping rate. Class 5 has less blocking than Class 1 because of lower data rate requirement and lower percentage in traffic mix. It was observed that both call blocking and dropping rates increase rapidly if the number of data calls exceeds the number of voice calls and vice versa.

5.5 Comparison with Non-Agent based RRM Approach

The aim of this experiment was to observe the results obtained by removing the software agents (i.e., removing intelligent load balancing and suggestion of least busy cell procedures). The simulation was run for different call generation rates up to a traffic load of 20 Erlangs with values of channel reservation, call queue length and waiting time obtained from the experiments number 1 to 3. Channel allocation in the proposed scheme is based on HCA. The results obtained from the experiments are shown in Figures 5.12 to 5.18.

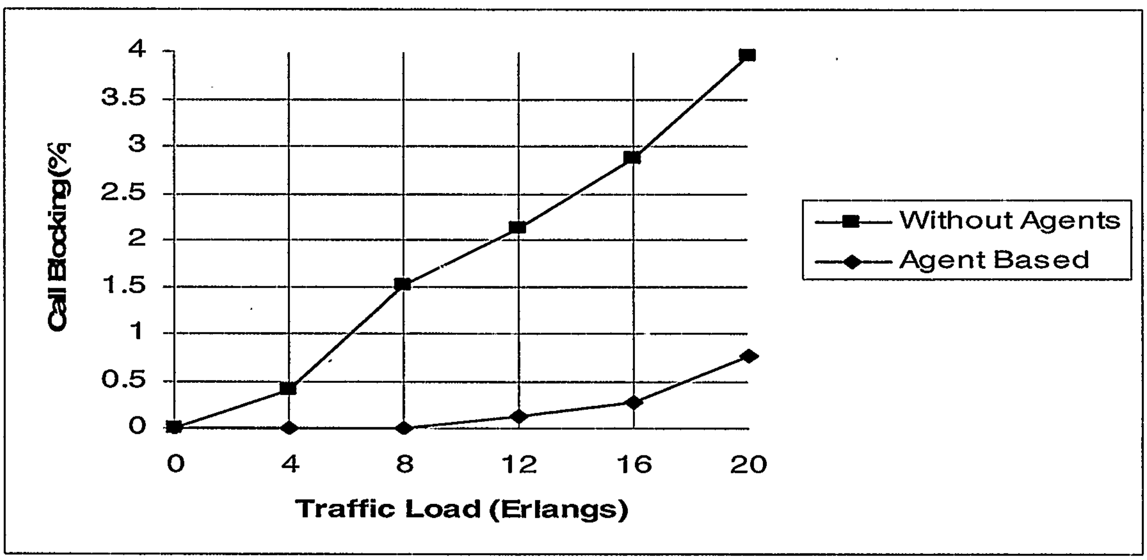


Fig 5.12 Call Blocking Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 1

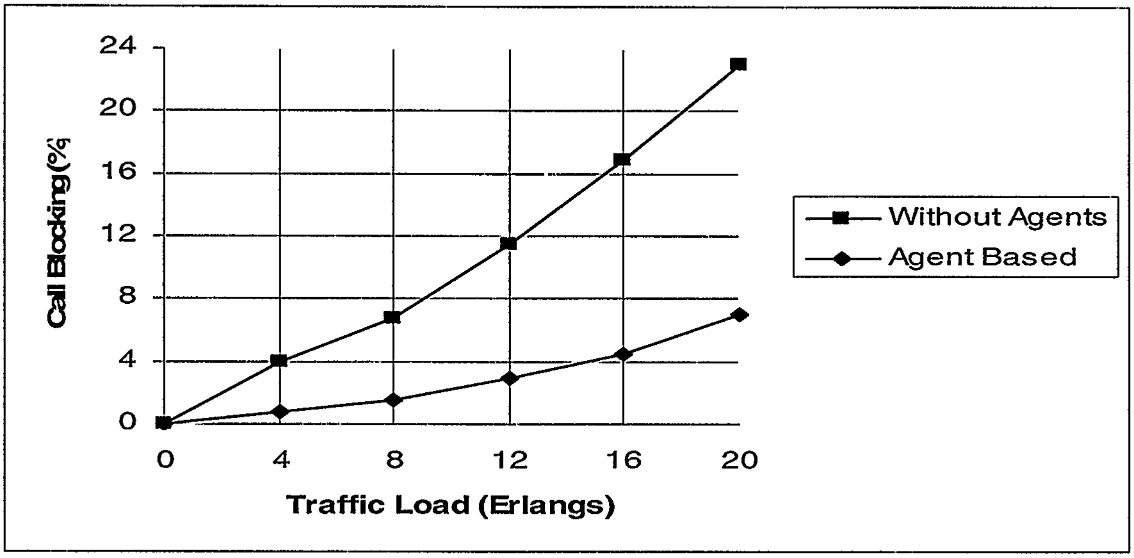


Fig 5.13 Call Blocking Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 2

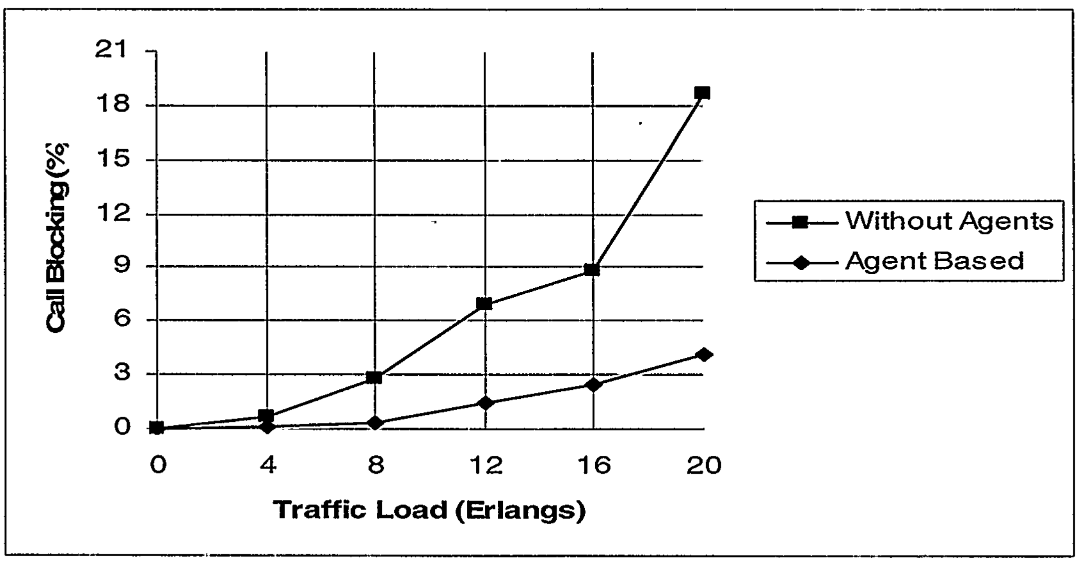


Fig 5.14 Call Blocking Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 3

It is observed from Figures 5.12 to 5.15 that as the traffic load increases in the network cell, the call blocking rate also increases. At high traffic loads such as 20 Erlangs, call blocking rate does not exceed 5% in the agent based scheme whereas without agent intelligence call blocking rate reaches approximately 20% which is far higher than acceptable limit of 10%. It is evident from Figures 5.12 to 5.15 that the proposed agent-based resource management scheme provides much better results as compared to the same scheme without agent intelligence. The improvement observed is in the order of approximately 400%.

A similar improvement in terms of call dropping rates is observed with the agent based scheme. At high traffic loads such as 20 Erlangs, call dropping rate does not exceed 1% and completely outperforms the scheme without agent intelligence. The improvement observed in this case is also in the magnitude of roughly 400% as shown in Figures 5.16 to 5.18

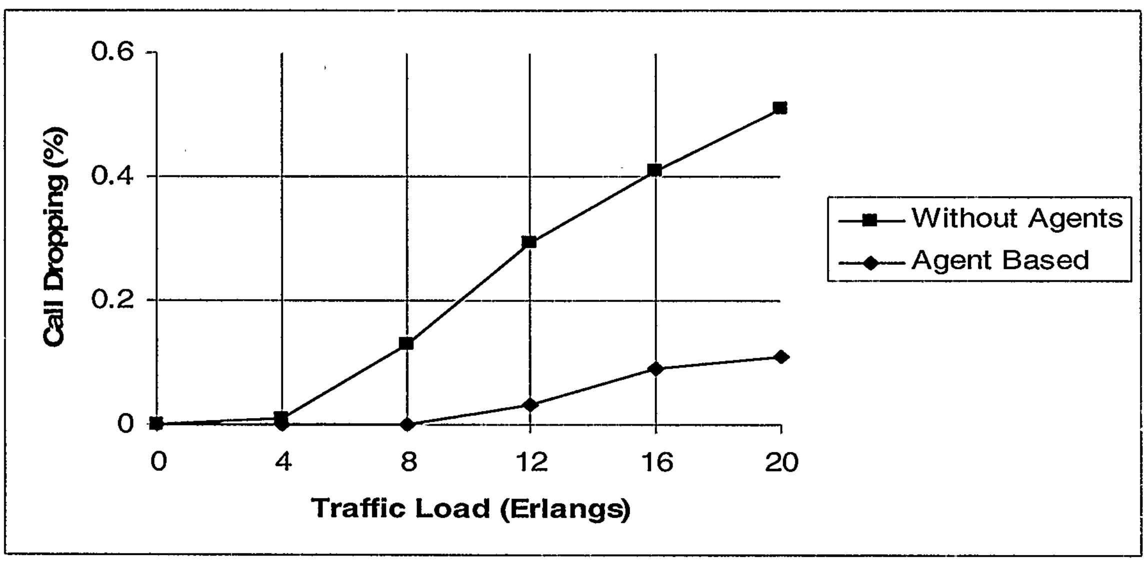


Fig 5.15 Call Dropping Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 1

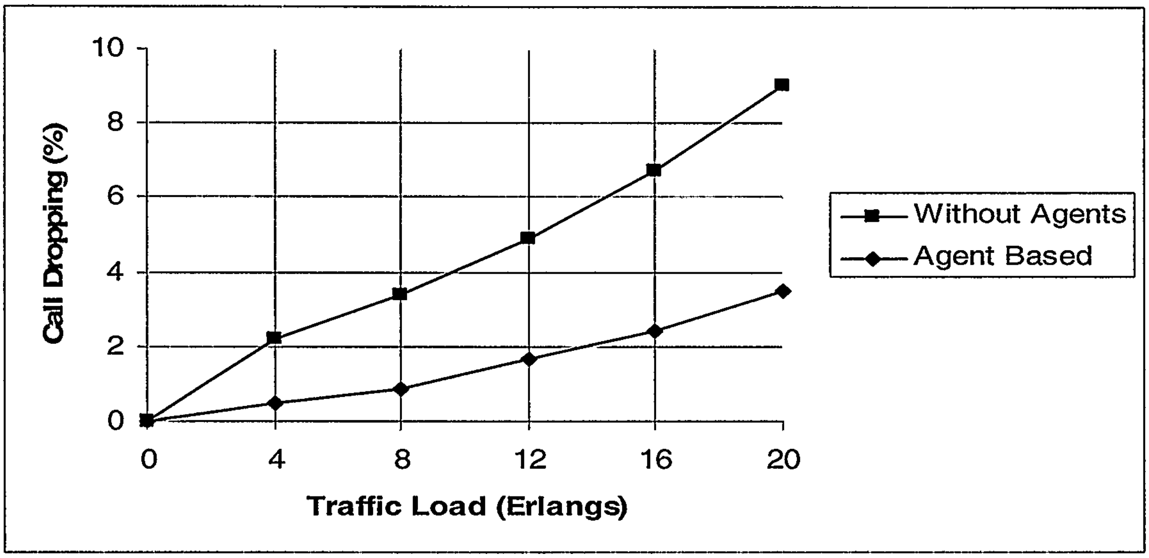


Fig 5.16 Call Dropping Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 2

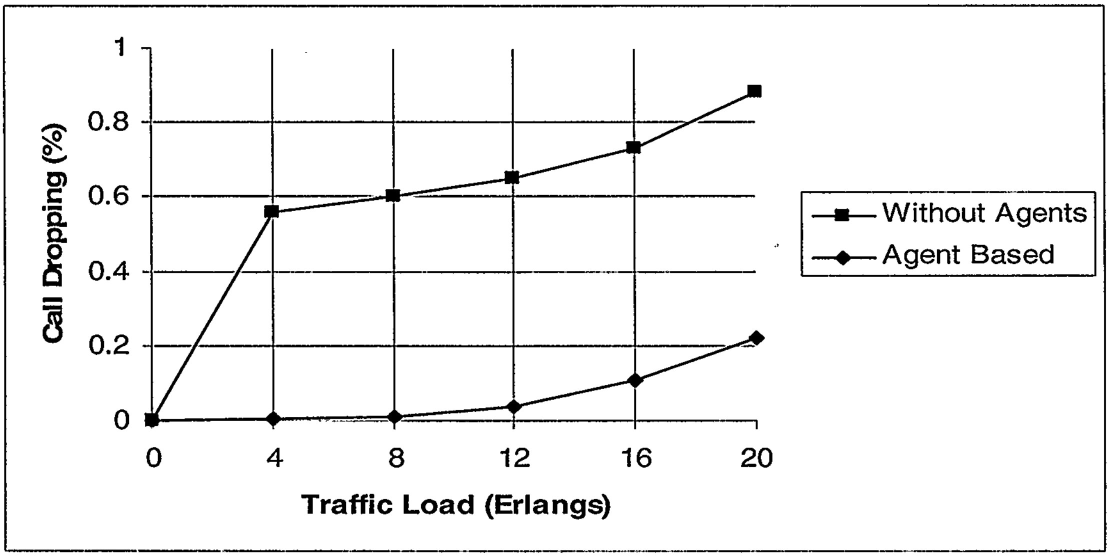


Fig 5.17 Call Dropping Rate in Agent Based and Without Agent Schemes (voice and data) for Traffic Mix 3

One of the goals of the proposed scheme was to evenly distribute the traffic load in the network. In other words, the aim was to reduce the difference between the traffic load value of the least busy cell and average traffic load in the network. An output parameter called ND (Downlink Factor (η_{DL}) Deviation) was defined as the percentage difference between η_{DL} value of cell with minimum η_{DL} and average η_{DL} in the network. ND and evenly distributed traffic load are inversely proportional i.e., lower values of ND represents a more evenly balanced traffic load. Figure 5.18 clearly shows that agent based scheme has a much better traffic distribution as compared to the scheme without agent intelligence. This is due to load balancing and channel borrowing algorithms described in chapter 4. Whenever channel borrowing is done, channels are borrowed from the least busy cell. According to load balancing algorithm whenever η_{DL} is more than 90%, the calls at the cell boundary are forced to execute handoff with the neighboring cell with the least η_{DL}. This helps to evenly distribute traffic load in the entire network.

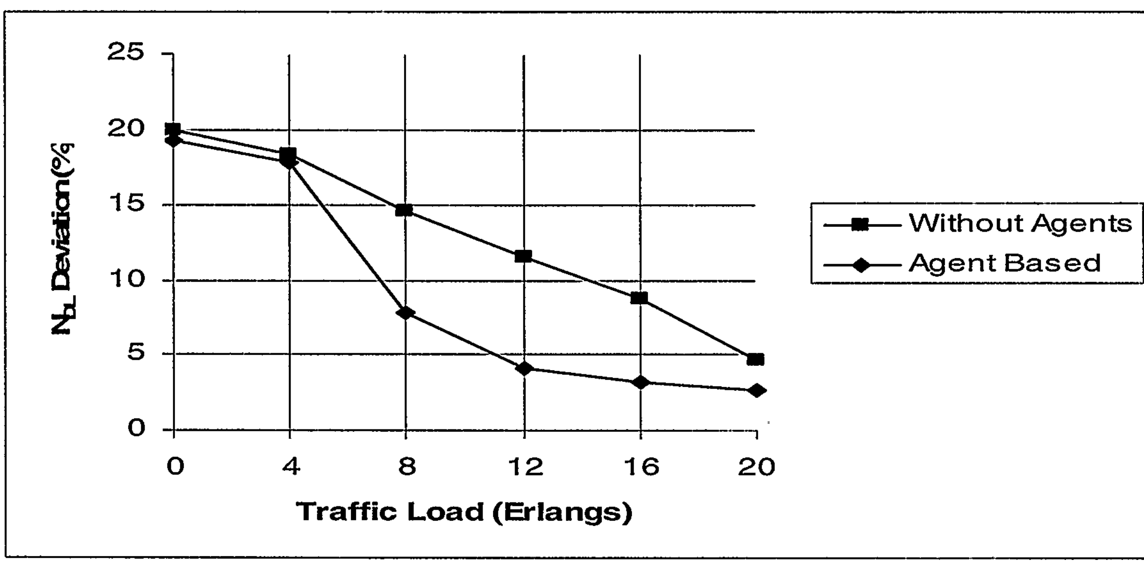


Fig 5.18 Downlink Factor Deviation in Agent Based and Without Agent Schemes (voice and data)

5.6 Comparison with Existing Techniques

The existing techniques for resource management in wireless networks can be broadly classified into two categories; techniques with agent intelligence and techniques without agent intelligence. There has been much research on both categories which were discussed in detail in chapter two. Figures 5.19 and 5.20 show the comparison with a few of the schemes without agent intelligence based on Traffic Mix 3

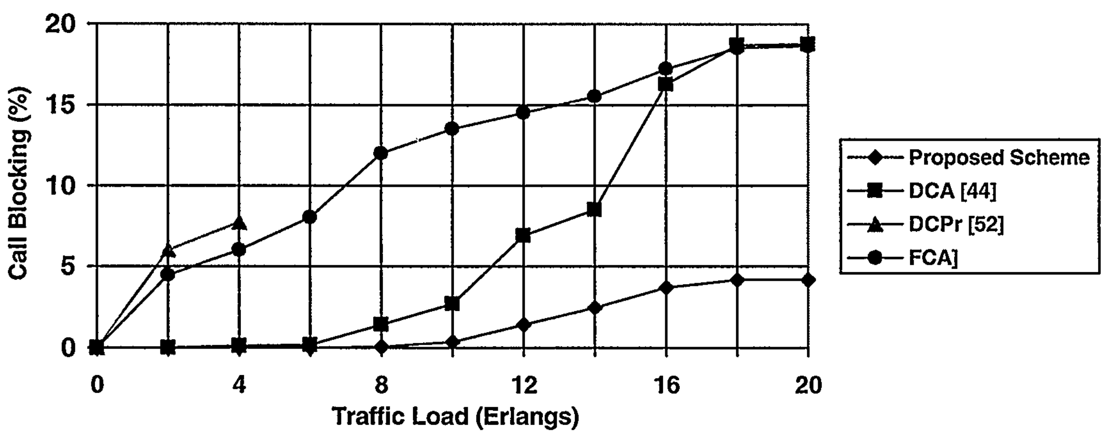


Fig 5.19 Call Blocking as Compared with Techniques without Agent Intelligence (voice and data)

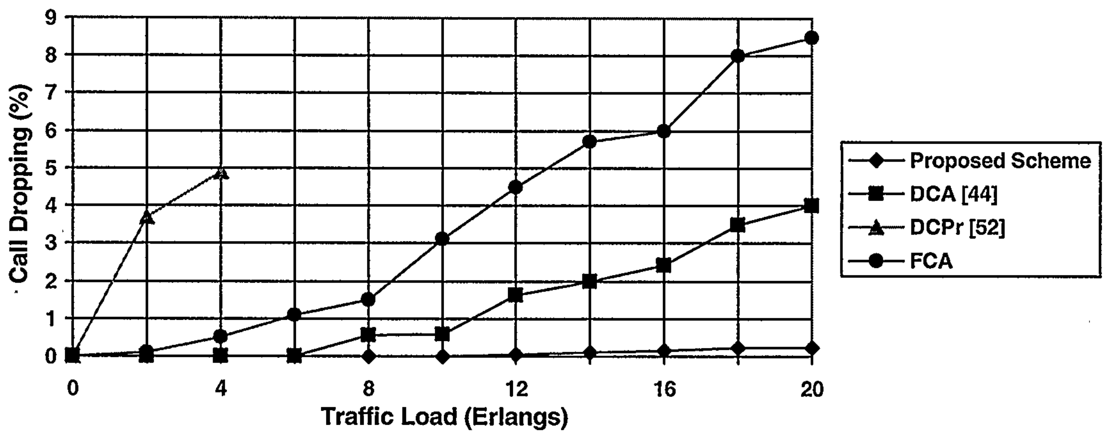


Fig 5.20 Call Dropping as Compared with Techniques without Agent Intelligence (voice and data)

Figures 5.19 and 5.20 show that call blocking and dropping rates in the proposed scheme are lower compared to those of the other schemes considered. The results indicate that in the proposed scheme at high traffic load such as 20 Erlangs, call blocking rate is 4.2% and call dropping rate is 0.2% which are much less than the corresponding numbers for the other schemes considered. This is because of intelligent channel borrowing and load balancing algorithms which were discussed in detail in chapter 4.

Another category of radio resource management techniques includes schemes based on software agents or some other form of artificial intelligence. These schemes mostly work on handover prediction methodology. Software agents are used to predict mobile users trajectory or arrival time based on different methods such as triangulation method, signal calculation, users history, et cetera. Figures 5.21 and 5.22 show the comparison of the results obtained from the proposed scheme with other agent based resource management schemes based on Traffic Mix 3.

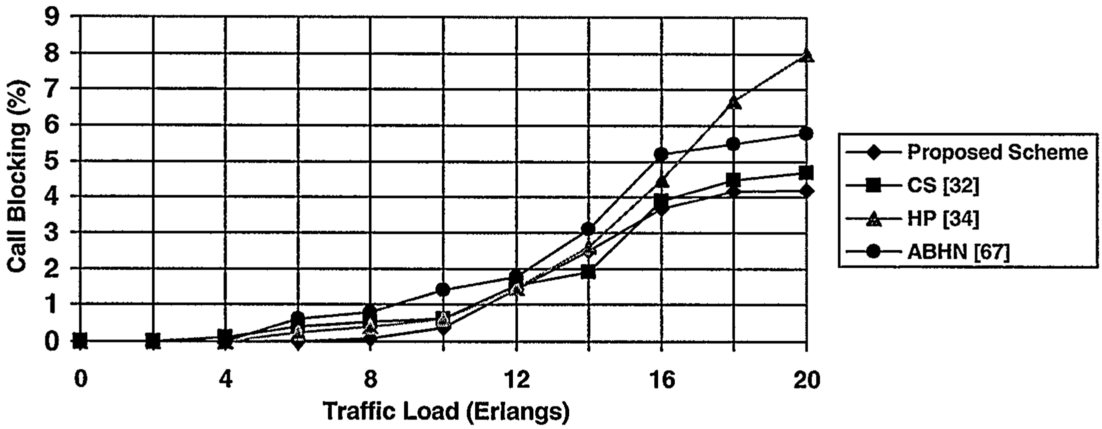


Fig 5.21 Call Blocking as Compared with Techniques with Agent Intelligence (voice and data)

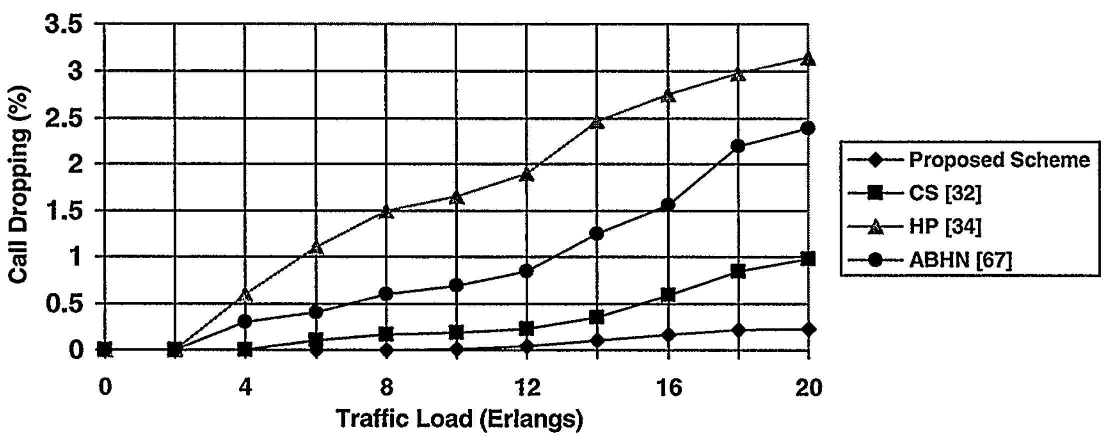


Fig 5.22 Call Dropping as Compared with Techniques with Agent Intelligence (voice and data)

As seen from Figures 5.21 and 5.22, the proposed scheme performs much better in terms of call blocking and dropping. To predict the handover, signal calculation method is adopted where whenever the received signal falls below the threshold value (S_{RSV}) listed in Table 4.2, the mobile station agent sends a reservation request to the destination Node B agent called Node-B agent. It is seen in Figure 5.21 that communications scheme presented in [32] provides results which are very close to the results provided by the proposed scheme in terms of call blocking. However, in terms of call dropping, the proposed scheme outperforms that of the previously proposed communications scheme by approximately 400%.

5.7 Overhead for Using Agent Technology

Agent technology provides several advantages over non agent based approach as shown in the results in previous sections but it requires some overhead for implementation. Mobile stations need to have more disk space to accommodate agent software, powerful processors and more memory for running agent application. Agent software on mobile stations would run continuously which would consume more battery. Thus, power sources with long longer supporting time would be required. All these issues are partially addressed by the existing hardware available for 3G devices.

5.8 Summary

In this chapter, results obtained from the simulation for evaluating the performance of the proposed agent based resource management scheme were presented. We used the third-generation wireless networks specifications for UMTS networks. For demonstrating the performance improvements, few agent-based and non-agent-based schemes were considered. The impact of intelligent algorithms on call dropping and blocking and distribution of traffic load were studied. The results demonstrate that the proposed scheme provides much better results as compared to the other existing schemes considered including schemes without agent intelligence. The results obtained in this chapter would serve as useful contributions in understanding UMTS network capabilities with built-in artificial intelligence in network elements. The results prove that the proposed scheme reduces call blocking and dropping probabilities and improves the load distribution across the network. All these improvements are done without suggesting any change in infrastructure which makes them significant. The results are useful to wireless service providers as a guidance to implementing and understanding the performance of 3G wireless networks.

CHAPTER SIX

Conclusions

6.1 Thesis Summary and Conclusions

In this thesis, the problem of radio resource management in third-generation wireless networks was discussed. Specifically, addressed were the issues of call admission control and load balancing for the wireless network service provider. Firstly, an overview of the evolution of wireless networks was provided with a focus on the call blocking, call dropping and load balancing problems. Three generations of wireless networks were discussed next and the various mechanisms for channel allocation and channel reservation were explained.

A survey of various channel allocation and channel reservation schemes in the literature was presented. The scheme addresses the issue of call admission control and load balancing in terms of new call blocking probability, call dropping probability and resource utilization. The shortcomings of these existing schemes were discussed and to overcome them a valuable agent based radio resource management scheme was developed and analyzed. The significance of the proposed scheme and desired goals were also discussed.

Analytical expressions were derived for implementing intelligent agent based algorithms for channel borrowing, channel allocation, channel reservation and load balancing. The network level simulation model was constructed using Visual Studio .NET package to evaluate the performance of the proposed scheme in a more realistic operating environment. For this, simulation model was described including traffic model, mobility model, simulation outputs, simulation parameters and resource management algorithms. The results were obtained by conducting four experiments. The first three experiments aimed at finding the best values for channel reservation, call queue length and waiting time while the objective of the fourth experiment was to obtain the final results based on results of the first three experiments.

The results obtained from the simulation demonstrate that the proposed scheme is able to provide much better results compared to the other existing schemes. The results also show that radio resources like channels and bandwidth can be better utilized without any extra infrastructural costs. Reduced call blocking and call dropping rates would increase network capacity and quality of service. Thus, this research benefits both the network provider and the customer. This thesis provides useful insights into understanding the capabilities of the third-generation wireless networks. The work done in this thesis should provide motivation for the network service providers to speed up the deployment of the third generation wireless networks with improved performance and enhanced multimedia services.

6.2 Suggestions for Future Work

We believe that the encouraging results obtained in this thesis provides substantial motivation for more research in the development of radio resource management techniques that are based on artificial intelligence. Some of the ways in which the work presented in this thesis can be extended are as follows:

1) The performance of the proposed algorithm needs to be evaluated using a UMTS test-bed or by performing experiments on the deployed networks. This will help in further establishing the advantages of the proposed scheme in real time.

2) In third-generation wireless networks, mobile stations would support multimedia applications demanding high data rates and long application run time. This would require mobile stations to have very efficient power management module and long lasting power sources which could be a very useful research area.

3) The proposed scheme improves the performance of the network. Implementing the proposed scheme on other third-generation networks such as CDMA2000, et cetera would be useful to ascertain if the results are universally applicable.

4) The proposed scheme increases the overheads due to use of agent technology. It would be very useful to investigate how to reduce the computational overheads by reducing the complexity of algorithms. This would make the agent application run on hardware with low processing power and memory.

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