GUARANTEED SERVICE MANAGEMENT IN MOBILE WIRELESS INTERNET

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DECLARATION

This dissertation represents research work carried out by the author and has not been submitted in an form to another University for degree purposes. All sources used in the dissertation have been dul acknowledged.

Signature:_______________________________

DEDICATION

To Nombuyiselo.

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ABSTRACT

The ubiquity of the mobile wireless Internet has led to the increased use of realime applications. Real-time applications are network resources hungry and propagation delay sensitive. These applications need service guarantees if they are to be acommodated on the mobile wireless Internet. It is, therefore, necessary to maintain the required QoS of these applications in the presence of user mobility with the use of resource reservation mechanism. This dissertation presents development of a resource management mechanism to allocate and guarantee the availability of network resources in the mobile wireless Internet.

A model tagged "Dynamic Mobile Resource Reservation Protocol (DMRSVP)" was proposed. DMRSVP comprises of the following: resource reseration, bandwidth allocation, mobility management, and next cell prediction components. The sectored cell approach next cell prediction scheme was modified by adding a resource reservation module. The resource reservation of DMRSVP is made up of a dynamic comparison algorithm for reserving resources in an exactly cell in which a mobile node will visit with open connection. The proposed model utilises HMIPv6 for managing mobility within a domain and the cooperation of hierarchies was adopted to manage mobilyt between domains. An algorithm tagged "connection swapping" was developed for DMRSVP to reduce both call blocking and call dropping probabilities. The simulation of DMRSVP was carried out using an object oriented programming environment, VB.net. The perfomance of DMRSVP was compared with the existing schemes (MRSVP and HMRSVP) through simulation. The network load, delay, call blocking probability (CBP) and call dropping probability (CDP) were used as the simulation parameters.

The results of the simulaions show that bandwidth utilisation of the three schemes between 0 and 2 seconds (sec) were the same, but after 10 sec, MRSVP utilised 160Kbps of bandwidth, while HMRSVP and DMRSVP utilised 138Kbps and 102Kbps of bandwidth respectively. This verifies thaDMRSVP

does not over utilise bandwidth. The proposed model (DMRSVP) blocked 5 reservation requests, while MRSVP and HMRSVP blocked 36 and 24 reservation requests respectively within 10 seconds. The signalling overload of the three protocols shows that MRSVP sent 225; HMRSVP sent 151, while the proposed DMRSVP sent 25 control messages over the period of 10 minutes. This implies that the proposed model does not overload the network with a control messages; this allows for more user data packets to be transmitted. The round trip delay of reservation set up of MRSVP was 45 sec; HMRSVP was 31 sec; while it took only 19 sec for DMRSVP to set up the reservation. CBP and CDP of the proposed model were measured. The simulation results show that DMRSVP has CBP of.02 and CDP of 0.05. These are lower values compared to what is obtained in the literature for other schemes.

Based on the results of the simulation, it was concluded that DMRSVP is more scalable and efficient than the classical MRSVP and HMRSVP. This isdue to the fact that DMRSVP takes into account mobility management but MRSVP does not. Again DMRSVP was integrated with the next prediction algorithm to predict the cell(s) in which a mobile node might visit. This makes DMRSVP not to over reserve the limited network resource.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Preamble

The phenomenal increase in handheld communication devices has played a major role in popularising the mobile Internet and real-time applications Mobile users expect to receive similar services in a mobile wireless Internet as in the wiredcounterpart. This necessitates guaranteeing Quality of Service (QoS). A QoS scheme needs to provide a mechanism for a network to distribute and manage shared resources (bandwidth, CPU time and buffers) over different flows. The current Internet is based on the best effort model which does not provide any guarantees to flows. Efforts aimed at finding schemes that guarantee QoS have led Internet Engineering Task Force (IETF) to propose two different approaches. These are the Integrated Services (IntServ) [Braden, et al 1994] and the Differentiated Services (DiffServ) [Blake, et al 1998].

IntServ is an improvement of the best effort model. IntServ QoS model adds two service classes to the best effort service class. These classes are Guaranteed Service (GS) and ControlLoad Service classes (CL). GS is designed for real-time data traffic that needs a guaranteed minimum delay. This service class guarantees that the packets will arrive attheir destinations within a certain delivery time and are not discarded if the flows traffic stays withinthe boundary of its traffic specification CL is designed for data traffic that accepts some delays, but is sensitive to network overload and loss of packets. IntServ introduced a mechanism of resource reservation for individual flows, and this is carried out by a signalling protocol known as the Resource rSerVation Protocol (RSVP) [Zhang, et al 1993]. IntServ is a flow-based QoS model. A user needs to create a virtual circuit from the source to destination. The main disadvantage of IntServ is that it is not scalable, because it requires peflow state in each node.

DiffServ was proposed as an improvement to IntServ. DiffServ is class-based unlike IntServ which is flow-based. DiffServ has two service classes apart from Best effort (BE). These are the Expedited Forwarding (EF) [Jacobson, et al 1999] and the Assured Forwarding (AF) [Heinamen, et al 1999] classes. In EF the arriving packets will experience almost an empty queue, and the departure rate should equal or exceed the arrival rate. AF assumes that the minimum amount of bandwidth is initially assigned to the flow. AF drops packets during network congestion. The scalability problem faced by IntServ is solved by mapping multiple flows into few service classes. The major problem with DiffServ is that it does not have hard guarantees on QoS. The drawbacks of IntServ and DiffServ become even more serious in a mobile wireless network environment. This is because the communicating devices are not fixed at all times, as in the wired Internet.

Efforts aimed at finding the standard resource reservation protocol for mobile wireless networks have not been adequate [Chan, et al 2000]. Talukdar et al 1997 proposed the Mobile Resource Reservation Protocol (MRSVP). MRSVP makes advance resource reservations at multiple locations where a mobile host may possibly visit during the service life time. MRSVP has the problem of over-reserving highly limited network resources. A possible solution to this wastage of resource is to predict the next cell that a mobile host will possibly visit. One such proposal of predicting the mobility of a mobile host is the sectored-cell approach [Nkambule, et al 2004]. This approach predicts the exact cell that a mobile host will visit. The protocol proposed in this research work takes into consideration the sectored-cell prediction scheme.

1.2 Statement of the Problem

Real-time applications are highly sensitive to delay and bandwidth. These applications need service guarantees if they are to be accommodated on the mobile wireless Internet. A response to this sensitivity of real-time data is the advance reservation of highly limited network resources. Therefore a resource reservation protocol that does notover-reserve the network resources is required to carry out this task in mobile wireless Internet. The currently proposed protocols are not adequate enoughto reserve network resources. Thisis because the current mobile wireless resource reservation protocols over-reserve the limited network resources, does not guarantee the availability of resourcesand do not support transmission of real-time multimedia applications in a mobilewireless environment. The current mobile wireless resource reservation protocols are not scalable, meaning that if the number of flows increases the performance of signalling protocol degrades.

In this work an attempt was made todevelop an optimal protocol for reserving network resourcesin advance for mobile node in the mobile wireless Internet. The optimal protocol is the one that is scalable, guarantees the availability of resources atthe time of handoff, does not over-reserve the limited network resourcesand supports both non real-time and real-time applications

1.3 Rationale for the Research

The dawn of the World Wide Web (WWW) has made the current best effortwired Internet grow in leaps and bounds. The popularity of the WWW is due to its multimedia features albeit in nonreal time. Users of mobile Internet are requestingthe same services to be offered on their network. This means that the development of a new end to end QoS provisioning architecture for the mobile Internet. One of the components required for QoS architecture is a Resource Reservation Protocol.

QoS architecture makes it possible for a mobile node to move from one cell to another in the mobile wireless environment. In order to guarantee QoS in the next cell the mobile host wilmove into, there has to be a mobile wireless resource reservation schemeavailable for the reservation of resources in this next cell. This research aims at developing an optimal protocol for the reservation of resourcesin advance.

1.4 Research Questions

i. How do we configure resources in advance?

ii. What optimal protocol can be used in themobile wireless Internet, which will satisfy both real time and non real-time applications?

1.5 Research Goal and Objectives

1.5.1 Goal

The goal of this research is to develop an optimal resource management mechanism that will accommodate both real-time and non-real time applications in the mobile wireless Internet.

1.5.2 Research Objectives

The specific objectives of this research areto:

i. analyse the theoretic framework of the existing mobile wireless resource reservation protocols;

ii. determine how to configure resources in advance, in a mobile wireless Internet;

iii. design an optimal mobile wireless resource managementprotocol for deterministic QoS guarantee;

iv. simulate the designed protocoland

v. compare our protocol's performance with similar existingprotocols.

1.6 Concept of QoS Provision in mobile wireless Internet

1.6.1. Overview of QoS Management

Quality of Service management is a very broad topic.Majoor, 2003 defines QoS management as an idea that transmission rates, error rates, jitter and other network characteristics can be measured, improved, and to some extent guaranteed in advance Forouzan, 2003 discusses the techniques that can be employed to improve QoS. These techniques apply in both wired and wireless networks. These techniques are scheduling, traffic shaping, resource reservation, and admission control. Scheduling is a mechanism used to decide which packet to send first from multiple queues and to treat those packets in a fair and appropriate manner.

Traffic shaping is used to control the traffic rate sent to the network. Resource reservation is used to reserve and allocate network resources before the actual transmission of data messages. The admission control is used by routers to accept or reject flows based on predefined parameters, such as the flow's specification. The QoS management techniques are as shown in figure 1.1.

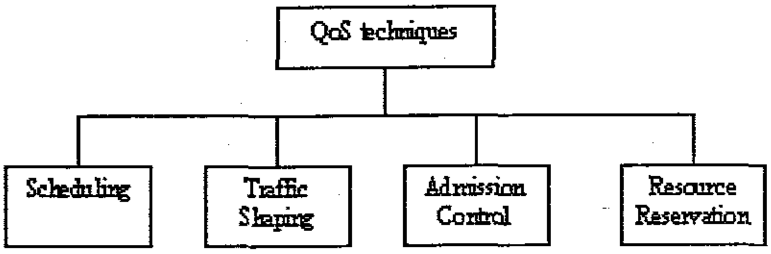

Figure 1. 1 QoS management.

1.6.2. Impact of Mobility on QoS Signalling

Mobile IP [Perkins, 1996] is an Internet Engineering Task Force (IETF) standard communications protocol that is designed to allow mobile device users to roam from one network to another while maintaining their permanent IP address. As the mobile node roams from one subnet to another it is assigned to the new Care-of-address. Care-of-address is temporary IP address assigned to mobile node in a foreign network. The mobile node care-of-address needs to be registered with its home agent (HA) in the home network. This registration is always done when the mobile node gets the new care-of-address. The registration of a new care-of-address is called binding update.

This means that mobile node haveto send some control message to home agent,and vice versa This home registration may be very expensive and very long ifthe mobile node is far away from its home network. The delay caused by home registration has a very bad impact on the QoS signalling protocol performance. Hierarchical Mobile IPv6 [Soliman, et al 2005] has been proposed as the solution to this problem of home registration and many more other problems associated with Mobile IP. Moredetails of Hierarchical Mobile IPv6 (HMIPv6)are discussed in chapter three.

1.6.3. Resource Reservation in Mobile wireless Networks

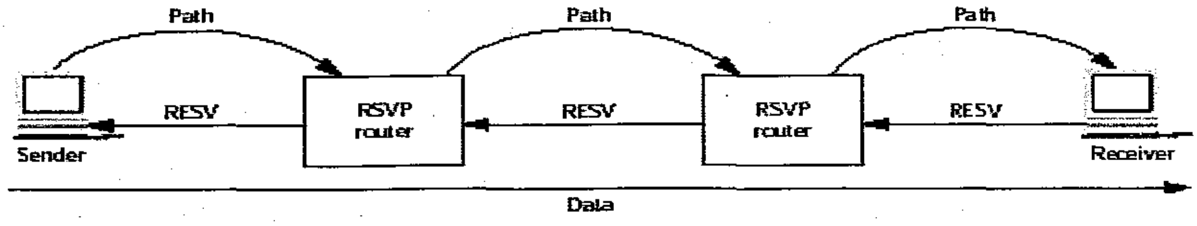

Figure 1. 2 RSVP Virtual Circuit

IETF declared RSVP [Zhang, et al 1993] as the standard protocol for resource reservation in wired IP Networks. RSVP is a signalling protocol that sets up a virtual circuit(figure 1.2) before the start of data transmission.

The RSVP sender sends a Path message with a flow specification (Fspec) through intermediate routers to the receiver. The receiver, having received the path message, may then send a Reservation message (Resv) along the reverse path that has been formed by the path message. The receiver isresponsible for reserving network resources based on the Fspec it got from the path message. Therefore RSVP supports receiver based reservation. The receiver sends RESV message to reserve network resources. RSVP is not scalable, because it has many control messages and it was primarilydesigned for wired networks [Kim, et al 2001].

Control messages thatare employed by RSVP are as follows:

Sender Tspec: A Path message is required to carry a Sender Tspec(traffic specification),

This defines the traffic characteristics of the data flow that the sender will generate. This Tspec is used by traffic control to prevent over-reservation, and perhaps unnecessary admission control failures.

TearDown: There are two types of RSVP teardown messages, PathTear and ResvTear. A PathTear message travels towards all receivers downstream from its point of initiation and deletes path state, as well as all dependent reservation state, along the way. A ResvTear message deletes reservation state and travels towards all sendes upstream from its point of initiation.A PathTear (ResvTear) message may be conceptualized as a reversedsense Path message (Resv message, respectively).

Error: There are two RSVP error messages, ResvErr and PathErr. PathErr messages are very simple; they are simply sent upstream to the sender that created the error, and they do not change path state in the nodes through which they pass. There are only a few possible causes of path errors. The handling of ResvErr messages is somewhat complex. Since a rquest that fails may be the result of merging a number of requests, a reservation error must be reported to all of the responsible receivers. In addition, merging heterogeneous requests creates a potential difficulty known as the "killer reservation" problem, in which one request could deny service to another. There are actually two killer-reservation problems.

Resv: Each receiver host sends RSVP reservation request (Resv) messages upstream towards the senders. These messages must follow exactly the reverse of the path(s) the data packets will use, upstream to all the sender hosts included in the sender selection. They createand maintain reservation state in each node along the path(s). Resv messages must finally be delivered to the sender hosts themselves, so that the hosts can set up appropriate traffic control parameters for the first hop.

MRSVP [Talukdar, et al. 1997] was proposed as an extension to RSVP to accommodate mobile hosts. MRSVP makes advance resource reservations at multiple locations whre a mobile host may possibly visit during the service life time. MRSVP reserves resource in the cells that have been specified in the mobile specification (MSpec) of the mobile host. This causes wastage of highly limited network resources.

MRSVP introduced the concept of active and passive reservations. A mobile host makes an active reservation from the current cell and makes passive reservations from other cells specified in its MSpec (figure 1.3). MRSVP is not scalable because of passive reservation ofnetwork resources that is done in locations that a mobile node will not even visit This leads to over-reservation of network resources. MRSVP depends on the mobility specification of a mobilenode in order to make reservation of resources.

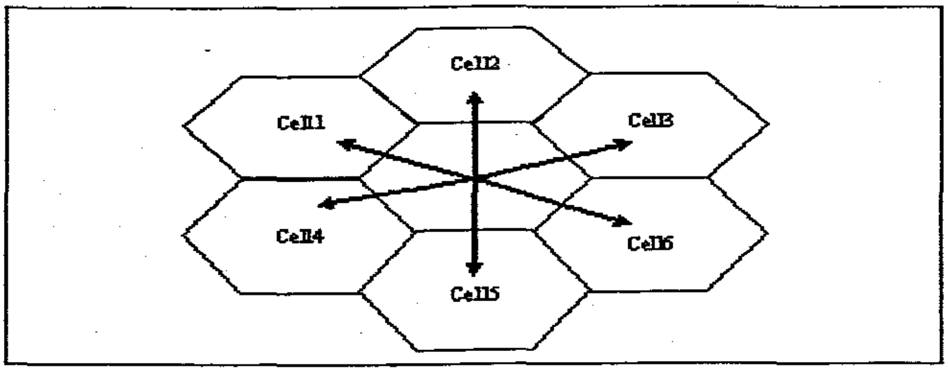

Figure 1. 3 Wireless environment

1.6.4. Soft-state Reservation

In soft state maintenance, resources are reserved for a small amount of time. Hence a flow state has a short life cycle and unless refreshed or updated, it is deleted after some period of time (the default RSVP's refresh period ≈ 30 sec). Thus, end-systems periodically transmit messages into the network to renew the reservations otherwise resources are released after timeout period. Softstate deals easily with the following conditions: changes in routes, loss of control messages, node failures, reclamation of obsolete resources, and dynamic membership of multicast groups. Soft-state improves QoS. For this reason the technique is widely used by many signalling protocols. However, it causes scalability problems within the network due to periodic refreshes required to maintain states. This problem is called processing overhead.

1.6.5. Hard-state Reservation

Hard state maintenance is a converse approach to soft state maintenance. States remain installed in the nodes unless explicitly removed by the receipt of a teardown message from the end system. Since management of hard state session is completely deterministic, the hard state setup approach must be reliable, with acknowledgements and retransmissions. The hard-state maintenance minimizes processing overhead at the routers. However, in a case where a path is broken, nodes may fail to release resources if nodes on path are unreachable.

1.6.6. Out-band signalling

Out-band signalling separates control messages from data messages. Control information is sent separately from data packets. This approach alleviates the burden on routers. Control packets will request resources prior to transmission of data. In this way, there will not be much processing done in the router except to check if data packets correspond to the reservation states assigned to them.

However, this approach introduces scalability concerns since the number of signalling messages sent into the network increases

1.6.7. In-band signalling

Signalling messages are piggybacked in normal data packets, meaning thathe control information is sent with data packets. This minimizes the number of control or signalling messages sent within the network. In-band signalling improves scalability since there is minimal number of messages. However, sending data packets with control messages can create unnecessary burden on the routers if there are not sufficient resources to accommodate these packets. Additionally, processingof unreserved data packets can increase protocol processing time and this may constitute unnecessary delay.

1.7 Characteristics of Mobile Wireless Real-time multimedia applications

Multimedia application is the combination of interactin of text, audio (voice), images, video, and graphics. Real-time communication is that type of communication in which information is received at (or nearly at) the instant it is sent. Anexample of real-time communication is cell phone voice call. The combination of real-time communication and multimedia application brings up the new interesting concept of real-time multimedia applications. The following are characteristics of realime multimedia applications:

i. Real-time multimedia applications are highly sensitive to propagaton delay and

ii. Real-time multimedia applications are network resources hungry.

From the characteristics of real-time multimedia application, it can be deduced that mobile wireless quality of service signalling protocol mustbe mobility aware to reduce the unnecessary propagation delay. Mobile wireless QoS signalling protocol must again include the next cell prediction scheme to avoid over reservation of network resources.

1.8 Methodology

The research approach that has beenfollowed in this research involves two methods. These methods are theoretical and formulative.

i. Theoretical Investigation Method

The theoretical part of this research involvs analysing related work. This analysisis done based on the theoretical framework thatis specifically developed for thistask.

ii. Formulative Method

The theoretical knowledge gined from the related work has been used as a foundation of this research. The formulative method of this research involves model formulation and proof of concept.

a. Model Formulation

Different resource management strategies arelooked at. A *critical evaluative and comparative* analysis of existing methods and algorithms for guaranteeing availability of resources in advancewas carried out. This analysis used to formulate the methods and algorithms foradvance reservation of resources in mobile wireless Internet.

b. Simulation of the Model

The proposed resource reservationalgorithm for guaranteeing the availability of network resources to mobile nodeswas simulatedusing VB.net programming language.

1.9 Organisation of the Dissertation

The remainder of this dissertation is organised as follows: Chapter two consists ofthe review of the related work. The chapter begins by giving the theoretical framework that is used to analyse the related work. In chapter three, DMRSVP is presented. The chapter begins byoutlining the design principle on which DMRSVP is based. This chapter present the proposed dynamic comparison and connection swapping algorithms. Chapter four outlines the computational implementation of the proposed

DMRSVP and the simulation results. This chapter gives the detailed performance analysis of DMRSVP. Finally chapter fivepresents the conclusion which consists of how the research objectives were achieved and possible future work for further reearch and results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Real-time applications are network resources 'hungry' and propagation delay sensitive. These applications need service guarantees if they are to be accommodated on the mobile wireless Internet. It is, therefore, necessary to maintain the required QoS of these applications in the presence of user mobility with the use of resource reservation mechanism. Quality of Service provision in a mobile wireless network is not a new concept to a research community. The mobility of the mobile node has the significant impact on the QoS provision for realtime applications. Therefore it is very necessary to configure network resources in advance for mobile node, because resources may not be available in the location where it is roaming into. This configuration of network resources in advance is through QoS signalling protocol.

Several researchers have addressed this issue of configuring network resources in advance for mobile node according to [Chan, et al 2000]. Most of the existing protocols are the combination of Mobile IP [Perkins, 1996] and Integrated Services [Braden, et al 1994] (InteServ) [Chan, et al 2000]. This chapter presents a critical analysis of existing mobile wireless resource reservation protocols. This analysis is based on a theoretical framework that is specially developed for this task. The framework is introduced in section 2.5 and related work is the subject of discussion in section 2.6. Before that, mobility architectures are introduced, followed by an overview of mobile wireless resource protocols and challenges associated with designing them.

2.2 Mobility Architectures

Mobility architectureis the mechanism that allows a mobile user to roam in mobile wireless network with an open connecion without getting disconnected or interrupted. Early architectures did not provide satisfactory QoS. This sectiongives the discussion on mobility architectures. Two types of mobility architectures are available, and they are linear architecture and thehierarchical architecture [Chan, et al 2000].

i. Linear Architecture

Linear architectureis that architecture wherenetwork nodes are not controlled by anyother node. The data that is sent or received takes a specific direction.

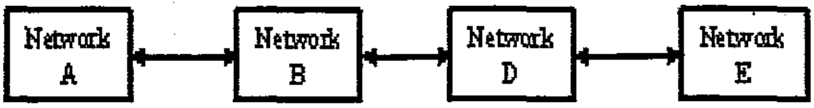

Figure 2. 1 *Example of Linear Mobility Architecture*

ii. Hierarchical Architecture

Hierarchical mobilityarchitecture is that architecture that has network nodes that are organised in different levels. The network node is arranged in a form of a hierarchy Hierarchical Architecture improves the performance of a signalling protocol. Thisis because it reduces a protocol overhead. The hierarchical architecture is as shown in figure 2.2Next we overview mobile wireless resource reservation and how it iscarried out.

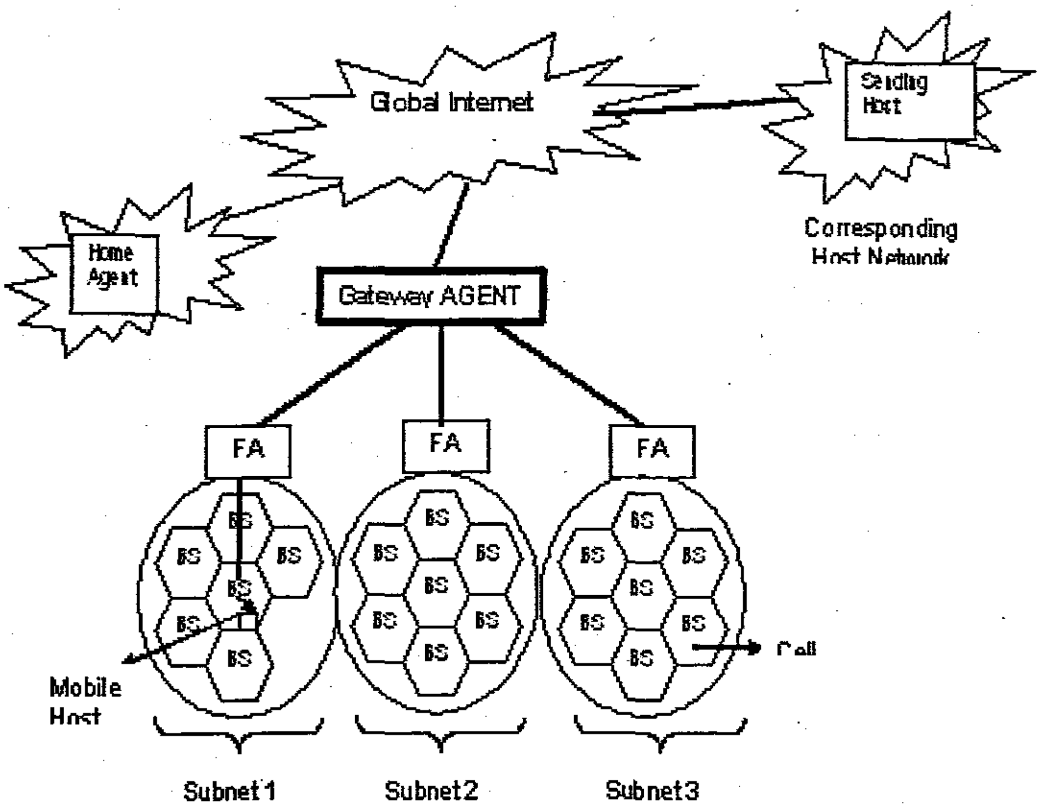

Figure 2. 2 *Generic hierarchical architecture*

2.3 Generic Mobile Wireless Resource Reservation Protocol

Mobile wireless resource reservation protocol can be developed in many different ways. A simplified overview of how resource reservation is carried out in the network can be described as follows:

Before a sender can start sending data packets in the network, a communication path has to be established first. Resource request messages containing theflow specification are created and sent by sender to a receiver via base station in its current network. At each router resources are reserved. The receiver will confirm reservation by sending a confirmation message to the senderUpon successful reservation indicated by a receipt of a confirmation message from the receiver, the sending host can then start data transmission immediately.

Resource reservation schemes can be classified ito various categories according to the way their resource reservation is carried out. The categories include reservation orientation, state maintenance, and signalling band. These categories can be described as follows

1) Reservation orientation defines the reservation initiator, their role in the traffic flow and the direction at which the reservation process is done. The reservation can either be sender-oriented or receiver-oriented;

2) State maintenance indicates the approach in which reservation states are created and maintained within the routers. Reservation protocols can be divided into two categories: soft state protocols and hard-state protocols and

3) Signalling band represents the way signalling messages are isolated from the actual data messages while being transmitted over the network. Signalling messages can either be separated or piggybacked on normal data messages. Two forms of signalling exist, in-band signalling and out-band signalling. Out-band signalling separates these messages and transmits them independently while in-band signalling sends these messages together.

The next section presents the design challenges of mobile wireless resource reservation protocols as *identified in* [Chan, et al 2000].

2.4 Design Challenges of Mobile Wireless Resource Reservation Protocol

Scalability

Reservation signalling has posed scalability concerns in the networks, especially in the access network, which is frequently congested with thousands of received flows. The access network receives a considerable number ofsignalling messages to process. The processing of these messages is not only time consuming but also creates a huge burden on the wireless network nodes. This may degrade the use of network resource and performance of a wireless network.

Complexity

Most of resource reservation protocols are complex. Complexity in reservation schemes is associated with the number of signalling messages a base station has to process in order to complete one reservation session. The number of tasks required to be scheduled during the processing also contributes to complexity issues. The challenge is to reduce both the task burden as well as volume of message which a router must handle.

High protocol overhead

As flows are received by nodes, the resource reservation protocol implemented in a node processes each flow. Protocol processing ovehead of a reservation protocol can be determined by factors such as: number of control messages sent, the sizes of these control messages and the refresh frequencies of control messages. Since wireless networks are limited on bandwidth, the protocol overhead has to be eliminated by all means Having discussed design challenges, what is the establishment of an analytical framework for reviewing works that are related to this research.

2.5 Framework for Analysing Related work

The review of related workwas carried out using the followinganalytical issues

i. Interface to Internet

Interface to the Internet is looking at the entity that connects to the global Internet. This entity can be base station, subnet agent or gateway agent.

ii. Architectural Structure

The functional architecture assumed by a mobile wireless resource reservation protocol can be either linear or hierarchical.

iii. Type of Reservation

Different schemes employ different types of reservation. Some schemes have active reservation. Active reservation is the reservation of network resource in the current cell of a mobile node. Passive reservation is a reservation of network resource that is done in advance before a mobile node enters any cell or subnet.

iv. Where to Pre-allocate Resources

This checks whether the scheme under analysis employs any next-cell prediction scheme. The cell prediction scheme is important to predict the cell(s) that the mobile node is likely to visit with an open connection. This improves the throughput of the network, because the network resource would not be wasted.

v. Messages Involved

The number of control messages that a scheme employs determines whether that scheme can affect the through-put of network. If a scheme has many different control messages, these messages would cause unnecessary network traffic.

vi. State

Resource reservation protocol can either maintain the state of reservation (soft state) or does not maintain it (hard state.) A hard-state is when a signalling protocol does not maintain the reservation state. A soft-state is where by a signalling protocol maintains a reservation state in each router along the path of flow. This maintenance of reservation state is usually done by sending a special control message periodically to all routers along the path of the open cnnection.

vii. Reservation Orientation

Resource reservation can be done by either sender or a receiver of the flowBoth sender and receiver base resource reservation protocols haveadvantages as well as disadvantages.

viii. Entity for Advance Resource Reservation

The entity that starts the process of resource reservation can be either mobile noditself or base station on behalf of a mobile node. For a base station to communicate with another base station is very simple and fast because base station themselves areconnected together using the fixed cables. Therefore the protocol that uses a gateway agent as an entity for advance resource reservatiohas a less setup time. Having put forward, these eight issues, we are set to use them in the next section fon review of existing mobile wireless resource reservation protocols.

2.6 Review of Related Work

The research works reviewed in this dissertation are categorised underthree main sections. These categories are mobile wireless resource reservation schemes, mobilitymanagement schemes and next cell prediction schemes.

2.6.1. Review of Mobile Wireless Resource Reservation Schemes

It is worth noting that subsequent discussions of related work are based on the previously mentioned theoretical framework.

a. **MRSVP: A Resource Reservation Protocol for Integrated Services Network with Mobile Hosts [Talukdar, et al 1997].**

Table 2. 1 MRSVP

Issues	Characteristics
Interface to Internet:	Gateway router connects directly to the Internet.
Architecture Structure:	This protocol has a linear architectural structure with proxy agent as the interface to the global Internet.
Type of Reservation:	Active reservation in a current cell. Passive reservation is done in the surrounding neighboring cells.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme. It reserves resource in the surrounding cells.
Messages Involved	Active path, Sender Spec, Forward Mspec
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	Proxy agent (Base station) reserves resources on the behalf of MH.

This protocol is summarised in table 2.1.Mobile IP protocol requires home agents and foreign agents for routing, MRSVP requires proxy agents to make reservations along the paths from the locations in the mobility specification (MSPEC) of the sender to the locations in the MSPEC of the receiver Ideally, the MSPEC is the object containing a set of locations the mobile node will visit while it participates in the flow. The proxy agent at the current location of a mobile node is called thdocal proxy agent; the proxy agents at the other locations in its MSPEC are calledremote proxy agents

The remote proxy agents will make passive reservations on behalf ofhte mobile node. A passive reservation is a reservation of network resources by themobile node or base station onbehalf of a mobile node to a subnet (subnet can be a cell) thatthe mobile node might possiblyvisit in a near future with an open connection. The mobile node does not use passive resource untilit is officially in that subnet. Therefore passive reservations can alsobe called advance reservation. The local proxy agent of a mobile node acts as a normal router for the mobile node and an active reservation is set up from the sender to the mobile node through its local proxy agent. MRSVP assumes that in a MSPEC of a mobile Node, each location is represented by the subnet address of the subnetwork covering that location. After the mobile node knows he IP addresses of its proxy agents, the most important task is to set up the paths of active and passive reservations.

If the mobile node is a sender of the flow, the paths of active reservation from the current location of the mobile node and the paths of passive reservations from its proxy agents are determined by the routing mechanism of the network. When the mobile node is a receiver, the paths of active and passive reservations to its current location and the proxy agents depend on the flow destination as follows:

i. The mobile node joins a multicast flow. In this case the mobile node directs the proxy agents to join the multicast group and the data flow paths are set up along the multicast routes.

ii. The mobile node initiates a unicast flow. In this case the paths may be set up by unicast routing or by multicast routing. In MRSVP, the two types of Path messages as well as two types of Resv messages are described next.

a. Active Path message: carries a SENDER_TSPEC for active reservation.

b. Passive Path message: carries a SENDER_TSPEC for passive reservation.

c. Active Resv message: carries a FLOWSPEC for active reservation; in addition, it may carry a FLOWSPEC for passive reservation when an active and apassive reservation are merged.

d. Passive Resv message: carries a FLOWSPEC of only passive reservation. A sender node periodically sends activePath messages to flow destination.

In addition, if the sender is mobile, its proxy agents will send passivePath messages. After the routes of active and passive reservations are set up, the mobile node and the proxy agents will start receiving the Path messages. On receiving aPath message the mobile node will send aResv message for active reservation. The actual resource reservation in MRSVP is done by a receiving nod Therefore MRSVP resource reservation is receiver oriented. If a proxy agent receivesPath messages for a multicast group, for which it is acting as a proxy agent, or for a mobile node from which it has received a request for acting as a proxy, it will make a passive reservation on the downstream link to which the mobile node will attach when it arrives in its subnet, and then send Resv message to make a passive reservation. Resv messages for active reservations are converted to *Resv* messages for passive reservation when they are forwarded towards nodes which contain only proxy agents of mobile senders and no active sender.

b. HMRSVP: A Hierarchical Mobile RSVP Protocol [Tseng, et al 2001]

The idea behind HMRSVP protocol is to integrate RSVP with a MobileIP regional registration protocol and make advance resource reservations only when the handoff delay tends to be long. Table 2.2 gives the summary of this protocol. The Mobile IP regional registration protocol localizes the registration process within a region when a mobile node makes an intraregion movement. A region refers to a cluster of routers or subnets encompassed by an enterprise or campus network. Mobility Agents (MAs) in a region are arranged hierarchically according to its topology.

Table 2. 2 HMRSVP

Issues	Characteristics
Interface to Internet:	Gateway mobility agent connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchically structure with only two interface to the Internet. Thetwo interfaces are not cooperating.
Type of Reservation:	Active reservation within the current region of the hierarchically mobile IP. HMRSVP establish the passive reservations only when the MH may make an inter-regional movement.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme. It reserves resources within the region (subnet).
Messages Involved:	All RSVP messages as given in (section1.6.3).
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	Proxy agent reserves resources on the behalf of MH.

HMRSVP adopts the hierarchical concept of Mobile IP regional registration and makes advance resource reservations for a mobile node only when the mobile node visitshte overlapped area of the boundary cells between two regions. HMRSVP only makes passive reservation if and only if the mobile node is doing inter-region handoff. If the mobile node is moving within a region HMRSVP will only make active reservation of netwok resources. In HMRSVP the sender keeps on sending path messages in order to maintain the state of the flow in router. Therefore HMRSVP is a soft state protocol.

c. An Algorithm of Dynamic Resource Reservation for multimedia Wireless Communication. [Wang, et al 2005].

Table 2. 3 An Algorithm of Dynamic Resource Reservation for multimedia Wireless Communication

Issues	Characteristics
Interface to Internet:	Base station connects directly to the Internet.
Architecture Structure:	Linear
Type of Reservation:	Active reservation in a current cell and passive reservation in the predicted cells.
Where to Pre-allocate Resources:	It includes the next cell prediction scheme. Of which can predict up to three possible cells.
Messages Involved:	All RSVP messages as given in (section 1.6.3).
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	Base station reserves resources on behalf of the mobile host.

Table 2.3 gives the summary of this algorithm based on our theoretic framework.This is resource reservation algorithm (figure2.3) to ensure the QoS. The algorithm can be divided into three parts namely resource prediction, resource reservation and checking mechanism. This algrithm assumes that, while the mobile node enters the cel and the cell begins to service it,the algorithm mechanism is installed and detects the signal strength of mobile node continuously.A mobile node enters the resource prediction process to predictthe possible ongoing path with the continuous measurement of signal strength. Otherwise, it is going to the resourcereservation mechanism which wouldestablish different thresholds oftransmitted datatype and then uses the threshold as the installed timepoint of created resource reservation.

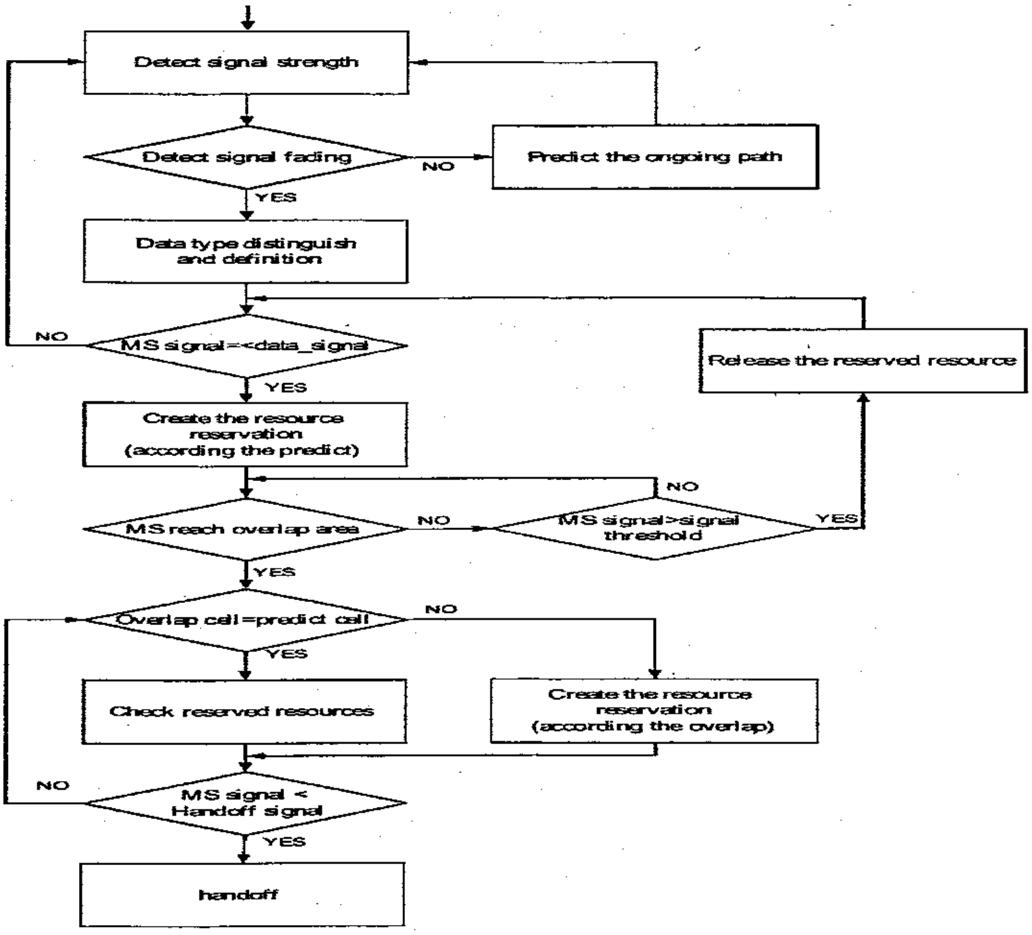

Figure 2. 3 *Dynamic Algorithm for Resource Reservation*

When the resources have been reserved, the scheme will go into check mechanism. Firstit detects whether the mobile node reaches the overlap area or not. The predicted cell is compared with the overlapped region, to know if the mobile node reaches the overlap area. If the results are the same, it will then modify resource reservation in detail. Otherwise, it releases the resources and re-establishes newly resources according to the overlap area.

d. Selective Establishment of Pseudo Reservations for QoS Guarantees in Mobile Internet. [Lee, et al 2004]

Selective Establishment of Pseudo Reservations (SEP) is for supporting seamless QoS guarantees in mobile wireless Internet. SEP consist of two steps, Concatenation of Reservation Path (CRP) and

Optimization for Reservation Path(ORP). In SEP, each base station takes charge of the RSVP process and supports mobility of mobile nodes. An advance reservation, called pseudo reservation, is used in place of the passive reservation in MRSVP. A pseudo reservation session is established in the same way as a normal RSVP session but no traffic is delivered over the session until it is activated. A current base station pre-establishes Pseudo Reservation Paths (PRPs) only at the neighbouring base stations to which a MH is likely to visit. Table 2.4 gives the summary of this protocol based on our theoretic framework.

If a MH moves to one of the neighbouring cells, the corresponding PRP (a PRP between the current cell and the previous cell) is activated and traffic is delivered through the activated PRP. The previous base station concatenates the original RSVP path with the activated PRP and forwards traffic on it. Resources allocated to a PRP can be temporarily used to deliver best-effort traffic until the PRP is activated. Each base station performs all the process including establishment, maintaining and release of a PRP. A PRP can be established and released using RSVP path, resv, and path teardown messages.

A SEP base station dynamically terminates useless PRPs after a MH leaves the current wireless cell. For a pseudo reservation the networks do not need to know whether a RSVP session is a pseudo or active reservation. SEP integrates pseudo reservation and path extension, into the leaf base stations. While traffic on the passive reservations should be blocked by the intermediate routers until they are activated, SEP enables only leaf base stations to know about the existence of PRPs and handle them in a manner different from active reservations.

Table 2. 4 SEP

Issues	Characteristics
Interface to Internet:	Base stations connect directly to the Internet.

Architecture Structure:	Linear
Type of Reservation:	Active reservation and Pseudo reservation (passive reservation)
Where to Pre-allocate Resources:	This protocol predicts the next possible cell by assuming that the MH can detect layer 2 beacons from multiple BSs simultaneously. Then compare the beacons, the strongest beacon is from the highly possible next cell.
Messages Involved:	CRP_initiate, CRP_inform, CRP_activate, RSVP path and Path teardown
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	BS reserves resource to new BS on behalf of the MH.

Since a PRP is always established between two leaf base stations, traffic blocking and forwarding over the PRP are performed by one of those two base stations without any additional features such as RSVP tunnelling. SEP performs the ORP process after a reservation path has been extended by the CRP process. Since CRP has been built on the "path extension" technique, a reservation path can be extended too long if a mobile node continuously moves across the wireless cells. ORP process replaces the extended reservation path with the optimized one laid along the shortest routing path between a sender and a receiver. The ORP process can be performed either by using multicast IP address or by using unicast IP address.

e. An Efficient QoS Scheme for Mobile Hosts [Paskalis, et al 2001]

An efficient QoS scheme for mobile hosts is a protocol that proposes theadoption of a mobility management by mobile wireless resource reservation protocols.This protocol extends RSVP. It again introduces RSVP Mobility Proxy (RSVPMP). RSVP-MP runs in a domain router. RSVPMP is the functional entity responsible for the RSVP message handling at the edge of the mobile wireless network. This protocol employs the very same mechanisms to create and maintain active and passive reservations as the classical MRSVP.Table 2.5 gives the summary of this protocol based on our theoretic framework.

Table 2. 5 An Efficient QoS Scheme for Mobile Hosts

Issues	Characteristics
Interface to Internet:	Gateway route called RSVP mobility proxy connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchically structure with only one interface to the Internet.
Type of Reservation:	Active reservation in current cell. Passive reservation is on the surrounding cells.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme. It reserves resource in the surrounding cells.
Messages Involved:	All RSVP messages. As given in (section1.6.3).
State:	Soft state protocol.
Entity for Advance Resource Reservation:	MH is responsible for reserving resources in the new BS.

There is no huge difference between this protocol and MRSVP, except that an efficient QoS scheme for mobile hosts is mobility aware. The mobile wireless protocol is said tobe mobility aware if its employs the mobility management schemeto reduce the number of control messages in a wireless link.

f. Quality-of-Service Signalling in Wireless IP-based Mobile Networks [Bless, et al 2003]

This is a continuation of the work done [Bless, et al 2003]. Qualityof-Service Signalling in Wireless IP-based Mobile Networks proposes the protocol called MobilityAware Reservation Signalling Protocol (MARSP). MARSP separates resource management signalling from mobility management signalling, by employing the separate resource management entity called Domain Resource Manager (DRM). Domain Resource Manager controls all resources at IP layer within a domain. It can be viewed as a dedicated logical entity for resource management purposes. DRM handles all RSVP messages for resource reservation and it is also responsible for admission control management. This centralisation of resource reservation brings up some serious problems. For example when the DRM is down the entire network will not function.MARSP is a mobility-aware QoS signalling protocol. This protocol supports anticipated handover with prereservation (passive reservation) of resouces before the mobile node is attached to the new base station. The summary of this protocol is given table 2.6.

Table 2. 6 Quality-of-Service Signalling in Wireless IP-based Mobile Networks

Issues	Characteristics
Interface to Internet:	Gateway mobility agent (Access Router) connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchically structure with only one

	interface to the Internet.
Type of Reservation:	Active reservation within the current cell. Passive reservation the surrounding cells.
Where to Pre-allocate Resources:	Does not involve any next cell prediction scheme.
Messages Involved:	All RSVP messages as given in (section1.6.3).
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	Receiver Initiated Reservation. Mobile node reserves the networks resources.

g. M-YESSIR: A Low Latency Reservation Protocol for Mobile-IP Networks [Khosravi, et al 2004]

M-YESSIR is a sender-oriented resource reservation protocol based on RTP that offers significantly lower code and run-time complexity compared to RSVP. The Reservation set-up over IP tunnel of M-YESSIR is identical to the one of YESSIR [Pan, and Schulzrinne, 1999]. The reservation setup takes place by adding a reservation request to the RTCP Sender Report (SR). To extend the reservation to the IP tunnel between the home agent and the foreign agent, or the mobile host, M-YESSIR use a mechanism similar to of RSVP over IP tunnels. Table 2.7 gives the summary of this protocol based on our theoretic framework.

Table 2. 7 M-YESSIR

Issues	Characteristics
Interface to Internet:	Gateway mobility agent (Access Router) connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchically structure with only one

	interface to the Internet.
Type of Reservation:	Active reservation within the current cell. Passive reservation is done in the neighbouring cells.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme.
Messages Involved:	RTCP BYE: This packet is sent to explicity cancel reservation states in proxy agents. Resv and Path messages as given in (section 1.6.3)
State:	Soft state protocol.
Reservation Orientation:	Sender based.
Entity for Advance Resource Reservation:	Sender Oriented Reservation. Mobile node reserves if the mobile node is a sender. Home Agent reserves the resources on the behalf of the mobile node, in case the mobile node is a receiver.

The end-to-end session reservation is converted to a 'tunnel' reservation over the IP tunnel between the HA and the FA or mobile. Inside the tunnel, the data packets are UDP (User Datagram Protocol transports data as a connectionless protocol) encapsulated at the HA with the HA address and careof-address as the source and destination address, respectively. The IP and UDP headers of the control packets (SR) are replaced with new headers containing the HA address and care-of-address as the source and destination address, respectively. Following the RTP convention, the port number is adjacent to the tunnelled data stream. This allows the YESSIR reservation daemons on the intermediate routers to function correctly without any changes. A "tunnel extension" is appended to the SR containing the Flow Id of the end-to-end session allowing the tunnel end point to reconstruct the data flow.

h. A Resource Reservation Protocol in Wireless Mobile Networks [Kim, et al 2001]

Table 2. 8 A Resource Reservation Protocol in Wireless Mobile Networks

Issues	Characteristics
Interface to Internet:	Gateway router called RSVP agent connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchically structure with only one interface to the Internet.
Type of Reservation:	Active reservation in current foreign agent. Passive reservation is on the surrounding foreign networks.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme. It reserves resource in the surrounding foreign networks.
Messages Involved:	It uses all RSVP messages and the following messages. Request QoS FA sends this message to its RSVP agent. SendRspec message RSVP agent sends this message to neighbouring foreign agents to reserve resources. PrepareResv message neighbouring foreign agents send this message to RSVP agent to make a prepared reservation. SwitchFlow message this message is generated by an RSVP agent to switch from the reserved reservation to prepared reservation, or vice versa, when a handoff occurs.
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	RSVP agent reserves resources onbehalf of MH.

Table 2.8 gives the summary of this protocol based on our theoretical framework. This protocol is based on RSVP but some modifications have been made so that RSVP works in mobile wireless Internet with reduced signalling overhead. For this purpose, the proposed protocol introduces RSVP agents. An RSVP agent is on top of several foreign agents. When sending node transmits a Path message to a mobile node using RSVP, the RSVP agent that is managing the reservation of the mobile node intercepts the Path message and then forwards it to the mobile node's foreign agent and neighbouring foreign agents to reserves resources in advanced.

When the mobile node handovers and sending node comes to know a new CoA of the mobile node, the sending node transmits a Path message to make a new RSVP tunnel the destination using the new CoA.

i. RSVP Mobility Support: A Signalling Protocol for Integrated Services Internet with Mobile Hosts [Chen, et al 2000]

This protocol is the combination of RSVP and Integrated Services (IntServ). The authors extend RSVP based on IP multicast [Deering,1989] to support mobile nodes. The mobility of a node is modelled as a transition in multicast group membership. To overcome mobility impact on service guarantees, the authors proposed that mobile node has to make resource reservation in advance at the locations (cell, subnet), where it may visit during lifetime of connection. These locations become the leaves of the multicast tree in this protocol. Table 2.9 gives a summary of this protocol based on our theoretical framework.

Table 2. 9 RSVP Mobility Support

Issues	Characteristics
Interface to Internet:	Gateway router connects directly to the Internet.

Architecture Structure:	This protocol has the hierarchical structure with only one interface to the Internet.
Type of Reservation:	Proposes three classes of reservation. The first class is conventional reservation (active reservation), second class is the predictive reservation (passive reservation in a predicted cells) and third class is temporary reservation temporarily uses he inactive bandwidth reserved by other data flows in a current cell.
Where to Pre-allocate Resources:	Predictive reservation reserves bandwidth along the multicast tree from the source to the neighbouring cells surrounding the current cell of mobile host
Messages Involved:	All the RSVP messages as given in (section1.6.3), and the following messages. SessionSpec message is sent by the current mobile receiver to its neighbouring mobile proxies to request them to join a multicast group. It includes the multicast address of the group to join. ProxyTear message is sent by current mobile proxy to explicitly tear down the Predictive reservation.
State:	Soft state protocol.
Entity for Advance Resource Reservation:	Mobile host reserves resource on the multicat group.

j. Performance Evaluation of a Lightweight Resource Reservation Protocol for Mobile Internet Hosts. (Sender-initiated and Mobility-support Reservation Protocol, SMRP) [Shangguan, et al 2000]

Table 2. 10 Sender-initiated and Mobility-support Reservation Protocol

Issues	Characteristics

Interface to Internet:	Gateway mobility agent connects directly to the Internet.
Architecture Structure:	Linear
Type of Reservation:	Active reservation within the current cell. Passive reservation in the surrounding cells.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme.
Messages Involved:	All RSVP messages as given in (section1.6.3).
State:	Soft state protocol.
Reservation Orientation:	Sender based.
Entity for Advance Resource Reservation:	Sender Initiated Reservation

This protocol is summarised in table 2.10. Performance Evaluation of a Lightweight Resource Reservation Protocol for Mobile Internet Hosts proposes the protocol named Sender-initiated and Mobility-support Reservation Protocol (SMRP). SMRP is basically a sender-initiated reservation approach. It combines the path selection and resource reservation into one process. A sender plays a key role in SMRP. A sender is responsible for finding the path and reserving specific QoS for particular data flows. A sender achieves this by generating and sending a Request message to receiver. A receiver in SMRP is responsible for informing the sender of the final reservation results along the whole path. This is done by directly replying the sender with an Echo message. A Request message is forwarded hop-hop along to the receiver. Each intermediate node along the data path processes the request message to make a reservation for a data flow.

k. RSVP Extensions for Real-Time Services in Hierarchical Mobile IPv6 [Huang, et al 2003]

QoS guarantees are one of the most important things in the next generation mobile wireless Internet. Although RSVP, which is a resource reservation protocol, processes signalling messages to establish

QoS paths between senders and receivers, RSVP was originally designed for stationary networks and not aware of the mobility of mobile nodes. Most signalling protocol have the problem of the protocol overhead, especialy during home registration just after the mobile node has been handed over to another base station. Table 211 gives the summary of this protocol based on our theoretial framework.

Table 2. 11 RSVP Extensions for Real-Time Services in Hierarchical Mobile IPv6

Issues	Characteristics
Interface to Internet:	Gateway mobility agent (Access Router, QoS Agent) connects directly to the Internet.
Architecture Structure:	This protocol has the hierarchical structure with only one interface to the Intemet (subnet). Gateway mobility agents of different subnets are partially cooperating.
Type of Reservation:	Active reservation (conventional reservation) within the current cell in subnet. Passive reservation (perreservation) is done in the neighbouing cells within the subnet.
Where to Pre-allocate Resources:	Does not include any next cell prediction scheme.
Messages Involved:	Resv and Path messages as given in (section 1.6.3) and following messages RoamNotify This message is used by a MN to notify the QA with the visiting location and mobile profile. Pre-reserveNotify: This message is used by a QA, according to the mobile profile, to notify the adjacent access routers to make pre-reservation. Pre-reserveTear: This message is issued by a QA to inform access routers to terminate the useless pre-reservation while MN moves into to

	a new cell. MGroupJoin: This message is used by a QA to inform the adjacent QAs to join the same multicast group and make pre-reservation for adjacent access routers when a MN moves into edge cells. TransientRESV: This message is used by a MN who wants to make transient reservation for best effort services. PreemptNotify: This message is sent by an AR to notify that a pre-reservation of real-time service has been made to pre-empt the transient reservation.
State:	Soft state protocol.
Reservation Orientation:	Receiver based.
Entity for Advance Resource Reservation:	Receiver oriented reservation.

The authors of RSVP Extensions for Real-Time Services in Hierarchical Mobile IPv6proposed a novel RSVP extension to support realtime services in Hierarchical Mobile IPv6 (HMIPv6) environments. The inclusion of Hierarchical Mobile IPv6 is to eliminate the protocol overhead after handovers. For intra-site mobility, the concept of QoS Agnt (QA) is proposed to handle the RSVP QoS update messages and provide the advanced reservation models for realtime services. For inter-site mobility, IP multicast can help to invite intersite QAs to make pre-reservation and minimize the service disruption caused by re-routing the data path during handover.

2.6.2. Review of Mobility Management Schemes

Mobility allows the mobile nodes to roam across the wide range of networks. Internet Protocol (IP) is the protocol that was designed to serve stationary host. This protocol has been reliable for this type of Internet usage, but with the growth of mobile communication devices, realtime requirements of the current Internet has brought challenges that could not be met using IP. The IETF proposed Mobile IP [Perkins, 1996] as a protocol which is meant to accommodate mobile users.

Mobile IP's first version, Mobile IPv4, has been adopted but it had some underlying drawbacks because there was considerable delay in the packets destined for the mobile node. The delays ar caused by the way packets are routed to the mobile node. The corresponding node which is the node that has packets to send to the mobile node does not recogniseeven if they are in the same network. Packets sent by the corresponding node to the mobile nde go through the Home Network (HN) then to the Foreign Network (FN) before deliveryto the mobile node.

The mobile node cannot receive messages directed to it, before it is connected to a foreign network. The home agent (the router in the mobile node'shome network) tunnels and redirects data meant for a mobile node, to the foreign agent (the router in the mobile node's foreign network). The foreign agent then directs the data to the mobile node. The mobile node then replies by directing the data stralg to the corresponding node. This routing mechanism is called Triangle Routing [Perkins, 1996]. It causes a lot of delay in the mobile node's data (figure2.4).

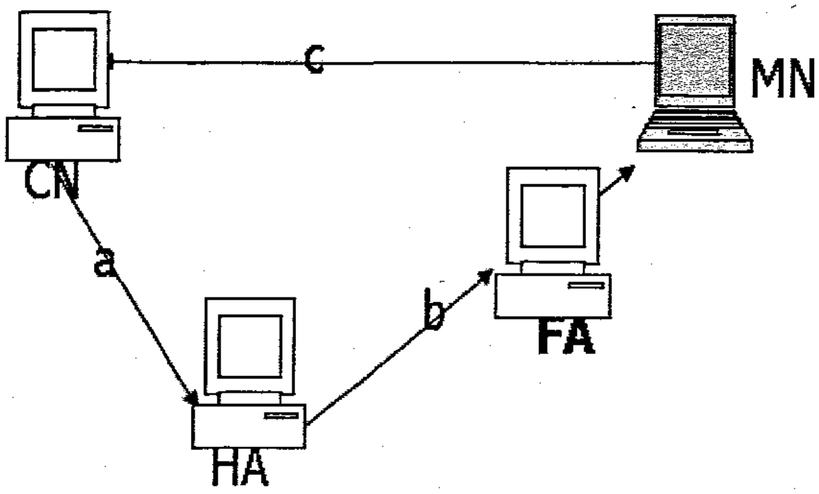

Figure 2. 4 *Mobile IP's Triangle Routing*

Route Optimisation was proposed as the solution to the problems of triangular routing [Chen, et al 2000]. The first process of routing packets is the same as in triangular routing, where packets from the corresponding node destined for the mobile node go via home agent. They are then tunnelled to the foreign agent before deliveryto mobile node.

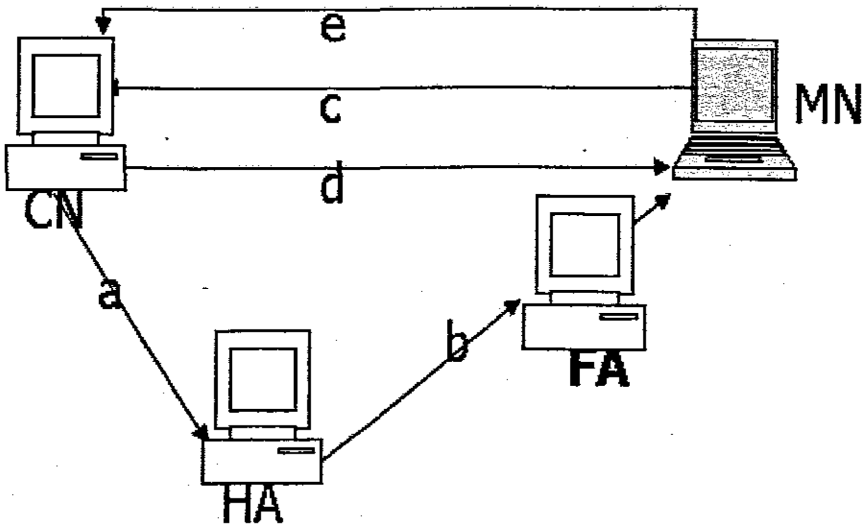

Figure 2. 5 *MIP's Route Optimisation*

In route optimisation the corresponding node communicates directly to mobile nodeThis protocol does not cater for a mobile node that moves from one network to another with an open connection. It also does not state what happens when the mobile node is moving from one foreign network to another.

Hierarchical Mobile IPv6 (HMIPv6) [Soliman, et al 2005] is the proposed enhancement of Mobile Internet Protocol versions 6 (MIPv6) [Johnson, et al 2004] that is designed to reduce the amount of signalling required and to improvehandoff speed for mobile connections. HMIPv6 was designed to reduce protocol overhead caused by home registration of a mobile node. HMIPv6 is a proposed standard from the Internet Engineering Task Force (IETF). MIPv6 defines a means of managing global (between-site) mobility, but doesn't address the issue of local (within-site) mobility separately. Instead, it uses the same mechanisms in both cases, which is an inefficient use of resources in the case of local mobility. HMIPv6 adds another level, built on MIPv6 that separates local from global mobility. In HMIPv6, global mobility is managed by the MIPv6 protocols, while local handoffs are managed locally.

A new node in HMIPv6 called the Mobility Anchor Point (MAP) serves as a local entity to aid in mobile handoffs. The MAP, which replaces MIPv4'sforeign agent, can be located anywhere within a hierarchy of routers. In contrast to the foreign agent, there is no requirement for a MAP to reside on each subnet. The MAP helps to decrease handoff-related latency because a local MAP can be updated more quickly than a remotehome agent Using MIPv6, a mobile node sends location updates to any node it corresponds with each time it changes its location, and at intermittent intervals otherwise. This involves a lot of signalling and processing, and requires a lot of resources. Furthermore, although it is not necessary for external hosts to be updated when a mobile node moves locally, these updates occur for both local and global moves. By separating global and local mobility, HMIPv6 makes it possible to deal with either situation appropriately.

HMIPv6 was proposed to reduce the overhead signalling that is experienced by network, during home registration by mobile nodeafter doing inter-domain handoff. This alone does not solve the problem completely, when mobile node roaming from one domain to another it has to do home registration. [Abdel-Hamid, and Abdel-Wahab, 2001] proposed the cooperation of foreign agents (gateway agents). This cooperation eliminates the need for mobile node to regiter its new care-of-address (CoA), since the gateway agents cooperate. The gateway agents simply pass the information regarding that particular mobile node that has done handoff to one another. This cooperation allows themobile node to keep a single CoA as long as it is roaming in foreign domains that are cooperating. Another advantage of this cooperation of hierarchies is the elimination of sigle point of failure. [Abdel-Hamid, and Abdel-Wahab, 2001] do not say anything on how to handle the mobility within a domain.

2.6.3. Review of Next Cell Prediction Schemes

The next cell prediction scheme is very impotant since it determines where to preallocate the network resources for a mobile node. According to Chan, and Senervirathe, 1999 the next cell prediction schemes are classified into categories namely neighbourhoodbase prediction and history-base prediction.

Schemes belonging under neighbourhoodbased prediction reserve network resources between the active cell and the set of the surrounding cells. This type of prediction algorithm overeserves the limited network resource since the mobile node will viit only one cell at give time. For example [Bless, et al 2003] proposed Advanced Reservation Signalling. This signalling scheme reserves resources only between the current cell (active cell) and neighbouring cells. Thus the network guarantees continuity of services between after the next handoff, but further commitments are subject to successful reservations at the new neighbouring cells. This scheme wastes network resource by reserving in all the surrounding cells.

Schemes belonging under history-based prediction use the user mobility history to predict the future movement of a mobile node. The Regular Path Recognition Method [Erbas, 2001] attempts to exploit regularity in human behaviour in terms of periodic delay activities such as travelling to work, school, supermarket, which results in probabilities that can be assigned to user paths. The more the use of recorded cells patterns are made, the more likely the path of the user is detected. In a way this mobility prediction method is an extension of mobility prediction model making use of the segment criterion and suffers from those same drawbacks. The accuracy of the path detection is subject to the amount of history profile of the user. This also assumes that user movements can be contained as a regular path.

Nkambule, et al 2004 propose an optimum next cell prediction scheme, which takes into account cell sectorisation in order to predict the next cell(s) a mobile node will move into. This approach does not keep individual mobile's previous mobility history. This scheme makes use of the cumulative movements made by all hosts over time. The cell is divided into two regions with respect to handoff occurrences as critical and non-critical region. Critical region is where most mobile nodes experience handoff. This is an overlapped region of two or more cells.

The base station keeps track of the mobile node's current position, which maybe obtained by using any radiolocation technique. The data regarding the points where a number of mobile nodes encounter handoff is stored in the base station, that data is used to form critical and non-critical regions of a cell. Each time a mobile node gets into critical region, its direction and relative signal strength is checked by a base station. If a mobile node is movig away from the current base station and the signal strength it is receiving from the neighbouring cell(s) is above the current cell's threshold the base station will then run a next cell prediction algorithm.

The prediction algorithm can be defined as fdlows:

Given that $S_{(i,j)}$ is sector identifier

Where: $S_{(i,j)} \in \{1,...6\}$, sectors in each cell

i is the current cell

j is the target cell

$P_c(x)$ = the probability that the mobile node will move to cell C

CR = critical region of the current cell

NCR = non-critical region

CP = current position of the mobile host (MH)

CRP = critical region representation point

P_t = threshold probability

Prediction Algorithm

IF MH is in CR THEN

IF MH is departing THEN

Associate MH current position with closest CRP

Compute $P_c(x)$

Prediction:

IF Current sector = $S_{(i,j)}$ AND $P_c(x) > P_t$ THEN

Target cell = Cell − j

Reserve resource in Cell – j

END IF

END IF

ELSE

Target cell = current cell

Monitor MH

END IF

$P_c(x)$ may be calculated by taking into account the position of the mobile node and its direction. Monitoring time interval depends on the size of the cell.In worst cases this scheme predicts two possible cells that mobile node will visit with the open connectionThis scheme does not say any thing about how the reservation of resources mustbe done.

2.6.4. A Brief Summary of Related Work

From the review of related work, it can be deduced that existing mobile wireless resource reservation protocols are complex since they have many control messages. These protocols have a high protocol overhead since all of them maintain soft state in the network nodes (base station). Therefore these resource reservation protocols arenot scalable. Most of the existing protocols over-reserve network resources, because they do not have a next cell prediction algorithm. Even those existing protocols that have next cell prediction algorithms still over-reserve resources, because the deployed next cell prediction algorithms are not precise with the prediction. From the review of related work it can the observed that HMPIv6 is the good mobility management scheme. Since it considers both mobility within domain and domain to domain mobility of the mobile node. The next cell prediction algotiim proposed by Nkambule,M. et al 2004 is better, since in the worst case can only predict two possible cells. Yet it does not say any thing about how to reserve resources.

2.4 A Concise overview of the Proposed Scheme

We propose a protocol known as DynamicMobile Resource Reservation Protocol (DMRSVP). The proposed scheme, DMRSVP, aims at offering an efficient QoS resource management mechanism that accommodates both real-time and non real-time services in a future mobile wireless Internet.The summary of DMRSVP based on our theoretical framework was presented in table 2.12 DMRSVP adopts the hierarchical concept of Hierarchical Mobile IP version 6 (HMIPv6) regional registrations and makes advance resource reservations for a mobile node only when the mobile node visits the overlapped area (critical region) of the neighboring cells. DMRSVP makes passive reservation on the predicted cell(s) only. DMRSVP employs the dynamic algorithm to reserves network resources to the predicted cell(s). The dynamic algorithm ensures that by the

Table 2. 12 DMRSVP

Issues	Characteristics
Interface to Internet	DMRSVP employs Gateway agent as the interface to the Internet.
Architecture Structure	The functional architecture of DMRSVP is hierarchical. DMRSVP uses HMIPv6 for mobility managementand cooperation of gateway agents
Type of Reservation	DMRSVP supports active reservation in a current cell and passive reservation in a predicted cell(s).
Where to Pre-allocate Resources	DMRSVP use Sectored-cell Approach Next Cell Prediction

	Scheme [Nkambule, et al 2004] to predict the next possible cell(s). It then dynamical reserves the network resources to the predicted cell(s).
Messages Involved	DMRSVP has only four types control messages. This would reduce the signalling overhead and complexity.
State Maintence	DMRSVP is a hard state protocol. This would reduce the protocol overhead that might be cause by the maintenance of the soft state.
Reservation Orientation	DMRSVP is both receiver and sender oriented resource reservation protocol.
Entity for Advance Resource Reservation	In DMRSVP base station is the entity for advance resource reservation. Since base station runs the next cell prediction scheme for mobile node, it is the better entity to place the resource request.

time of handoff, it has reserved the required amount of resources toan exact cell mobile node will visit. Even if the prediction algorithm predicted two cells as the possible cellsthat may be visited by mobile node, the DMRSVP would still be able to reserve network resourcesonly to the exact cell the mobile node will handoff into.

CHAPTER THREE

METHODOLOGY AND MODEL DEVELOPMENT

3.1 Introduction

The previous chapter presented a number of existing mobile wireless resource reservation protocols and their limitations, stating that these existing mobile wireless resource reservation protocols are not scalable. In order to address the limitations we proposed a Dynamic Mobile Resource Reservation protocol (DMRSVP). The proposed scheme (DMRSVP) uses HMIPv6 for mobility management, a modified version of sectored-cell approach for next cell prediction and call admission control algorithm for resource reservation. The sectored-cell approach for next cell prediction scheme is modified by adding the dynamic resource reservation algorithm to it.

3.2 DMRSVP Design Principles

The design of DMRSVP uses the features of the generic mobile wireless resource reservation protocol (section 2.3) and additional new dynamic features have been incorporated to make DMRSVP simple, scalable and efficient.

The design objectives are to:

i. provide efficient resource reservation scheme for mobile wireless Internet;
ii. provide scalability and minimal complexity
iii. provide low protocol overhead and
iv. separate control packets from data packets.

A brief description for the above mentioned design objectives is given below.

3.2.1 Efficient Resource Reservation Scheme

A mobile wireless resource reservation protocol must notover-reserve network resources, since mobile wireless environment is very limited when it comes to resources (bandwidth, CPU time, queues). Therefore a resource reservation protocol must be incorporated with a good next cell prediction algorithm, to predict where the mobile nodewill handoff into. This will make a mobile wireless resource reservation to be efficient, since it is going to reserve the network resource only in the predicted cells. This improves the utilisation of network resource in mobile wireless Internet. Again, for a resource reservation protocol to be efficient it must support both sender and receiver reservation. This means that both sender and receiver can initiate the process of resource reservation. Therefore, efficiency is introduced via a next-cell prediction algorithm and mandatory sender and receiver reservation mechanism.

3.2.2 Scalability and minimal complexity

A mobile wireless resource reservation protocoldoes need nor to be complex. The design of mobile wireless resource reservation needs to eliminate the complexity that is cased by transmitting control messages as part of user data. Therefore the mobile wireless signalling protocol must separate control messages from user data packets. Again for resource reservation protocol to be simple it must have few different types of control messages. For a mobile wireless resource reservation protocol to be scalable, it needs to have low protocol overhead. This can be achieved by hard state maintenance. This would reduce the number of control messages in a network. Again a mobile wireless resource reservation protocol needs to be mobility aware. This can be achieved by incorporating the mobility management scheme with a mobile wireless resource reservation protocol.

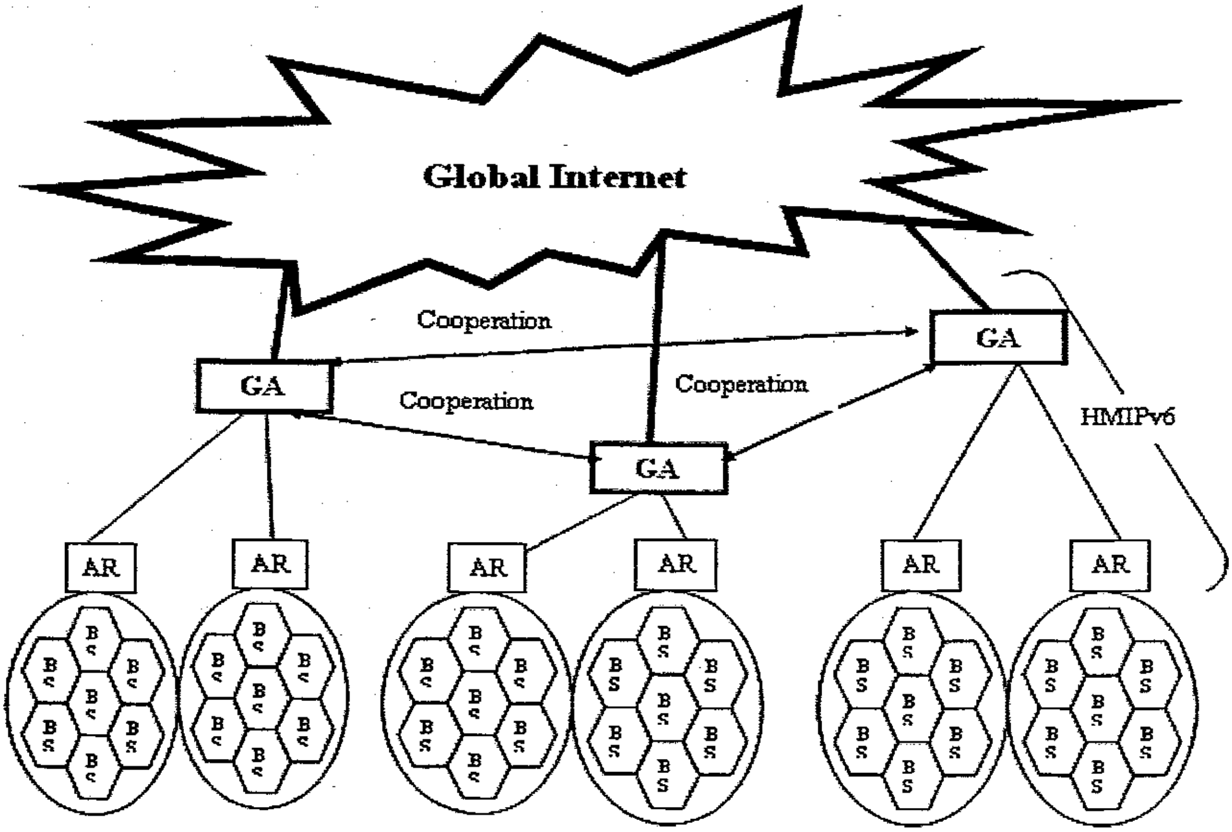

Figure 3. 1 *Functional Architecture for DMRSVP*

3.3 Building Blocks and Components of DMRSVP

3.3.1 Functional Architecture

The functional architecture structure of DMRSVP is hierarchical, comprising of Domains, Gateway Agents (GA), Subnets, Access Router (AR), Cells, Base Stations (BS) and Mobile Nodes (MN), (see figure 3.1). This architecture is the combination of Hierarchical Mobile IPv6 architecture, Cooperation of foreign agent hierarchies and the sectored cell approach A hierarchical structure is chosen, because it reduces the need for binding update [Tseng, et al 2001]. Hierarchical structure improves the performance of a signalling protocol by reducing protocol overhead after handoff [Tseng, et al 2001].

The AR controls six cells. On top of a domain is GA. The GA is responsible for controlling a domain. The domain is made-up of a number of access routers, and cells. HMIPv6 takes care of mobility within a domain. The use of HMIPv6 reduces a protocol overhead that is experienced when a mobile node is doing handoff. This means that HMIPv6 reduces the need for home registration, if a mobile node is roaming within a region (domain). The gateway agents on top of domain themselves cooperate to further reduce the need for home registration after Inter-region handoff. This functional architecture reduces the need for home registration.

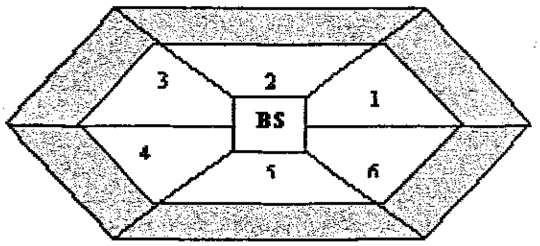

Figure 3. 2 *Adopted Cell Structure* [Nkambule, M. et al 2004]

Therefore the proposed functional architecture reduces the protocol overhead that is caused by a home registration after intra and inter-regional handovers of a mobile node. The shaded part of cell (*Figure 3.2*) represents the critical region of the cell.

3.3.2 Control Messages

The basic protocol control (signalling) messages are REQUEST, REPLY, ERROR, TEAR_DOWN and CHANGE as described in the next subsection.

4 bits	8 bits	3 bits
Version	Traffic Class	Message Type
Payload Length	Message Source	Message destination

Figure 3. 3 *Common Header*

a. Common Header of Signalling Messages

Figure 3.3 is the common header forsignalling messages employed by the proposed DMRSVP.

Version : 4 bits

Protocol version number.

Traffic Class : 8 bits

This field is for Priority number.

Message Type: 3 bits

This field is for signalling message type number. Since DMRSVP has five types of control messages. Field value indicate REQUEST "000", REPLY (Positive Reply "001", Negative Reply "010"), CHANGE "011" and TEAR_DOWN "100"

Payload Length : 16 bits

This field is for the sum of all bits forming the control message.

Message Source : 3 bits

Message source isthe entity in which the message was originated.

Message Destination: Message destination is the entitythat the control Message is intended for.

b. Details of Control Messages

i. REQUEST Message

This is a reservation request message sent downstream or upstream by the receiver to request reservation of resources. It includes QoS level requirement of a requesting node. This specifies the amount of resources a node will require to transmit its data. Each Request message includes the amount of resources required to be reserved, source and destination address. The source address determines the point where the reservation starts and the destination address the point where it should end.

ii. REPLY message

This message is sent by nodes to deliver feedback information regarding the success or failure of the reservation request process. A reply is either a reject or an approval and it is based on the admission control decision. In case of handoff request, the reply message would be generated by the predicted base station(s) and sent upstream to the mobile nodeif it is approval of reservation In case of rejection the reply would be sent to the current base station of the mobile nodeA mobile node receiving a reply message needs to start comparison if it is necessay. The reply messageis always sent upstream.

iii. ERROR message

This message is sent by network entities to report error information any kind of error regarding individual connection (flow). A network node (network entity) in which an error occurred sends an error message upstream to the previous entityfrom which the REQUEST or CHANGE message was received from. The error message propagates downuntil it reaches the sending host.

iv. CHANGE message

This message is sent by the predicted base station to access router to confirm that it has admitted mobile node from the neighbouring cell (withinthe same region). The access router then changes the status of that predicted base station to current base station for that specific mobile nodeSame process occurs in case of the gateway agent. If the gateway receives the CHANGE message from predicted access router, the status of that access router is changed tothe current access router.

v. TEAR_DOWN message

This message is sent by access router or gateway agent after pacessing CHANGE message. The TEAR_DOWN is sent to a former current base stationof a specific mobile node that has just been admitted by other base station,to explicitly release resources without having to wait for the lifetime of the flow to expire.

3.3.3. Resource Reservation

DMRSVP adopts the hierarchical structure A hierarchical structure can be divided into three parts which are region (domain), subnet and a cell.A resource reservationof DMRSVP is then divided into three parts. The three parts ae as follows:

i. Intra-subnet resource reservation

This reservation of resources takes place when a mobile node is roaming within a subnet. This means that a mobile node roams between cells that are inthe same subnet.

ii. Inter-subnet resource reservation

This reservation of resources takes place when a mobile node is roaming from one subnet to another subnet, but within the sameregion.

iii. Inter-region resource reservation

This reservation of resources takes places when a mobile node is roaming from one region (dnain) to another region.

a. Intra-subnet Resource Reservation

Once a mobile node has entered a critical region of a cell, the sectored cell approach for next cell prediction algorithm [Nkambule, et al 2004] predicts the possible cell(s) that a mobile nodewould visit. The base station is an entity that runs the next cell prediction algorithm. After the prediction algorithm has produced the results, BS would then send a REQUEST (REQ) message to predicted base station (PBS). The predicted base station (PBS) would then reserve the required resources using an admission control protocol, discussed in section 3.3.3 The PBS(s) would then send REPLY message to the mobile node.

It is very possible for the PBS to contact mobile node (MN) since the mobile node is in critical region (overlapped region) and REQ message sent by a current BS contained an address of MN. If a next cell prediction algorithm resulted into two PBSs, this means that MN would receive two replies. The MN will then have to do some comparison between the signal strength of the two predicted base stations. The comparison improves the network resource utilisation Since at the end of the comparison the network resources would be reserved to a specific cell, in which a mobile node is visiting with an open connection.

Once a mobile node is in a critical region and is going away from the current cell according, the BS would run prediction algorithm to predict the possible cell(s) that mobile node would visit. After the prediction BS sends REQ message to the predicted cell(s). The PBS would reserve the required resource then send a REPLY message to a mobile node. A mobile node would have to do a comparison if it receives the two replies. MN runs a dynamic algorithm (figure 3.4) to reserve resources to an exact cell it would handoff into. After a comparison has been finished, the selected PBS sends CHANGE message to access router to change a tunnel from old base station to the new base station (predicted base station). The sequence diagram for this explanation is given in figure 3.4.

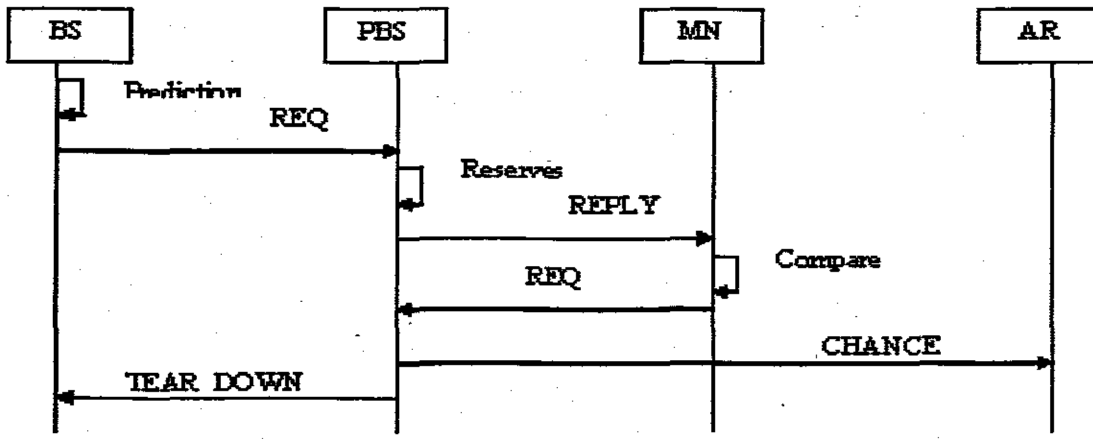

Figure 3. 4 *Intra-subnet resource reservation*

A dynamic Comparison Algorithm can be defined as follows

Compare : Compare makes DMRSVP to be totally unique from the existing mobile resource reservation protocols. Compare uses the dynamic algorithm to reserve resources.

Where: S_{PBS1} Signal strength of PBS1 when received by a MN

S_{PBS2} Signal Strength of PBS2 when received by a MN

t Time set by MN after doing comparison of signal strengths from the predicted base stations. t value is decremented after some certain time interval.t value must be such that itwould expire before a mobile node has to do handoff.

Dynamic Comparison Algorithm

```
If MN receives = Two REPLY messages, Then
 Compare:    Case1
             S_PBS1 > S_PBS2
             Reserve 60% on PBS1 and Reserve 40% on PBS2
             Set t
             End CASE1
             Case2
             S_PBS2 > S_PBS1
             Reserve 60% on PBS2 and Reserve 40% on PBS1
             Set t
             End CASE2
 When t = 0 do
             Compare      If S PBS 1 > S PBS 2 then
                          Reserve 80% on PBS1 and Reserve 20% on PBS2
                          Else
                              If S PBS 2 > S PBS 1 then
                              Reserve 80% on PBS2 and Reserve 20% on PBS1
                             End If
                          End If
        End Compare
When handoff = true do
             Compare If S PBS 1 > S PBS 2 then
                          Reserve 100% on PBS1 and Release PBS2
                          Else
                                If S PBS 2 > S PBS 1 then
                                Reserve 100% on PBS2 and Release PBS1
                                End If
                          End If
             End Compare
End Compare
Else
   Reserve 50% to the PBS

  When Handoff = true reserve 100% to the PBS

End If
```

Figure 3. 5 *Dynamic Comparison Algorithm*

Figure 3.5 is the novel algorithm that has been proposed to reserve resource in the exact cell that mobile node would handoff into. This dynamic algorithm(flowchart, figure 3.6) prevents the over reservation of network resources by comparing thesignal strengths of the two predicted base stations. The algorithm would reserve 60% of the required resources to the PBS that has ben found to be stronger, reserving 60% not 100% improves the utilisation 6 network resource since this is done in advance. Then 40% of the required resourcewould be reserved to a weakerpredicted base station.

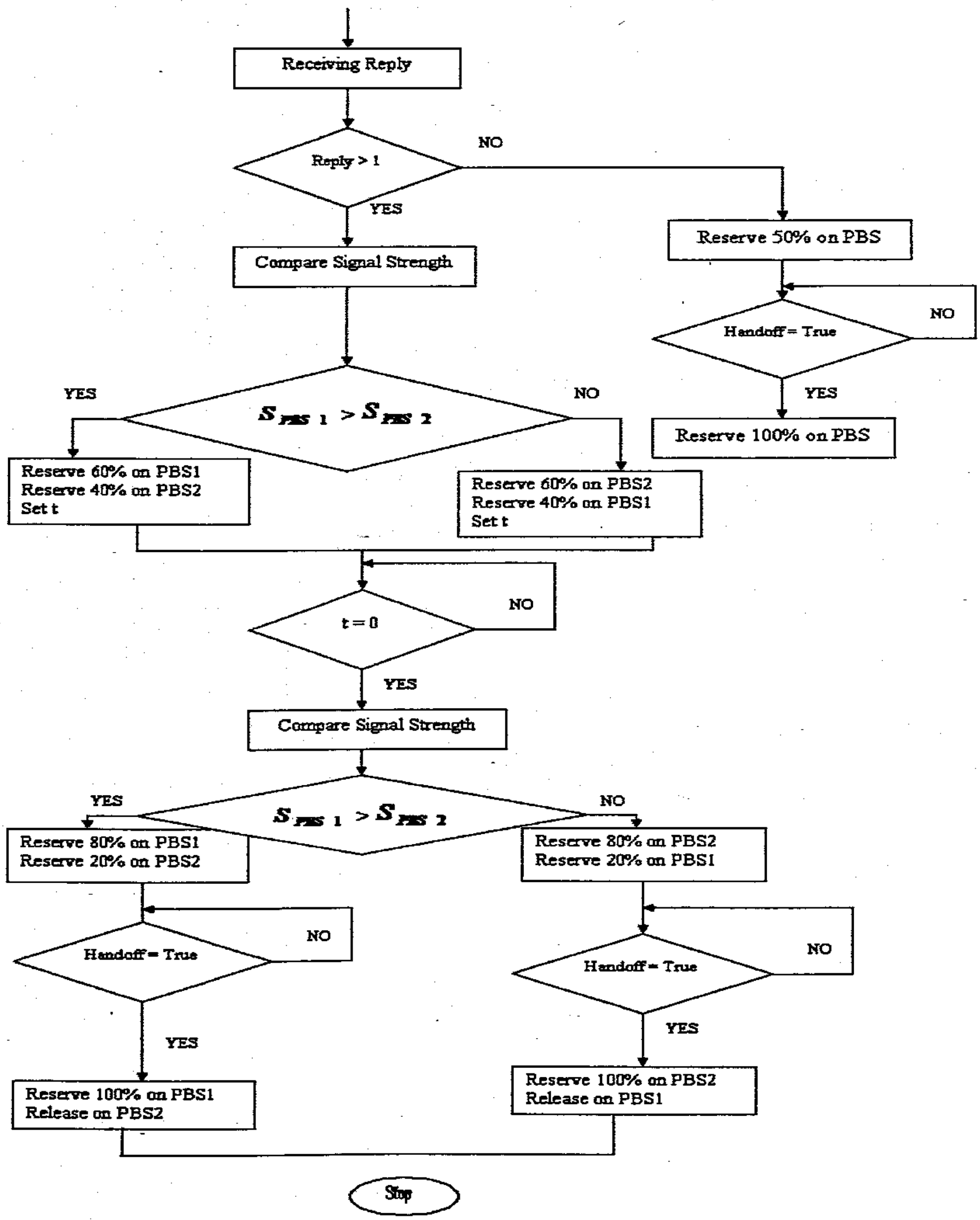

Figure 3. 6 *Flow Chart for Dynamic Comparison Algorithm*

This is done to guarantee that even if the mobile node changes its route by going to the weaker PBS it would still find some resources. After the mobile node has reserved resources, it sets a timer. The value of timer should be such that it will expire (reaches zero) before a mobile node has to undergo the handoff process. When the timer expires the mobile node does comparison again. The mobile node will reserve 80% to a stronger PBS and 20% to weaker PBS. MN would not set a timer after this comparison but it would wait till handoff time.

During handoff it will do a comparison then reserve 100% of the resources to the stronger PBS. This means that the mobile node is going to handoff to a stronger PBS. The MN would then release the resources on a weaker PBS. This algorithm guarantees that resources would definitely be available to mobile node by time of handoff.

b. Inter-Subnet Resource Reservation

This reservation is almost the same as the intrasubnet reservation, except that CHANGE message is sent to the gateway agent of that particular domain where the two subnets belong.

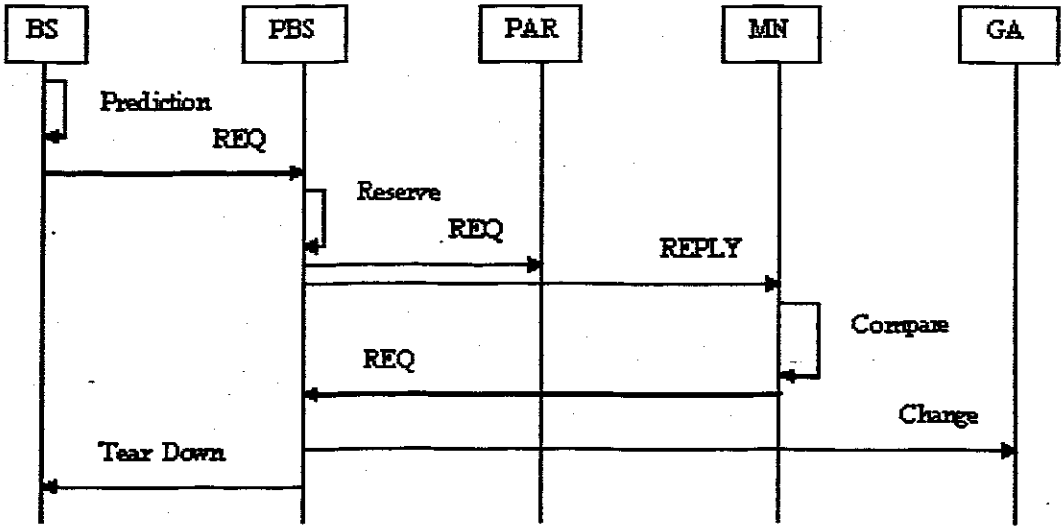

Figure 3. 7 *Inter-Subnet resource reservation*

c. Inter-region Resource Reservation

This reservation is almost the same as the first two reservations. This reservation reserves network resources if the mobile node is roaming to a cell that is in a different domain than its current domain. Inter-region resource reservation makes use of Internet Group Message Protocol (IGMP) [Deering, 1986]. IGMP message is used to add the predicted gateway agent (PGA) of the predicted base station as a member of a multicast group (members are corresponding host (CH) and current gateway agent (GA) of a mobile node).

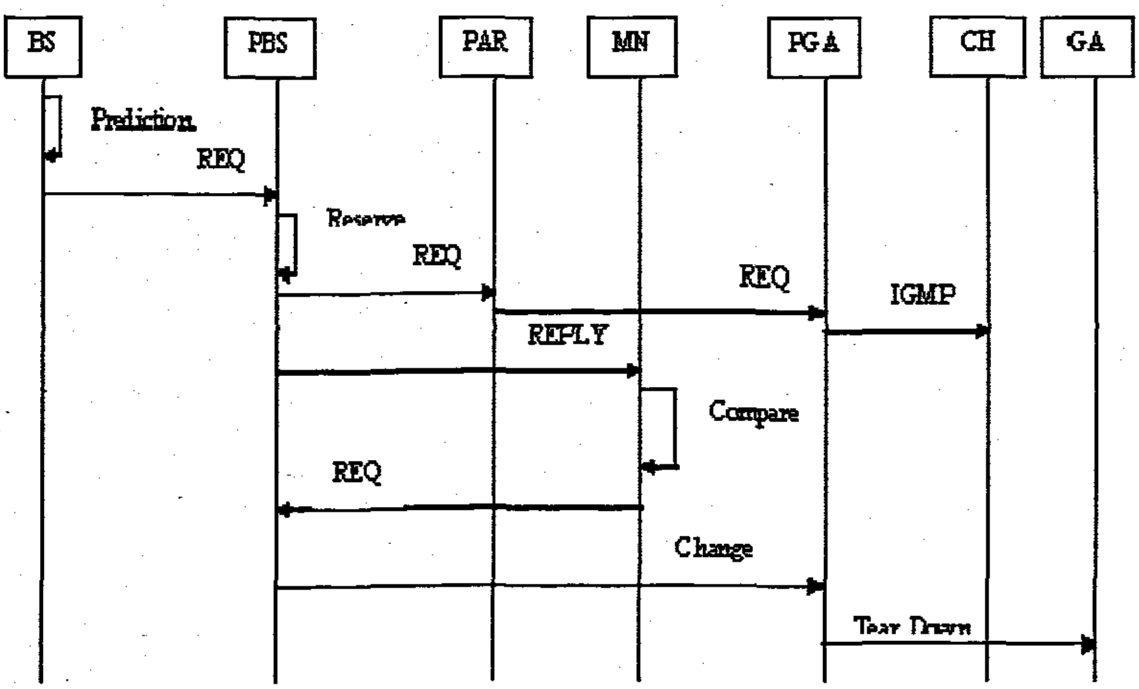

Figure 3. 8 *Inter-region resource reservation*

This will make the PGA to start receiving packets intended for a mobile host. PGA would then push the packets down the hierarchy to the PBS, then a mobile node. The PGA sends a Tear_Down message to a current GA of mobile node to release the reserved resources. This guarantees that the mobile node will not be interrupted when doing handoff. This joining of PGA as member of multicast group in advance reduces the latency time for setting up the new tunnel. The sequence diagram for this reservation is given in figure 3.8

d. State Maintenance

DMRSVP is purely hard state protocol. The network node hold reserved resources up until they are explicitly released. To explicitly release the held resources, the network node has to send the Tear_Down message containing the details of the resources that need to be released.

e. Setting-up Reservation

DMRSVP supports both sender and receiver reservation orientation. This implies that a mobile node would always be the reserving entity. If the mobile node is a sender of a flow, it will then reserve network resources. The same process is proposed if the mobile node is the receiver of a flow the mobile node would have to reserve the network resources. The reservation of network resources creates states in network nodes. DMRSVP does not maintain these states, since it supports hard-state maintenance of reservation states. The sequence diagram showing the setting up of reservation is given in figure 3.9. This setting-up of resource reservation is done by a new call (call originating within a cell).

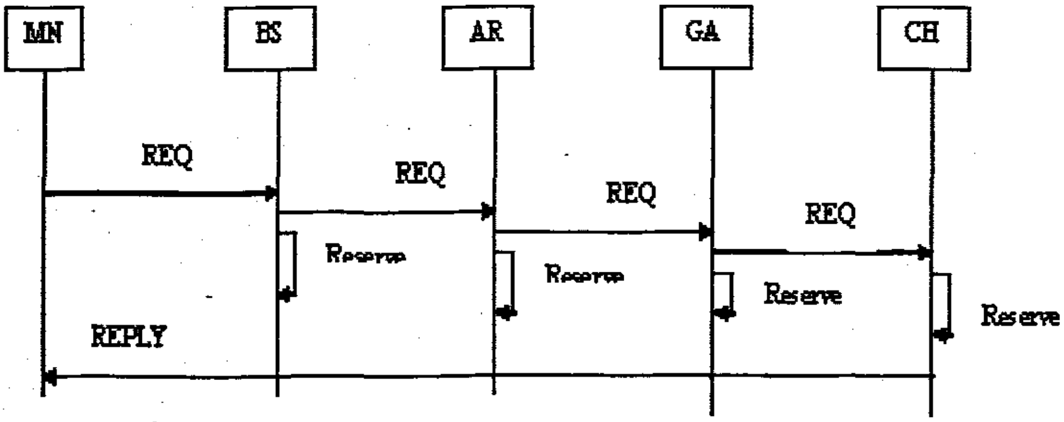

Figure 3. 9 *Setting-up resource reservation*

Once a mobile node has data to send, it sends REQ message containing FlowSpec to BS. BS would copy the FlowSpec and forward REQ message to the next level network node that is AR and reserve required resources if it has enough resources. BS would then set a timer. Same process would take place in AR. This process would go till it reaches a corresponding host (CH). CH would reserve resource and set a timer. CH would send a REPLY message to MN only if it has special requirements. If a timer in any network node expires, that node releases the resources for that particular flow then send TEAR_DOWN message to other nodes to explicit releases the held resources. But if a network node does not have enough resource it simply blocks that call.

3.3.4 Admission Control

Admission control refers to the task of deciding whether or not a certain connection request would be admitted into, and supported by, the network. Admission control is essential for real-time multimedia applications [Chao, C and Chen, W. 1997]. These types of applications are known to specify a lower bound on network resources, below which they cannot function. If the network cannot support this minimum need, the connection request must be denied. A new connection that is denied access into the network is said to be blocked.

A state of the art bandwidth allocation scheme [Chiu, M. and Bassiouni, M. 2000] that inspired us to propose our bandwidth allocation scheme, assumes that the traffic offered to mobile wireless network belongs to one of the two classes:

- Class I: real-time multimedia traffic, such as interactive audio and video, and
- Class II: non-real-time data traffic, such as email and web applications.

This bandwidth allocation scheme uses the max-min to fairly borrow bandwidth from all current connections. This scheme keeps a pool of bandwidth reserved for handoffs. This reserved pool is used for Class I handoffs only, with the assumption that real-time connections have more strict QoS requirements than Class II connections. This reservation of certain amount of highly limited bandwidth for class I flows degrades the utilisation of bandwidth.

a. Proposed Bandwidth Allocation Scheme

The bandwidth allocation scheme that is proposed here adopts traffic classes presented [Malla, A. 2001].

Traffic Classes

- Class I – real-time non-adaptive multimedia traffic
- Class II – real-time adaptive multimedia traffic
- Class III – non real-time data traffic

The parameters that must be specified in a connection request are connection class, expected bandwidth and minimum bandwidth.The minimum bandwidth represents the minimum bandwidth in which a specific connection can tolerate. The difference between expected bandwidth and minimum bandwidth is the borrowable bandwidth from that specific connection.

i. New connection

A new connection of any class, is accepted into a cell only if its expected bandwidth is less than or equal to the total available bandwidth of cell at the time of connection request is received, or if its minimum bandwidth is less or equal to total available bandwidth, or else if its minimum bandwidth is less or equal to the total borrowable bandwidth plus available bandwidth of all calls of class II and III. If connection cannot be given its expected or minimum bandwidth using all available and total borrowable bandwidth, the connection is rejected.

Let Total available bandwidth of the cell be T_{AV},

Expected bandwidth of new request be Exp_n,

Minimum bandwidth of new request be Min_n, Total borrowable bandwidth in a cell be T_{BB}

Borrowable bandwidth $= Exp_n - Min_n$ 3.1

$$T_{BB} = \sum_{i=1}^{n} (Exp_i - Min_i) \quad 3.2$$

Where n is number of connection of class II and III, Exp is the expected bandwidth and Min is the minimum bandwidth.

A new connection request is accepted or rejected by cell based onthe following algorithm:

```
If ( Exp_n <= T_AV ) Then
        Accept request
    Else If ( Min_n <= T_AV ) Then
        Accept request
    Else If ( Min_n <= T_AV + T_BB )
        Accept request
      Else
        Block request
        End If
      End If
End If
```

ii. Handoff Management

The way handoff requests are accepted to a cell, differs for eah class. It is assumed that connections of class III want to continue even if the bandwidth allocated is very small since they do not have strict QoS requirements and delay insensitive. Class III handoff request is not dropped as long as there is some amount of available bandwidth in new cell. Therefore for class III connection, minimum bandwidth is not honoured all the times.

For class I or II handoff request is accepted, if its expected bandwidth is less or equal to total available bandwidth of a cell, if its minimum bandwidth is less or equal to total available bandwidth plus total borrowable bandwidth of a cell, or when its minimum bandwidth is less or equal to the total availabl plus borrowable bandwidth orthe bandwidth achievedafter connection swapping.

iii. Connection Swapping

When a mobile node requests for handoff into a cell that des not have enough bandwidth, hat particular cell would have to scan all connections of the mobile nodes that are in the critical region, to get the traffic class and direction. If the traffic class of the scanned connection is class III, and the direction is away or not moving, the base stationwould negotiate with the current base station of the mobile node. In this process the current base station releases the bandidth held by mobile node that is requesting handoff connection. The scanned mobile node is then allocated to that bandwidth, since class III bandwidth would always be less than class I and II.

Hence the bandwidth held by the scanned mobile node can be allocated to handoff request. This process is called connection swapping, since at the end of the process the handoff requestwould be accepted and connection of class IIIwould be made to the cell of mobile node that requested handoff. The bandwidth achieved from connection swapping is simply called achieved bandwidth. The class III connection that is swapped should not fed the process of swapping.

Connection Swapping Algorithm

Let Minimum bandwidth of handoff request be Min_h

Swapping: CASE

$Min_h > T_{AV} + T_{SS}$

PBS scans

PBS release bandwidth held by scanned MN

PBS allocate released bandwidth to handoff MN

PBS send CHANGE to BS of handoff MN

BS release bandwidth held by handoff MN

BS allocate released bandwidth to scanned MN

END CASE

Figure 3. 10 *Connection Swapping*

The total achieved bandwidth is the sum of bandwidth that has been achieved by swapping two or more connections

Let Total achieved bandwidth be T_{AB},

Achieved bandwidth is Ab,

Expected bandwidth of handoff request be Exp_h,

$$T_{AB} = \sum_{j=1}^{k}(Ab_j) \qquad 3.3$$

Where k is the number of all swapped connection.

A handoff connection request is accepted or rejected by cell basd on the following:

Class III handoff connection request

If ($T_{AV} > 0$ OR $T_{BB} > 0$) Then

Accept request

Else

Drop request

End If

Class II and III handoff connection request

If ($Exp_k <= T_{AV}$) Then

Accept request

Else If ($Min_k <= T_{AV}$) Then

Accept request

Else If ($Min_k <= (T_{AV} + T_{BB})$) Then

Accept request

Else If ($Min_k <= (T_{AV} + T_{BB} + T_{AB})$)

Accept request

Else

Drop call

End If

End If

End If

End If

iii. Connection Termination

When connection terminates, the freed bandwidth is used tofill the bandwidth of connections that are currently functioning below theexpected bandwidth, as the caseof bandwidth borrowing. This is done using max-min fairness mechanism. The leftovers are used to replenish the total available bandwidth of a cell.

3.4 Simulation Parameters

The proposed DMRSVP model is simulated to evaluate its performance. The simulation parameters used to evaluate the performance of the proposed DMRSVP are:

i. Network Load

This parameter is for checking the scalability of the proposedQoS signalling scheme under different network conditions. The load is directly proportional to the availability of network resources.

ii. Delay

This parameter is for finding the roundtrip delay for resource reservation setup of QoS signalling protocol. This is for checking the efficiency of the proposed DMRSVP.

iii. Call Blocking Probability

Call blocking probability (CBP) is the probability that the networkwould block a new call request. The purpose of this parameter wasto find out how many new calls are blocked in a given time when any QoS signalling protocol is functioning.

iv. CDP

Call dropping probabilty (CDP) is the probability that the network would drop the handoff call request. The aim of this parameter is to findout how many handoff calls are droppedin a given time when any QoS signalling protocol is functioning.

v. Time

Time is one of the very important performance parameters. Since the behave of QoS signalling protocol is observed for given period of time.

CHAPTER FOUR

SIMULATION AND COMPUTATIONAL IMPLEMENTATION OF THE PROPOSED SCHEME

4.1 Introduction

In this chapter the evaluation of the proposed DMRSVP was carried outusing the simulation technique. The results of the simulation were compared with other QoS signalling protocols such as MRSVP [Talukdar, et al 1997] and HMRSVP [Tseng, et al 2001].

4.2 Simulation Model

The wireless environmentfor the simulator is the functional architecture of DMRSVP shown infigure 3.1. For simulation purposes thewireless environmentis made up of two gateway agents,with each of these gateway agents controlling two access routers. Each access router is on top of only three cells. Each cell is sectored into six sectors as proposed by Nkambule et al 2004 (figure 3.2). Each individual cell is connected to the access router through wireless linkof fixed capacity. Every cell has a base station, with a fixed bandwidth capacity, andmobile nodes roam within the two domains.

4.3 Simulation Environment

The simulator was implemented using Microsoft Visual Basic.Net on the Microsoft Visual Studio.Net 2003 environment. The VB.Net language was chosen because it is object oriented and supports easy development of simulation. This makes VB.net advantageous and easily deployable. The simulation was run on a PC running Microsoft Windows XP Professional operating system with 512 MB RAM capacity and Intel Pentium 4 Mobile processor.

A complete class diagram, detailed description of each object and source code of the simulatoris as shown in the Appendix.

4.3.1 Simulation Graphical User Interface

This section presents the actual simulation graphical user interface (GUI) and their functions. Figure 4.1 presents the main GUI for simulation of DMRSVP.

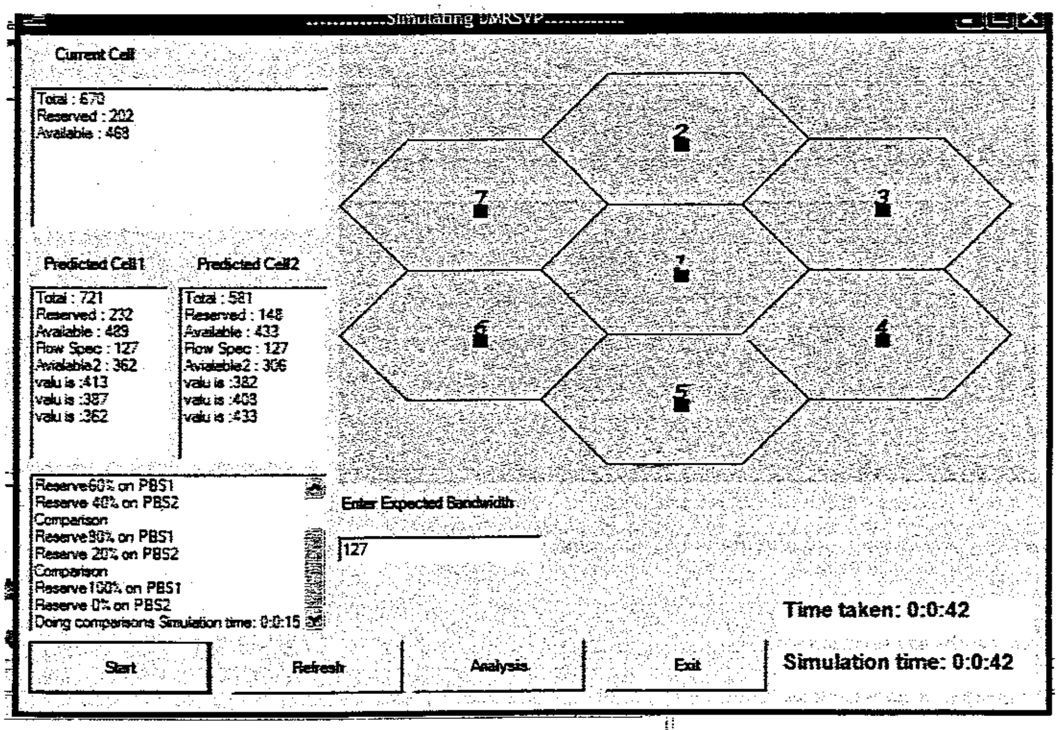

Figure 4. 1 *Main GUI for simulating DMRSVP*

The above GUI is used for testing the performance of the dynamic comparison algorithm.The start button initiates the simulation, but the simulationwould not happen if the user has not entered the expected bandwidth to be reserved. The refreshbutton is for clearing the entirescreen and brings the initial screen. The analysis button takes the user to the excel file where all simulation details are recorded.

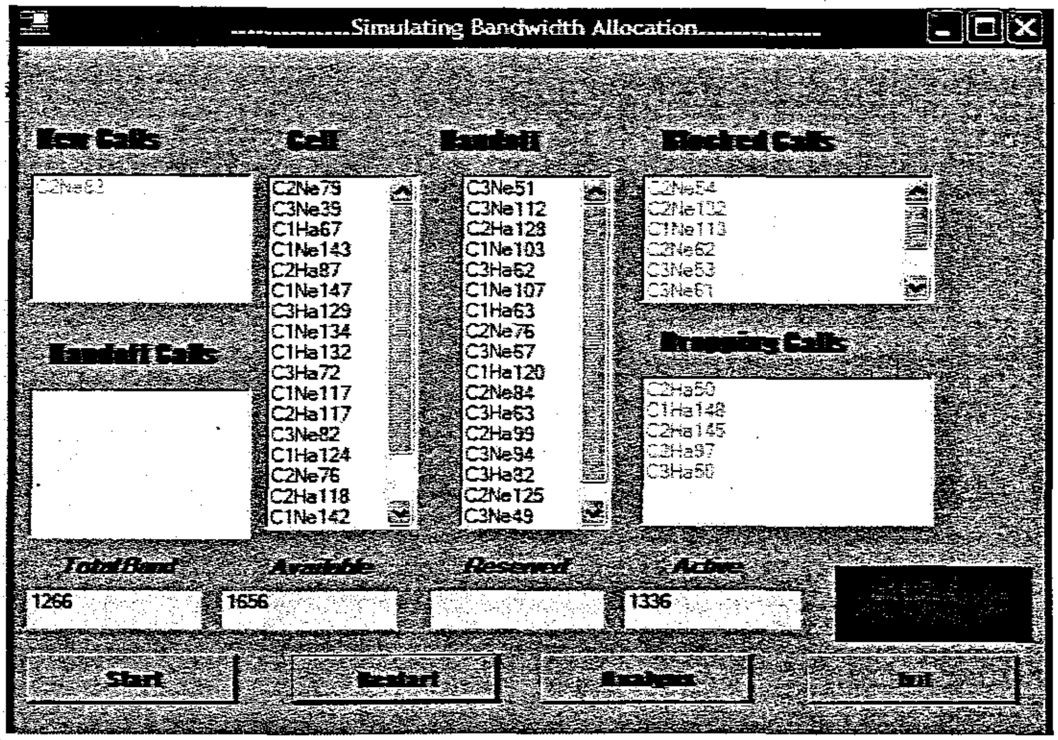

Figure 4. 2 *Bandwidth Allocation Simulation GUI*

Figure 4.2 is the GUI used when testing performance of connection swapping. Figure 4.2 shows the details of call analysis. The simulator generates calls randomly. Each call has its own resource requirements. The proposed bandwidth allocation scheme is used to accept the call in a cell.

4.4 Simulation Results and Performance Analysis

This section presents the simulation results obtained through a set of experiments. Each experiment was conducted in order to observe the behaviour of the proposed model The experiments conducted evaluated the scalability and efficiency properties of DMRSVP with varying performance parameters.

4.4.1 Experiment 1: Bandwidth Utilisation

This is the aggregate capacity currently utilised on a link or path at a given time. This parameter is used to measure the bandwidth utilized by control messages, and home registration signallingEach control message occupies 25Kb of bandwidth.

Results

Table 4.1 shows simulation results. The results were obtained by keeping a record of the bandwidth occupied by the control messages of eachof the three QoS signalling schemes under observation at a given time. The results of table 4.1 are plotted on graph figure 4.3.

Table 4. 1 *Bandwidth Utilisation*

Time	DMRSVP	HMRSVP	MRSVP
1	50	50	50
2	75	75	75
3	75	115	125
4	80	120	135
5	89	127	150
6	95	127	150
7	95	127	150
8	100	131	157
9	102	133	159

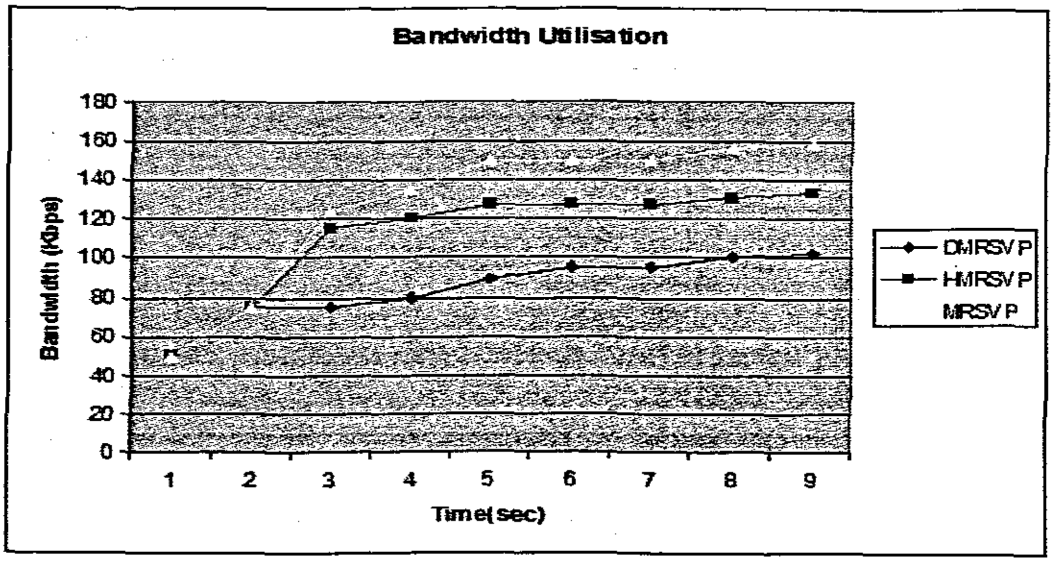

Figure 4. 3 *Bandwidth utilisation*

From figure 4.3 it can be observed that MRSVPutilised the highest bandwidth.This is due to the fact that MRSVP has linear mobility structure and does not employ any mobility management mechanism. HMRSVP occupies a smaller amount of bandwiddththan MRSVP. This is because Mobile IP is employed by HMRSVP and hierarchical functional structureIt is obvious that the proposed DMRSVP utilises a smallest amount of bandwidth compared to the other two schemes. This is due to a fact that DMRSVP employs Hierarchical Mobile IPv6 for mobility management and cooperation of hierarchies. DMRSVP does not support soft state maintenance; this has helped this scheme not to occupy larger amount of bandwidth. Therefore DMRSVP has a good utilization factor than MRSVP and HMRSVP. This is because DMRSVP control messages utilises a far less bandwidth, leaving the rest of bandwidth to accommodate more data packets.

4.4.2 Experiment 2: Reservation Blocking Probability

It is a mission of any resource reservation scheme to have small reservatioblocking probability. The blocking probability is calculated by keeping the track of all blockedeservation divided by the sum all reservation requests.

Results

Table 4.2 shows the number of blocked reservation requests for each of the three resource reservation protocols. The plotted version of table4.2 is given in figure 4.4.

Table 4. 2 *Reservation Blocking*

Time	MRSVP	HMRSVP	DMRSVP
0	0	0	0
3	5	1	1
6	9	4	1
9	15	7	2
12	20	11	3
15	24	14	3
18	30	17	4
21	34	20	5
24	37	23	5

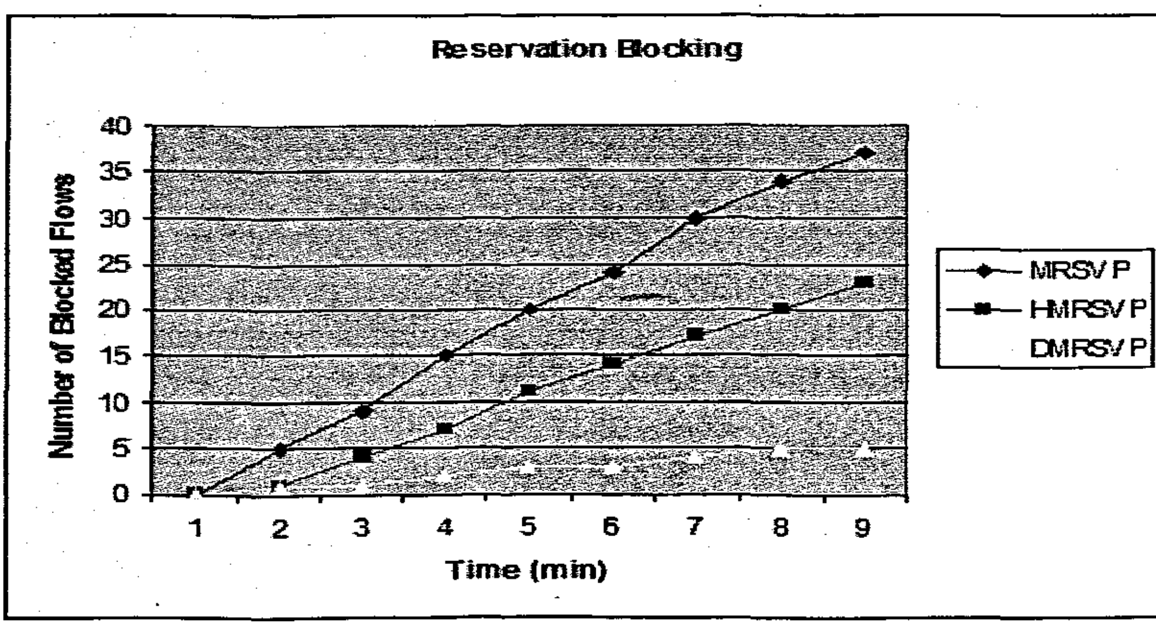

Figure 4. 4 *Reservation blocking probabilities*

When the offered load increases, the reservation blocking probability increases in all the schemes. It is obvious that the greater the offered load, the smaller theavailable resources, thus the higher the reservation blocking probabilities. It can be observed that reservation blocking probabilities of MRSVP and HMRSVP are larger than of the proposed DMRSVP. This is because MRSVP and HMRSVP do not have any next cell prediction scheme. MRSVP eserves much more resources in neighbouring cells, the HMRSVP reserves resources in a subnet; this causes a shortage of network resources. On the other hand, DMRSVP has the lowest reservation blocking probability, this is because of the dynamic comparison algorithm that is used to reserve resources to a specific cell in which a mobile node would handoff into. This improves the utilisation of resources as a result more connections would be accommodated. This dynamic algorithm makes the entire DMRSVP to be more efficient than MRSVP and HMRSVP.

4.4.3 Experiment 3: Signalling Overload

The scalability property of a protocol can be evaluated in terms of overhead growth on the network considering the size of the network, the number of mobile nodes and the number of correspondent nodes. One of the most important criteria that affect the scalability property of a mobile wireless resource management scheme is its signalling load, i.e. the bandwidth used by the control messages, such as the REQUEST and Binding Update messages.

In this section, we compare the signalling load of MRSVP and HMRSVP with the signalling load introduced with our proposal on the mobile wireless. The signalling load is calculated by counting the number of control message (signalling message) of each of the QoS signalling scheme. The scheme is more scalable if it has few control messages on the network. The fewer the signalling messages on the network, the more data packets on the network.

Results

The results of the protocol overhead are presented in table 4.3 and figure 4.5.

Table 4. 3 *Protocol Overhead*

Time (sec)	Load	MRSVP	HMRSVP	DMRSVP
1	50	20	20	0
2	75	60	20	10
3	100	80	50	10
4	125	115	55	12
5	150	130	80	15
6	175	152	90	17
7	200	160	120	19
8	225	185	130	21
9	250	195	150	25
10	275	225	155	25

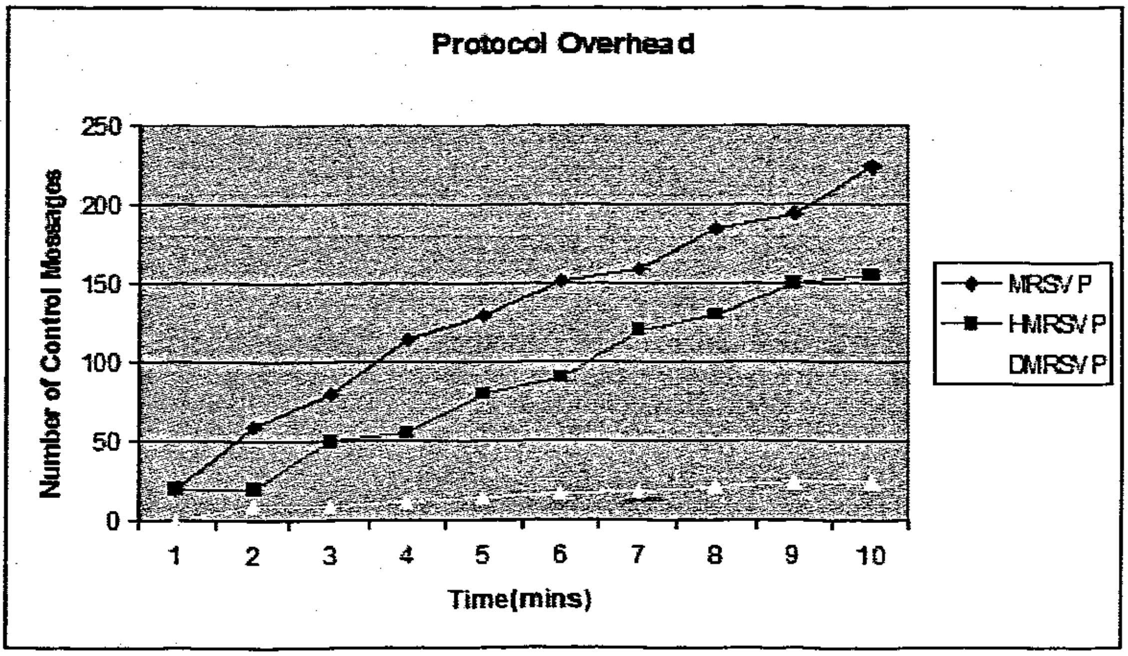

Figure 4. 5 *Protocol Overhead*

Figure 4.5 presents results ofprotocol overhead caused bybinding update and state maintence of each of the three schemes under discussion. MRSVP has th highest overhead This is due to the fact that it does not include any mobility managementto reduce overhead thatis caused by binding update. Also MRSVP support soft state maintence. For HMRSVP to have the large overhead is because of Mobile IP that is employed as the mobility management schemeas well as soft state maintence The proposed DMRSVP causes the smallest signalling loadon the wireless network This is because DMRSVP does not maintain any state(hard state) and, the use of HMIPv6 for mobility management together with a cooperation of foreign hierarchieshas reduced the need for binding update This proves that DMRSVP is scalable and efficient.

4.4.4 Experiment 4: Round-trip Delay

The delay is one of the most important performance parameter. High delay affects the transmission of real-time applications very badly, since realtime applications are very sensitive to delay. This experiment was conducted by recordng the time taken by node that is reserving resource to receive the reservation responseat the average network load.

Results

The results of the above mentioned experiment is presented in table 4.4 and figure 4.6.

Table 4. 4 *Round Trip Delay*

MRSVP	HMRSVP	DMRSVP
45	31	19

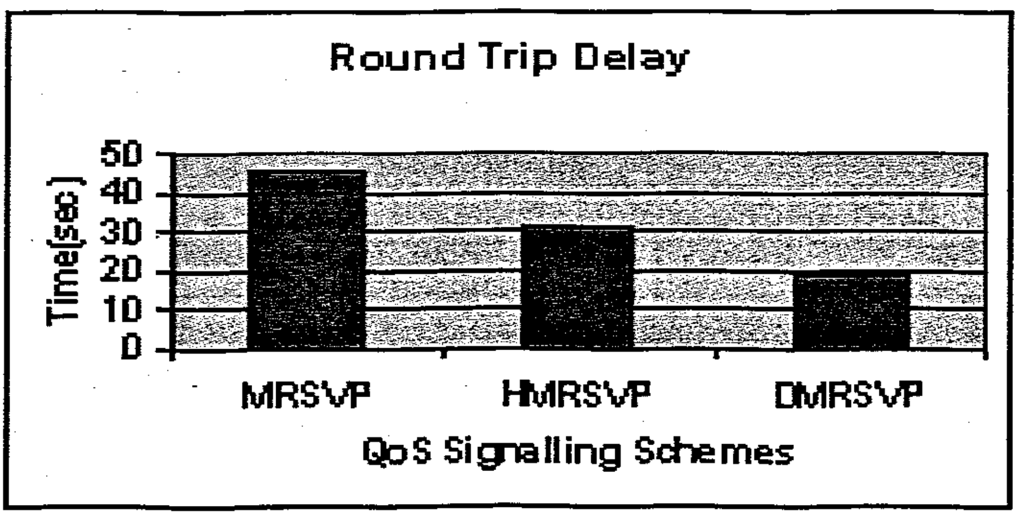

Figure 4. 6 *Round-trip Delay*

Figure 4.6 shows the simulation results that were obtained after tesing the round trip time taken to set-up resource reservation by each ofthe three QoS signalling schemes under discussion. MRSVP has the largest delay compared to theother two protocols. DMRSVP has the smallest delay compared to the other two schemes. Figure 3.8 in chapter 3 is the sequences diagram for settingup resource reservation employed by DMRSVP. DMRSVP starts by forwarding the REQ message before reserving reaurce this help to reduce the reservation set-up time that contributes to roundtrip delay for the REQ.

4.4.5 Experiment 5: Call Blocking Probability and Call Dropping Probability

The probability that a network might block a new call is known as call blockingprobability (CBP). When a handoff connection request is denied resources is said to be dropped. The probability that a cell or network might drop a handoff request is called call dropping probability (CDP). The admission control and bandwidth allocation schemes strive to minimise CBP and CDP. For a mobile user, dropping an ongoing call is generally more unacceptable than blocking a new call request. Therefore, minimizing the CDP is usually a main objective of admission control and bandwidth allocation schemes [Chao, et al 1997].

Let C_b be a sum of blocked calls in a given time, C_d be a sum of dropped calls in a given time T_c

$$CBP = \frac{C_b}{T_c} \qquad 4.1$$

and

$$CDP = \frac{C_d}{T_c} \qquad 4.2$$

We simulated the proposed bandwidth allocation algorithms to show the impact of call swapping in CDP and CBP. The total available bandwidth was set to be a fixed value.

Results

Table 4. 5 *Call Analysis*

Number of Calls	Admitted Calls	New Calls	Handoff Request	Blocked	Dropped
81	69	45	36	10	2
283	246	131	112	32	5

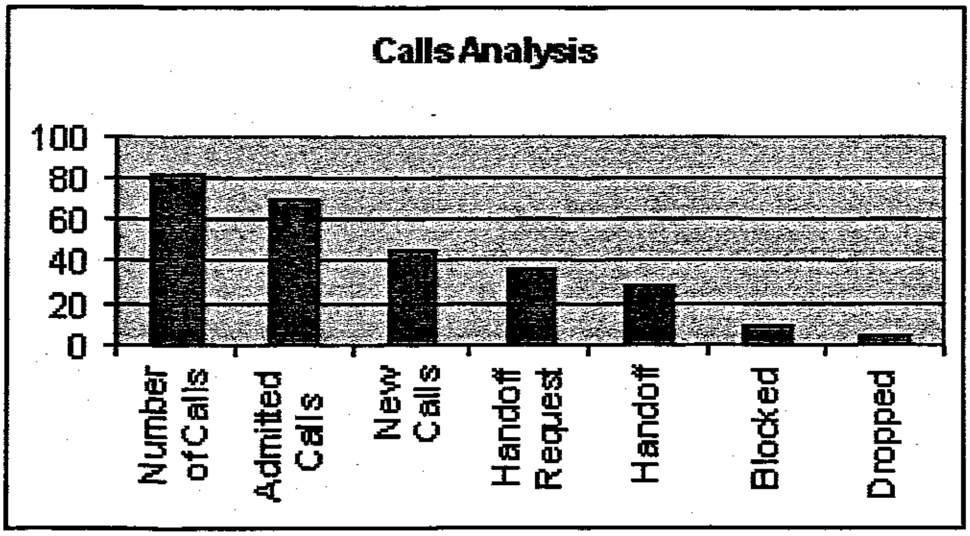

Figure 4. 7 *Number of All Calls*

Figure 4.7 shows the number of calls generatedby the simulator in 86 seconds. Each generated call had its own bandwidth requirement.From figure 4.7 it can be observed that out of81 calls that were generated, 69 calls were admitted into a cell.The other 12 calls that were not admitted,10 of those calls were blocked and only2 calls dropped. The 81 generated calls are made up of 45 new calls (originated within a cell) and 36 handoff request calls (from neighbouring cells)This gives the opportunity to calculate the CBP and CDPusing equation 4.1 and 4.2 respectively.

$$CBP = \frac{10}{45} \qquad 4.3$$

$$CBP = 0.22$$

$$CDP = \frac{2}{38} \qquad 4.4$$

$$CDP = 0.05$$

Equation 4.3 and 4.4 shows the effect of the proposed call swapping. The use of DMRSVP together with its call admission control algorithm that uses newly proposed call swapping reduces the CBP and CDP. This means that more calls will be accepted to into the cell.

Table 4. 6 *CDP and CBP without Call Swapping*

New Calls	Handoff Calls	Calls Blocked	Calls Dropped
0	0	0	0
2	2	0	0
4	4	0	0
6	6	1	0
7	8	2	0
8	10	3	1
9	12	4	2
10	14	5	2
11	14	6	3
12	14	7	3

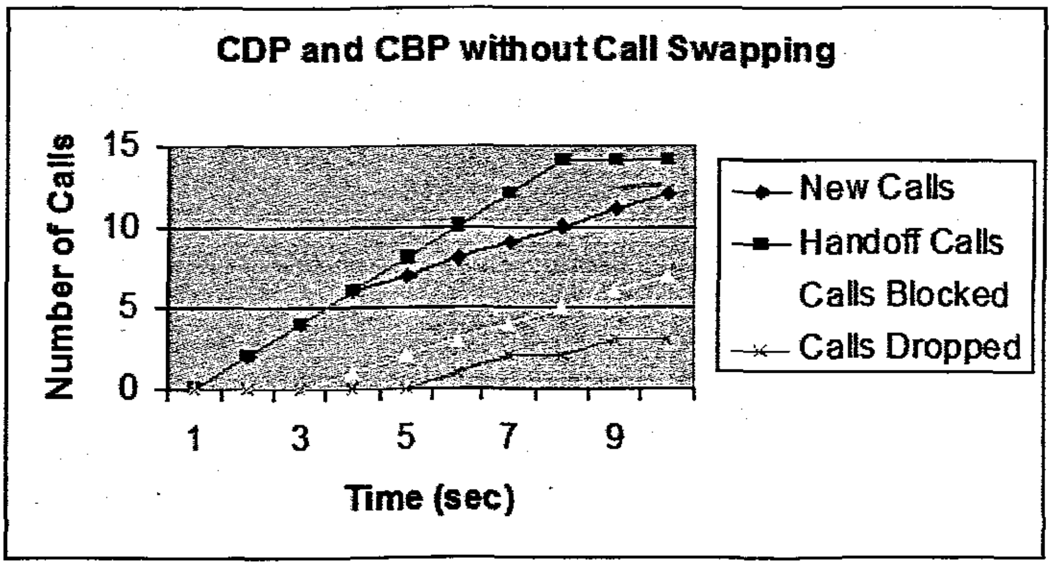

Figure 4. 8 *CDP and CBP without connection swapping*

The figure4.8 shows the number of new calls, handoff calls that were accepted into the cell in ten seconds. The graph shows that more new calls were blocked than dropped calls. It can be seen in figure 4.8 that between 0s and 4s the new and handoff calls were accepted into cell at the same rate. The graph shows that our algorithm slowly blocks new calls; this reduces CBP because few new calls were blocked in at the end of the simulation. It can be seen that the rate at which blocking of new calls grows at a constant rate. This is due to modification parameter included in our algorithmwhich uses the sum of total borrowed bandwidth withthe total available bandwidth as the condition of accepting new calls to the cell. The call dropping starts at 5.5s, itthen grows up very fast and this means that bandwidth borrowing alone fails at some stage.

The following figure shows the impact of connection swapping since the rsults of table 4.6 were obtained without using the connection swapping.

Table 4. 7 *CDP and CBP with Call Swapping*

New Calls	Handoff Calls	Calls Blocked	Calls Dropped
0	0	0	0
2	2	0	0
4	4	0	0
6	6	0	0
7	8	1	0
8	10	1	0
9	12	2	0
10	14	3	1
11	14	4	1
12	14	5	2

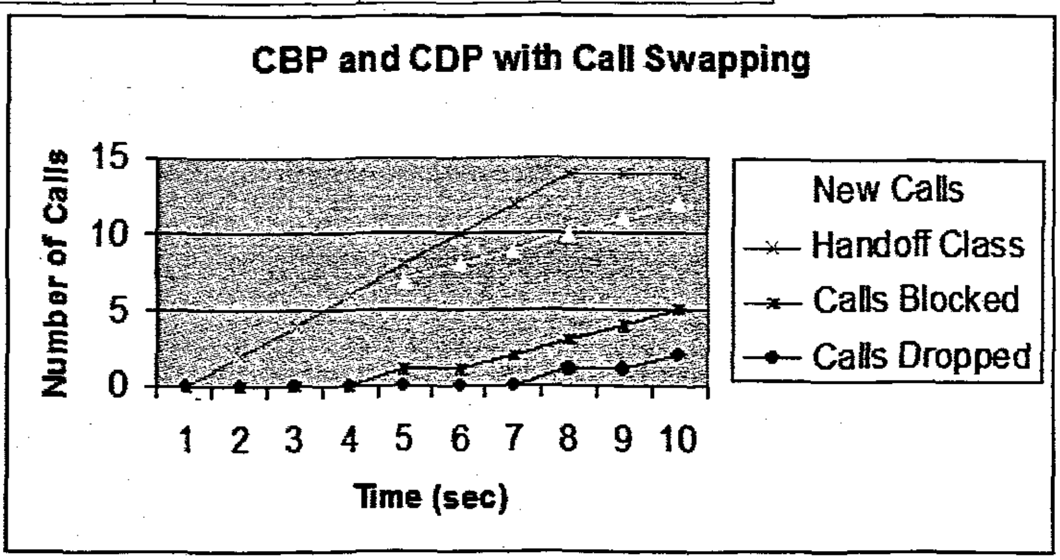

Figure 4. 9 *CDP and CBP with connection swapping*

Figure 4.9 shows that very few handoff calls were dropped. From time 0sto time 7s no handoff call was dropped. This shows some improvement, in figure 4.8 took only 5.1s to start dropping handoff calls. Figure 4.9 also shows that call dropping grows very slowly. This is because of the connection swapping. Connection swapping made acell to accept many handoff calls. This reduced CDP.

The results of these experiments are in consonance with the fact that flexibility of DMRSVP and connection swapping reduces CDP at the same time allowing new calls to share the bandwidth through bandwidth borrowing. These experiment results have again proved that DMRSVP is scalable and efficient. The scalability of DMRSVP is provd by this proposed protocol having a very low protocol overhead (figure 4.5)

4.4.6 Simulator and Experiments Limitations

The limitations of the simulation and the experiments conducted are as follows:

i. The simulator that was used for this research isnot a commercial product; we developed it specifically for this research This opens possible errors during the development that might have affected the simulation and the results.

ii. The calls together with their resource requirements were randomly generated. This might have influenced the simulation results.

4.4.7 Performance Analysis Conclusion

The performance analysis has shown that DMRSVP meets its design objectives asthey are outlined in section 3.2 The performance analysis has also shown that bandwidth allocation scheme that is proposed in this research work minimises CBP and CDP. This improves the utilisation of resources since many calls are accepted. The complete package of DMRSVP comprises resource reservation through dynamic comparison algorithm and bandwidth allocation that uses the call swapping, DMRSVP might be scalable and efficient but it has the following problems:

i. Both dynamic comparison and call swapping algorithms introduce some implementation complexity and

ii. Both algorithms need some little more time during setup, but they yield goodresults.

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this work we analysed and compared the performance of several mobile wireless resource reservation schemes. The challenges of designing the mobile wireless resource reservation scheme were presented in this dissertation The resource reservation mechanism needs to guarantee the availability of the limited network resources to mobile nodes at the time of handoff. This promotes the continuity of service.

However the development of mobile wireless resource management mechanism has been hindered by many open issues in QoS provision [Chan, et al 2000]. Issues like mobility management, allocation of the limited bandwidth, next cell prediction and the list of these open issues is endless. This research work proposes and implements an optimal resource management mechanism, known as the Dynamic Mobile Resource Reservation Protocol (DMRSVP) that accommodates both real-time and non-real time applications in the mobile wireless Internet.

DMRSVP comprised of three components i) resource reservation and bandwidth allocation, ii) mobility management and iii) next cell prediction. The mobility management component is a HMIPv6 [Soliman, et al 2005]. DMRSVP uses HMIPv6 to manage the mobile nodes mobility within the hierarchy. DMRSVP adopts the concept of the cooperation of hierarchies [Abdel-Hamid, A. and Abdel-Wahab, H. 2001]. Both HMIPv6 and the cooperation of hierarchies reduce the need for mobile node to undergo the binding update process. This reduces the number of control messages on the network, making DMRSVP to be more scalable. DMRSVP make use of the sectored-cell approach [Nkambule, et al 2001] for predicting the next cell the mobile node would visit with an open connection. We modified the sectoredcell approach by adding the resource reservation module The first component of DMRSVP is the resource reservation andbandwidth allocation. This researchwork proposes two novel algorithms, i) dynamic comparison algorithmfor reserving resources and ii) bandwidth allocation algorithm.

To achieve the goal of this research work the following objectives were set: firstto analyse the theoretical framework of the existing mobile wireless resource reservation protocols, this objective has been successfully achieved. The analysis of related work was done through the theoretial framework that we developed specifically for this task The knowledge gained from related work, was used to determine how to configure resources in advance, in a mobile wireless InternetThis is the second objective of this research andthis objective was successfuly achieved. The third objective has been achieved by proposing DMRSVPwhich is the resource management mechanism for mobile wireless Internet.

The simulation of theproposed model was conducted to evaluate and compare the performance with similar schemes available in the literature.DMRSVP performance was compared with performance of MRSVP [Talukdar, et al 1997] and HMRSVP [Tseng, et al 2001]. The simulation results showed that DMRSVP had the lower reservation blocking probability (figure 4.4) and CDP of 0.22 of which is the lower value compared with other similar existing shemes in the literature. Therefore DMRSVP is more scalable and efficient than MRSVP and HMRSVP.

5.2 Future Work

DMRSVP scheme focuses on resource reservation and bandwidth allocationThe scheme should be extended to include buffer management formobile wireless Internet and handoff management The results obtained from the simulation showed that the proposed scheme is suitable for mobile wireless environment. However, the simulation is only an approximation of the reality; therefore another future objective is to observe the behaviour of DMRSVP in a real network. The test-bed should be constructed. The results to be obtained from the test could be used to write the request for comments (RFC) to be published on IETF the Internet standard making body. The resource management is probably one of the most fundamental problems in mobile ad hoc networks. Exploring the ways of extending the proposed DMRSVP to also accommodate mobile ad hoc networks is also recommended.

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APPENDIX

1. Class Diagram

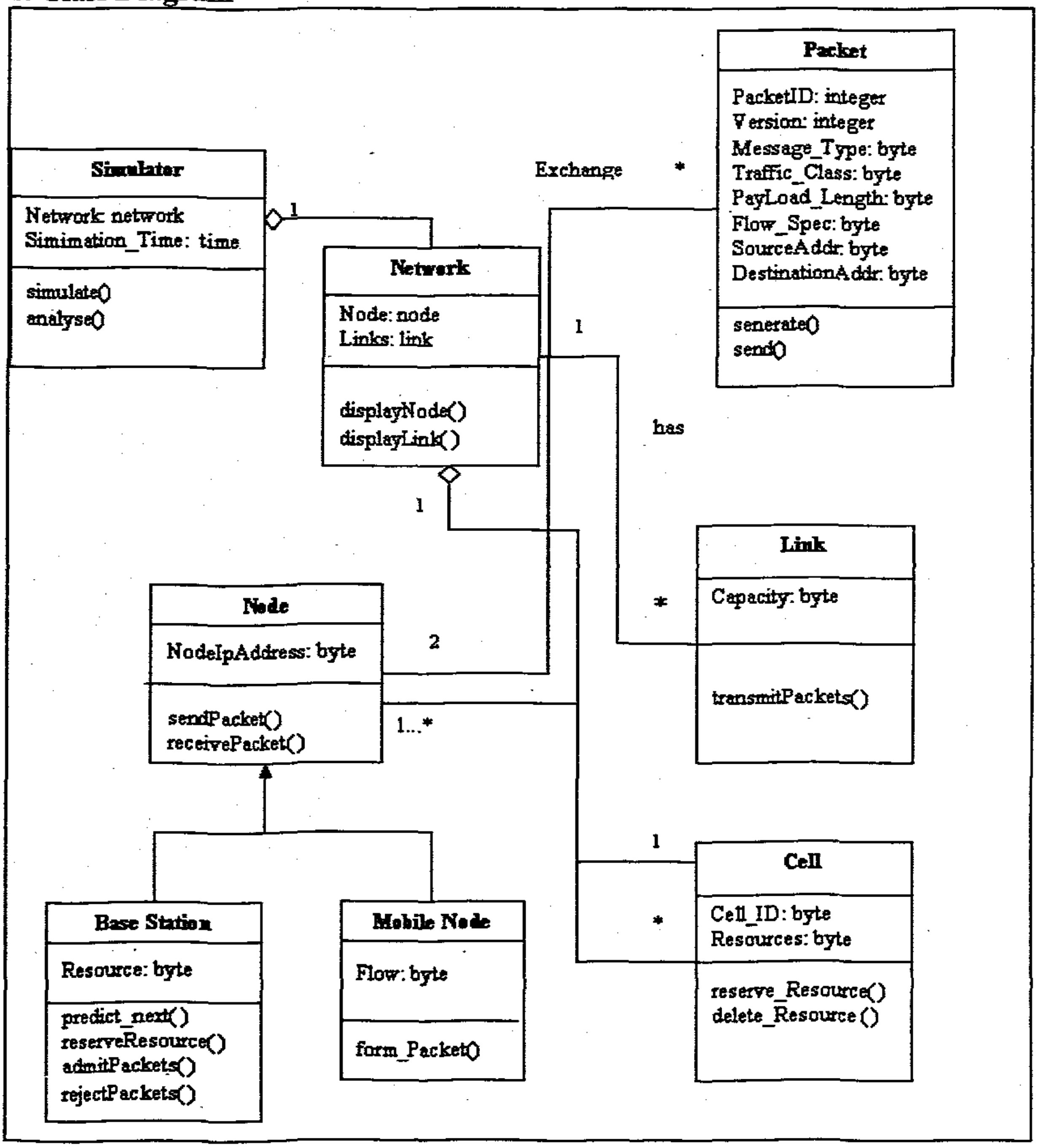

figure 5.1 *Class Diagram*

1. Class Description

Simulator: This is the container class for all classes. It consists of networkwith their nodes. Within the Simulator, users are able to enter and view simulation statistics.

Network: This class contains the entities of nodes connected by links. Within the network, nodes and links can be added and displayed.

Node: This class is one of the fundamental building blocks of the network. There are two types of nodes associated with the network classused in the simulation, a base stationand a mobile node. Each node is uniquely identified by an IPaddress.

Base station: This class represents a network node that acts as a gateway, access router and base station for packets from source to destination. Abase station performs admission control and resource reservation for the packets (flows).

Packet: This class representsthe message that is transmitted over the network.

Mobile Node: This class represents a mobile node in the wireless access network. A mobile node is able to send as sender and receiveas receiver packets

Link: This is wireless link. This class representsthe connections between nodes in the network. A link transmits packets from one node to another.

2. Simulation Code

```
Imports System.IO
Imports System.Threading
Imports System.Drawing
Imports System.Drawing.Drawing2D
Imports Microsoft.VisualBasic

Public Class Form1
  Inherits System.Windows.Forms.Form


  Dim Ccell As Collection
  Dim Pbs1 As Collection
  Dim Pbs2 As Collection
```

```
Dim c As Cell = New Cell
Dim bs As Integer
Dim base As BaseStation = New BaseStation
Dim ArrAvail As Integer() = New Integer(2) {}
Dim BandCell1 As Integer() = New Integer(4) {}
Dim BandCell2 As Integer() = New Integer(4) {}
Dim capacity As Integer() = New Integer(3) {}

Public s As String

Public aval, aval2, aval3, band, nofCells, strN, Arrcount, x, y, n As Integer
Dim selected As Integer
Dim ffdad As Integer
Dim rcells As Random = New Random
Dim str As Random = New Random
Dim st1 As Random = New Random
Dim corner As Point1() = New Point1(6) {}
Dim number As Integer
Dim num As Integer
Public hour As Integer = 0
Public min As Integer = 0
Public sec As Integer = 0
Public hour1 As Integer = 0
Public sec1 As Integer = 0
Public level As Integer = 1
Dim y1 As String
Public min1 As Integer = 0
Dim count As Integer = Prediction()
Dim p1 As Point1
Dim p2 As Point1
Private drawArea As Graphics
Private myPen As Pen
Private br As SolidBrush = New SolidBrush(Color.Blue)
Private Sub cmdExit_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdExit.Click
  Me.Close()
End Sub
Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MainTimer.Tick
  Dim s As String = hour & ":" & min & ":" & sec
  sec = sec + 1
  If sec = 60 Then
    sec = 0
    min = min + 1
  End If
  If min = 60 Then
    min = 0
    hour = hour + 1
  End If
  If hour = 24 Then
    hour = 0
  End If
  lblTime.Text = "Simulation time: " & s
End Sub
Private Sub Display(ByVal send As System.Windows.Forms.ListBox)
  Reservatoion()
  send.Items.Add("Total : " & base.TotalM())
  send.Items.Add("Reserved : " & base.ReserveM())
  send.Items.Add("Available : " & Avialable())
  send.Items.Add("Flow Spec : " & band)
  send.Items.Add("Avialable2 : " & Avialable2())
  ArrAvail(Arrcount) = Avialable2()
  Arrcount = Arrcount + 1
End Sub
Private Sub Display1(ByVal send As System.Windows.Forms.ListBox)
  Reservatoion()
  send.Items.Add("Total : " & base.TotalM())
  send.Items.Add("Reserved : " & base.ReserveM())
```

```
    send.Items.Add("Available : " & Avialable())
End Sub
Private Sub Reservatoion()
    Try
        band = Integer.Parse(txtBandwith.Text())
    Catch ex As FormatException
        StopEverything()
        MessageBox.Show("invalid", "number formate", MessageBoxButtons.OK, MessageBoxIcon.Information)
        txtBandwith.Text() = ""
    End Try
    aval = base.Generate()
    aval2 = base.LeftDand(aval, band)
End Sub
Property Avialable() As Integer
    Get
        Return aval
    End Get
    Set(ByVal Value As Integer)
        aval = Value
    End Set
End Property
Property Avialable2() As Integer
    Get
        Return aval2
    End Get
    Set(ByVal Value As Integer)
        aval2 = Value
    End Set
End Property
Private Function Prediction()
    nofCells = rcells.Next(1, 5)
    Return nofCells
End Function
Private Sub TDisplay_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles TDisplay.Tick
    If (count = 1) Then
        lbDisplay.Items.Add("One BS is Predicted")
        Display1(lbCBS)
        Display1(lbPBS1)
        Display1(lbPBS2)
        ffdad = Avialable2() + (band - (band * 0.5))
        FTimer.Start()
        count = count + 5
    ElseIf (count = 2 Or count = 4 Or count = 5) Then
        number = True
        lbDisplay.Items.Add("Two BS is Predicted")
        lbDisplay.Items.Add("this would come soon")
        Display(lbPBS1)
        BandCell1(n) = Avialable()
        capacity(0) = base.TotalM()
        Display(lbPBS2)
        BandCell2(n) = Avialable()
        capacity(1) = base.TotalM()
        n += 1
        Display1(lbCBS)
        capacity(2) = base.TotalM()
        Compare1.Start()
        count = count + 5
    ElseIf (count = 3) Then
        lbDisplay.Items.Add("One BS is Predicted")
        Display1(lbCBS)
        Display1(lbPBS2)
        Display1(lbPBS1)
        ffdad = Avialable2() + (band - (band * 0.5))
        FFTime.Start()
        count = count + 5
    End If
```

```
End Sub
Private Sub cmdStart_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdStart.Click
  number = str.Next(0, 2)
  bs = st1.Next(1, 7)
  MainTimer.Start()
  Stop_Timer.Start()
  environment()
  Thread.Sleep(2000)
  lbPBS1.Items.Clear()
  lbPBS2.Items.Clear()
  TDisplay.Start()
  If (count = 1 Or count = 3) Then
    MoveMB.Start()
  Else
    TwoBs.Start()
  End If
End Sub
Private Sub Compare(ByVal bs1 As Integer, ByVal bs2 As Integer)
  strN = str.Next(1, 3)
  If (strN = 1) Then
    lbDisplay.Items.Add("Comparison")
    lbDisplay.Items.Add("Reserve" & bs1 & "% on PBS1")
    lbDisplay.Items.Add("Reserve " & bs2 & "% on PBS2")
  Else
    lbDisplay.Items.Add("Comparison")
    lbDisplay.Items.Add("Reserve " & bs1 & "% on PBS2")
    lbDisplay.Items.Add("Reserve " & bs2 & "% on PBS1")
  End If
End Sub
Property StrNM() As Integer
  Get
    Return strN
  End Get
  Set(ByVal Value As Integer)
    strN = Value
  End Set
End Property
Private Sub Compare1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Compare1.Tick
  If (level = 1) Then
    Compare(60, 40)
    If (StrNM() = 1) Then
      aval3 = Percentage(band, 0.6, 0)
      lbPBS1.Items.Add("valu is :" & aval3)
      BandCell1(n) = aval3
      aval3 = Percentage(band, 0.4, 1)
      lbPBS2.Items.Add("valu is :" & aval3)
      BandCell2(n) = aval3
      n += 1
    Else
      aval3 = Percentage(band, 0.6, 1)
      lbPBS2.Items.Add("valu is :" & aval3)
      BandCell2(n) = aval3
      aval3 = Percentage(band, 0.4, 0)
      lbPBS1.Items.Add("valu is :" & aval3)
      BandCell1(n) = aval3
      n += 1
    End If
    level = level + 1
  ElseIf (level = 2) Then
    Compare(80, 20)
    If (StrNM() = 1) Then
      aval3 = Percentage(band, 0.8, 0)
      lbPBS1.Items.Add("valu is :" & aval3)
      BandCell1(n) = aval3
      aval3 = Percentage(band, 0.2, 1)
      lbPBS2.Items.Add("valu is :" & aval3)
```

```
            BandCell2(n) = aval3
            n += 1
        Else
            aval3 = Percentage(band, 0.8, 1)
            lbPBS2.Items.Add("valu is :" & aval3)
            BandCell2(n) = aval3
            aval3 = Percentage(band, 0.2, 0)
            lbPBS1.Items.Add("valu is :" & aval3)
            BandCell1(n) = aval3
            n += 1
        End If
        level = level + 1
    ElseIf (level = 3) Then
        Compare(100, 0)
        If (StrNM() = 1) Then
            aval3 = Percentage(band, 1.0, 0)
            lbPBS1.Items.Add("valu is :" & aval3)
            BandCell1(n) = aval3
            num = 1
            aval3 = Percentage(band, 0.0, 1)
            lbPBS2.Items.Add("valu is :" & aval3)
            BandCell2(n) = aval3
            n += 1
        Else
            aval3 = Percentage(band, 1.0, 1)
            num = 2
            lbPBS2.Items.Add("valu is :" & aval3)
            BandCell2(n) = aval3
            aval3 = Percentage(band, 0.0, 0)
            lbPBS1.Items.Add("valu is :" & aval3)
            BandCell1(n) = aval3
            n += 1
        End If
        level = level + 1
    End If
End Sub
Sub StopEverything()
    lbPBS1.Items.Clear()
    lbPBS2.Items.Clear()
    lbDisplay.Items.Clear()
    TDisplay.Stop()
    Compare1.Stop()
    TwoBs.Stop()
    MoveMB.Stop()
    ComToBs.Stop()
    count = Prediction()
    level = 1
    Arrcount = 0
    min1 = 0
    sec1 = 0
    x = 0
    y = 0
    bs = 0
    FFTime.Stop()
    FTimer.Stop()
    lbCBS.Items.Clear()
    c.count = 0
    txtBandwith.Text() = ""
    pDisplay.Refresh()
    Stop_Timer.Stop()
    lblStop_Timer.Text() = ""
End Sub
Private Sub cmdStop_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdStop.Click
    StopEverything()
End Sub
Private Function Percentage(ByVal value As Integer, ByVal perc As Double, ByVal para As Integer) As Double
```

```
    Return ArrAvail(para) + (value - (value * perc))
  End Function
  Private Sub environment()
    c.DrawCell("1", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
          New Point(x, y), New Point(x, y), drawArea, myPen, 200, 130)
    corner(0) = New Point1(200, 130)
    corner(1) = New Point1(300, 130)
    corner(2) = New Point1(350, 180)
    corner(3) = New Point1(300, 230)
    corner(4) = New Point1(200, 230)
    corner(5) = New Point1(150, 180)
    c.DrawCell("2", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
        New Point(x, y), New Point(x, y), drawArea, myPen, 200, 30)
    c.DrawCell("3", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
          New Point(x, y), New Point(x, y), drawArea, myPen, 350, 80)
    c.DrawCell("4", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
      New Point(x, y), New Point(x, y), drawArea, myPen, 350, 180)
    c.DrawCell("5", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
New Point(x, y), New Point(x, y), drawArea, myPen, 200, 230)
    c.DrawCell("6", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
      New Point(x, y), New Point(x, y), drawArea, myPen, 50, 180)
    c.DrawCell("7", New Point(x, y), New Point(x, y), New Point(x, y), New Point(x, y), _
  New Point(x, y), New Point(x, y), drawArea, myPen, 50, 80)
  End Sub
  Private Sub MoveMB_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MoveMB.Tick
    Dim b As SolidBrush = New SolidBrush(Color.BlueViolet)
    Dim b1 As SolidBrush = New SolidBrush(Color.Khaki)
    If (c.p(0).XM = c.p(bs).XM) Then
      If (c.p(0).YM < c.p(bs).YM) Then
        drawArea.FillRectangle(b1, c.p(0).XM, c.p(0).YM - 6, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).YM += 6
      ElseIf (c.p(0).YM > c.p(bs).YM) Then
        drawArea.FillRectangle(b1, c.p(0).XM, c.p(0).YM + 6, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).YM -= 6
      End If
    ElseIf (c.p(bs).YM < c.p(0).YM) Then
      If (c.p(0).XM < c.p(bs).XM) Then
        drawArea.FillRectangle(b1, c.p(0).XM - 6, c.p(0).YM + 2, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).XM += 6
        c.p(0).YM -= 2
      ElseIf (c.p(0).XM > c.p(bs).XM) Then
        drawArea.FillRectangle(b1, c.p(0).XM + 6, c.p(0).YM + 2, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).XM -= 6
        c.p(0).YM -= 2
      End If
    ElseIf (c.p(bs).YM > c.p(0).YM) Then
      If (c.p(0).XM < c.p(bs).XM) Then
        drawArea.FillRectangle(b1, c.p(0).XM - 6, c.p(0).YM - 2, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).XM += 6
        c.p(0).YM += 2
      ElseIf (c.p(0).XM > c.p(bs).XM) Then
        drawArea.FillRectangle(b1, c.p(0).XM + 6, c.p(0).YM - 2, 5, 5)
        drawArea.FillRectangle(b, c.p(0).XM, c.p(0).YM, 5, 5)
        c.p(0).XM -= 6
        c.p(0).YM += 2
      End If
    End If
    If (c.p(0).XM = c.p(bs).XM) Then
      Stop_Timer.Stop()
    End If
  End Sub
```

```
Private Sub TwoBs_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles TwoBs.Tick
    If (bs = 6) Then
        c.MoveFP1ToP2(c.p(0), corner(0), drawArea)
        If (c.p(0).XM >= corner(0).XM - 4 And c.p(0).YM >= corner(0).YM - 4) Then
            TwoBs.Stop()
            lbDisplay.Items.Add("Doing comparisons " & lblTime.Text())
            ComToBs.Start()
        End If
    Else
        c.MoveFP1ToP2(c.p(0), corner(bs), drawArea)
        If (c.p(0).XM >= corner(bs).XM - 4 And c.p(0).YM >= corner(bs).YM - 4) Then
            TwoBs.Stop()
            lbDisplay.Items.Add("Doing comparisons " & lblTime.Text())
            ComToBs.Start()
        End If
    End If
End Sub
Private Sub ComToBs_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles ComToBs.Tick
    If (StrNM() = 1) Then
        If (bs = 6) Then
            p1 = corner(0)
            p2 = c.p(bs)
            c.MoveFP1ToP2(p1, p2, drawArea)
        Else
            p1 = corner(bs)
            p2 = c.p(bs)
            c.MoveFP1ToP2(p1, p2, drawArea)
        End If
        'Stop_Timer.Stop()
    ElseIf (StrNM() = 2) Then
        If (bs = 6) Then
            p1 = corner(0)
            p2 = c.p(1)
            c.MoveFP1ToP2(p1, p2, drawArea)
        Else
            p1 = corner(bs)
            p2 = c.p(bs + 1)
            c.MoveFP1ToP2(p1, p2, drawArea)
        End If

    End If
    'If (p1.YM >= p2.YM - 3 And p1.XM >= p2.XM - 3) Then
    '   Stop_Timer.Stop()
    'End If
End Sub
Private Sub cmdAnalysis_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdAnalysis.Click
    TestLateBinding()
End Sub
Sub TestLateBinding()
    Dim xlApp As Object
    Dim xlBook As Object
    Dim xlSheet As Object
    Dim p, q As Integer

    ' Create a variable to hold a new object.
    xlApp = CreateObject("Excel.Application")

    'Late bind an instance of an Excel workbook.
    xlApp = GetObject("C:\Nyandeni\Masters\Results\FinalSimulation\Simulator\Results.XLS")
    xlApp.Parent.Windows(1).Visible = True
    xlApp.Application.Visible = True

    'Late bind an instance of an Excel worksheet.
    xlSheet = xlApp.Worksheets(1)
    xlSheet.Activate()
    xlSheet.Application.Visible = True ' Show the application.
```

```
' Place some text in the second row of the sheet.
xlSheet.Cells(1, 1) = 1
xlSheet.Cells(2, 1) = 2
xlSheet.Cells(3, 1) = 3
xlSheet.Cells(4, 1) = 4
xlSheet.Cells(1, 8) = capacity(0)
xlSheet.Cells(1, 9) = capacity(1)
xlSheet.Cells(1, 10) = capacity(2)
For p = 2 To 3
  For q = 1 To 4
    If (p = 2) Then
      xlSheet.Cells(q, p) = BandCell1(q - 1)
    Else
      xlSheet.Cells(q, p) = BandCell2(q - 1)
    End If
  Next
Next
If (StrNM() = 1) Then
  xlSheet.Cells(1, 4) = BandCell1(0)
  xlSheet.Cells(2, 4) = BandCell1(1)
  xlSheet.Cells(3, 4) = BandCell1(2)
  xlSheet.Cells(4, 4) = BandCell1(3)
Else
  xlSheet.Cells(1, 4) = BandCell2(0)
  xlSheet.Cells(2, 4) = BandCell2(1)
  xlSheet.Cells(3, 4) = BandCell2(2)
  xlSheet.Cells(4, 4) = BandCell2(3)
End If
End Sub
Private Sub Stop_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Stop_Timer.Tick
  y1 = hour1 & ":" & min1 & ":" & sec1
  sec1 = sec1 + 1
  If sec1 = 60 Then
    sec1 = 0
    min1 = min1 + 1
  End If
  If min1 = 60 Then
    min1 = 0
    hour1 = hour1 + 1
  End If
  If hour1 = 24 Then
    hour1 = 0
  End If
  lblStop_Timer.Text = "Time taken: " & y1
End Sub
Dim fft As Integer
Dim vs As Integer = 2
Private Sub FFTime_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles FFTime.Tick
  If (fft < 2) Then
    lbPBS1.Items.Add("Available" & vs & " " & ffdad)
    ffdad = ffdad - (band - (band * 0.5))
    lbDisplay.Items.Add("50% is Reserved in PBS1")
    fft += 1
    vs += 1
  ElseIf (fft < 2) Then
    lbPBS1.Items.Add("Available" & vs & " " & ffdad)
    ffdad = ffdad - (band - (band * 0.5))
    lbDisplay.Items.Add("50% is Reserved in PBS1")
    fft += 1
    vs += 1
  End If
End Sub
Private Sub FTimer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles FTimer.Tick
  If (fft < 2) Then
    lbPBS2.Items.Add("Available" & vs & " " & ffdad)
```

```
            ffdad = ffdad - (band - (band * 0.5))
            lbDisplay.Items.Add("50% is Reserved in PBS2")
            fft += 1
            vs += 1
        ElseIf (fft < 2) Then
            lbPBS2.Items.Add("Available" & vs & " " & ffdad)
            ffdad = ffdad - (band - (band * 0.5))
            lbDisplay.Items.Add("50% is Reserved in PBS2")
            fft += 1
            vs += 1
        End If
    End Sub
End Class


Public Class Route
    Sub New()
    End Sub
    Public Sub Send(ByVal sender As Collection, ByVal reciever As Collection)
        If (sender.Count > 0) Then
            reciever.Add(sender.Item(1))
            sender.Remove(1)
        End If
    End Sub
End Class

Public Class Point1
    Sub New()
        x = 0
        y = 0
    End Sub
    Dim x As Integer
    Dim y As Integer
    Sub New(ByVal newX As Integer, ByVal newY As Integer)
        x = newX
        y = newY
    End Sub
    Property XM() As Integer
        Get
            Return x
        End Get
        Set(ByVal Value As Integer)
            x = Value
        End Set
    End Property
    Property YM() As Integer
        Get
            Return y
        End Get
        Set(ByVal Value As Integer)
            y = Value
        End Set
    End Property
End Class


Public Class Packet
    Dim sourceAd As String
    Dim destinationAd As String
    Dim type As String
    Dim version As String
    Dim payload As String
    Dim con As Convert
    Dim FlowSpec As String
```

```
    Sub New()
        sourceAd = "00000000"
        destinationAd = "00000000"
        type = "00000000"
        version = "00000011"
        payload = "00000000"
        FlowSpec = "00000000"
    End Sub
    Sub New(ByVal source As Integer, ByVal dest As Integer, ByVal type As Integer, ByVal version As Integer, ByVal payload As
Integer, ByVal flowSpec As Integer)
        sourceAd = con.ByteToBinary(source)
        destinationAd = con.ByteToBinary(dest)
        type = con.ByteToBinary(type)
        version = con.ByteToBinary(version)
        payload = con.ByteToBinary(payload)
        flowSpec = con.ByteToBinary(flowSpec)
    End Sub
    Property SouceAdM() As String
        Get
            Return sourceAd
        End Get
        Set(ByVal Value As String)
            sourceAd = Value
        End Set
    End Property
    Property DestiAdM() As String
        Get
            Return destinationAd
        End Get
        Set(ByVal Value As String)
            destinationAd = Value
        End Set
    End Property
    Property TypeM() As String
        Get
            Return type
        End Get
        Set(ByVal Value As String)
            type = Value
        End Set
    End Property
    Property VersionM() As String
        Get
            Return version
        End Get
        Set(ByVal Value As String)
            version = Value
        End Set
    End Property
    Property PayloadM() As String
        Get
            Return payload
        End Get
        Set(ByVal Value As String)
            payload = Value
        End Set
    End Property
    Property FlowSpecM() As String
        Get
            Return FlowSpec
        End Get
        Set(ByVal Value As String)
            FlowSpec = Value
        End Set
    End Property
End Class
```

```
Imports System.IO
Imports System.Text
Public Class Convert
   Dim address As Byte
   Dim flowSpec As Byte
   Dim v() As Byte
   Public Sub New()

   End Sub
   Public Function ByteToBinary(ByVal bytLetter As Integer) As String
      Dim intLetter As Integer = bytLetter
      Dim intPowers() As Integer = New Integer() {1, 2, 4, 8, 16, 32, 64, 128}
      Dim strLetter As String
      For i As Integer = UBound(intPowers) To 0 Step -1
         If intLetter - intPowers(i) >= 0 Then
            intLetter -= intPowers(i)
            strLetter &= 1
         Else
            strLetter &= 0
         End If
      Next i
      Return strLetter
   End Function
End Class
```

```
Imports System.IO
Imports System.Threading
Imports System.Drawing
Imports System.Drawing.Drawing2D
Public Class Cell
   Public p As Point1() = New Point1(7) {}
   Dim x, y, i As Integer
   Public count As Integer = 0
   Sub New()

   End Sub
   Dim b As SolidBrush = New SolidBrush(Color.BlueViolet)
   Dim b1 As SolidBrush = New SolidBrush(Color.Khaki)
   Public Sub DrawCell(ByVal num As String, ByVal p1 As Point, ByVal p2 As Point, ByVal p3 As Point, ByVal p4 As Point, ByVal
p5 As Point, ByVal p6 As Point, ByVal drawself As Graphics, ByVal mypen As Pen, ByVal x As Integer, ByVal y As Integer)
      Dim style As FontStyle = FontStyle.Bold
      style = FontStyle.Bold Or FontStyle.Italic
      Dim cr As Font = New Font("Courier New", 14, style)
      p1 = New Point(x, y)
      p2 = New Point(x + 100, y)
      p3 = New Point(x + 150, y + 50)
      p4 = New Point(x + 100, y + 100)
      p5 = New Point(x, y + 100)
      p6 = New Point(x - 50, y + 50)
      Dim pts() As Point = {p1, p2, p3, p4, p5, p6}
      drawself.DrawPolygon(mypen, pts)
      Dim b As SolidBrush = New SolidBrush(Color.Black)
      drawself.FillRectangle(b, x + 50, y + 50, 10, 10)
      b.Color() = Color.Red
      drawself.DrawString(num, cr, b, x + 45, y + 35)
      p(count) = New Point1(x + 45, y + 35)
      count += 1
   End Sub
   Public Sub DrawCell(ByVal p1 As Point, ByVal p2 As Point, ByVal p3 As Point, ByVal p4 As Point, ByVal p5 As Point, ByVal p6
As Point, ByVal drawself As Graphics, ByVal x As Integer, ByVal y As Integer, ByVal br As Brush)
      p1 = New Point(x, y)
      p2 = New Point(x + 100, y)
```

```
p3 = New Point(x + 150, y + 50)
p4 = New Point(x + 100, y + 100)
p5 = New Point(x, y + 100)
p6 = New Point(x - 50, y + 50)

Dim pts() As Point = {p1, p2, p3, p4, p5, p6}
drawself.FillPolygon(br, pts)
End Sub
Public Sub MoveFP1ToP2(ByVal p1 As Point1, ByVal p2 As Point1, ByVal drawself As Graphics)

  'x = (p2.XM - p1.XM) / 6
  'y = (p2.YM - p1.YM) / 6

  If (p1.XM = p2.XM) Then
    If (p1.YM < p2.YM) Then

      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.YM += GetY(p1, p2)
    ElseIf (p1.YM > p2.YM) Then

      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.YM -= GetY(p1, p2)

    End If
  ElseIf (p2.YM < p1.YM) Then
    If (p1.XM < p2.XM) Then

      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.XM += GetX(p1, p2)
      p1.YM += GetY(p1, p2)
    ElseIf (p1.XM > p2.XM) Then

      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.XM += GetX(p1, p2)
      p1.YM += GetY(p1, p2)
    End If
  ElseIf (p2.YM > p1.YM) Then
    If (p1.XM < p2.XM) Then
      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.XM += GetX(p1, p2)
      p1.YM += GetY(p1, p2)
    ElseIf (p1.XM > p2.XM) Then
      drawself.FillRectangle(b, p1.XM, p1.YM, 5, 5)
      Thread.Sleep(500)
      drawself.FillRectangle(b1, p1.XM, p1.YM, 5, 5)
      p1.XM += GetX(p1, p2)
      p1.YM += GetY(p1, p2)
    End If
  End If
End Sub
Function GetX(ByVal p1 As Point1, ByVal p2 As Point1) As Integer
  Return (p2.XM - p1.XM) / 6
End Function
Function GetY(ByVal p1 As Point1, ByVal p2 As Point1) As Integer
  Return (p2.YM - p1.YM) / 6
End Function
```

```
End Class


Public Class BaseStation
    Dim APbs1 As Integer() = New Integer(2) {}
    Dim APbs2 As Integer() = New Integer(2) {}

    Dim rTotal As Random = New Random
    Dim rResev As Random = New Random
    Dim total, resev, Avialable As Integer
    Sub New()

    End Sub
    Public Function Generate() As Integer
        total = rTotal.Next(500, 1000)
        resev = rResev.Next(100, 400)
        Avialable = total - resev
        Return Avialable
    End Function
    Public Function LeftDand(ByVal avaliable As Integer, ByVal banbtoRes As Integer) As Integer
        Avialable = avaliable - banbtoRes
        Return Avialable
    End Function
    Property TotalM() As Integer
        Get
            Return total
        End Get
        Set(ByVal Value As Integer)
            total = Value
        End Set
    End Property
    Property ReserveM() As Integer
        Get
            Return resev
        End Get
        Set(ByVal Value As Integer)
            resev = Value
        End Set
    End Property
End Class


Public Class frmBand
    Inherits System.Windows.Forms.Form
    Dim gn As GenerateR = New GenerateR
    Public coll As ArrayList = New ArrayList
    Public newC As ArrayList = New ArrayList
    Public handOfC As ArrayList = New ArrayList
    Public DrobC As ArrayList = New ArrayList
    Public BlockC As ArrayList = New ArrayList
    Dim str, str1 As String
    Dim mg As Merge = New Merge
    Dim cl As Cell1 = New Cell1
    Dim r1, r2, r3, i, j As Integer
    Dim x1, x2, x3, x4, x5, x6 As Integer
    Dim stri As String = "nix"
    Public hour As Integer = 0
    Public min As Integer = 0
    Public sec As Integer = 0

#Region " Windows Form Designer generated code "

    Public Sub New()
        MyBase.New()
```

```
    'This call is required by the Windows Form Designer.
    InitializeComponent()

    'Add any initialization after the InitializeComponent() call

  End Sub

  'Form overrides dispose to clean up the component list.
  Protected Overloads Overrides Sub Dispose(ByVal disposing As Boolean)
    If disposing Then
      If Not (components Is Nothing) Then
        components.Dispose()
      End If
    End If
    MyBase.Dispose(disposing)
  End Sub


  Private Sub cmdExit_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdExit.Click
    Me.Close()
  End Sub

  Private Sub INCalls_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles INCalls.Tick
    Dim numbofReq As Integer = gn.GernRandomN(0, 3)
    gn.AttachClassAndTy(numbofReq)
    If (cl.ACBM() < cl.TotalBM And cl.ReBM <= cl.TotalBM) Then
      cl.AVBM() = cl.TotalBM - (cl.AVBM() + mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
      cl.ReBM() += mg.GetElementInColl(gn.Ccol1, r1).ReqBandM
      lblAvailable.Text = cl.AVBM()
      If (mg.GetElementInColl(gn.Ccol1, r1).cltypeM = "Ne") Then
        lstNew.Items.Add(mg.GetElementInColl(gn.Ccol1, r1).ClaM & "" & mg.GetElementInColl(gn.Ccol1, r1).cltypeM & "" &
mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
        newC.Add(gn.Ccol1(r1))
        x6 += 1
      Else
        lstHand.Items.Add(mg.GetElementInColl(gn.Ccol1, r1).ClaM & "" & mg.GetElementInColl(gn.Ccol1, r1).cltypeM & "" &
mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
        handOfC.Add(gn.Ccol1(r1))
        x6 += 1
      End If

      r1 += 1

    End If
    If (cl.ACBM() >= cl.TotalBM) Then
      If (mg.GetElementInColl(gn.Ccol1, r1).cltypeM = "Ne") Then
        Me.lstBlock.Items.Add(mg.GetElementInColl(gn.Ccol1, r1).ClaM & "" & mg.GetElementInColl(gn.Ccol1, r1).cltypeM & ""
& mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
        BlockC.Add(gn.Ccol1(r1))
        x6 += 1
      Else
        Me.ListDrop.Items.Add(mg.GetElementInColl(gn.Ccol1, r1).ClaM & "" & mg.GetElementInColl(gn.Ccol1, r1).cltypeM & ""
& mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
        DrobC.Add(gn.Ccol1(r1))
        x6 += 1
      End If
      r1 += 1
    End If
  End Sub

  Private Sub cmdStart_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdStart.Click
    cl.TotalBM = gn.GernRandomN(1000, 1500)
    lblTotal.Text = cl.TotalBM
    TMain.Start()
```

```
    continue()
  End Sub
  Function search(ByVal stra As String) As Boolean
    Dim found As Boolean = False
    For x3 = 0 To lstCell.Items.Count - 1
      If (lstCell.Items.Item(x3) = stra) Then
        found = True
        x3 = lstCell.Items.Count - 1
      End If
    Next
    Return found
  End Function
  Sub RemoveFromList(ByVal Array As ArrayList, ByVal lbox As ListBox)
    If (lbox.Items.Count > 0) Then
      Array.RemoveAt(0)
      lbox.Items.RemoveAt(0)
      lbox.Refresh()
    End If
  End Sub
  Sub puase()
    INCalls.Stop()
    TInHand.Start()
    OutCalls.Stop()
    RemFCell.Stop()
    Display.Stop()
    TTakeBand.Stop()
  End Sub
  Sub continue()
    INCalls.Start()
    TInHand.Start()
    OutCalls.Start()
    RemFCell.Start()
    Display.Start()
    TTakeBand.Start()
  End Sub
  Sub AddTLbox(ByVal array As ArrayList, ByVal lbox As ListBox, ByVal posi As Integer)
    lbox.Items.Add(mg.GetElementInColl(array, posi).ClaM & "" & mg.GetElementInColl(array, posi).cltypeM & "" &
mg.GetElementInColl(array, posi).ReqBandM)
    cl.ACBM() += mg.GetElementInColl(array, posi).ReqBandM
    cl.ReBM() -= mg.GetElementInColl(array, posi).ReqBandM
    lblActive.Text = cl.ACBM()
    lblReserved.Text = cl.ReBM()
    If (mg.GetElementInColl(array, posi).cltypeM = "Ne") Then
      RemoveFromList(gn.Ccol1, lstNew)
      r1 = gn.Ccol1.Count

    End If
  End Sub
  Sub FirstListToSecondList(ByVal lstOne As ListBox, ByVal scd As ListBox)
    scd.Items.Add(lstOne.Items.Item(0))
    cl.ReBM() -= GetNumber(lstOne)
    lstOne.Items.RemoveAt(0)
    lstOne.Refresh()
  End Sub
  Sub FListToList(ByVal lstOne As ListBox, ByVal scd As ListBox)
    scd.Items.Add(lstOne.Items.Item(0))

  End Sub


  Private Sub OutCalls_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles OutCalls.Tick
    If (lstNew.Items.Count > 0) Then
      FirstListToSecondList(lstNew, Me.lstCell)
      cl.ACBM += Me.GetNumber(lstCell)
      Me.lblActive.Text = cl.ACBM()
    End If
```

```
End Sub
Function GetNumber(ByVal lbox As ListBox) As Integer
   Dim str2 As String
   Dim x As Integer
   str = lbox.Items.Item(0)
   For i = 4 To str.Length - 1
      str1 &= str.Chars(i)
      str2 = str1
   Next
   str1 = ""
   Return Integer.Parse(str2)
End Function
Function GetNumber(ByVal st As String) As Integer
   Dim str2 As String
   str = st
   For i = 4 To str.Length - 1
      str1 &= str.Chars(i)
      str2 = str1
   Next
   str1 = ""
   Return Integer.Parse(str2)
End Function
Private Sub RemFCell_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles RemFCell.Tick

   If (lstCell.Items.Count > 0) Then
      cl.AVBM += Me.GetNumber(lstCell)
      cl.ACBM -= Me.GetNumber(lstCell)
      FirstListToSecondList(lstCell, lstHandoff)
      Me.lblActive.Text = cl.ACBM()
      lstCell.Refresh()
   End If
End Sub

Private Sub TMain_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles TMain.Tick
   Dim s As String = hour & ":" & min & ":" & sec
   sec = sec + 1
   If sec = 60 Then
      sec = 0
      min = min + 1
   End If
   If min = 60 Then
      min = 0
      hour = hour + 1
   End If
   If hour = 24 Then
      hour = 0
   End If
   lblTime.Text = "   " & s
End Sub

Private Sub TInHand_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles TInHand.Tick
   If (gn.Ccol1.Count > r1 And cl.ReBM <= cl.TotalBM) Then
      cl.AVBM() = cl.TotalBM - (cl.AVBM() + mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
      cl.ReBM() += mg.GetElementInColl(gn.Ccol1, r1).ReqBandM
      lblAvailable.Text = cl.AVBM()
      If (mg.GetElementInColl(gn.Ccol1, r1).cltypeM = "Ha") Then
         lstHand.Items.Add(mg.GetElementInColl(gn.Ccol1, r1).ReqBandM)
      End If

      r1 += 1

   End If
End Sub

Private Sub Display_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Display.Tick
```

```
    If (lstHand.Items.Count > 0) Then
      FirstListToSecondList(lstHand, Me.lstCell)
      cLACBM += Me.GetNumber(lstCell)
      Me.lblActive.Text = cLACBM()
    End If
End Sub
Sub BorrowBand()

    For j = 0 To lstCell.Items.Count - 1
      If (GetFstring(lstCell.Items.Item(j), 0, 1).Equals("C3")) Then
        TakeBand(j)
        stri = lstCell.Items.Item(j)
      End If
    Next
End Sub
Sub TakeBand(ByVal i As Integer)
    Dim s As Integer = Me.GetNumber(lstCell.Items.Item(i))
    s = s - 30
    cLAVBM() += s
    cLACBM() -= s
    Dim st As String = GetFstring(lstCell.Items.Item(i), 0, 3)
    lstCell.Items.RemoveAt(i)
    st &= s
    lstCell.Items.Insert(i, st)
End Sub
Function GetFstring(ByVal st1 As String, ByVal start As Integer, ByVal last As Integer) As String
    Dim str1 As String
    For i = start To last
      str1 &= st1.Chars(i)
    Next
    Return str1
End Function

Private Sub TTakeBand_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles TTakeBand.Tick
    If (lstCell.Items.Count > 1 And search(stri) = False) Then
      puase()
      BorrowBand()
      continue()
    End If
End Sub
Sub TestLateBinding()
    Dim xlApp As Object
    Dim xlBook As Object
    Dim xlSheet As Object
    Dim p, q As Integer
    ' Create a variable to hold a new object.
    xlApp = CreateObject("Excel.Application")
    'Late bind an instance of an Excel workbook.
    xlApp = GetObject("C:\Nyandeni\Masters\Results\FinalSimulation\Ssimulator\simulate\Result.XLS")
    xlApp.Parent.Windows(1).Visible = True
    xlApp.Application.Visible = True
    'Late bind an instance of an Excel worksheet.
    xlSheet = xlApp.Worksheets(1)
    xlSheet.Activate()
    xlSheet.Application.Visible = True ' Show the application.
    ' Place some text in the second row of the sheet.
    For p = 1 To x6
      For q = 1 To 2
        If (q = 1) Then
          xlSheet.Cells(p, q) = p
        Else
          xlSheet.Cells(p, q) = mg.GetElementInColl(gn.Ccol1, p - 1).ReqBandM()
        End If

      Next
```

```
    Next
    ' Place some text in the second row of the sheet.
    For x1 = 1 To newC.Count
      xlSheet.Cells(x1, 3) = mg.GetElementInColl(newC, x1 - 1).ReqBandM()
    Next
    ' Place some text in the second row of the sheet.
    For x2 = 1 To handOfC.Count

      xlSheet.Cells(x2, 4) = mg.GetElementInColl(handOfC, x2 - 1).ReqBandM()

    Next
    ' Place some text in the second row of the sheet.
    For x4 = 1 To BlockC.Count

      xlSheet.Cells(x4, 5) = mg.GetElementInColl(BlockC, x4 - 1).ReqBandM()

    Next
    ' Place some text in the second row of the sheet.
    For x5 = 1 To DrobC.Count

      xlSheet.Cells(x5, 6) = mg.GetElementInColl(DrobC, x5 - 1).ReqBandM()

    Next
    xlSheet.Cells(17, 6) = p - 1
    xlSheet.Cells(17, 7) = newC.Count + handOfC.Count
    xlSheet.Cells(17, 8) = newC.Count
    xlSheet.Cells(17, 9) = handOfC.Count
    xlSheet.Cells(17, 10) = Me.lstHandoff.Items.Count
    xlSheet.Cells(17, 11) = BlockC.Count
    xlSheet.Cells(17, 12) = DrobC.Count

  End Sub

  Private Sub cmdPause_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdPause.Click

    If (cmdPause.Text = "Pause") Then
      cmdPause.Text = "Restart"
      puase()
    Else
      cmdPause.Text = "Pause"
      continue()
    End If

  End Sub

  Private Sub cmdAnalysis_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cmdAnalysis.Click
    TestLateBinding()
  End Sub
End Class

Public Class Merge
  Dim cla, cltype As String
  Dim reqBand As Integer
  'Public Ccol1 As ArrayList = New ArrayList
  'Public Ccol2 As ArrayList = New ArrayList
  Sub New()
    cla = ""
    cltype = ""
    reqBand = 0
  End Sub
  Sub New(ByVal classof As String, ByVal rtype As String, ByVal request As Integer)
    cla = classof
    cltype = rtype
    reqBand = request
  End Sub
  Sub addToCall(ByVal Ccol1 As ArrayList)
```

```
      Ccoll.Add(New Merge(cla, cltype, reqBand))

    End Sub
    Public Function GetElementInColl(ByVal Ccoll As ArrayList, ByVal position As Integer) As Merge
      Dim ma As Merge
      If (position >= 0 And position < Ccoll.Count) Then
        ma = Ccoll.Item(position)
      End If
      Return ma
    End Function

    Property ClaM() As String
      Get
        Return cla
      End Get
      Set(ByVal Value As String)
        cla = Value
      End Set
    End Property
    Property cltypeM() As String
      Get
        Return cltype
      End Get
      Set(ByVal Value As String)
        cltype = Value
      End Set
    End Property
    Property ReqBandM() As Integer
      Get
        Return reqBand
      End Get
      Set(ByVal Value As Integer)
        reqBand = Value
      End Set
    End Property
  End Class

  Public Class GenerateR
    Sub New()

    End Sub
    Dim Rnum As Random = New Random
    Dim ma As Merge = New Merge
    Dim i As Integer
    'class and type of a request
    Public Ccoll As ArrayList = New ArrayList
    Dim CL As String() = New String() {"C1", "C2", "C3"}
    Dim RType As String() = New String() {"Ne", "Ha"}
    'generate a random integer
    Function GernRandomN(ByVal min As Integer, ByVal max As Integer) As Integer
      Return Rnum.Next(min, max)
    End Function
    'attaching class,type and request
    Sub AttachClassAndTy(ByVal number As Integer)
      For i = 0 To number
        ma = New Merge(CL(GernRandomN(0, 3)), RType(GernRandomN(0, 2)), GernRandomN(50, 150))
        ma.addToCall(Ccoll)
      Next
    End Sub

  End Class

  Public Class Cell1
    Sub New()
```

```
    End Sub
    Dim totalB As Integer
    Dim AVB As Integer
    Dim ReB As Integer
    Dim ACB As Integer
    Dim BoB As Integer

    Sub Swap()

    End Sub
    Function BorrowBand(ByVal minB As Integer) As Integer
        AVBM() = AVB - (minB - AVB)
        Return (minB - AVB)
    End Function
    Property TotalBM() As Integer
        Get
            Return totalB
        End Get
        Set(ByVal Value As Integer)
            totalB = Value
        End Set
    End Property
    Property AVBM() As Integer
        Get
            Return AVB
        End Get
        Set(ByVal Value As Integer)
            AVB = Value
        End Set
    End Property
    Property ReBM() As Integer
        Get
            Return ReB
        End Get
        Set(ByVal Value As Integer)
            ReB = Value
        End Set
    End Property
    Property ACBM() As Integer
        Get
            Return ACB
        End Get
        Set(ByVal Value As Integer)
            ACB = Value
        End Set
    End Property
    Property BoBM() As Integer
        Get
            Return BoB
        End Get
        Set(ByVal Value As Integer)
            BoB = Value
        End Set
    End Property
End Class
```