A Practical Assessment of Network Orientated Load Control for the Intelligent Network

by

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Thesis submitted as a requirement for the attainment of the degree of Masters of Engineering

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I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of MSc in Telecommunication is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work

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TABLE OF CONTENTS

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Abstract

The purpose of this thesis is to assess a new method of controlling load in Intelligent Networks (INs). This will be done through the analysis of experimentation results and comparison with existing methods of IN load control. This exercise will result in the investigation and validation of the proposed benefits being offered by this new methodology and the unveiling of its disadvantages. The methodology is known as network-orientated load control for the IN.

Network-orientated load control is demonstrated using the MARINER Service Traffic Load Control System developed by the European Commission's Advanced Communication, Technologies and Services (ACTS) Multi-Agent Architecture for Distributed Intelligent Network Load Control and Overload Protection (MARINER) Project. This system is shown to be a network-orientated load control application operating at the service level, built specifically for Intelligent Networks.

Network-orientated load control is then assessed by deploying the MARINER System on a model of the IN, and running an exhaustive series of experiments. These experiments are structured to test the proposed benefits, limitations and disadvantages of network-orientated load control.

The conclusions drawn from the results of these trials are then compared with existing IN load control characteristics, and used to make an assessment of network-orientated load control for the Intelligent Network.

Acknowledgements

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Finally, I would like to thank you, the reader, for acknowledging my work by attempting to assimilate it and possibly re-using it.

Thank you all.

1 INTRODUCTION

1.1 Motivation

The purpose of this thesis is to assess a new method of controlling load in Intelligent Networks (INs). This will be done through the analysis of experimentation results and comparison with existing methods of IN load control. This exercise will result in the investigation and validation of the proposed benefits being offered by this new methodology and the unveiling of its disadvantages. The methodology is known as network-orientated load control for the IN.

This document is suitable for both newcomers to the field of Intelligent Networks and Load Control, as well as experts interested in new methods of the application of Load Control to Intelligent Networks.

1.2 Objectives

The objectives of this body of work are as follows:

- The introduction and demonstration of network-orientated load control for the IN
- The validation of network-orientated load control through experimentation
- The comparison of network-orientated load control to existing IN load control methodologies
- The investigation of the limitations and disadvantage of network-orientated load control

1.3 Methodology

As a means of introducing and demonstrating network-orientated load control, the MARINER Service Traffic Load Control System developed by the European Commission's Advanced Communication, Technologies and Services (ACTS) Multi-Agent Architecture for Distributed Intelligent Network Load Control and Overload

Protection (MARINER) Project [MARINER] is used. The MARINER System is a network-orientated load control application operating at the service level, built specifically for Intelligent Networks.

Further, in order to accurately assess the operation of network-orientated load control, a model of the IN is used. This model emulates the operation existing Intelligent Networks conforming to the International Telecommunication Union IN Capability Set 2 [Q1200] standard.

The benefits, limitations and disadvantages of network-orientated load control is then investigated using an exhaustive set of trials on the IN model, with the MARINER System applied to it.

The conclusions drawn from the results of these trials are then compared with existing IN load control characteristics.

1.4 STRUCTURE

Chapter 2 introduces the Intelligent Network. This introduction includes a brief history of its development followed by a theoretic description of the Intelligent Network Conceptual Model (INCM). These descriptions are then enhanced by examples of existing service implementations. The chapter then explains the role of the Intelligent Network in today's context, and then focuses on load control elements of the INCM in line with the objectives of this document. An example of an Intelligent Network overload, occurring in April 2000, is then given as a means of analysing the operation and effectiveness of these load control elements in 'real' environments. Finally, the chapter concludes with a summary. Readers familiar with the Intelligent Network need not read this chapter.

Chapter 3 describes the Intelligent Network model used as the trial platform for the network-orientated load control methodology. It goes through the motivation and objectives of the model, as well as its design and development. This is followed by a description of the model structure and operation. A summary of the chapter is then presented.

Chapter 4 introduces the MARINER Service Traffic Load Control System as an implementation of network-orientated load control for Intelligent Networks. A description of the motivation and objectives of both network-orientated load control and the MARINER System is given. This is followed by a theoretical description of the operational algorithm and the system operation. Then a treatment of the implementation of the system is given, before the chapter is summarized.

Chapter 5 describes the experiments that were carried out on the MARINER System and their results. First, the experiment setup is described. This is followed by descriptions of the experiments and their results. These descriptions are categorized into three groups; the integration experiments, which investigate the validity of the MARINER System as a network-orientated load control system, and its integration to the IN.; the evaluation results, which evaluate the various aspects of the MARINER System; and the robustness experiments, which explore the limitations of the MARINER System. The chapter is then summarized.

Chapter 6 compares network-orientated load control to existing IN load control mechanisms and presents the conclusions of this body of work. First, the MARINER System is compared with three representative load control methodologies using the criteria and conclusions put forth in Chapter 5. Then, the thesis conclusions are presented, followed by a brief description of the future work to be carried out based on these conclusions.

2 THE INTELLIGENT NETWORK

2.1 INTRODUCTION

The Intelligent Network (IN) is an architectural concept that provides for the real time execution of network services and customer applications in a distributed environment of interconnected computers and switching systems. Its definition also includes support for the creation, implementation and management of these services and applications [Fayn96].

Instead of supporting the building of customised, performance-intensive services, it was realised quite early on that the IN would be much more useful and universally acceptable if it adhered to certain principles of independence. Namely,

- Service independence. The IN supports all services that use the common service independent building blocks (SIBS – see § 2.3.2). Among the current IN services are the Freephone service, the Virtual Private Network (VPN) service, the Ringback service and the Account Card Calling service.
- Switch independence. The IN maintains a clear logical separation between the service execution functions, and the basic switching functions.
- Network independence. Although first developed for the public switched telephone network (PSTN), the IN concept is applicable to several different types of networks, which include the mobile communications network, packet switched public data network (PSPDN), integrated service digital network – both narrow-band (N-ISDN) and broad-band (B-ISDN).

The rest of this chapter will provide a basic introduction to the Intelligent Network. First, a brief history is detailed. This is followed by a description of the Intelligent Network Conceptual Model. Then, examples of IN service implementations using this model are described. Following this is a section on the current and future role of the IN, followed by a focus on its load control abilities. Then, the chapter summary is presented.

2.2 HISTORY

It was not until 1986 that the phrase "Intelligent Network" had come to be associated with the architectural concept described above. However, its roots lie in the 1960s, when the first Stored Program Control Exchanges were deployed and introduced computer technology into the telecommunication network. These systems could support services such as Call Forwarding, Call Waiting and Centrex on a local level.

By the late 60s, rudimentary 800 number services, such as the Inward Wide Area Telecommunication Service (INWATS), were already available in long distance networks. These services were deployed on crossbar switches, which made implementation complex and cumbersome. In 1976, the advent of the first electronic switches in the AT&T long distance network greatly eased this burden.

However, it was only in the mid 70s, that the key innovation for IN was first deployed. The Common Channel Signalling No 6 (CC6, which was known as Common Channel Interoffice signalling or CCIS in the US) was initially used only for the transmission of address digits and trunk status information. It was soon proposed that the signalling system be used for communication between a network database and the switches in the network, and this laid the foundation for the IN concept.

In the early 80s, the concept saw fruition when two services based on it; the Calling Card and 800 number service (CCIS INWATS) were deployed. This development triggered work at Bell Labs of the US towards creating an open platform with primitive messaging between the switch and the service execution entity, which could be used to create different services. The initial result of these activities was the Direct Service Dialling Capabilities (DSDC) architecture and the first services implemented on it were the 800 number service and the Software Defined Network (SDN), the predecessor of the Virtual Private Network service. This architectural concept soon spread all over the globe, with France and Germany introducing the Freephone service in 1983 and the UK in 1985, using AT&T products. In Japan, NTT implemented its own Freephone service in 1985.

In 1984, Bell Systems was dissolved into the Regional Bell Operating Companies (RBOCs). As a result, Bellcore (the research company associated with the RBOCs) began work on the total separation of service features from the switching process, particularly influenced by the RBOCs multiple-vendor equipment supply. This first IN endeavour at the local network level resulted in a version of IN called IN2 which, while being very ambitious, was never realised. Then the Multivendor Interactions Forum was formed to include the many equipment vendors in the development process. What came out of it was the Advanced Intelligent Network (AIN) which is being implemented in the US in small steps (AIN 0.1 was launched in 1992) [Vasic99].

In 1989, the International Consultative Committee for Telegraph and Telephone (CCITT, now International Telecommunication Union or ITU-T) and the European Telecommunication Standardisation Institute (ETSI) started work on the standardisation of IN. A phase structured development process was started, which aimed to completely define the target IN architecture. Each phase of development intended to define a particular set of IN capabilities, known as Capability Sets, which contained the services and service features that could be constructed with the available functionality at that particular evolution of the IN. In March 1992, the first capability set (CS-1) was approved, but a revised version was released in 1995, known as CS-1R. Currently, the latest approved version is the CS-2.

2.3 THE CONCEPTUAL MODEL

The Intelligent Network Conceptual Model (INCM) was designed to incorporate the concepts which define the IN. In itself, it should not be considered to be an architecture, but rather a model for the design and description of Intelligent Networks [Q1201].

The INCM offers four different views of the IN, each on a different level of abstraction – called a "plane" – and defines the mapping between those views. These planes are depicted in Figure 2.1 [Q1201], each representing a different aspect of service building. The two upper planes focus on service creation and implementation, whereas the lower two planes addressing the physical IN architecture.

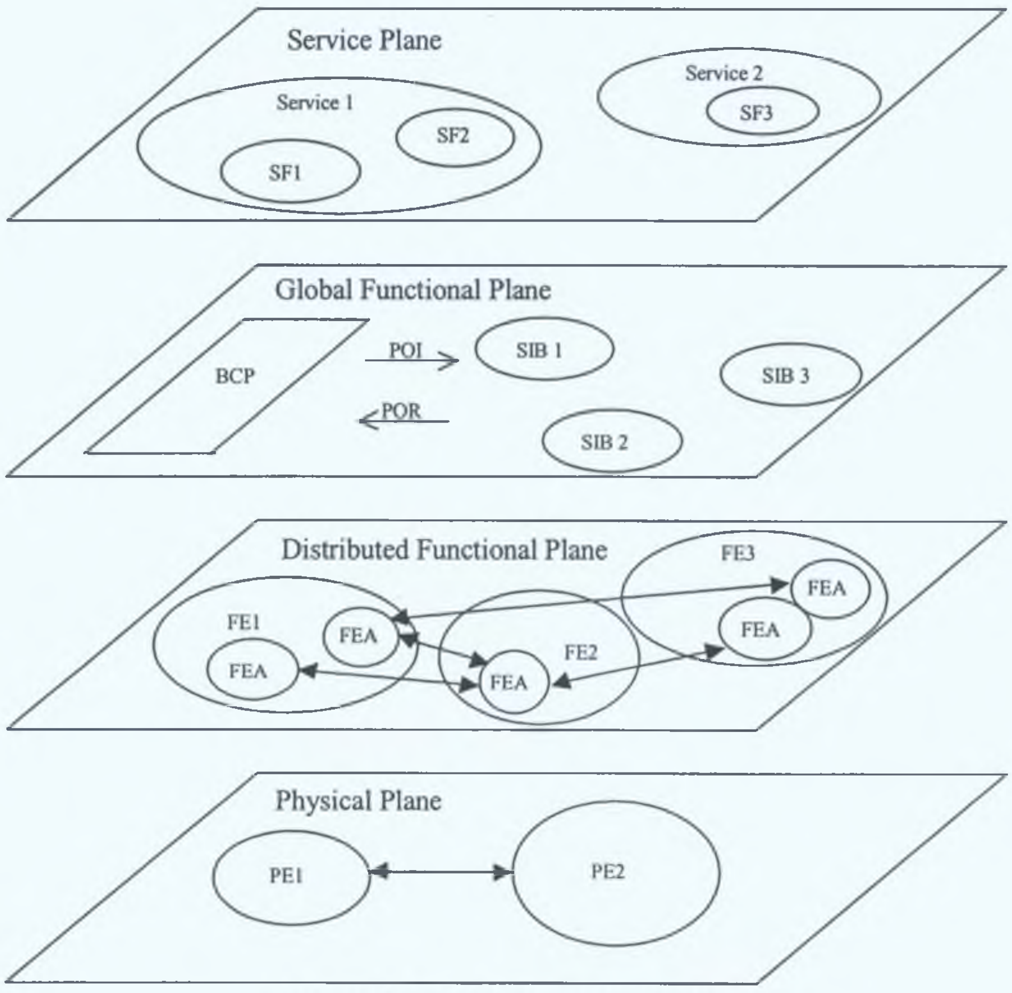


Figure 2.1 – IN Conceptual Model

2.3.1 Service Plane (SP)

This is the uppermost plane of the INCM, which offers the most abstract view of the Intelligent Network. It describes services from the user's perspective, and is not concerned with how the services are implemented within the network. The services are composed of one or more service features, which may either be core features that carry the main functionality of the service, or optional parts offered as enhancements to the telecommunication service [Q1202][Q1222].

2.3.2 Global Functional Plane (GFP)

The plane second from the top presents a view demonstrating the IN view of service creation by putting together modules of reusable network functionality. It does not include a view of the network and its details. These "modules of reusable network functionality" are called Service Independent Building Blocks (SIBs) and have formal descriptions that include service-specific and instance-specific parameters, possible execution outcomes and results, as well as errors that may occur.

The Basic Call Process (BCP) is a special SIB that is invoked for all calls, and handles basic connectivity. Services in the SP are described in the GFP in terms of the point at which the BCP should be interrupted (Point of Initiation or POI), the chain of SIBs that need to be executed, and the point at which the BCP is resumed once the IN-specific processing is completed (Point of Return or POR). Figure 2.2 illustrates service description in the GFP [Q1203][Q1223].

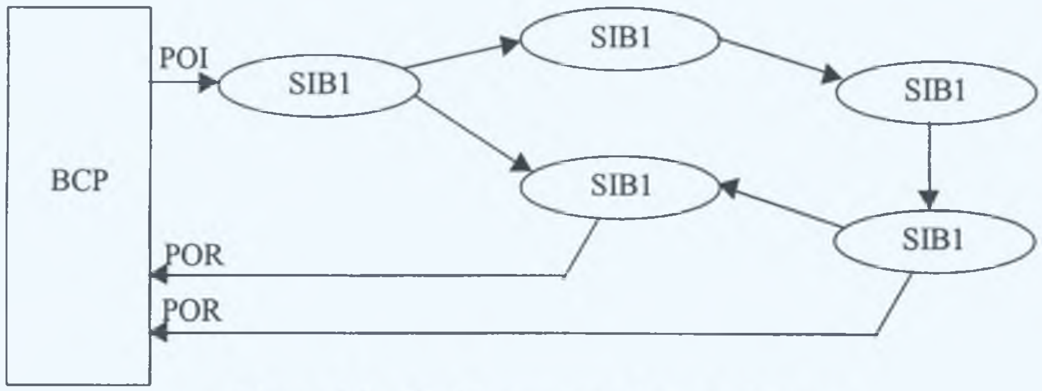
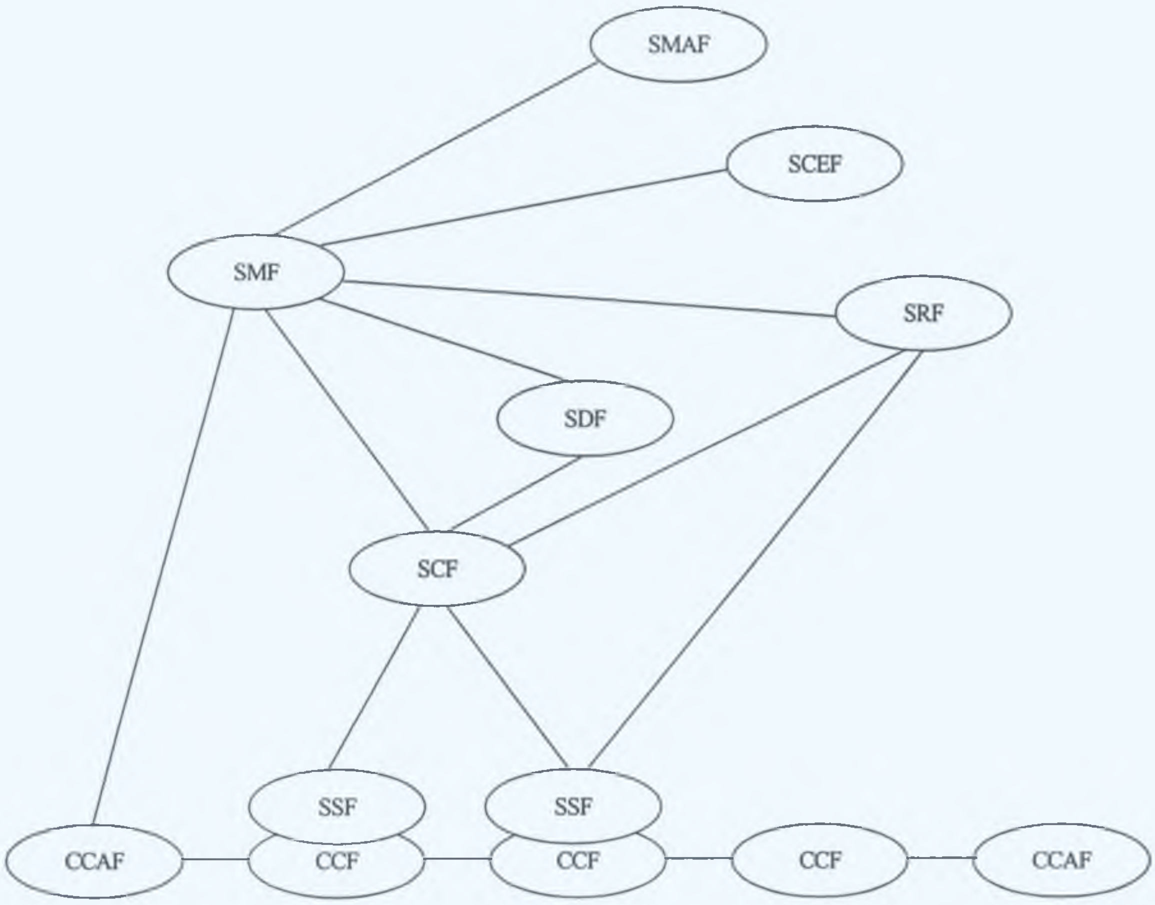


Figure 2.2 – GFP Representation of a Service

2.3.3 Distributed Function Plane (DFP)

This plane offers a view of the network as a collection of Functional Entities (FEs). The physical location of these functional entities is not visible. Each FE can perform a number of Functional Entity Actions (FEAs) and the FEs communicate by sending Information Flows (IFs) to each other. The FEAs are further broken up into Elementary Functions (EFs). SIBs in the GFP are realised in the DFP by a sequence FEAs and their resulting IFs. Figure 2.3 depicts the IN DFP Model [Q1204][Q1224].



CCAF – Call Control Agent Function
CCF – Call Control Function
SCEF – Service Creation Environment Function
SCF – Service Control Function
SDF – Service Data Function
SMAF – Service Management Access Function
SMF – Service Management Function
SRF – Service Resource Function
SSF – Service Switching Function

Figure 2.3 – The IN Distributed Function Model

The following FEs are related to the execution of IN services:

- The *Call Control Agent Function (CCAF)* provides the user with access to the network and serves as an agent between the user and the service-providing capabilities of the Call Control Function.
- The *Call Control Function (CCF)* carries the basic call and/or connection functionality, acting at the request of the CCAF. It provides triggers for accessing IN functionality.
- The *Service Switching Function (SSF)* processes the triggers received from the CCF and identifies the service control triggers. It manages the signalling between the CCF and the SCF and modifies the call processing in the CCF, when requested by the SCF. The CCF and SSF are tightly coupled and are usually implemented together. The reason they are maintained as separate FEs is that the SSF is used to represent the IN-specific part of the switching functionality. The CCF, on the other hand, represents the non-IN, basic call processing functionality.
- The *Service Control Function (SCF)* is the central functional entity of the IN. It controls the execution of IN implemented services. It performs service processing primarily through the communication with the SSF, from which requests for processing arrive and to which the SCF sends related call control instructions. The SCF also interacts with SDF to get or set network-stored information required by the service and with the SRF when special resources are required.
- The *Service Data Function (SDF)* contains customer and network data and is queried by the SCF during service processing.
- The *Service Resource Function (SRF)* contains specialised hardware resources required for IN services, mainly for user interaction, such as announcement players, tone generators, voice recognition and digit collection devices. Other SRFs include text to speech synthesisers, protocol converters and conference bridges. It is controlled during service processing through interactions with the SCF.

The FEs related to service creation and management are described below:

- The *Service Creation Environment Function (SCEF)* provides an environment for the definition, development, testing and online deployment of services.
- The *Service Management Access Function (SMAF*) is the equivalent of the CCAF in the service management domain of the IN. It provides managers with access to the SMF.
- The *Service Management Function (SMF)* allows the deployment and provision of IN services and manages and updates most of the other FEs (CCF, SSF, SCF and SDF). It also provides online management functions, such as the collection of billing and statistical information.

2.3.4 Physical Plane (PP)

On the physical plane, a full view of the physical network is available. It shows the Physical Entities (PEs) present in the network and where the functional entities are located, in terms of physical entities. The PEs associated with IN service execution are as follows:

- The *Service Switching Point (SSP)* is a switch that contains the CCF and the SSF. In the case that it is a local exchange, it also contains the CCAF
- The *Service Control Point (SCP)* contains the SCF and may also contain the SDF.
- The *Service Data Point (SDP)* contains the SDF.
- The *Intelligent Peripheral (IP)* contains the SRF and possibly a CCF/SSF to provide external access to its switching matrix.

The service creation and management PEs are listed below:

- The *Service Management Point (SMP)* contains the SMF and possibly the SMAF when the manager is working directly on the SMP machine. It may also include the SCEF.
- The *Service Creation Environment Point (SCEP)* contains the SCEF.
- The *Service Management Access Point (SMAP)* contains the SMAF. It is a point of access for a manager to the SMP and behaves like a terminal attached to the SMP.

There are three other PEs defined in for the IN which, unlike those listed above, do not have a one-to-one mapping with a FE.

- The *Adjunct (AD)* operates somewhat like the SCP, with the exception that it is directly connected to the SSP without a signalling network separating the two. The AD is used mainly when high-speed communication between the two entities is required.
- The *Service Node (SN)* is similar to the AD in that it is directly connected to an SSP. However, apart from a SCF, it also contains a SDF, SRF and a CCF/SSF. The CCF/SSF is not accessible from outside the SN, while the SRF has such accessibility. The SN may be used as any other IP by any SCF.
- The *Service Switching and Control Point (SSCP)* combines the SSP and SCP in one node. It contains the SCF, SDF, CCAF, CCF SSF and possibly the SRF. Although the functionality provided is the same as that of a separate SSF and SCF, the interfaces between these FEs within the SSCP are proprietary [Q1205].

An important aspect of this view of the IN is the definition of protocols, which are used for the communication between PEs, depending on which FEs they contain. The protocol used is known as the Intelligent Network Application Protocol (INAP). It is a user of the Remote Operations Service Element (ROSE) protocol, which contains primitives suitable for communication between physically remote entities and is standardised through the ITU-T recommendations X.219 and X.229. ROSE, in its turn, is contained in the upper layer of the Transaction Capabilities Application Part (TCAP) [Q771]. TCAP may use the lower layers of most protocols for network layer functionality, and in the case of INAP, the SS7 signalling stack is used [Q1208][Q1228].

2.4 EXAMPLE SERVICE IMPLEMENTATIONS

This section introduces the possible implementations of three IN services using the four views described in the INCM. These services are also those that were implemented in the IN Model described in Chapter 3.

2.4.1 The Restricted User Service

2.4.1.1 SP View

Basic call forwarding allows the user to redirect incoming calls to a different number transparent to the calling party. The Restricted User Service is a variation of this service, in which the calling party must enter a specified Personal Identification Number (PIN) before the call is forwarded to the other number [MARINERD4].

2.4.1.2 GFP View

This service comprises the following SIBs:

- *Basic Call Processing (BCP) – Initial Message Flows*

  This SIB sets a trigger for incoming calls to the service user. In the event of an incoming call, the SIB initiates the chain of SIBs required to execute this service.

- *User Interaction*

  This SIB prompts the calling party for the PIN number, and collects the digits.

- *Verify*

  This SIB verifies the PIN number.

- *BCP – Call Setup*

  This SIB connects the calling party to the forward destination.

2.4.1.3 DFP View

The DFP view for this service is illustrated by the Information Flows between the Functional Entities in Figure 2.4.

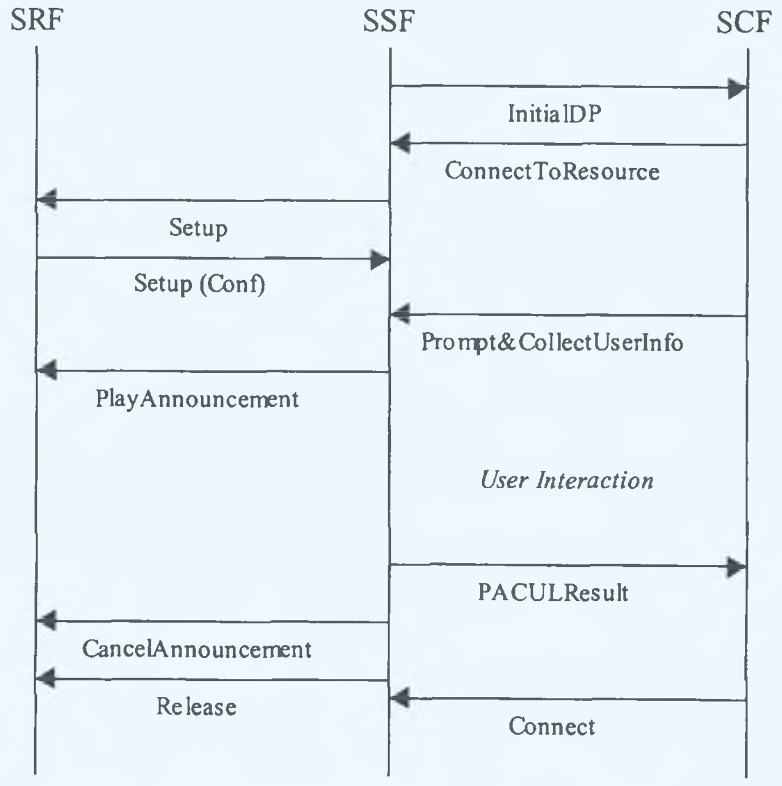


Figure 2.4 – Information Flows of Restricted Access Call Forwarding Service

2.4.1.4 PP View

The Physical Entities utilised for this service are the IP, SSP and SCP.

2.4.2 The VPN Service

2.4.2.1 SP View

The VPN Service creates a logical sub-network spanning a single or multiple IN network domains, which appears to a specific group of users as a private network, providing the type of services normally associated with private exchanges [MARINERD4].

2.4.2.2 GFP View

This service comprises the following SIBs:

- *Basic Call Processing (BCP) – Initial Message Flows*

  This SIB arms a trigger for users who initiate this service during call processing. When the trigger is encountered, the SIB initiates the chain of SIBs required to execute this service.

- *Status Notification*

  This SIB captures the private number of the called party input by the calling party.

- *Translate*

  This SIB checks the private number against the network database and gets the network number of the called party

- *BCP – Call Setup*

  This SIB connects the two parties. It them monitors for an off-hook by the calling party and ends the service processing.

2.4.2.3 DFP View

The DFP view for this service is illustrated by the Information Flows between the Functional Entities in Figure 2.5.

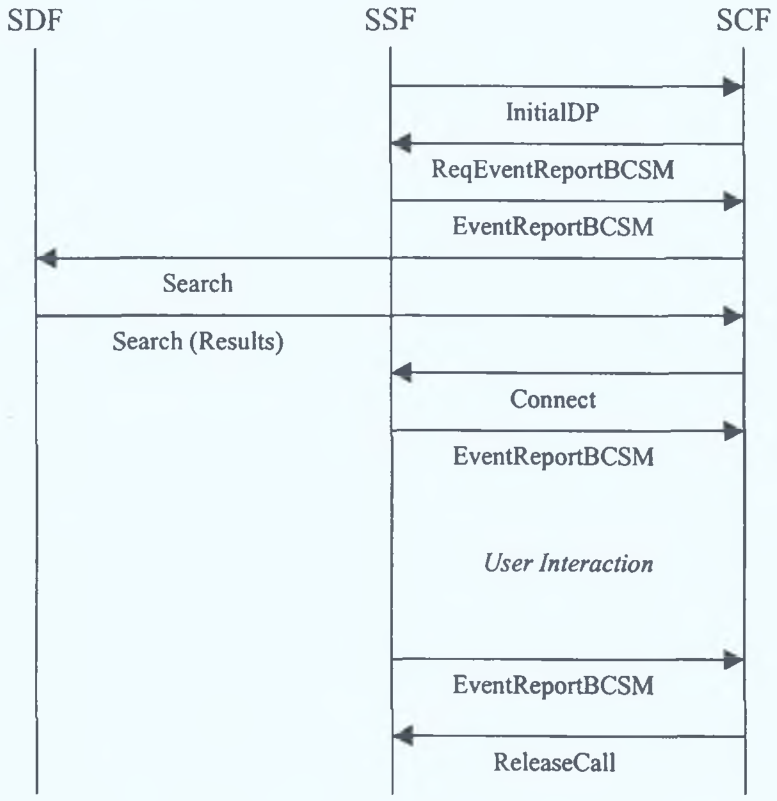


Figure 2.5 – Information Flows of VPN Service

2.4.2.4 PP View

The Physical Entities utilised in the VPN service are the SDP, SSP and SCP.

2.4.3 The Automated Ringback Service

2.4.3.1 SP View

This service allows a calling party, upon receipt of an engaged tone for a specific called party, to request that a call be automatically initiated to that called party once their present call has been terminated [MARINERD4].

2.4.3.2 GFP View

This service comprises the following SIBs:

- *Basic Call Processing (BCP) – Initial Message Flows*

  This SIB arms a trigger for users who initiate this service during when the engaged tone is encountered. When trigger is set off, the SIB initiates the chain of SIBs required to execute this service.

- *User Interaction*

  This SIB informs the calling party that the ringback service is in operation.

- *BCP – Event Report*

  This SIB monitors for the termination of the called party's present call.

- *BCP – Call Initiation*

  This SIB initiates a call to the called party and monitors for an off-hook.

- *BCP – Call Setup*

  This SIB re-connects to the calling party and monitors for an off-hook.

  - *BCP-Call Setup*

  This SIB returns both parties to normal call processing.

2.4.3.3 DFP View

The DFP view for this service is illustrated by the Information Flows between the Functional Entities in Figure 2.6.

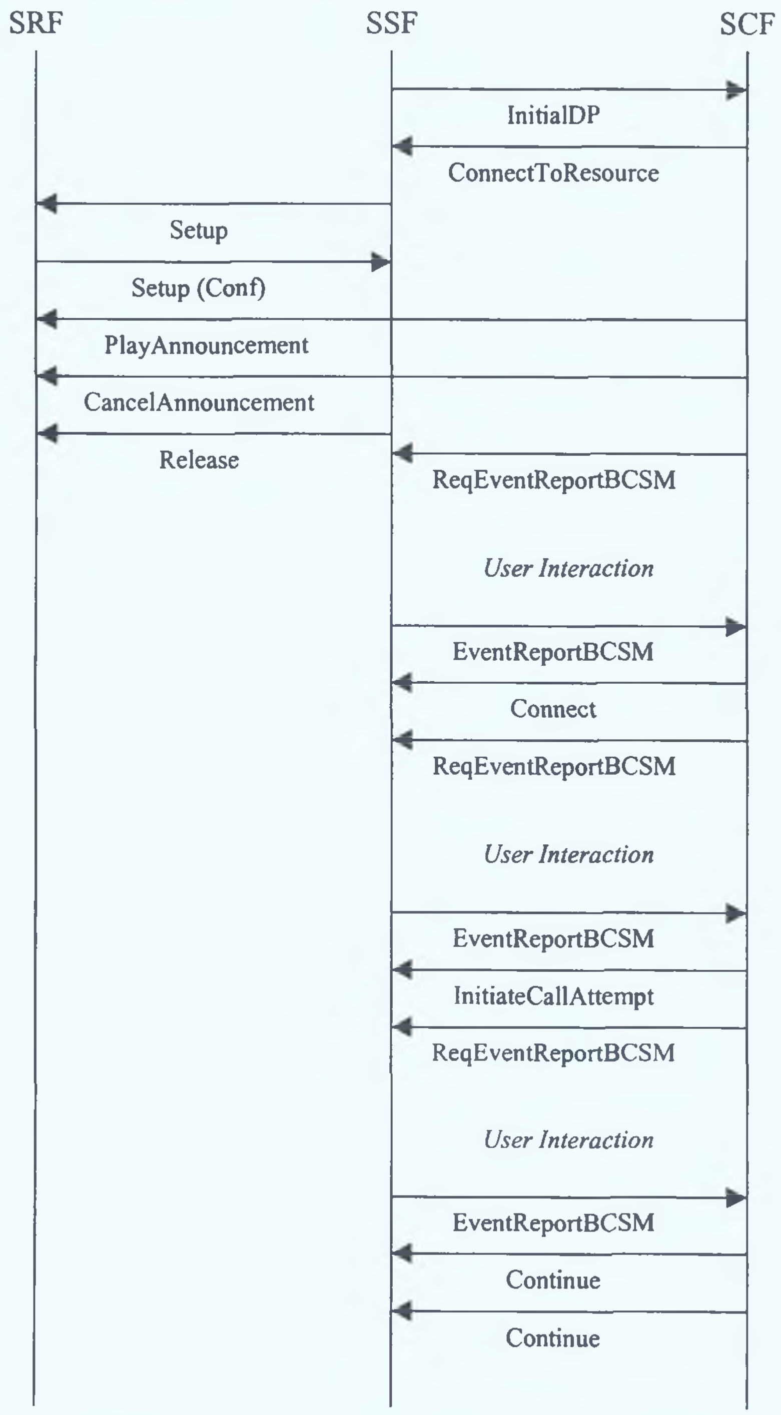


Figure 2.6 – Information Flows of Ringback Service

2.4.3.4 PP View

The Physical Entities utilised in the Automatic Ringback service are the IP, SSP and SCP.

2.5 Current and Future Role Of The intelligent Network

Today, more than 80% [Mine98] of the PSTN operators use the IN, or one of its derivatives, to execute telecommunication services. These services range from, Automated Ringback to Telebanking.

With the IN having had the lion's share of investment and customer trust for so long, operators moving to wireless technologies such as GSM and GPRS, as well as Internet Telephony, want to maintain the IN as the de facto telecommunication service execution architecture. Research projects such as the EURESCOM's P916 [P916] and ETSI's TIPHON [TIPHON] are currently attempting to standardise methods in which this can be achieved.

2.6 Load Control Mechanisms

The IN CS-2 provides two mechanisms for controlling the traffic going into an SCF, in the event of congestion. These are Call Gapping and the Service Filter SIB [Q1224].

- Call Gapping – This mechanism is activated by the SCP, upon congestion, by sending a Call Gap request to the SSP. It involves the use of a timer set to expire after a gap interval *g*. For each call arriving at the switch, the gap interval timer is checked. If the timer is inactive, the call is accepted and the timer is set. Until this timer expires, all further arriving calls will be unconditionally blocked. After the gap interval has elapsed and the timer is inactivated, the first call to arrive is accepted and serviced and the gap interval timer is set again. This mechanism is illustrated in Figure 2.6 [Tsolas92].

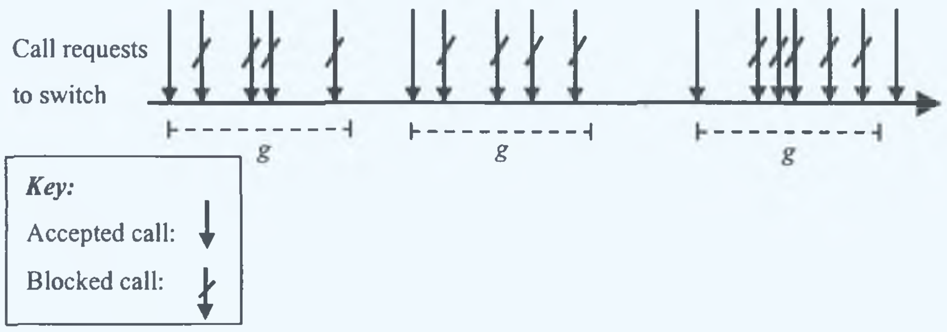


Figure 2.9 - Call Gapping Mechanism

- Service Filter SIB - the SIB limits the number of calls that are allowed through an IN by filtering calls with given characteristics. The filtering is applied only to those calls related to IN-provided service features that request the assistance of IN functions. Calls are blocked at the SSP and provided treatment for a specified duration (which may be infinite) at specified intervals. Service Filter is initiated by the subscriber.

These mechanisms have the following characteristics:

- reactive – they react to a resource overload after it has commenced, rather than ensuring that traffic is prevented from gaining access to the resource in instances where it would cause one or more resources to overload. More predictive controls that 'see' and control overloads as it approaches would be more efficient;
- node-oriented - they aim to protect individual resources from overload. Lack of interaction between independent controls can have undesirable effects, such as the propagation of overload throughout the network. A network-oriented approach, where control decisions are co-ordinated in a manner that ensures optimal performance of the network as a whole would be more desirable;
- static – they rely on static parameters to control traffic load, therefore they cannot provide optimal control in all traffic conditions, with the result that they tend to cause oscillations in resource utilisation. In addition use of static control parameters makes them difficult to configure in large-scale networks that may provide a changing mix of service offerings. To overcome these difficulties dynamic controls, which continually compute control parameters based on information regarding current traffic conditions are required;

- operate at a low level (typically throttling requests based on dialled digits) – they cannot provide a sufficient degree of differentiation between service types and traffic sources. Application-level controls, which are straightforward to configure, would allow the network operator greater flexibility in the setting of priorities between service types, thereby helping to ensure that Quality-of-Service constraints specified in Service Level Agreements (SLAs) are always met.

The next section illustrates these characteristics through a brief case study of an Intelligent Network overload that occurred in Easter 2000.

2.6.1 Intelligent Network Overload Case Study

In Easter 2000, an Intelligent Network utilising the Call-Gapping load control mechanism experienced abnormal continuous spiky traffic, which lead to a network-wide crash. The sequence of events was as follows [Khorasani01]:

- early that morning, all set-top boxes of a certain Satelite Television Operator (STO) began pushing calls to the STO's 0800 number . These boxes were configured to repeat calls to engaged destination numbers for a fixed period, then sleep for a while and try again. This pattern was repeated for a day.
- the Intelligent Network SCP node started to get flooded with 0800 calls, and triggered call gapping. However, due to a miss-configuration, the SSP it was coupled to did not correctly interpret the call gapping messages and continued to flood the SCP with requests. Simultaneously, the SSP itself ran out of resources and started issuing "resource limitation" signals requesting the SCP to reject incoming requests. The SCP however, possibly due to the tremendous load, ignored these requests, which lead to the congestion of the SS7 signalling links and the crash of the SSP.
- The backup and redundancy systems of the network then began redirecting the traffic to other SSP-SCP couplings, which also subsequently crashed. This was possibly due to a combination of existing high traffic levels and the abnormal call-flows being seen. This lead to the falling over of a large portion of the network within 5 hours.

2.7 SUMMARY

The Intelligent Network (IN) began as Stored Program Control Exchanges in the 1960's. Since then, it evolved into an architectural concept that provides for the real time execution of network services and customer applications in a distributed environment of interconnected computers and switching systems.

This concept is formalised in the Intelligent Network Conceptual Model (INCM). The INCM offers four different views of the IN, each on a different level of abstraction – called a "plane" – and defines the mapping between those views. The two upper planes focus on service creation and implementation, whereas the lower two planes address the physical IN architecture. Staring from the uppermost plane, they are the

- Service Plane - it describes services from the user's perspective, and is not concerned with how the services are implemented within the network
- Global Function Plane – it presents the IN view of service creation by putting together modules of reusable network functionality. It does not include a view of the network and its details.
- Distributed Function Plane - it offers a view of the network as a collection of Functional Entities (FEs). The physical location of these FEs is not visible.
- Physical Plane - it shows the Physical Entities (PEs) present in the network and where the functional entities are located, in terms of physical entities.

Currently, the IN hosts a multitude of services to a major part of the telecommunication service customer base. Further, current research trends point towards the extension of the use IN into the wireless communication and Internet domains.

With so much reliance on this architecture, its load control capabilities have become of paramount importance to network operators. Currently, these capabilities are limited to static, localised, message level gapping mechanisms initiated by the network resource when it experiences an overload. The Easter 2000 crash clearly illustrates that these mechanisms are circumspect and not robust enough to handle unpredictable traffic conditions.

3 THE INTELLIGENT NETWORK MODEL

3.1 INTRODUCTION

The previous chapter described the Intelligent Network Conceptual Model (INCM) through its four levels of abstraction. This chapter goes on to describe a software model of some of the Functional Entities of the INCM built according to the definitions set out in the Distributed Functional Plane level of abstraction. This is done through the description of the design, development and operation of the model. First however, the motivation and objectives of the model is presented.

3.1.1 Motivation

The IN model was built to fill the need for a tool with which the performance of new IN applications and services could be tested and realistically evaluated before their deployment on 'live' networks. The scope of the usage this tool is as follows:

- an application development test-bed upon which a mechanism could be exposed to various extremes in real environments and improved to show better performance and robustness
- a simulation environment with which the performance of existing networks could be used as benchmarks
- an evaluation platform upon which the relevant performance meters of an application or service could be measured and reported.

This model was used to test and evaluate the MARINER Service Traffic Load Control System (described in Chapter 4) as an enhancement to the existing IN load control mechanisms as described in § 2.6

3.1.2 Objectives

The motivations of the IN model resulted in a set of objectives that governed the following stages of its development. These objectives are as follows:

- To operate according to the definitions set out in the IN Capability Set 2 Distributed Functional Plane.
- To reflect the operation of currently deployed INs as closely as possible.
- To match the performance of currently deployed INs within the limitation set by the scale of the model.
- To be easily configurable for any number of nodes.
- To easily enable the introduction and execution of any number of service types.
- To enable the modelling the different incoming service traffic load patterns.
- To enable the user to monitor the performance of the individual IN nodes and the network as a whole.

3.1.3 Design and Development

The realisation of the above objectives posed certain requirements on the development process of the model. The model had to be distributed, flexible, platform independent and robust.

- Distribution - In order to accurately reflect a real network, the modelled IN entities had to be distributed, operating independent of each other.
- Flexibility - the emulation of differing numbers of entities, service types and traffic patterns required that the model be flexible enough to easily accommodate the introduction and withdrawal of IN entities and service types, and changes in service request arrival rates.
- Independence – in order for the model to operate over large distributed systems, it had to be independent of the various operating systems used.

- Robust – in order to reliably carry out the trials and experiments with various traffic loads, the model had to be robust, with well-defined error conditions and recovery mechanisms.

These characteristics in turn shaped the design methodology and the choice of implementation tools.

- Common Object Request Broker Architecture (CORBA) – using CORBA allowed for the implementation of distributed software entities which seamlessly located and communicated with each other. This allowed the model to be distributed.
- Object Orientation (OO) – using the OO methodology in the design allowed for a completely modular implementation, which easily accommodated the introduction and withdrawal of various objects. This allowed the model to be flexible.
- Java – the need for platform independence, and the use of OO, made Java the natural choice of an implementation language. It also made it relatively easy to implement a Graphic User Interface to the model for monitoring purposes.

3.2 Structure and Operation

The figure below illustrates the entities that comprise the IN Model, and their inter-relations. The many-to-one connections of SSF to SCF was based on IN models appearing in [Nyberg94][Kihl99][Kwiatkowski94].

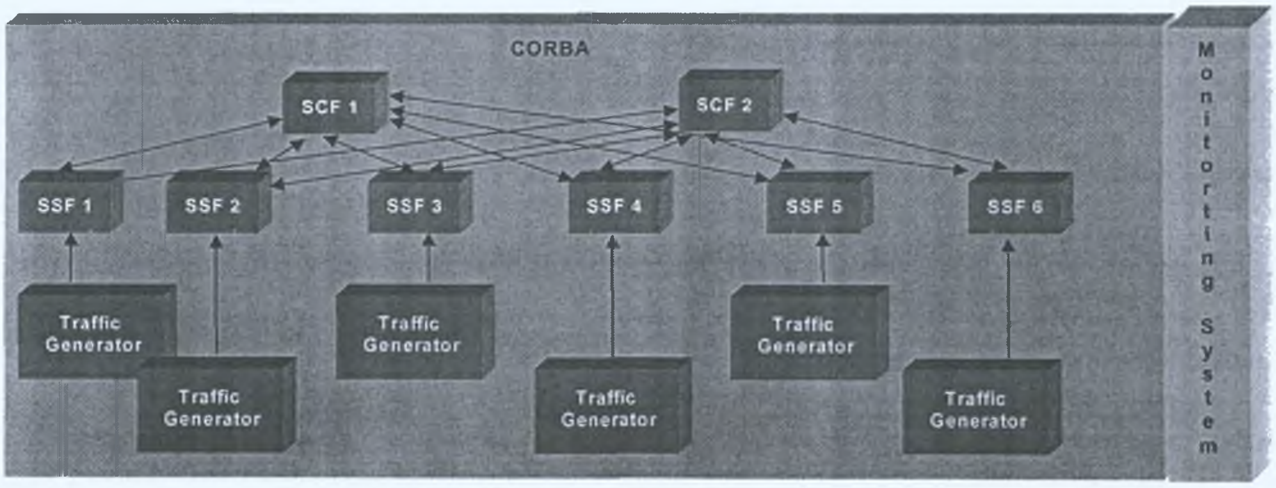


Figure 3.1 – The IN Model

The rest of this section will explain the operation of these entities individually.

3.2.1 Service Switching Function

The SSF is structured as illustrated in Figure 3.2.

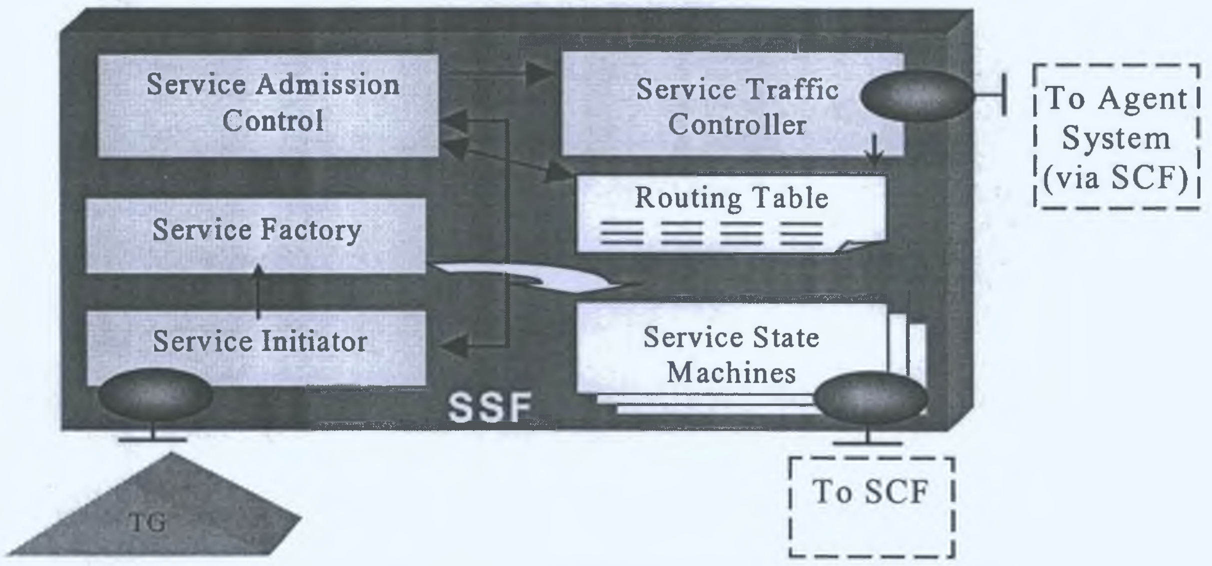


Figure 3.2 – SSF Structure

The following steps describe the operation of the SSF [MARINERD8]:

- The Traffic Generator sends a service request to the SSF interface
- The Service Initiator queries the Service Admission Control on whether to accept the service request
- The Service Admission Control informs the Service Traffic Controller of the incoming request and checks Routing Table for an execution SCF address for that service type. If one exists, the SCF address is returned to the Service Initiator with a positive query result.
- The Service Initiator starts a Service Factory, which creates the Service State Machine for that particular service type.
- The Service State Machine executes the SSF side states for the service type and communicates INAP operations with the SCF

- The Service Traffic Controller monitors the service request arrival rate and updates the Routing Table with service type SCFs

3.2.2 Service Control Function

The SCF structure is illustrated in Figure 3.3.

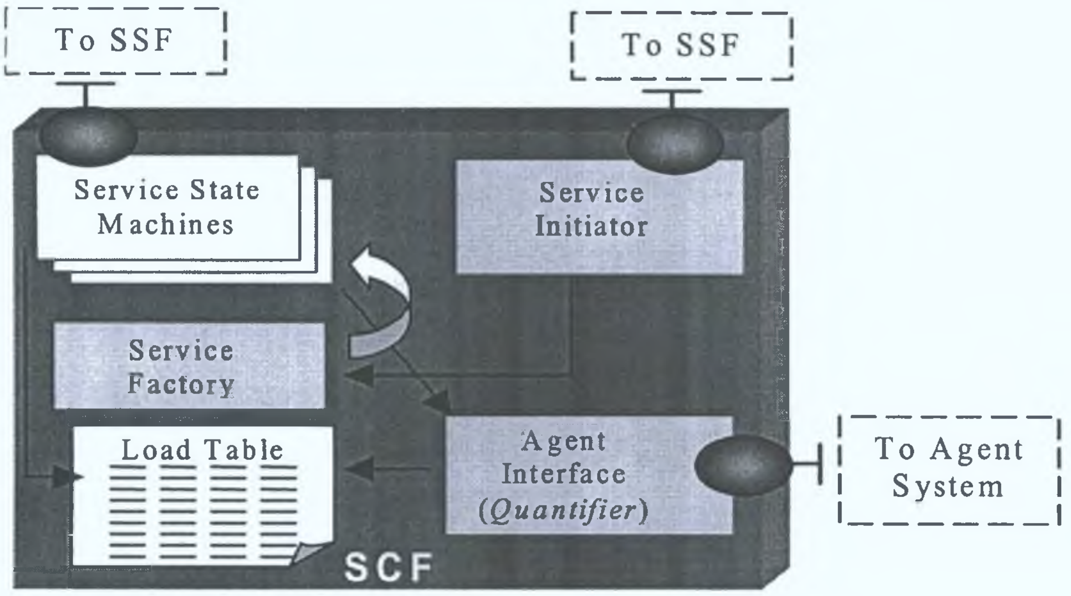


Figure 3.3 – SCF Structure

The following steps describe the operation of the SCF [MARINERD8]:

- On receiving a service execution request from the SSF, the Service Initiator starts a Service Factory.
- The Service Factory creates the Service State Machine for the service type requested.
- The Service State Machine executes all the SCF side states of the service type and communicates the service INAP operations with the SSF.
- The Service State Machine Interface also forwards messages to and from the SSF Service Traffic Controller to the Agent Interface.
- The Agent Interface provides the Agent System with all the information pertaining to the SCF load and processing capacity, and traffic arrival rates at the SSFs.

3.2.3 Traffic Generators

The Traffic Generator generates service requests to the SSF. The service requests are generated randomly from a Poisson distribution with a configurable mean arrival rate. The TG also contains the functionality to trigger an immediate or delayed burst in traffic to allow for the modelling of bursty and unpredictable traffic patterns.

3.2.4 Monitoring System

The monitoring system was designed to provide both a long and short-term view of the operation of the IN Model. Performance information is periodically extracted from the various entities of the IN Model. This information is then fed into a Graphic User Interface (GUI) and saved to a spreadsheet.

The GUI provides the user with the real time performance of the model through various micro and macro views of the user's choice.

The spreadsheet provides the user with long term trends in the model's performance through various graphs of the user's choice.

3.3 Summary

This chapter introduced and described the IN Model. It was built as a tool for the gauging of the performance of most new mechanisms and applications built for the IN. In doing so, a set of objectives was developed for the model.

These objectives stressed that the model be conformant to the current IN standards, and perform within the limitations of currently deployed INs. They also required that the model be scaleable, flexible and configurable so as to model the various network environments and incoming traffic patterns. Further, the need for a means of monitoring the performance meters of the model was stressed.

In order to meet these objectives, the model had to be designed to be distributed, system independent, flexible and robust. These design constraints led to the choice of methodology and implementation tools that were used in the development of the model.

Finally, this chapter detailed the structure and operation of the model as a whole, and each of its entities individually.

The IN model described in this chapter was developed as part of the MARINER Project. This candidate was responsible for the design and development of all the components of the IN model. This endeavour however, would have been impossible without the guidance and advice of the rest of the MARINER Project participants, especially the TELTEC IN Group.

Chapter 5 of this document will describe and illustrate examples of the successful usage of the IN model in evaluating the MARINER Service Traffic Load Control System.

4 NETWORK ORIENTATED LOAD CONTROL: THE MARINER SYSTEM

4.1 INTRODUCTION

Changing regulatory environments world-wide are driving the evolution towards a more open communication infrastructure, with an ever increasing number of licensed carries and service providers demanding interconnects at different functional levels. Exposure to the Internet has raised customer expectations for the types of services that should be offered by the public telecommunications infrastructure, principally that they support a mix of media types, can be customised to meet the individual's needs and that they will be available on-demand, regardless of user location or terminal equipment capabilities. These trends are encouraging development of more open, technologically heterogeneous and dynamically evolving networks where the task of dimensioning resources to meet the performance requirements of an, as yet unknown, set of services and their associated usage demands is increasingly difficult. In this context the requirement for a managed load control system is becoming more and more a necessity when designing a service environment that will meet the prevailing commercial and regulatory requirements.

With current trends towards the convergence of the Internet, mobile telephony and traditional landed networks, much research is going into the utilisation of the stability and reliability of Intelligent Networks for the implementation of the converged services [P916][Wathan99].

As described in § 2.6, currently deployed IN load control techniques tend to focus on the protection of individual network resources, detecting overload after it occurs and subsequently invoking rate-based throttling mechanisms configured by means of static parameter values. In closed, over-dimensioned networks where overloads rarely occurred these controls have proven adequate. However, in the open, resource-constrained networks of the future, existing controls are inadequate in that they are static, reactive, node-orientated and operate at the message level [Korner94]. This is illustrated by the crash of Easter 2000, as described in § 2.6.1.

These observations point towards the conclusion that the extended use of existing approaches would not meet the service levels required now and in the immediate future in order to support, for example, multiple service providers, greater IN interconnectivity and GSM CAMEL services. In order to meet the challenge of providing functionally enhanced services with the capability for greater interconnectivity within an improved service level environment, a network orientated load control mechanism is required. This mechanism has the following capabilities [Korner91]:

- Network Orientated – it monitors all nodes in its domain and distributes traffic evenly between the available nodes such that traffic is only quenched when the whole network is operating at maximum capacity [Lodge97].
- Proactive – it uses this network wide view of the IN to discern the onset of an overload, and takes measures to distribute and control the incoming traffic.
- Adaptive – its control parameters continuously adapt to the latest network conditions. This allows it to always have a realistic view of network usage and incoming traffic [Langlois91].
- Application Orientated – it operates at the application level, controlling and distributing service requests according to the service type and its importance to the operator [RajaRatnam96].

The MARINER project has developed a dynamic service traffic load control system based on these characteristics. The remainder of this chapter describes the manner in which this system accomplishes the above in two phases. First, a theoretical treatment of the operation of the system is detailed. Then, a description of the implementation of the system is given.

4.2 Theoretical Description

The MARINER System fundamentally consists of two types of monitoring and control entities and a single actuating module. Namely, these are the Resource Monitoring Agent (RMA), the Resource Allocation Agent (RAA) and the Service Traffic Controller (STC). These entities utilise token-based algorithms to accomplish network-wide, application-level load control [MARINERD8]. This section describes the token concept and the algorithm used, along with the operation and communication of these entities. The MARINER information flows mentioned below are defined in Appendix A.

4.2.1 The Token-based Approach

Traffic load control can be viewed as a distributed resource allocation problem. On one hand, there is the desire to serve arriving service requests, which are often unpredictable and bursty with regard to time, rate and volume. On the other hand, all the resources in the network have finite capacity and must be managed for optimal allocation amongst the arriving requests. In the MARINER model, resource usage is controlled by means of tokens – if an arriving request is to be admitted to the network then it is granted a token that allows it use all the resources it will need for the duration of the service session. By matching the number of tokens generated to the number of service sessions that can be handled by the network the strategy ensures that resources will not overload.

Tokens are generated by RAAs, which uses information received from RMAs regarding future resource availability and expected future service-request arrival rates. The RAA employs an optimisation algorithm for the generation of tokens. Once generated the token_allocations are communicated to the STCs. Tokens are then used by STCs to allow service sessions access to the resources (e.g. SCP central processors, databases) they need to complete successfully – they are representative of the 'quantity of resource' that will be used by a session. The main benefits of employing a token-based control strategy are that the number of sessions admitted can be strictly controlled, thereby preventing overloads during periods of high traffic loading and that token generation can be readily tailored to enforce service level priorities based on factors such as revenue generating potential and SLA constraints. The token generation algorithm is described below.

This algorithm was developed by the MARINER Project [ETSI_SUB]. To describe the algorithm in detail the following notation is introduced. Consider a network that consists of I SCFs, J service types, and K SSFs. Moreover, let i, j, and k denote an arbitrary SCF, service type, and SSF respectively, and let $r(j)$ denote the revenue generated by a class j request.

All STCs at SSFs maintain IJ pools of tokens, one for each SCF and service type pairing. Each time SCF i is fed with a type j session initiation one token is removed from the associated pool at the STC. An empty pool indicates that future requests for that service type will be rejected at that SSF. The pools are refilled as a result of the token generation process, carried out at the RAA. Inputs to the token generation process are estimated rates of service session request arrivals at SSFs, available processing capacity over a period of T time units (the length of the next interval), and service session processing requirements.

Available processing capacity, c_i and service session processing requirements, $\boldsymbol{p_i} =, p_i(1), \ldots ,p_i(J)$ are indicated directly in the `resource_data` messages sent from the RMA to the RAA. Estimated rates of service session request arrivals at SSFs are calculated by the RAA using information contained in all the `resource_data` and `notification` messages it has received; they are denoted by $\boldsymbol{q_k} = q_k(1), \ldots ,q_k(J)$. Note that if interval duration, T, is of the order of tens of seconds then the arrival rates measured/estimated over the past interval will be a good prediction of the arrival rates in the coming interval. The RAA will also use profit values, $\boldsymbol{r_k} = r_k(1), \ldots ,r_k(J)$, which are pre-specified by the network operator during the token generation process; these allow for the enforcement of priorities between service types based on their relative profit value. Profit values will take into account aspects such as revenue generated by successful sessions of that service, financial penalties associated with rejecting a session of that service type, or customer-perceived service importance.

Tokens are generated such that expected overall utility, measured as total profit, over the next T time units is maximised. The method is to allocate tokens one by one such that the expectation of marginal utility to marginal cost is maximised in each allocation. During the process, records are kept of the total remaining processing capacity, the number of tokens that have been generated, and the costs associated with the transactions. These records are denoted by s_i, $n_{i,k}(j)$, and $c_{i,k}(j)$ respectively.

The marginal utility u of an additional token is the expected profit associated with it. It is computed as the profit associated with consuming it times the probability that it will be consumed during the interval. Let $u_k(j)$ be the marginal utility associated with allocating a type j token to SSF k and let $n_k(j)$ be the total number of type j tokens held by SSF k. By interpreting the expected number of service requests $q_k(j)$ as the average of a Poisson distribution, we obtain $u_k(j)$ as

$$u_k(j) = r_k(j) \sum_{w=n_k(j)+1}^{\infty} q_k(j)^w / w! e^{-q_k(j)}$$

The marginal cost v of an additional token is the expected revenues from alternative ways of spending the same resources. It is computed as the total revenue expected from all alternative allocations of the same amount of processing capacity. Let $v_i(j)$ be the marginal cost associated with issuing a type j token from SCF i. By using the definition of utility above we obtain $v_i(j)$ as

$$v_i(j) = \sum_{j'=1}^{J} \sum_{k'=1}^{K} \frac{p_i(j)}{p_i(j')} u_{k'}(j')$$

For computational purposes it is convenient to rewrite the equation above as $v_i(j) = p_i(j) w_i$ where

$$w_i = \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{u_k(j)}{p_i(j)}$$

Let an (i, j, k)-allocation refer to assigning a type j token from SCF i to SSF k. The marginal utility per marginal cost $\delta_{i,k}(j)$ of such an action is

$$\delta_{i,k}(j) = u_k(j) / v_i(j)$$

Thus $\delta_{i,k}(j)$ expresses the derivative of the utility function with respect to the processing required for an (i, j, k)-allocation. The generation process seeks to maximise total overall utility by distributing the resources in a series of allocations such that each allocation results in a maximal increase in overall utility. The optimal allocation in each step is thus the one with the highest derivative.

We are now ready to state the algorithm formally:

```
Step 1: Initialisation.
        For all SSFs $k = 1, ..., K$:
          For all SCFs $i = 1, ..., I$ and all services $j = 1, ..., J$:
            Set the allocations $n_{i,k}(j) = 0$ and costs $c_{i,k}(j) = 0$.
          For all services $j = 1, ..., J$:
            Set all marginal probabilities $\pi_k(j) = e^{-q_i(j)}$
            Set all accumulated probabilities $\Pi_k(j) = 1 - \pi_k(j)$.
            Set all marginal utilities $u_k(j) = r_k(j)\Pi_k(j)$.

        For all SCFs $i = 1, ..., I$:
          Set all remaining processing capacities $s_i = c_i$.
          Set all accumulated ratios $w_i = \sum_{j=1}^{J}\sum_{k=1}^{K}\frac{u_k(j)}{p_i(j)}$.
          For all services $j = 1, ..., J$ and all SSFs $k = 1, ..., K$:
            Set the allocations $n_{i,k}(j) = 0$ and costs $c_{i,k}(j) = 0$.
          For all services $j = 1, ..., J$:
            Set all marginal costs $v_i(j) = p_i(j)w_i$.
        Step 2: Identify optimal allocations.
        For all SCFs $i = 1, ..., I$ for which $s_i>0$, all services j = 1, ..., J, and all
        SSFs $k = 1, ..., K$:
          List the allocations that maximise $\delta_{i,k}(j)$.
Step 3: Arbitrage between several optimal allocations.
        If more than one allocation is optimal, select one candidate $(i', j', k')$ as
        described in § 4.2.1.1.
Step 4: Perform optimal allocation.
        Let $n_{i'}(j') = n_{i'}(j') + 1$.
        Let $c_{i'}(j') = c_{i'}(j') + u_{k'}(j')$.
        Let $s_{i'} = s_{i'} - p_{i'}(j')$.
    Step 5: Update internal variables.
        Let $\pi_{k'}(j') := \pi_{k'}(j') q_{k'}(j') / n_{k'}(j')$.
        Let $\Pi_{k'}(j') := \Pi_{k'}(j') - \pi_{k'}(j')$.
        Let $u_{k'}(j') = r_{k'}(j') \Pi_{k'}(j')$.
        For all SCFs $i = 1, ..., I$, let $w_i := w_i - r_{k'}(j') \pi_{k'}(j') / p_i(j')$.
        For all SCFs $i = 1, ..., I$ and all services $j = 1, \ldots, J$ let $v_i(j) = p_i(j) w_i$.
    Step 6: Loop statement.
        If there exists at least one SCF $i$ for which $s_i > 0$, then go to step 2, else
        STOP.
```

When the process terminates, all supplies (in terms of processing capacity) will have been distributed between the demands (in terms of tokens). Token allocations are stored in an *IJK*-dimensional matrix which is placed into `token_allocation` messages that are sent to the RMAs that submitted `resource_data` messages.

4.2.1.1 Arbitration

If, at any round in the algorithm, some utilities *u* and demands *v* are identical, *e.g.* because of identical SCFs or identical arrival predictions, several candidates will be identified in step 2. From the point of view of global utility, this is not a problem and any candidate can be selected from the list, *e.g.* at random. It may, however, be preferable to apply other criteria when selecting a candidate. A culling procedure among the candidates can be applied; which may contain a number of steps as follows:

Supplies s_i: To ensure even loads, lightly loaded SCFs are preferred to heavily loaded ones. This is achieved by identifying the maximal supply among the transaction candidates and excluding the ones with a lower supply.

Step size $p_i(j)$: To maximise expected overall utility, larger steps in terms of resources spent must be preferred to smaller ones. This is achieved by identifying the maximal step size among the transaction candidates and excluding the ones with smaller step sizes.

Provider concentration $n_i(j)$: To ensure stability against sudden load changes with respect to specific services, SCFs are encouraged not to focus on particular services. This is achieved for each service by identifying the transaction candidates that refer to the lowest number of issued tokens and excluding the ones that have issued more tokens.

Fairness $n_k(j)/q_k(j)$: To ensure fairness, even under conditions where the demand is much higher or much lower than the supply, utilities must be brought to 0 or $r_k(j)$ independent of allocation $n_k(j)$. This is achieved for each SSF and service by identifying the transaction candidates that have issued the lowest allocation of tokens relative to demand and excluding the ones that have higher relative allocations.

Supplier concentration $n_k(j)$: To ensure stability against sudden load changes with respect to specific services, SSFs are encouraged not to focus on particular SCFs for particular services. This is achieved for each SCF and service by identifying the transaction candidates that have issued the lowest number of tokens and excluding the ones that have issued more tokens.

If more than one candidate remains after the culling procedure above more criteria can be added, and eventually random selection applied to ensure an unbiased distribution of tokens.

4.2.2 Operation in Normal Traffic Loading Conditions

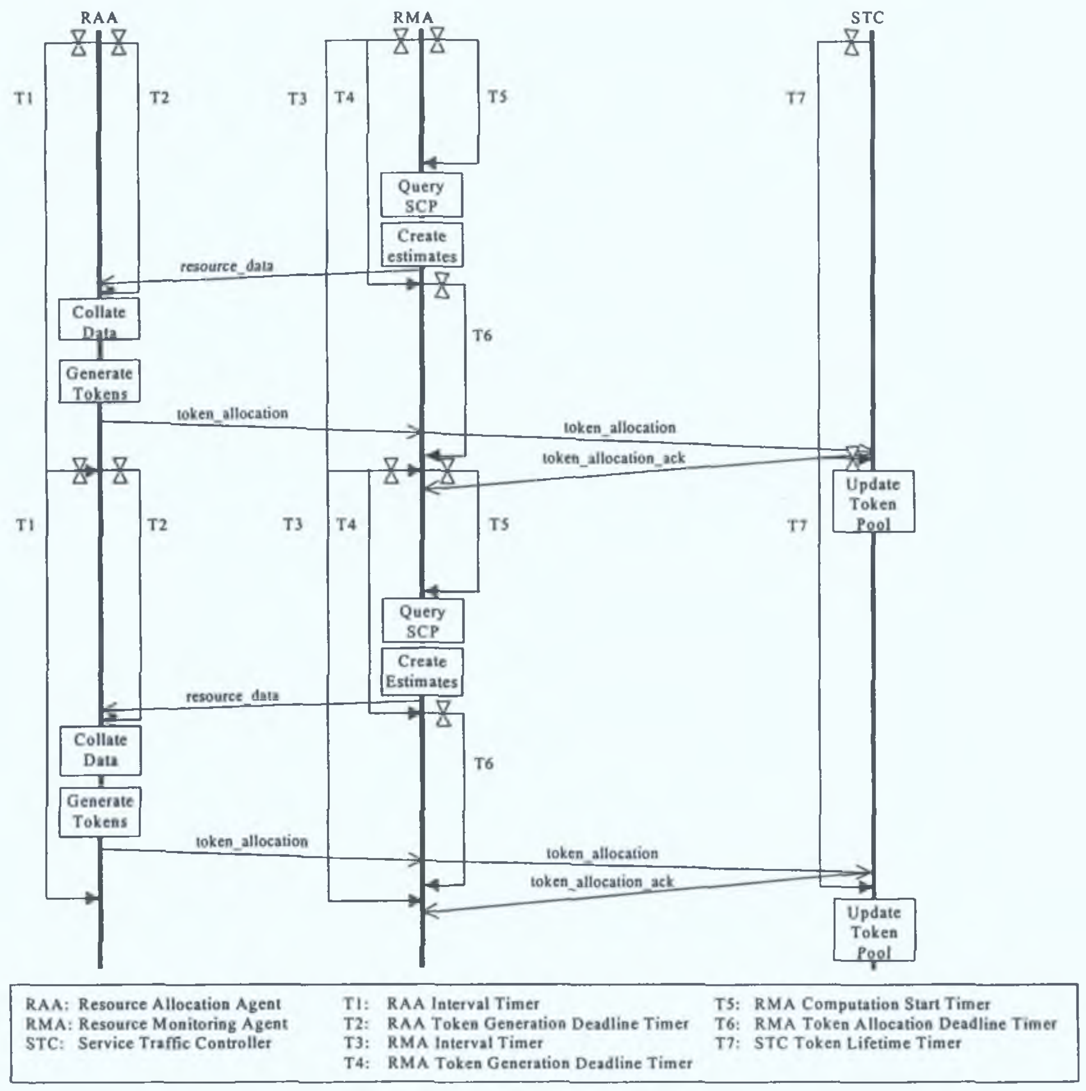


Figure 4.1: Service traffic control under normal traffic loading conditions

The Message Sequence Chart shown in Figure 4.1 illustrates the operation of the token-based control strategy in normal conditions (i.e. when the volume of service traffic arrivals is not sufficient to cause overload of any network resources). The figure shows a RMA associated with a network resource; for the purposes of this document it is assumed that only one type of resource (an SCP central processor) is being controlled, however the MARINER system can be used to control multiple resource types. Token generation takes place at discrete intervals corresponding to expiry of timer T1, the duration of which is set by the RAA. During token generation, sufficient tokens are allocated to control service traffic over the coming interval.

Prior to token generation the RMA will (at expiry of T5) access performance data from the SCF regarding the current rate at which service sessions are being initiated by SSFs. This information is collected on a per-service, per-SSF basis. In normal conditions no service session requests are being rejected at the SSFs, therefore these rates are indicative of service session arrival rates, which can in turn be used as an estimate of arrival rates for the coming interval. The RMA also accesses data that allows it to estimate the processing costs per service type and currently available processing capacity at the SCF. Once it has collected this information it forwards it to the RAA (in a `resource_data` message) so that it arrives before the specified token generation deadline.

Once the token generation deadline is reached the RAA will collate the information received from all RMAs into service session arrival rates per service per SSF, service processing costs per service per SCF and individual SCF processing capacities. The RAA will use these as inputs into the token generation process. Token allocations are generated on a per service, per SSF, per SCF basis, i.e. a token is used at a particular SSF to admit a session of a particular type which will use the resources of a particular SCF. The RAA inserts token allocations into a data structure of SSFs, SCFs and service identifiers. This data structure, along with the time to the next token generation and the token generation deadline is sent in a `token_allocation` message to all the RMAs that submitted `resource_data` messages. The token_allocation message also contains an intervalID parameter that can be used by the other entities to ascertain the validity of the message when it is received.

On receiving a `token_allocation`, the RMA extracts the information regarding the next token generation time and forwards the `token_allocation` message to the SSFs indicated therein. The RMA forwards the `token_allocation` message to the SSFs such that it reaches them as close to the beginning of the next interval as possible. In doing so it utilises previous measurements of the latency between the sending of a `token_allocation` and the subsequent reception of the `token_allocation_ack` acknowledgement message. It is noted that if the RAA places complete token allocation information (relating to all SSFs and all SCFs) into the `token_allocation` messages sent to each RMA then SSFs will receive multiple copies, thereby increasing the robustness of the system. For large networks this may prove too large a communication overhead, in which case the RAA may reduce the amount of messaging through selective filtering of the information contained in the `token_allocations` sent to RMAs.

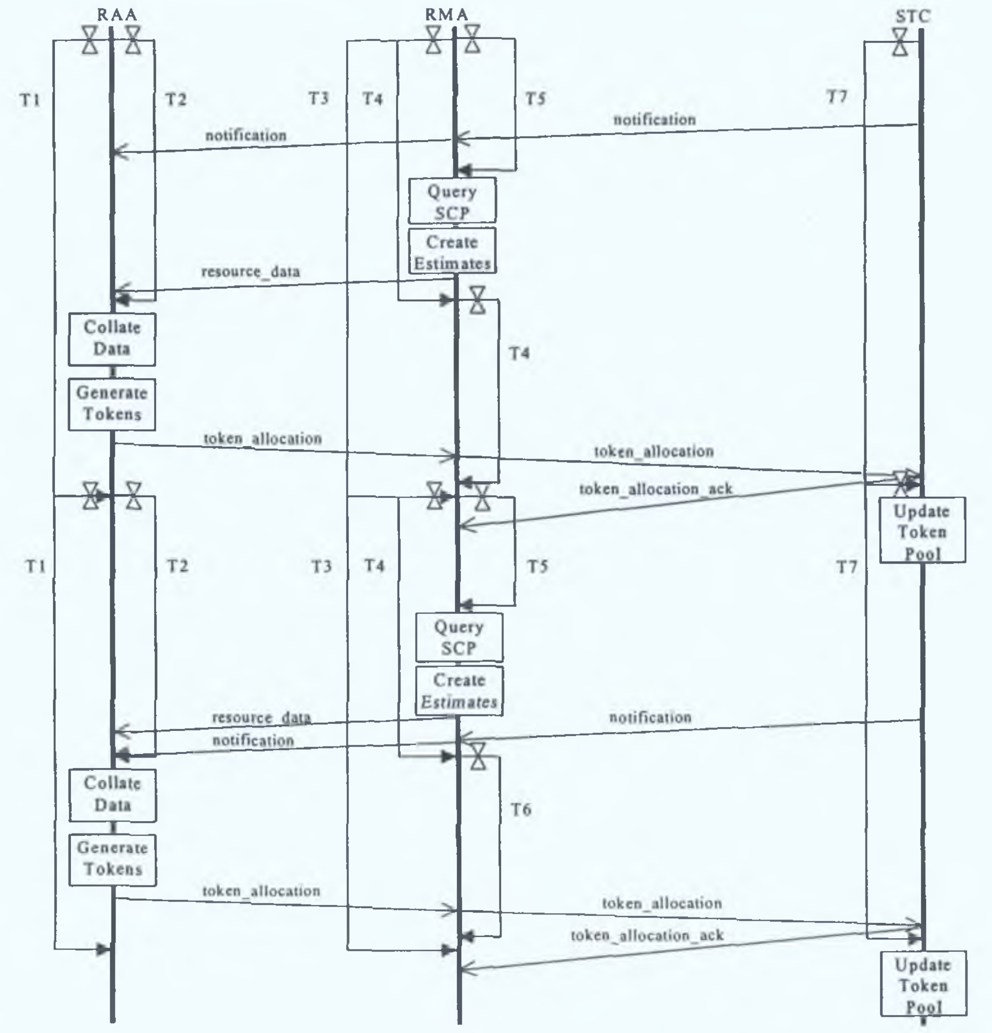
When the SSF receives the `token_allocation`, it is passed to the STC, which extracts the tokens allocated to it from the data structure, updates its internal token pool and sends a `token_allocation_ack` message to the RMA. New token allocations invalidate old ones. Each time a service session request arrives at the SSF, the STC is queried on whether to accept it. The STC uses its token pool as the basis for deciding whether to accept a request or not. It can use tokens on a continuous basis or employ a more complex algorithm based, for example, on measurements of the current rate of token usage with the aim of imposing an even rate of token usage over the interval until the next allocation arrives. In any case once tokens for a particular service type are exhausted, future requests for sessions of that type will be rejected.

4.2.3 Operation in High Traffic Loading Conditions

During conditions of high loading, where tokens are being exhausted rapidly at one or more SSFs the estimates of service session request arrival rates generated by the RMAs will not accurately reflect the actual arrival rates at the SSFs. In order to indicate to the RAA that it is likely to require more tokens for a particular service type than had been allocated for the current interval an STC will send one or more `notification` messages to the SCF/RMAs.

A `notification` message can indicate two types of situation, either (a) tokens for a service type are expected to become exhausted before the end of the current interval, or (b) the tokens have been exhausted and a number of requests have been rejected. In the former case the `notification` is sent when a pre-specified threshold percentage of the tokens have been used and the `notification` indicates the fraction of the interval that has passed before this threshold was reached. In the latter case the `notification` simply indicates the fraction of the interval that had passed and the number of requests that have been rejected.

The STC sends `notification` messages to the RMAs, which forward them to the RAA at the same time they send the RAA their own estimates (in `resource_data` messages) of SSF arrival rates. The RAA then uses the information in the RMA estimates and the `notification` messages to form its own estimates of arrival rates. The operation of the system in high loading conditions is illustrated by Figure 4.2.



RAA:	Resource Allocation Agent	T1:	RAA Interval Timer	T5:	RMA Computation Start Timer
RMA:	Resource Monitoring Agent	T2:	RAA Token Generation Deadline Timer	T6:	RMA Token Allocation Deadline Timer
STC:	Service Traffic Controller	T3:	RMA Interval Timer	T7:	STC Token Lifetime Timer
		T4:	RMA Token Generation Deadline Timer		

Figure 4.2: Service traffic control under high traffic loading conditions

4.2.4 Dynamic Timing

The degree of effectiveness of the token-based control is to an extent dependant on two temporal constraints: firstly `resource_data` messages from the RMA should arrive at the RAA before the token generation deadline; secondly at least one `token_allocation` message should be received at the STC before the start of the next interval. To allow the system dynamically adjust its operational parameters so that both of these timing constraints are met two error messages are introduced: `late_data_warning` and `late_alloc_warning`.

The operation of the system in response to the reception of a `late_data_warning` message is illustrated by Figure 4.3. By keeping the length of Timer T5 as long as possible the RMA attempts to get an as up-to-date an estimate as possible of the load of its associated SCF resources. However if T5 is too long the `resource_data` message sent to the RAA will arrive late and no tokens will be allocated for the SCF for the coming interval. Upon reception of a late `resource_data` the RAA sends the originating RMA a `late_data_warning` message, which causes the RMA to reduce the length of subsequent T5 timers. The `late_data_warning` indicates the amount of time after the token generation deadline that the `resource_data` arrived; this value is used in the calculation of the amount by which T5 should be reduced. It is noted that if the RAA sets the token generation deadline conservatively, it may still be able to take account of a 'late' `resource_data` message (arriving sometime within some preset time after T2 expiry) and subsequently send a `token_allocation` to the RMA in question. After a pre-specified number of intervals the RMA may increase T5, however this should not be done if the RMA has received `notification` messages during those intervals.

The operation of the system in response to the reception of a `late_alloc_warning` message is illustrated by Figure 4.4. The RAA uses timer T2 to ensure the token generation process starts in sufficient time to allow the propagation of `token_allocation` messages to all STCs in advance of the start of the next interval. Whilst meeting this constraint is its priority the RAA also attempts to keep T2 as long as possible so that the information received from RMA/STCs and used as input to the token generation process is as up-to-date as possible.

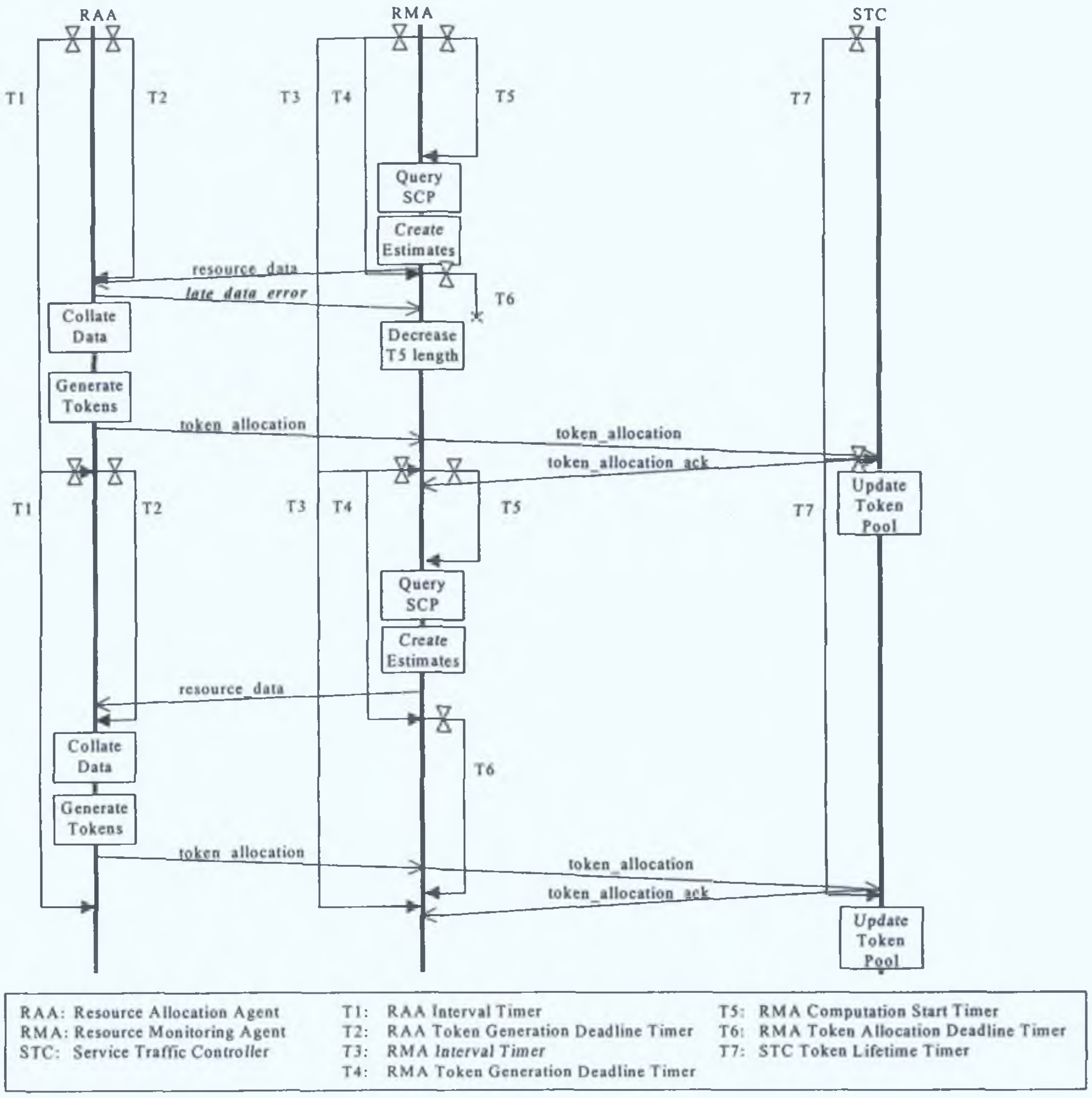

RAA
RMA
STC
T1
T2
T3
T4
T5
T6
T7
Query SCP
Create Estimates
resource_data
late_data_error
Collate Data
Decrease T5 length
Generate Tokens
token_allocation
token_allocation_ack
Update Token Pool
RAA: Resource Allocation Agent
RMA: Resource Monitoring Agent
STC: Service Traffic Controller
T1: RAA Interval Timer
T2: RAA Token Generation Deadline Timer
T3: RMA Interval Timer
T4: RMA Token Generation Deadline Timer
T5: RMA Computation Start Timer
T6: RMA Token Allocation Deadline Timer
T7: STC Token Lifetime Timer

Figure 4.3: Response of system to `late_data_warning` message

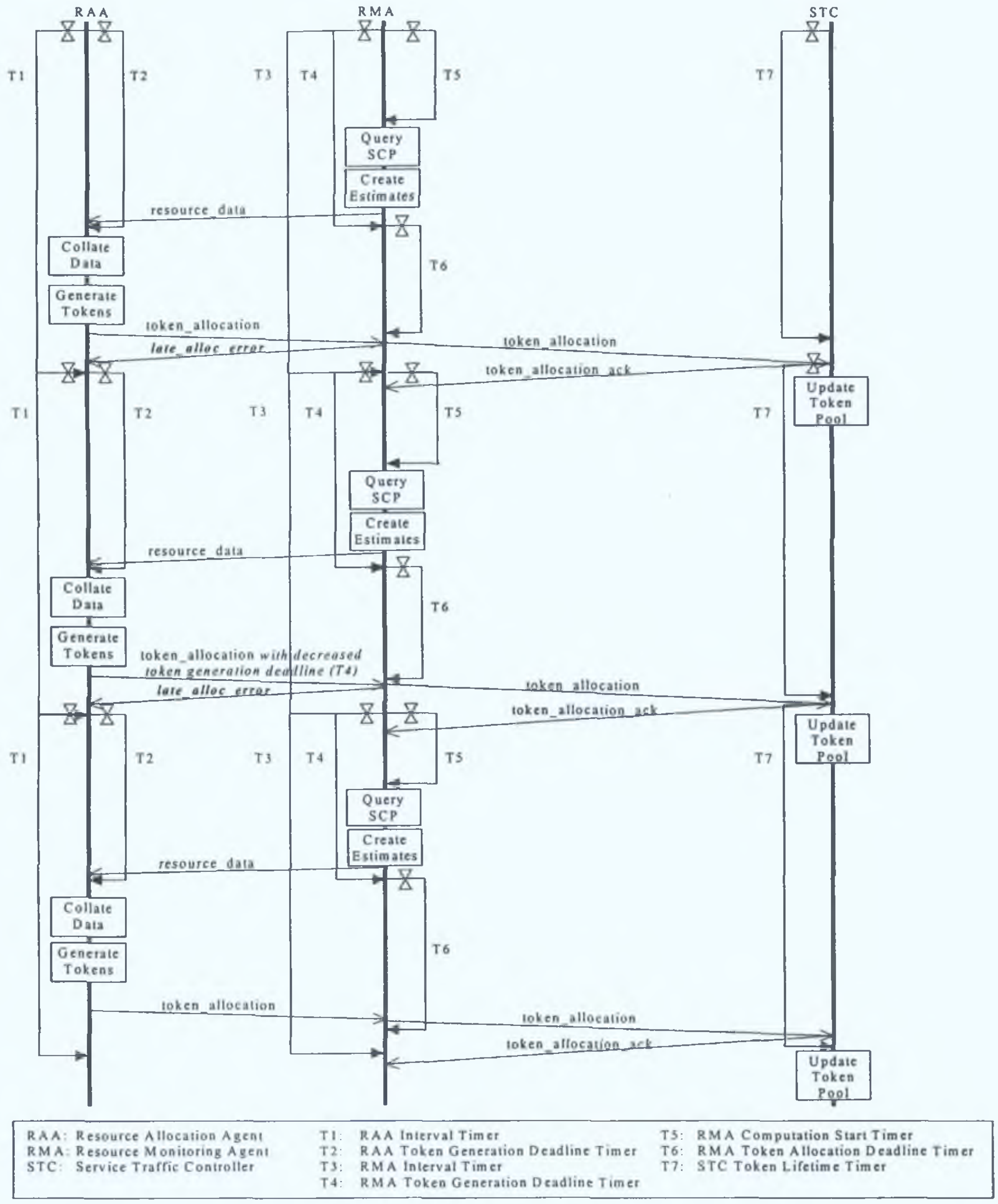

RAA
RMA
STC
T1
T2
T3
T4
T5
T6
T7
Query SCP
Create Estimates
resource_data
Collate Data
Generate Tokens
token_allocation
late_alloc_error
token_allocation_ack
Update Token Pool
token_allocation with decreased token generation deadline (T4)
RAA: Resource Allocation Agent
RMA: Resource Monitoring Agent
STC: Service Traffic Controller
T1: RAA Interval Timer
T2: RAA Token Generation Deadline Timer
T3: RMA Interval Timer
T4: RMA Token Generation Deadline Timer
T5: RMA Computation Start Timer
T6: RMA Token Allocation Deadline Timer
T7: STC Token Lifetime Timer

Figure 4.4: Response of system to `late_alloc_warning` message

As indicated previously the RMA attempts to forward `token_allocation` messages so that they reach their destination STC in time for the *next* interval. If the RMA receives the `token_allocation` from the RAA too late to make this possible, it sends a `late_alloc_warning` to the RAA, indicating the time interval by which the received `token_allocation` was late. On receiving this message, the RAA decreases the token generation deadline by an amount calculated using the lateness interval indicated in the `late_alloc_warning`. In the event that the RAA receives a `late_alloc_warning` requiring the token generation deadline to be less than a pre-specified fraction, *Deadline_Limit*, of the interval length, the interval length is increased instead. The token generation deadline is communicated to the RMAs in `token_allocation` messages, therefore the newly calculated deadline cannot be used for the current interval; as illustrated in Figure 4.4, it comes into effect for the next interval.

4.3 Implementation

This section provides a description of the implementation of the MARINER Service Traffic Load Control System. Figure 4.3 illustrates the structure of the of the MARINER System implementation.

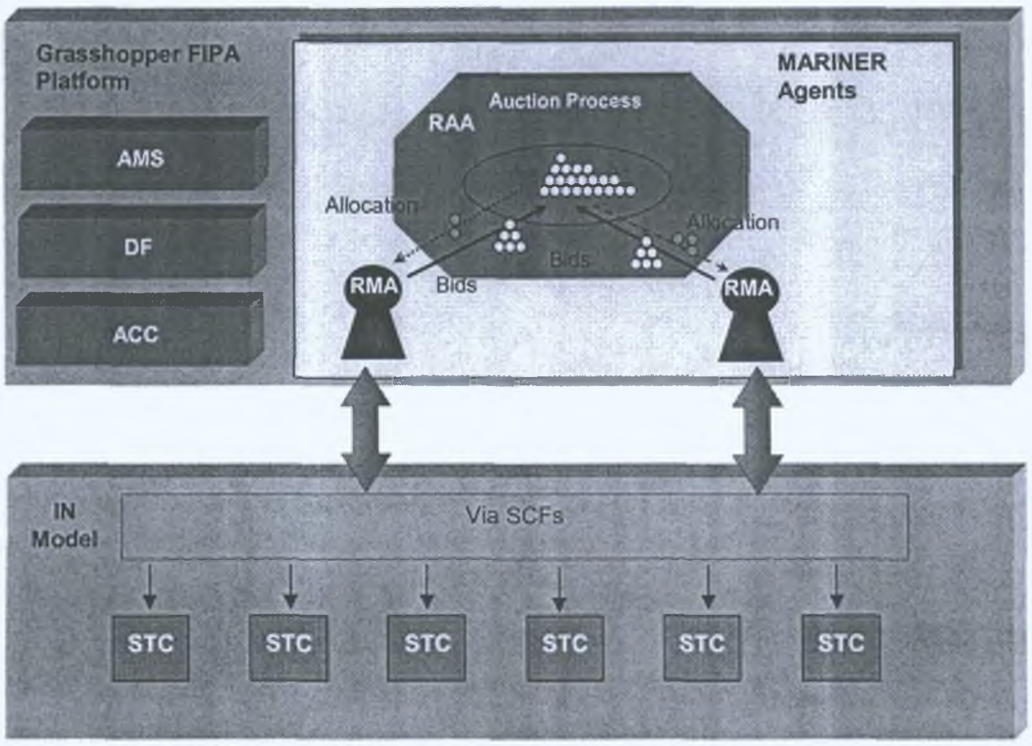


Figure 4.3 – MARINER System Implementation

The Resource Monitoring Agents (RMA) and the Resource Allocation Agents (RAA) were implemented on the IKV++ Grasshopper Intelligent Agent System. The Service Traffic Controller (STC) was implemented as part of the SSF in the IN Model described in Chapter 3. The rest of this section describes the Grasshopper System and the three entities.

4.3.1 The Grasshopper Intelligent Agent System

Grasshopper^{TM} [GRASSHOPPER] is a mobile agent development and runtime platform that is built on top of a distributed processing environment. It is implemented in Java, and is designed conformant to the Object Management Group's Mobile Agent System Interoperability Facility (MASIF)[MASIF].

The implementation for the MARINER System includes Grasshopper FIPA extensions that includes the following agents:

- the Agent Communication Channel (ACC), which facilitates agent communication
- the Directory Facilitator (DF), which allows agent to locate each other
- the Agent Management Service (AMS), which manages the agent start-up and maintains a list of live agents.

4.3.2 Service Traffic Controller

The STC, residing within the SSF, controls the acceptance of new service session requests at the SSF through the use of token allocations received from an RAA. It:

- accepts `token_allocation` messages from RMAs and uses the *intervalID* parameter contained therein to decide whether to update its data. If an update is to be done it extracts and stores token allocations for the next interval and the length of that interval;
- at the expiry of current interval timer (T7), it updates the token pool and starts a new interval timer using the new token allocations and interval length contained in the `token_allocation`(s);

- on receipt of a `token_allocation` message, it optionally calculates token usage thresholds per service that once surpassed will trigger the sending of a `notification` message during the next interval. This calculation is based on token allocations and pre-specified threshold percentages for each service;
- receives requests for permission to accept a new service session from the SSF. It checks the corresponding token pool. If the session is to be accepted, it indicates this and the destination SCF address to the SSF and subtracts a single token from the corresponding token pool. If the session is to be rejected it indicates this to the SSF;
- sends a `notification` to RMAs when the number of tokens remaining for a particular service falls below the pre-calculated service threshold. This `notification` indicates the service type and the fraction of the interval that has passed up to the time when the `notification` is generated;
- optionally sends one or more `notification` to RMAs when it has exhausted its tokens for a particular service (or set of services). These `notification` messages can be sent immediately upon token exhaustion and/or at subsequent time intervals. In the latter case the `notification` will indicate the number of service session requests that have been rejected since token exhaustion;
- optionally re-uses the last `token_allocation` message it received if a new one has not been received at the expiry of current interval timer (T7).

A more detailed description of the implementation of this function with the SSF is available in Appendix B.

4.3.3 Resource Monitoring Agent

The Resource Monitoring Agent is associated with one or more network resource types. In the case of the SCF, it monitors the SCF resources' available processing capacity, estimates session arrival rates on a per service per SSF basis and reports this information to the RAA. It:

- sends and receives messages to and from the RAA and STCs;

- upon expiry of timer T5 accesses data relating to current service request arrivals rates by service and SSF at the SCF. Also accesses data that relates to the SCF resources' available processing capacity and the processing cost for sessions of the service types supported by that SCF. Places this information in a `resource_data` message and sends this to the RAA;
- receives `token_allocation` messages from the RAA and extracts information regarding the interval length and token generation deadline. Uses this information to calculate the duration of timers T4, T5 and T6;
- forwards `token_allocation` messages to STCs;
- upon receipt of a `late_data_warning`, decreases the length of timer T3 by an amount calculated using the information on the latency of the bid contained in the `late_data_warning`;
- keeps measurements of the latency between itself and STCs and uses this information to ensure that the STC receives the `token_allocation` messages as close to the beginning of the new interval as possible;
- sends a `late_alloc_warning` to the RAA if `token_allocation` is received after the expiry of timer T6.

A more detailed description of the implementation classes of this function is available in Appendix C.

4.3.4 Resource Allocation Agent

The RAA controls network resource loads in a co-ordinated manner through receiving data from RMAs and STCs, the running of the token generation process and the propagation of token allocation to STCs. It:

- upon expiry of timer T2 (or at some preset time thereafter) collates data received in `resource_data` messages from the RMAs to form estimates of service arrival rates on a per service per SSF basis. If `notification` messages have been received then the information contained therein is also used in the formation of service arrival rate estimates;

- sends `late_data_warning` messages to RMAs whose `resource_data` messages arrived after the expiry of T2. The `late_data_warning` indicates the degree of latency of the `resource_data` message;
- runs the token generation process to generate token allocations on a per SCF, per SSF, per service type basis;
- sends `token_allocation` messages containing the token allocations, the duration of the next interval, and the token generation deadline, to all RMAs;
- shortens T2 if a `late_alloc_warning` message is received. The new token generation deadline will only be sent out with the next `token_allocation` and therefore only be enforced in the following interval;
- increases the interval length if the newly calculated token generation deadline corresponds to less than the *Deadline_Limit* of the current interval length.

A more detailed description of the implementation classes of this function is available in Appendix C.

4.4 Summary

With the exponential growth of the telecommunication service traffic spurred by changing regulations and the convergence of the internet, mobile telephony and landed networks, current load control mechanisms for Intelligent Networks are seen as inadequate in that they are reactive, node-orientated, static and operate at the messaging level.

Network orientated load control mechanisms provide a solution to these inadequacies in that they are inherently network-orientated, proactive, dynamic and operate at the service-level. The MARINER Service Traffic Load Control System attempts to provide the IN with a network orientated load control mechanism that is better prepared to handle the challenges on the horizon. This is accomplished through the following steps:

- Resource Monitoring Agents monitor the current loads of the IN resources (such as the SCF processing capacity) and service traffic arrival rates. This data is periodically reported to the Resource Allocation Agent.
- The Resource Allocation Agent uses this data to assess the various IN resources' availability and traffic arrival rates at the SSFs. Using these assessments, it periodically allocates resource usage to the SSFs using the Service Traffic Controllers built into them according to the service type priority level (profit) set by the operator.
- The Service Traffic Controllers distribute incoming service traffic to the IN resources according to the resource usage information it received from the Resource Allocation Agent. If it exhausts the resource usage allocated to it for a particular service type before the next allocation arrives, the Service Traffic Controller begins to reject service requests of that type and notifies the Resource Allocation Agent of this.
- If the Resource Allocation Agent receives notifications from the Service Traffic Controllers, it processes them, discerns the nature (service type, extent and location) of the impending overload, and reassigns resources to maximise network-utilisation and operator-profit from the overload while protecting individual nodes from overloading.

This candidate was responsible for the design and development of the Service Traffic Controller and significantly contributed to the development of the Resource Allocation Agent and the Resource Monitoring Agent. This endeavour however, would have been impossible without the contributions, guidance and advice of the rest of the MARINER Project participants, especially the TELTEC IN Group and IKV for the Grasshopper FIPA Platform.

The next chapter uses experimental data to verify the operation and performance of the MARINER System.

5 EXPERIMENTS AND RESULTS

5.1 INTRODUCTION

This chapter details the experiments that were carried out on the MARINER Service Traffic Load Control System as part of the effort to demonstrate and analyse the performance of this system as a network orientated load control mechanism for the Intelligent Network. These experiments explore the following characteristics of the MARINER System:

- adaptive load control – its ability to integrate with the IN, and adapt its load control parameters to the network and traffic conditions
- network-orientation - the ability to balance load among the available nodes, maximising network utilisation while protecting individual nodes from overloads
- service-orientation – the ability to differentiate between service types, and maximise service profit (§ 4.2.1) as set by the operator.
- proactive – its ability to distribute and control a spontaneous traffic overload.
- robustivity - the ability of the system to recover from node or agent malfunctions and lost or corrupted communication
- the limitations of the system

The experiments were structured into three phases, with each phase feeding its results into the next phase, while further testing the conclusions drawn from the previous phase. The first phase comprised the integration experiments. These experiments verified that the Trial Platform operated according to the MARINER System as described in Chapter 4, hence confirming that all subsequent experiments performed on the Trial Platform were indeed testing the MARINER System. Further, the experiments were also used to test that the MARINER System integrated successfully with the IN Model described in Chapter 3. This was followed by the evaluation experiments. These experiments tested the performance of the MARINER System against the criteria set out in § 5.1.1. Finally, the robustness experiments were carried out. These tested the robustness of the MARINER System in various error conditions and explored its limitations. In describing the above process, this chapter is structured in the following manner. First, the experimental setup is described. This is followed by sections on the experiments and results from each phase of the experiment process. Finally, the results of the experiments are summarised and analysed. Further descriptions of these trials are available in [MARINERD8][Wathan2000].

5.1.1 Evaluation Criteria

The Evaluation Experiments that were carried out analysed the performance and behaviour of the MARINER System against the following criteria.

- Overload Protection

  The load control system must control the network load to match the offered load in all circumstance except when the offered load exceeds the safe maximum of 90% of the capacity of the network. In the case when the offered load exceeds the safe maximum, the load control system must maintain the network load at the safe maximum. In the case when the offered load increases or decreases rapidly, the load control system must ensure that the accepted load matches the offered load as closely as possible without exposing the network to an offered load above the safe maximum.

- Load Distribution

  The load control system must ensure the equal distribution of the offered load among all nodes within the controlled network. In the case where the offered load comprises multiple service types, the load control system must ensure the equal distribution of the offered load of each service type among all nodes capable of executing that service type.

- Service Differentiation

  The load control system must always ensure that the network capacity is utilised such that the network profit is maximised. Specifically, in the case where the offered load exceeds the safe maximum capacity of the network, the load control system must distinguish between the service types that make up the offered load and ensure that the service requests are rejected according to their profit value to the network, the least profitable being the first to be rejected.

These criteria were chosen due the fact that they were considered by this candidate to accurately measure the effectiveness and practical value of any load control system. This consideration is supported in [Arvidsson99] where it is stated that they accurately represent the viewpoints of the network operator, network users, and the network itself. These criteria have also been used to evaluate other network management systems including the Global IN Congestion Control Strategy [Lodge2000], and Automatic Call Restriction [Williams94], as well as in the discussions presented in [Arvidsson97], [Pettersson96], [Williams2002], [Hnatyshin2001], [Dovrolis2000] and [Mohapi2000].

Other popular criteria used for the evaluation of load control systems are Service Fairness [Lodge2000], [Folkestad96], Source Fairness [Whetten2000][P8132000] and Minimisation of User Delay [Kant95][Williams2002]. These criteria were deemed unsuitable for use in the evaluation of the MARINER System for the following reasons.

- Service Fairness

  Service Fairness is defined by [Rumsewicz96], [Galletti92] and [Tsolas92] as a strategy where, in response to an overload, the load control system should reject only the service type that is causing the overload. This criterion was not chosen because it ignores the fact that most current networks are governed by multiple Service Level Agreements ensuring that services types are distinguished and treated based on their importance and urgency to both the network provider and the network user. In the event of an overload, it is therefore more important that the network attempts to service the most number of requests of the most important service rather than reject service requests based on the service type causing the overload.

- Source Fairness

Source Fairness is defined by [Hac98] as a criterion where, in response to an overload, the load control system should ensure that it only rejects load from the sources (SSPs) causing the overload. This criterion was not chosen because it too does not distinguish between Service Types and their importance to the Network Operator and Users.

- Bound User Delay

  Bound User Delay is defined by [Kant95] as a requirement for the load control system to ensure that the average length of time each user must wait for service implementation to be completed should not be exceed a Maximum User Delay during an overload. This criterion was not chosen due to the fact that it was considered to be pertinent only for load control systems operating at the service-messaging levels, which could lead to service completion times varying by large amounts during an overload. Since the load control system being evaluated in this paper operates at the service level, once a service request is accepted, the resources it requires (represented by tokens in the SSP) are committed, ensuring no large discrepancies between service completion times during an overload.

5.2 Experimental Setup

5.2.1 Trial Platform

The Trial Platform consists of a CORBA-based IN Model described in Chapter 3, the Grasshopper Platform and the MARINER System described in Chapter 4.

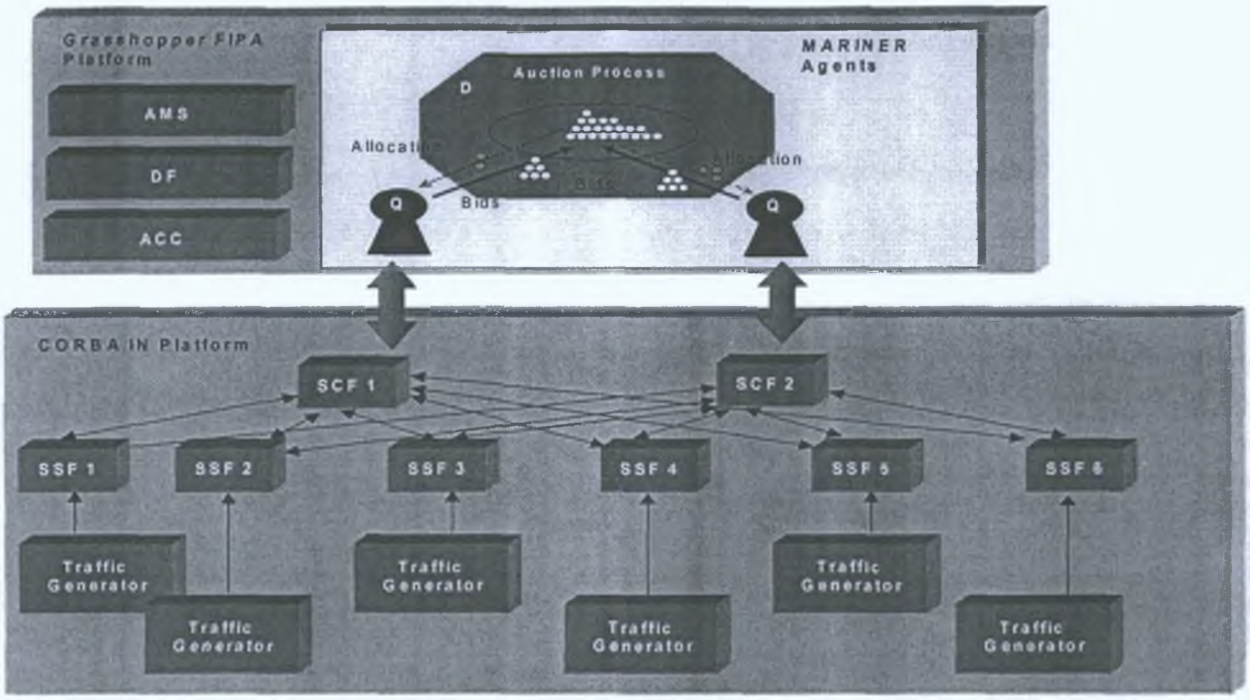


Figure 5.1 – The Trial Platform

The IN Model served to model a distributed IN environment containing SCPs, SSPs and Traffic Generators. The SSPs were equipped with Service Traffic Controllers (STCs) as described in § 4.3.2. The STCs were set to send Notifications only when tokens for a particular service type were exhausted, and to re-use the last token_allocation if a new one did not arrive in time. The design also included the integration of load control agents, while providing maximum de-coupling between the operations of the IN Model and the agents. Hence, making it possible to introduce new versions of agents and load control strategies without necessitating modifications to the model.

For the purposes of the trial, the model is able to execute three different services. The design of the model however allows for the inclusion of further service with only minor modifications. The three services are as described below.

5.2.1.1 Service 0: Restricted User

This service was implemented as described in § 2.4.1 (See Appendix B). The total numbers of instructions carried out at each network element are as follows:

SSP: *135,000* instructions[RB1]

SCP: *160,000* instructions

The profit associated with a successful session of the Restricted Access Call Forward service is 1 profit unit.

5.2.1.2 Service 1: Virtual Private Network

The service was implemented as described in § 2.4.2 (See Appendix B). The total number of instructions carried out at each network element is as follows:

SSP: *97,500* instructions

SCP: *240,000* instructions[RB2]

The profit associated with a successful session of the VPN service is 5 profit units.

5.2.1.3 Service 2: Automatic Ringback

The service was implemented as described in § 2.4.3 (See Appendix B). The total numbers of instructions carried out at each network element are as follows:

SSP: *242,500* instructions[RB3]

SCP: *300,000* instructions

The profit associated with a successful session of the Ringback service is 10 profit units

5.2.2 Standard Trial Configuration and Assumptions

The standard configuration for the experiments were as follows:

- An IN network comprising of 6 SSPs and 2 SCPs running on a single system.
- Traffic Generators generating service requests of all three types to the IN network at an equal rate.
- 2 RMAs and one RAA operating on the Grasshopper Platform running on a single system.

It should be noted that in order to obtain meaningful results, both the load offered to the network and the load processed by the SCFs are measured as percentages of the total processing capacity of all the SCFs in the network. Therefore, in the case where 100% load is offered to the network, all the SCFs in the network would have to be working at full capacity in order to service all the requests being generated by the Traffic Generator.

Further, auction intervals are used as a measure of the passage of time in the experiments, where on auction interval is the fixed interval in milliseconds between to auction processes within the Distributor Agent.

The following assumptions are used in all experiments:

- Service users never abandon ongoing service sessions, thus it is not necessary to implement the signalling required for premature session termination.
- Processing requirements remain constant for a particular signal over all sessions of that service type.
- All network links are identical and provided by 10MB Ethernet.
- All SCFs have identical hardware and software configurations and support all services.
- The targeted safe maximum load for an SCF is 90% [Sabourin91].
- All [NW4]Traffic Generators originate requests for services according to independent Poisson processes.
- Any delay at SSFs is related to processing only.
- For all scenarios, the mean arrival rates for all services are equal unless stated otherwise.

5.3 Integration Experiments

The integration experiments investigated all aspects of the Trial Platform in order to verify that it operated in accordance with the MARINER System, as described in § 4.2. This was done to verify that all subsequent experiments carried out on the Trial Platform did indeed test the performance of the MARINER System. These experiments were carried out during the development period of the system so that the results could be fed-back into the development process and used to improve the system.

5.3.1.1 Basic Platform Setup

Objective(s) of experiment:	To verify that the MARINER Agent System interacts with the IN Model such that the platform operates as described in § 4.2.1
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the Grasshopper agents on it. Turn on traffic generation at 35% steady load and verify that token allocations are taking place and that load is being distributed.

5.3.1.2 Agent Dynamic Timing

Objective(s) of experiment:	To verify that MARINER Agents dynamically adjust their timing values to adapt to the environment as described in § 4.2.3.
Experimental setup:	Standard Configuration.
Experimental procedure:	Proceed as in experiment 1 with the interval set at 60 seconds and the RMA and RAA timers set at an initial value of 35s. Under a 35% steady load verify that token allocations are taking place and monitor the timing values of the MARINER Agents.

5.3.2 Integration Results

5.3.2.1 Experiment 1: Basic Platform Setup

Through the duration of this experiment, the IN Model successfully generated and executed services while the MARINER Agents monitored and controlled the network load through the implementation of the market-based strategy in the manner described in § 4.2

Further to achieving its objectives, this experiment allowed for the fine-tuning of the configuration parameters of both the IN Model and MARINER System, hence assuring consistency throughout the remainder of the trial.

5.3.2.2 Experiment 2: Agent Dynamic Timing

This experiment tests the ability of the RMA and RAAs to dynamically adapt their operation times to the network environment. The results of the experiment should show the RMA Computation Start Period (T5 in Figure 4.3) increase at the beginning until it reaches the point where the RMA is accessing the SCP at the very latest it can without missing the token generation deadline. At this stage, the RMA Computation Start Period will fluctuate about this point as the RMA attempts to increase it further and the RAA sends late_data_warnings, forcing the RMA to decrease it. This fluctuation allows the RMA to rapidly adjust to a change in the network.

In the RAA, the results should show the RAA increasing the Token Generation Deadline Period (T2 in Figure 4.4) until it reaches a point where the Token Generation Procedure occurs as late as it can, while ascertaining that the token_allocation reaches the STC at the beginning of the next Interval. At this stage, the Token Generation Deadline Period should fluctuate about this point as the RAA attempts to increase it further and the RMA sends late_allocation_warnings, forcing the RAA to decrease it. This fluctuation allows the RAA to rapidly adjust to a change in the network.

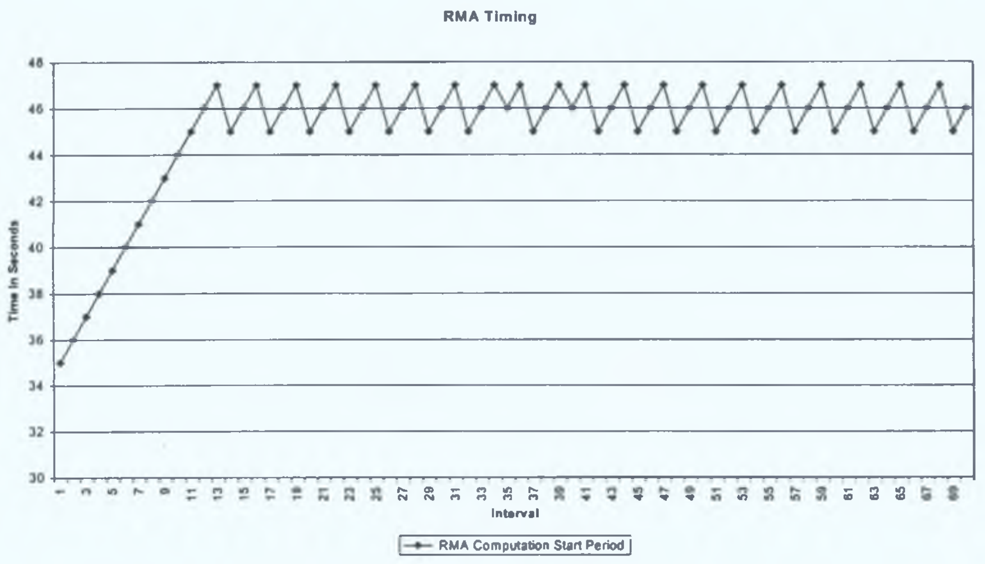


Figure 5.2 – RMA Dynamic Timing

The graph shows that the RMA Computation Start Timer is working as expected. From its initial value of 35s, it gradually increases with every interval to the 47s. At this point, the RAA sends a late_data_warning to the RMA causing it to reduce the Timer period to 43s. It then attempts to increase the period in the subsequent intervals until a warning is received. This cycle repeats itself for the duration of the experiment.

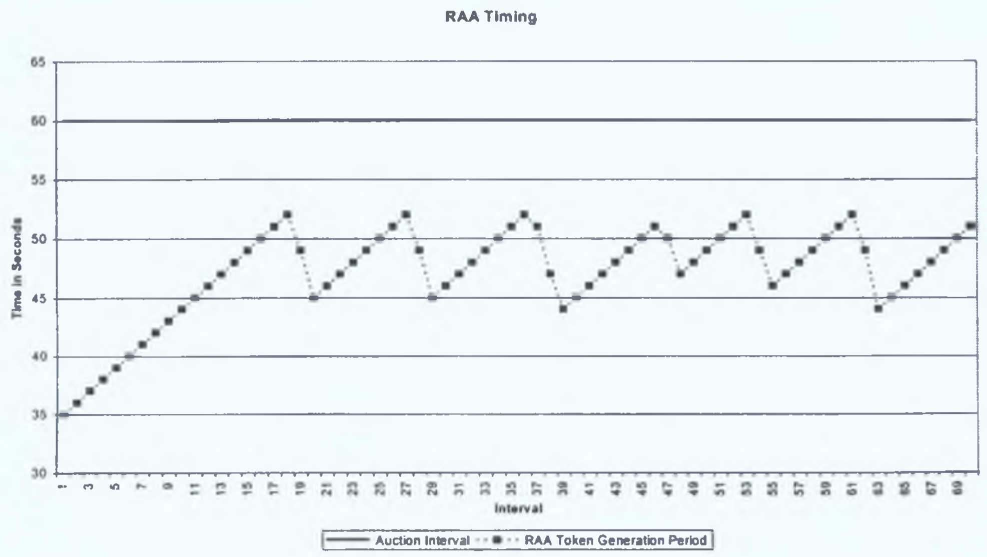


Figure 5.3 – RAA Dynamic Timing

The graph shows that the RAA Token Generation Timer is working as expected. From its initial value of 35s, it gradually increases with every interval to the about 52s. At this point, the RMA sends a late_allocation_warning to the RAA causing it to reduce the Timer period to about 45s. It then attempts to increase the period in the subsequent intervals until a warning is received. This cycle repeats itself for the duration of the experiment. The interval length stays at 60s.

The results of this section have shown that Trial Platform does work as described in § 4.2, in accordance to the MARINER System. This finding allows all subsequent experiments on the Trial Platform to test and demonstrate the performance of the MARINER System.

5.4 Evaluation Experiments

The Evaluation experiments tested the load control and overload protection aspects of the Trial Platform and hence, the MARINER System.

5.4.1.1 Normal Load Under Steady State

Objective(s) of experiment:	To verify that the system operates as required under a steady state load.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.4.1.2 Excessive Load Under Steady State

Objective(s) of experiment:	To verify the operation of MARINER agents under excessive steady state load.
Experimental setup:	Standard Configuration with traffic generator set for arrival rates amounting to:
	2.1 95% Load

2.2 120% Load

Experimental procedure: Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation with services 0 and 2 having a normal (as in Experiment 1) arrival rate and service 1 having an elevated arrival rate so that the total traffic generated is as described in he experimental setup. Capture load information for the network. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.4.1.3 Excessive Load for Limited Periods

Objective(s) of experiment: To verify the operation of MARINER agents under excessive load for limited periods.

Experimental setup: In this case, the network load is modified by having a higher arrival rate for Service 1 that only last for a short period as follows. First the network is exposed to normal load for 30 intervals, then to an overload for 10 intervals, simulating a spontaneous high traffic period. This is followed by an exposure to 75% of the overload for 10 intervals, simulating rejected customers re-dialling. Finally, the network is exposed to a normal load. The extent of the overload is as follows:

3.1 95% Load

3.2 120% Load

Experimental procedure: Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation as described in experimental setup and capture load information for the network. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.4.1.4 Localised Excessive Load For Limited Periods

Objective(s) of experiment:	To verify the operation of MARINER agents under excessive localised load for limited periods.
Experimental setup:	In this case use normal load for all nodes except one SSP. At this SSP generate excessive traffic of 120% Load for 10 intervals followed by excessive traffic of 75% of 120% load for 10 intervals. Then, resume normal loading.
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation as described in experimental setup and capture load information for the network. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.4.2 Evaluation Results

In this section, the theoretical result of each of the evaluation experiments is first presented. This is followed by the observed result, presented in graphic form. At the end of each experiment, the obtained results are analysed.

The presented graphs are as follows:

- The first graph shows the individual and average SCP loads as a percentage of their full processing capacity across the duration of the experiment. This graph serves to explore the degree of success achieved by the Mariner System in balancing the load across the network, and protecting the network in an overload.
- The next graph shows the difference between the load arriving into the network and the load accepted for execution. It serves to illustrate the sensitivity of the Mariner System.
- The third graph displays the breakdown of the services being executed by the network. The degree of success achieved in evenly balancing the services accepted in normal loads and the preferential treatment of the more profitable services in

overloads is illustrated in this graph. The graph also illustrates an estimate of the traffic load being offered to the IN model.

5.4.2.1 Experiment 1: Normal Load Under Steady State

In this experiment, the network load should remain at 35%, matching the offered load as closely as possible. All SCPs should receive an equal distribution of the accepted load, and hence should closely match the average SCP load. Further, with the network load well below the safe network maximum of 90%, all three services should be treated equally, with no service requests being rejected by the IN network.

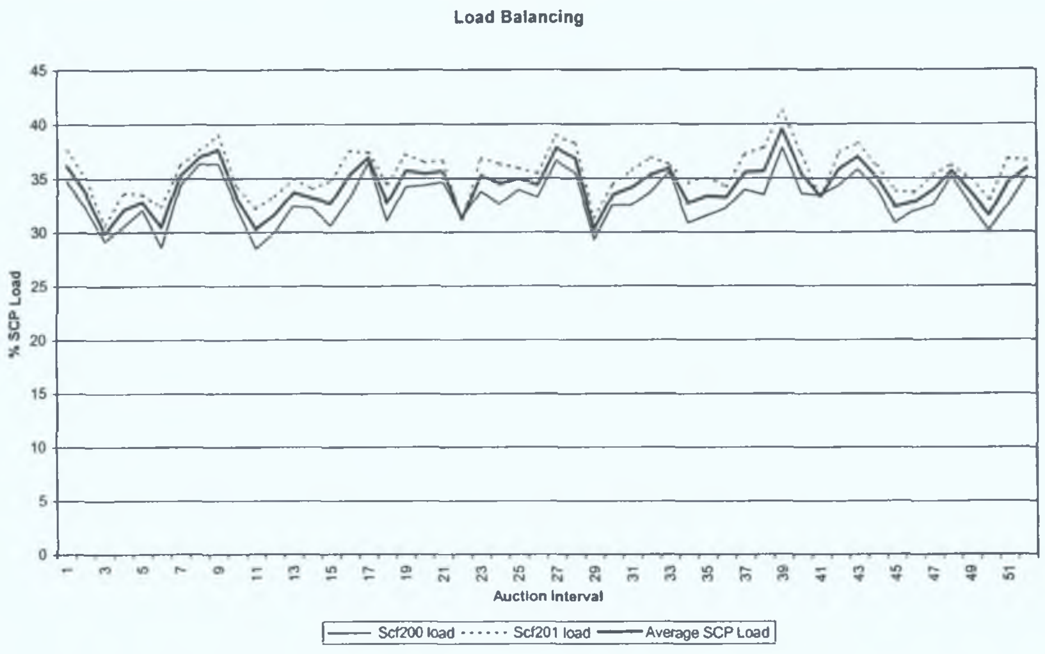


Figure 5.4 – Load Balancing at Normal Load

The graph shows that under a steady load of 35%, the SSPs distribute load evenly between the available SCPs .

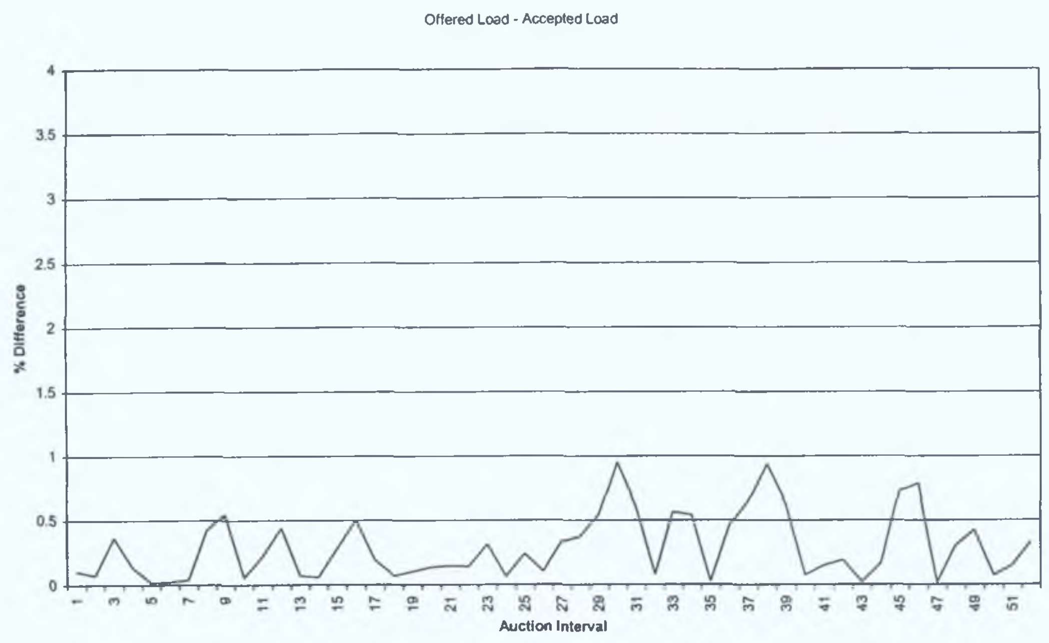


Figure 5.5 – Load Difference at Normal Load

This graph shows that less than 1% of the offered load was ever rejected by the SSPs when the system was under a steady load of 35%.

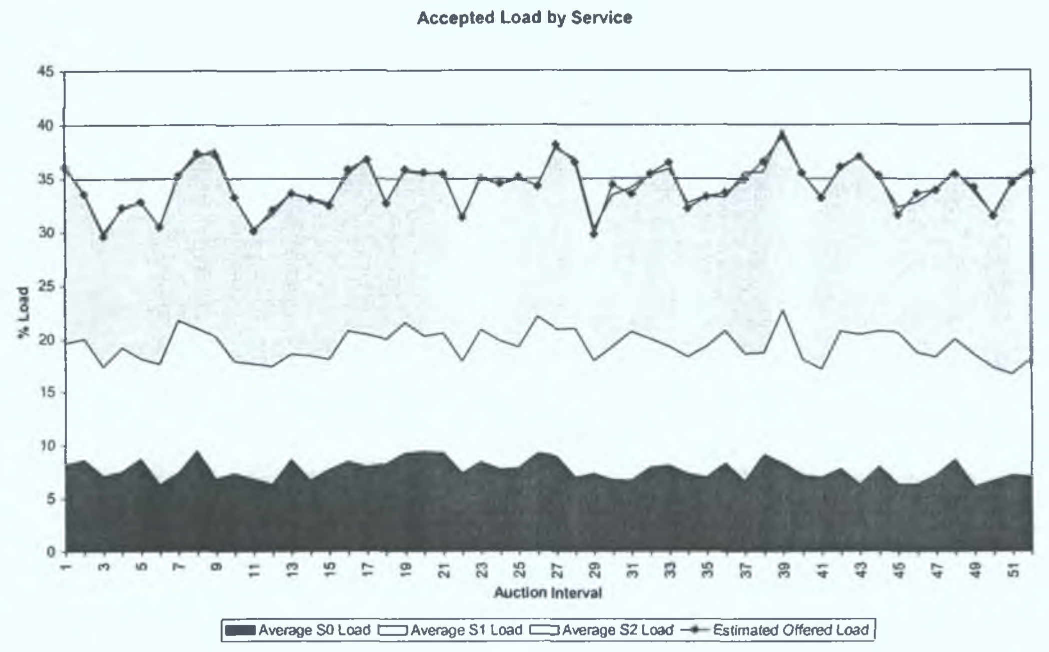


Figure 5.6 – Service Balancing at Normal Load

Figure 5.6 confirms that under normal steady state conditions, the network treated the three services equally, with an insignificant number of service rejections.

The results above verify that the MARINER System successfully controls and distributes the offered load when the traffic is at a steady normal level.

5.4.2.2 Experiment 2.1: 95% Excessive Load Under Steady State

In this experiment, the MARINER agents should maintain the network load at the safe maximum of 90%, quenching only 5% of the offered load. Further, the requests for the less profitable services should the ones most quenched.

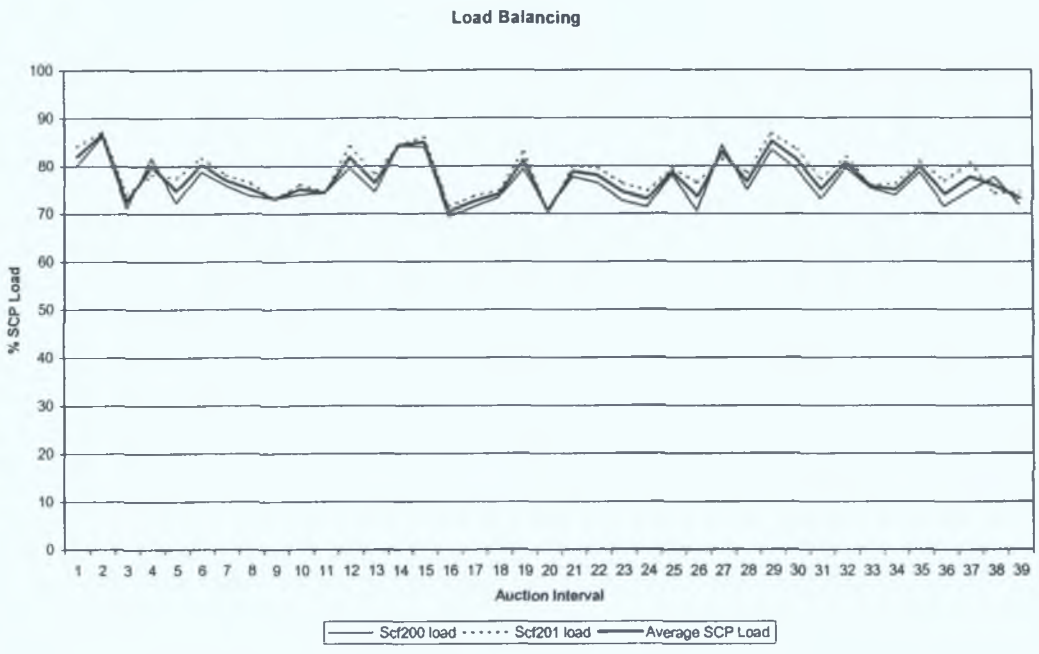


Figure 5.7 – Load Balancing at 95% Load

The graph shows that under a steady load of 95%, the SSPs distribute load evenly between the available SCPs .

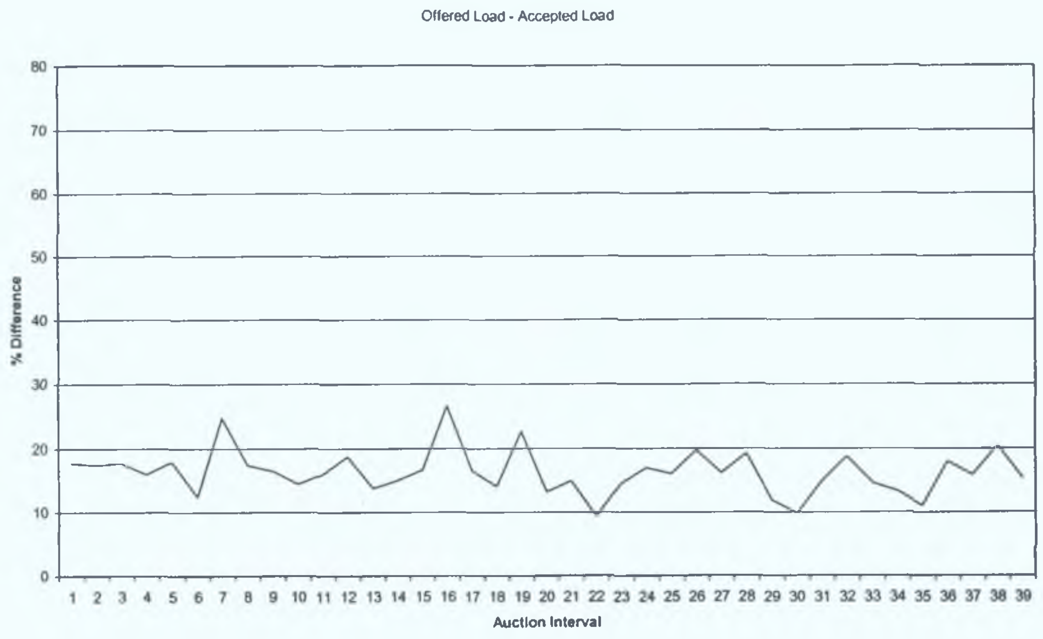


Figure 5.8 – Load Difference at 95% Load

This graph shows that approximately 20% of the offered load was rejected when the system was offered a steady load of 95%.

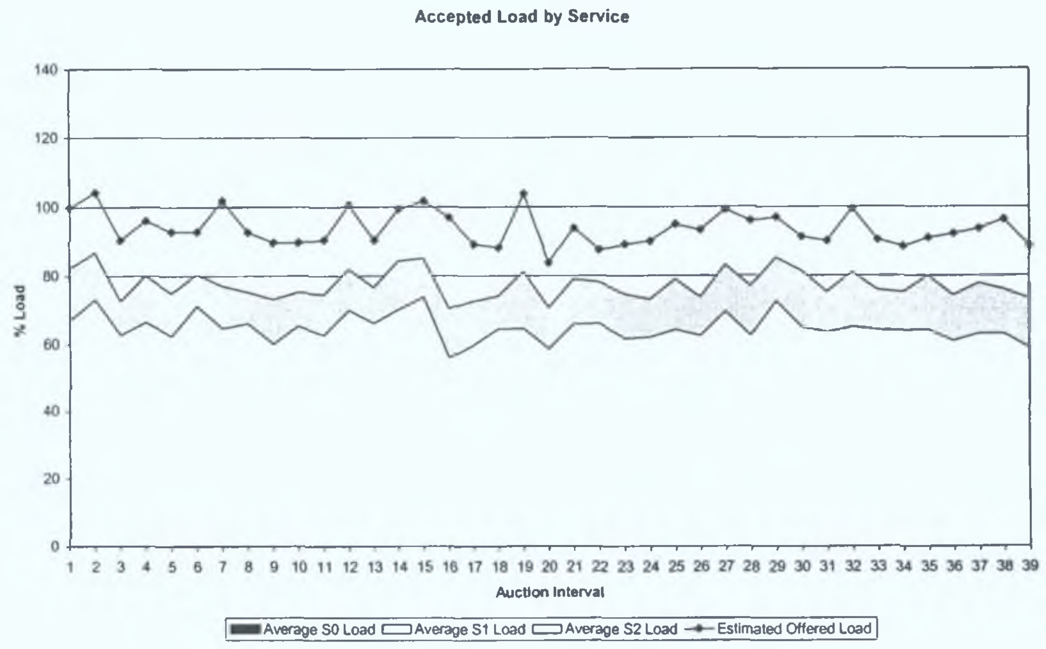


Figure 5.9 – Service Balancing at 95% Load

Figure 5.9 shows that under an excessive load of 95%, the network rejected the service with the lowest profit value (Service 0) and accepted all requests of the service with the highest profit value (Service 3).

The results above verify that the MARINER System successfully maximises profit and distributes the offered load when the traffic is at a steady excessive level just above the 90% SCP safe limit. However, they also show that at this level, the accepted load is over-controlled such that 15% of the offered load was unnecessarily discarded. The reason behind this is that at a level so close to the safe limit, the inaccuracy of the single notification option set in the experimental setup (§ 5.2.2) is magnified. Setting the STC to send multiple notifications would solve this problem.

5.4.2.3 Experiment 2.2: 120% Excessive Load Under Steady State

In this experiment, the MARINER agents should maintain the network load at the safe maximum of 90%, quenching 30% of the offered load. Further, the requests for the less profitable services should the ones most quenched.

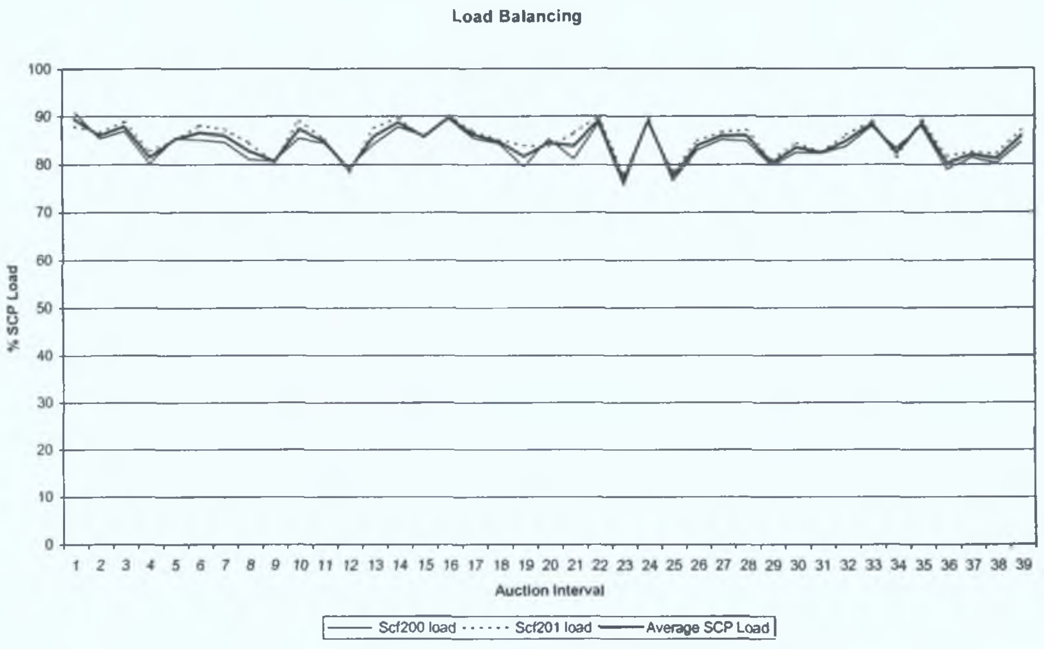


Figure 5.10 – Load Balancing at 120% Load

The graph shows that under a steady load of 120%, the SSPs distribute load evenly between the available SCPs.

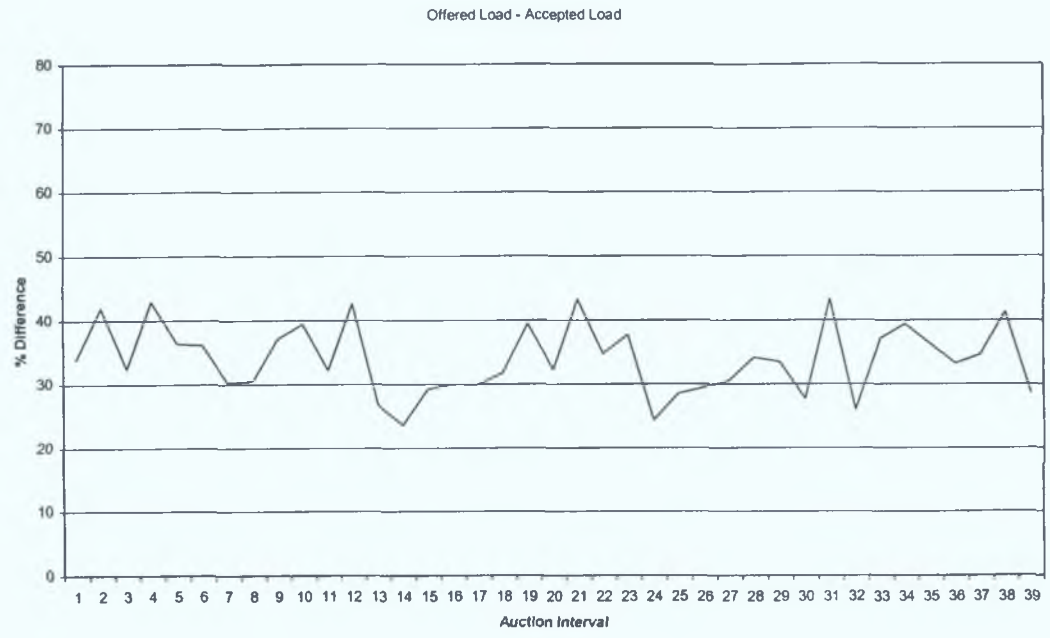


Figure 5.11 – Load Difference at 120% Load

This graph shows that approximately 35% of the offered load was rejected when the system was under a steady load of 120%.

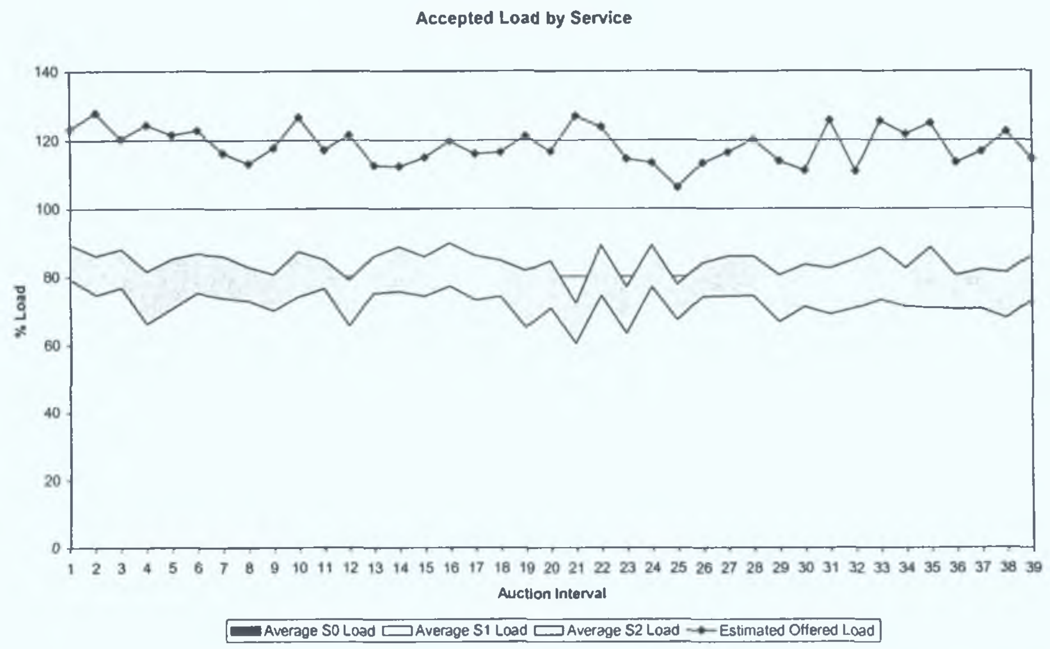


Figure 5.12 – Service Balancing at 120% Load

Figure 5.12 shows that under an excessive load of 120%, the network rejected the service with the lowest profit value (Service 0) and accepted all requests of the service with the highest profit value (Service 3).

The results above verify that the MARINER System successfully maximises profit and distributes the offered load when the traffic an excessive level. It is also observed that a slight amount of over-controlling is still manifested by the system with approximately 5% of the load being unnecessarily discarded. As in experiment 2.1, this is a result of using the single notification option in the STC. It should be noted that the degree over-controlling is drastically reduced with higher overloads. A more accurate result could be achieved using the multiple notification option.

5.4.2.4 Experiment 3.1: Excessive Load of 95% for 20 Intervals

In this experiment, the MARINER agents should maintain the network load at 35% until the arrival of the spike. Then, the network load should increase with the offered load until reaching the 90% safe maximum, and be maintained at that level for the duration of the spike. At this stage, 5% of the arriving service requests should be quenched, with the less profitable services having the most number quenched. When the spike falls to 75% of its value, the network load should fall with it, and accept all service requests. At the end of the spike, the network load should fall back to 35%, and all service requests should be serviced.

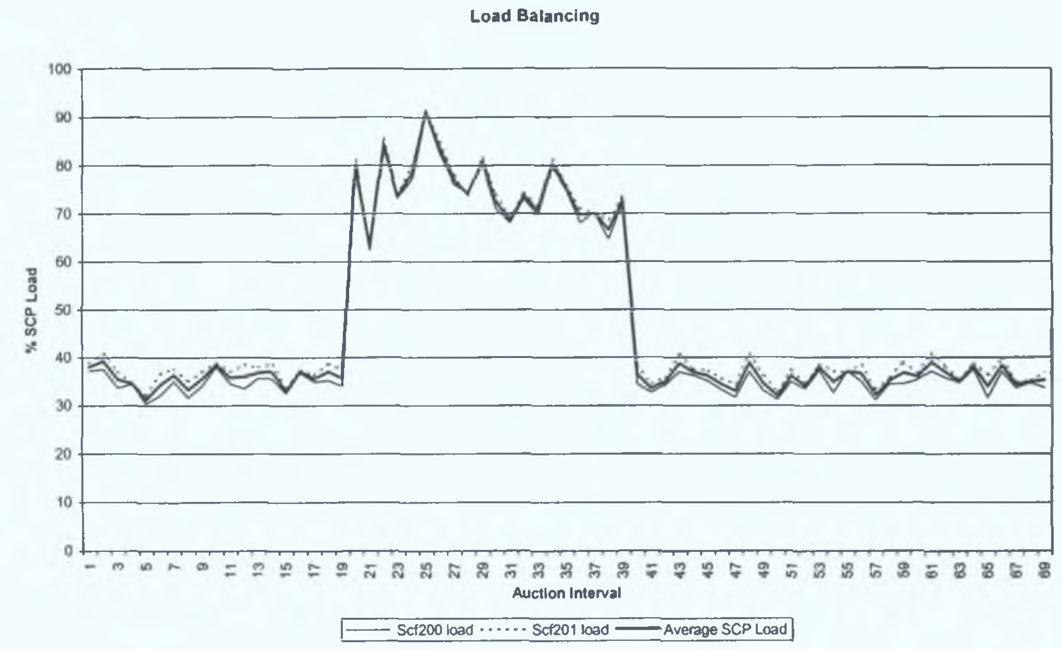


Figure 5.13 – Load Balancing at 95% Spike

The graph shows the network load was distributed evenly between the available SCPs throughout the experiment.

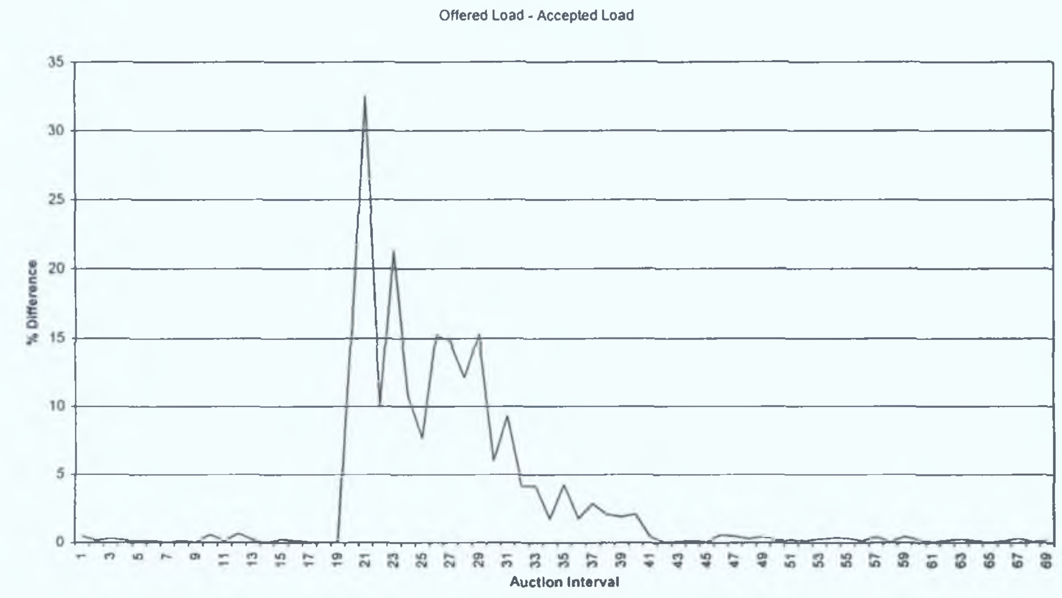


Figure 5.14 – Load Difference at 95% Spike

The figure above illustrates that the network accepted nearly all the offered load in the periods before and after the traffic spike. In the first phase of the spike, when the offered load was at the 95% level, the network initially rejects about 30% of the offered load, but gradually settles to about 15%. In the second phase of the spike, the network eventually settles to rejecting about 3% of the offered load.

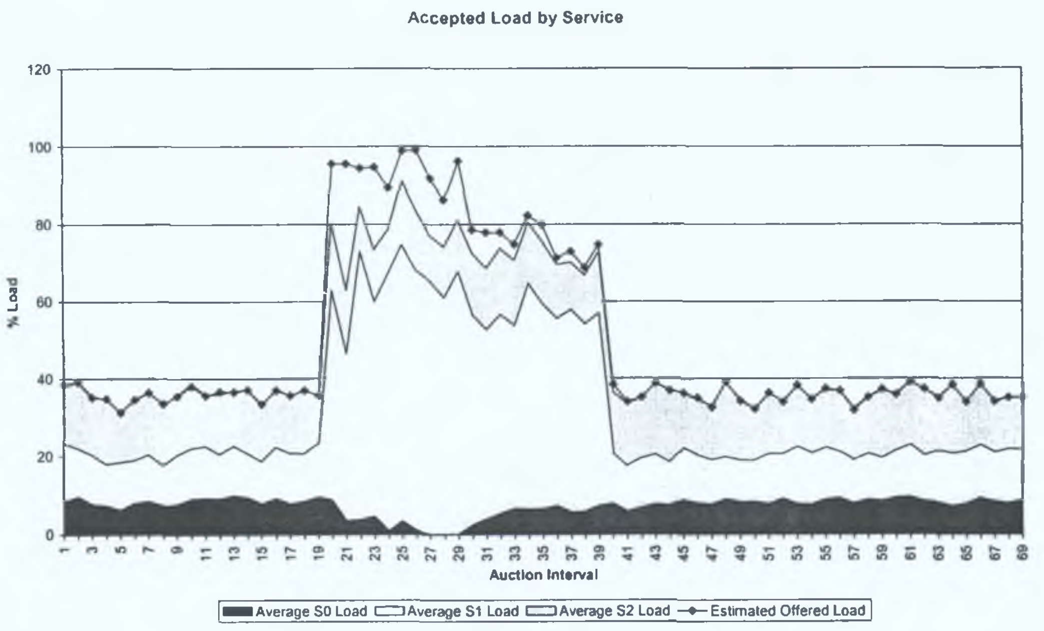


Figure 5.15 – Service Balancing at 95% Spike

The figure shows that all service requests were accepted in the periods before and after the spike. In the first phase of the spike, the system gradually rejected all of the least profitable service requests (Service 0) and none of the most profitable service requests (Service 2). In the second phase of the spike, the system rejected only a small proportion of the Service 0 requests.

The results of this experiment show that the MARINER System is successfully able to adapt to spontaneous multi-phased sharp increases in traffic. The individual graphs show that the offered load was successfully controlled and distributed, while the network was protected against the sudden overload.

A point of note is that the network has a tendency to over-control the accepted load on the on-set of a spike, but quickly adapts to the optimum level. This effect is a result of the MARINER System attempting to ensure protection against an overload whilst the traffic level is rising.

5.4.2.5 Experiment 3.2: Excessive Load of 120% for 20 Intervals

In this experiment, the MARINER agents should maintain the network load at 35% until the arrival of the spike. Then, the network load should increase with the offered load until reaching the 90% safe maximum, and be maintained at that level for the duration of the spike. At this stage, 30% of the arriving service requests should be quenched, with the less profitable services having the most number quenched. When the spike falls to 75% of its value, the network load should fall with it, and accept all service requests. At the end of the spike, the network load should fall back to 35%, and all service requests should be serviced.

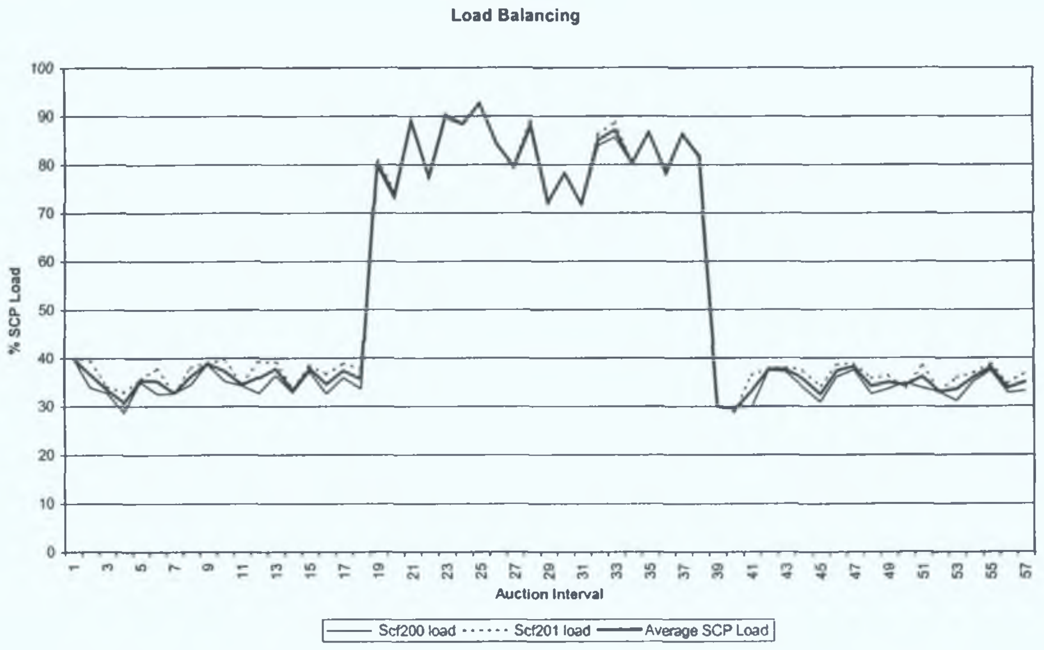


Figure 5.16 – Load Balancing at 120% Spike

The graph shows the network load was distributed evenly between the available SCPs throughout the experiment.

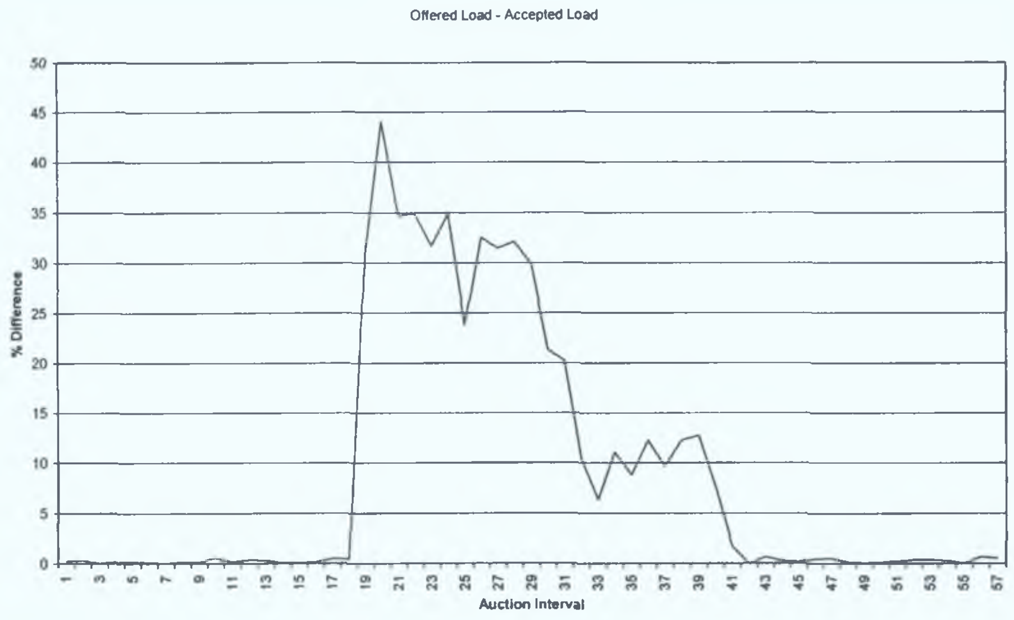


Figure 5.17 – Load Difference at 120% Spike

The figure above illustrates that the network accepted nearly all the offered load in the periods before and after the traffic spike. In the first phase of the spike, when the offered load was at the 120% level, the network initially rejects about 47% of the offered load, but gradually settles to about 30%. In the second phase of the spike, the network eventually settles to rejecting about 10% of the offered load.

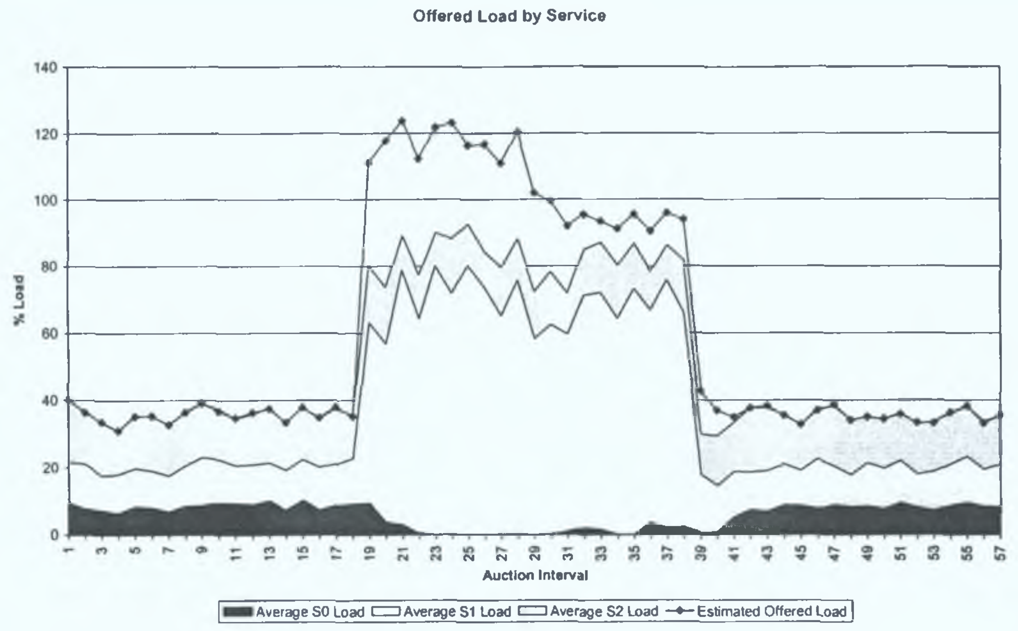


Figure 5.18 – Service Balancing at 120% Spike

The figure shows that all service requests were accepted in the periods before and after the spike. In the first phase of the spike, the system gradually rejected all of the least profitable service requests (Service 0) and none of the most profitable service requests (Service 2). In the second phase of the spike, some of the Service 0 requests were accepted.

The results of this experiment show that the MARINER System is successfully able to adapt to spontaneous multi-phased sharp increases in traffic to an extreme level. The individual graphs show that the offered load was successfully controlled and distributed, while the network was protected against the sudden overload.

A point of note is that the network has a tendency to over-control the accepted load on the on-set of a spike, but quickly adapts to the optimum level. This effect is a result of the MARINER Architecture attempting to ensure protection against an overload whilst the traffic level is rising.

5.4.2.6 Experiment 4: 120% Localised Excessive Load for 20 Intervals

Although the spike only occurs at a single SSP, the MARINER Agents should have a similar response towards the network as in the event of the global spikes in Experiment 3.

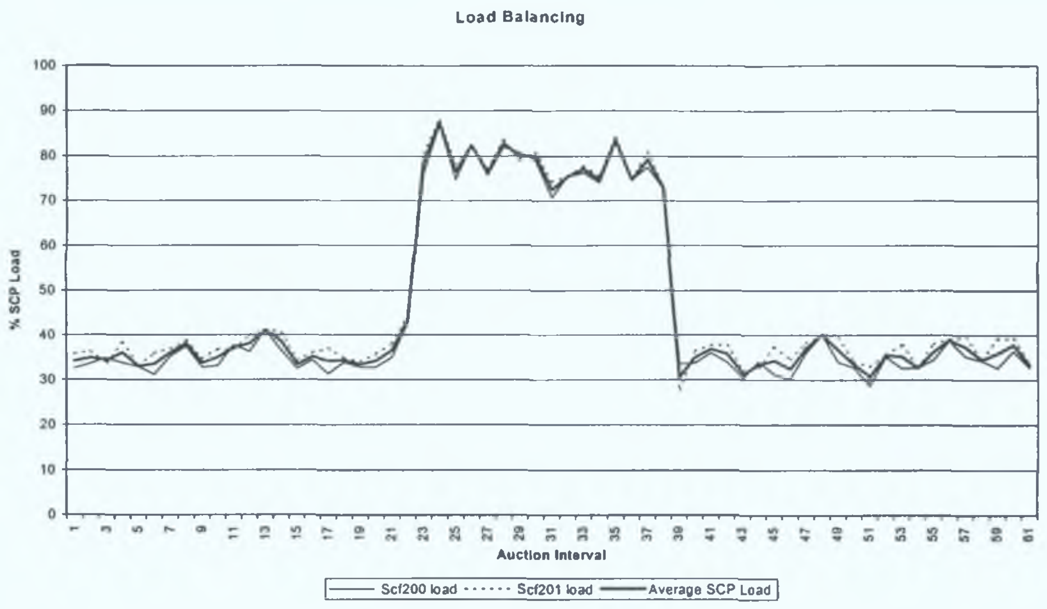


Figure 5.19 – Load Balancing at Localised 120% Spike

The graph shows the network load was distributed evenly between the available SCPs throughout the experiment.

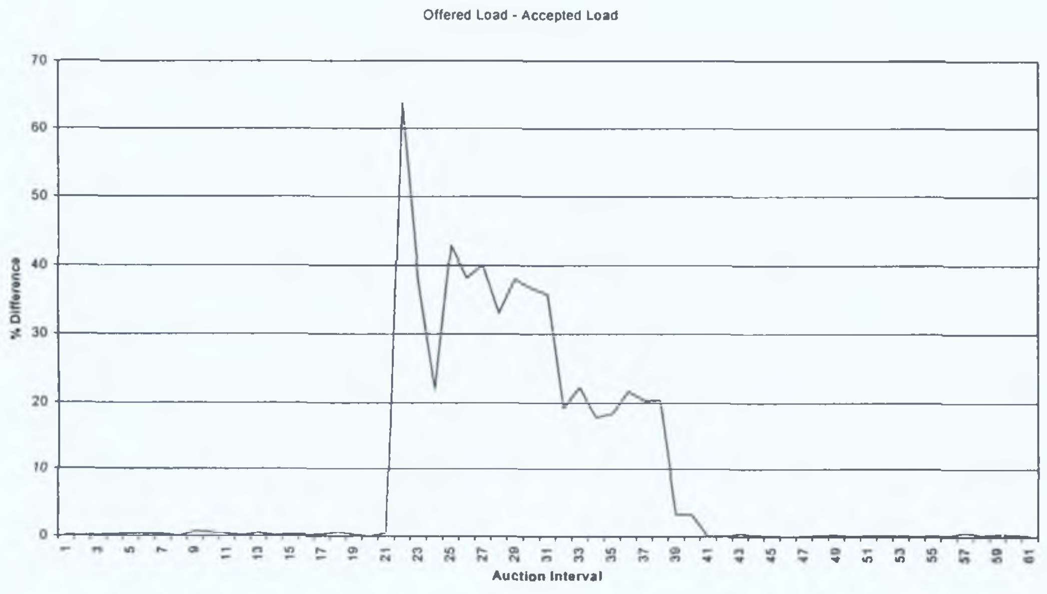


Figure 5.20 – Load Difference at Localised 120% Spike

The figure above illustrates that the network accepted nearly all the offered load in the periods before and after the traffic spike. In the first phase of the spike, when the offered load was at the 95% level, the network initially rejects about 60% of the offered load, but gradually settles to about 35%. In the second phase of the spike, the network eventually settles to rejecting about 20% of the offered load.

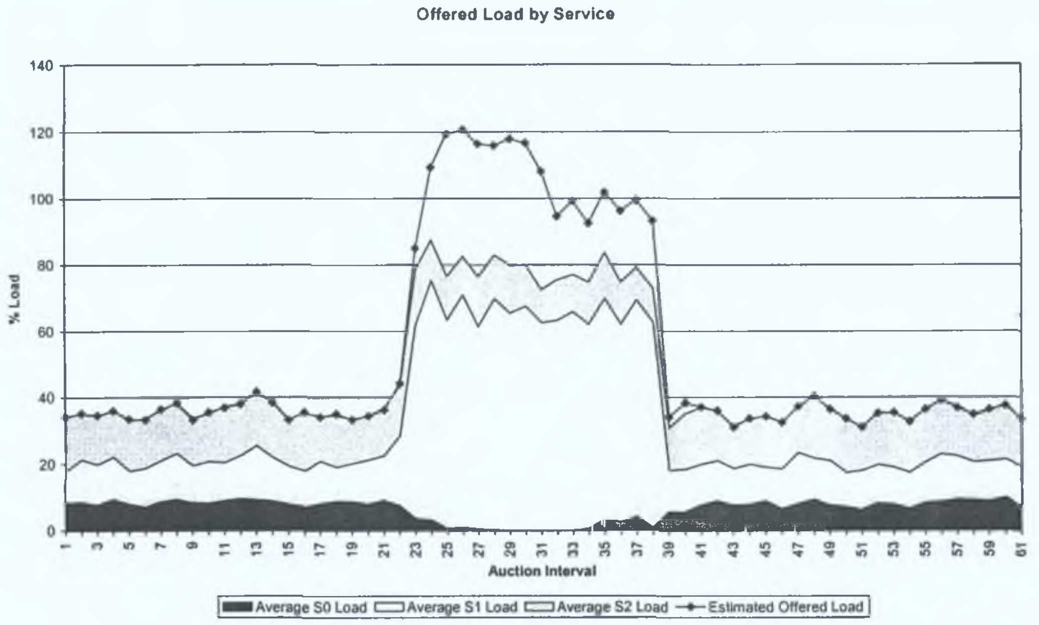


Figure 5.21 – Service Balancing at at Localised 120% Spike

The figure shows that all service requests were accepted in the periods before and after the spike. In the first phase of the spike, the system gradually rejected all of the least profitable service requests (Service 0) and none of the most profitable service requests (Service 2). In the second phase of the spike, the system rejected only a small proportion of the Service 0 requests.

The results of this experiment show that the MARINER System is successfully able to adapt to local spontaneous multi-phased sharp increases in traffic. The individual graphs show that the offered load was successfully controlled and distributed, while the network was protected against the sudden overload.

A point of note is that the network has a tendency to over-control the accepted load on the on-set of a spike, but quickly adapts to the optimum level. This effect is a result of the MARINER System attempting to ensure protection against an overload whilst the traffic level is rising.

5.5 Robustness Experiments

The robustness experiments were designed to exhaustively examine the robustness and limitations of the Trial Platform and hence the MARINER System. The experiments were categorised into three error conditions, namely

- the malfunctioning of platform components
- the increase in network delays
- the loss of communication messages

5.5.1.1 RMA Malfunction

Objective(s) of experiment:	To verify that the system operates correctly when the RMA malfunctions.
Experimental setup	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at an excessive steady state rate of 95% and capture load information for the network. Force a RMA shutdown and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.2 RAA Malfunction

Objective(s) of experiment:	To verify that the IN System operates correctly when the RAA malfunctions.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals, force a RAA shutdown and monitor the IN Platform for 15

intervals. Increase traffic generation to 120% for 20 intervals and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly. Repeat the experiment and shutdown the RAA during the spike. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.3 SCP Malfunction

Objective(s) of experiment:	To verify that the system operates correctly when an SCP malfunctions.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at a steady state rate of 85% and capture load information for the network. After 15 intervals, force an SCP to shutdown and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.4 SSP Malfunction

Objective(s) of experiment:	To verify that the system operates correctly when an SSP malfunctions.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at a steady state rate of 85% and capture load information for the network. After 15 intervals, force an SSP to shutdown and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.5 resource_data Delay

Objective(s) of experiment:	To verify that the system operates when a resource_data message from the RMA is delayed.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals, force a delay in a resource_data message from one RMA and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.6 token_allocation Delay

Objective(s) of experiment:	To verify that the system operates correctly when an token_allocation is delayed.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals, force a delay in a token_allocation from the RAA and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.7 resource_data Message Loss

Objective(s) of experiment:	To verify that the system operates correctly when a resource_data message from the RMA is lost.
Experimental setup:	Standard Configuration

Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals , force one RMA to not send a resource_data message and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.8 **token_allocation** Message Loss

Objective(s) of experiment:	To verify that the system operates correctly when a token_allocation message to one of the RMAs is lost.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals, force the RAA not to send a token_allocation to one of the RMAs and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.9 **notification** Message Loss

Objective(s) of experiment:	To verify that the system operates correctly when a SSP notification message to one of the RMAs is lost.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 120% and capture load information for the network. After 15 intervals, force the SSP not to send a notification to one of the SCPs and

	monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.1.10 **token_allocation_ack Message Loss**

Objective(s) of experiment:	To verify that the system operates correctly when SSP token_allocation_ack message to one of the RMAs is lost.
Experimental setup:	Standard Configuration
Experimental procedure:	Configure a standard IN network and deploy the MARINER agents on it. Start traffic generation at the normal steady state rate of 35% and capture load information for the network. After 15 intervals, force the SSP not to send a token_allocation_ack message to one of the SCPs and monitor the IN Platform. By analysis of the loading data verify that the MARINER agents are operating correctly.

5.5.2 Robustness Experiments Results

In this section, the theoretical result of each of the evaluation experiments is first presented. This is followed by the observed result presented in graphic form and an analysis of the result.

5.5.2.1 Experiment 1: RMA Malfunction

In the event that a RMA were to malfunction and shutdown, the processing capacity of the SCP it represents would not be made available to the SSPs, and hence the RAA would not allocate any tokens for it. This would mean that the SSPs would stop sending service requests to this SCP and the load on it would diminish to zero. This situation would prevail until the subsequent intervention by the management system which would re-install the coupling between one of the SSFs and the SCF, with the use of only traditional IN Load Control and no load distribution by that SSF, as described in § 2.6.

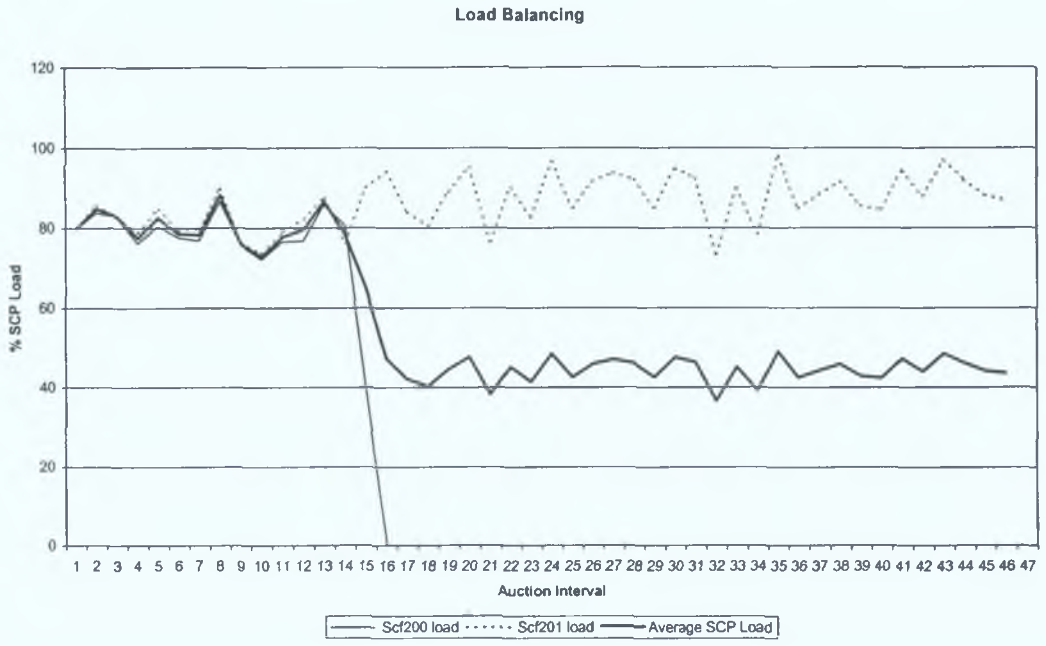


Figure 5.22 – RMA Malfunction

The results of this experiment show that when a RMA malfunctions, the load on the SCP it represents diminishes to zero, reducing the overall capacity of the network. The

MARINER System, however, continues to protect the network against the excessive offered load, and continues to control and distribute the available capacity in the network.

5.5.2.2 Experiment 2: RAA Malfunction

As stated in § 4.3.2, the STC has been equipped with a safety mechanism that re-uses the last token_allocation in the event that the SSP does not receive a new token_allocation at the beginning of the current interval. This process is repeated until a new token_allocation is received.

A malfunction and subsequent shutdown of the RAA will result in a stoppage new token allocations to the STCs. The STCs should then continue to use the last token_allocation they received, until intervention by the network management system, whereby the traditional IN distribution and load control described in § 2.6 is re-installed.

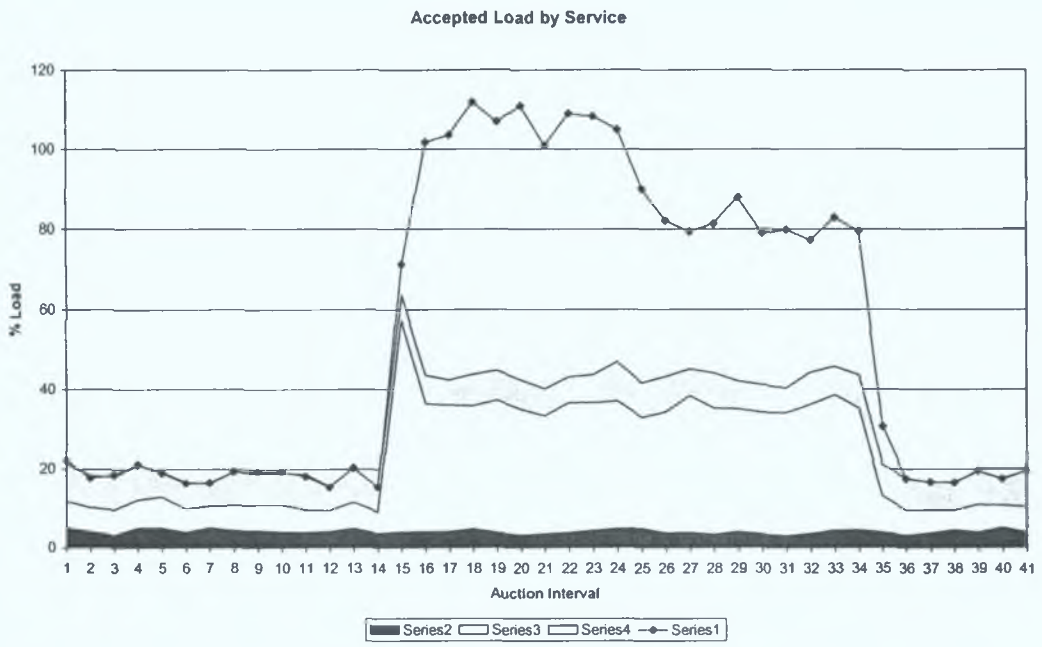


Figure 5.23 – RAA Malfunction at Normal Load

This result shows that if the RAA shutdown during a normal loading period, the MARINER System is not able to modify is accepted load pattern to maximise profit when exposed to a spontaneous increase in traffic. However, the system continues to operate and protect the network against the overload.

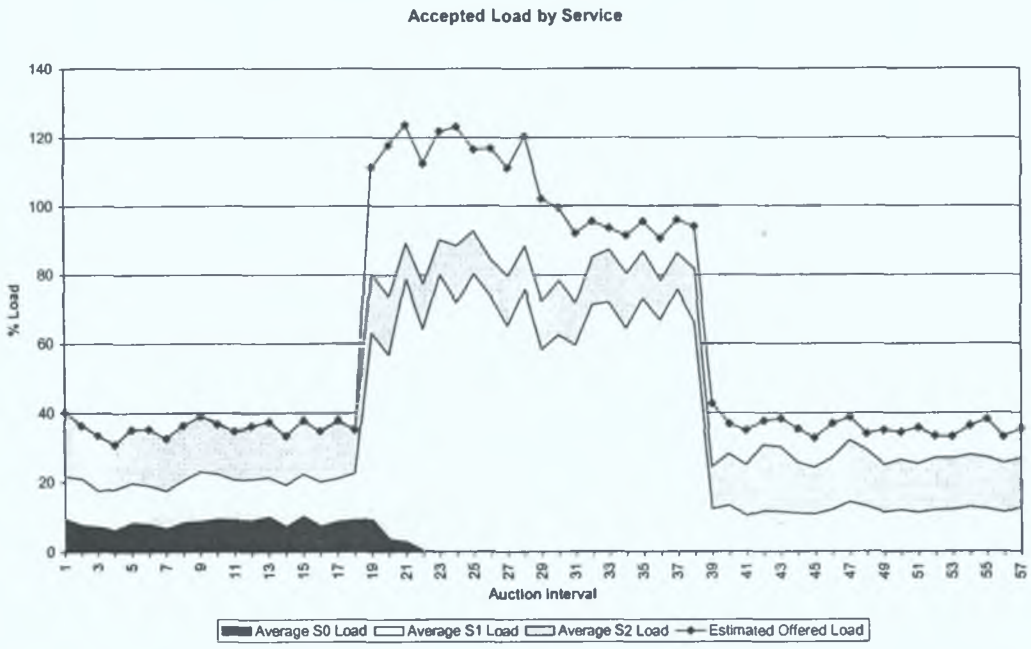


Figure 5.24 – RAA Malfunction at Spike

This result shows that if the RAA malfunctioned during a period of excessive load on the network, the service type(s) rejected during the overload would continue to be rejected once the offered load resumes its normal levels. The MARINER System however, continues to protect the network and distribute the rest of the service load(s).

5.5.2.3 Experiment 3: SCP Malfunction

The effect of a SCP malfunction and subsequent shutdown on the system as a whole would be very similar to that of a RMA malfunction. The RMA would cease to be able to contact the malfunctioned SCP and hence stop sending resource data to the RAA. This would result in no tokens being allocated for the malfunctioned SCP and the SSPs ceasing to forward service requests to that SCP. The only notable difference between the effects of the two malfunctions is that in the interval within which the SCP malfunctions, the SSPs would continue to forward requests to that SCP, but would no processing would take place, hence resulting in those service requests being dropped. Therefore, for some part of an interval, the system would not be functioning at maximum profit value.

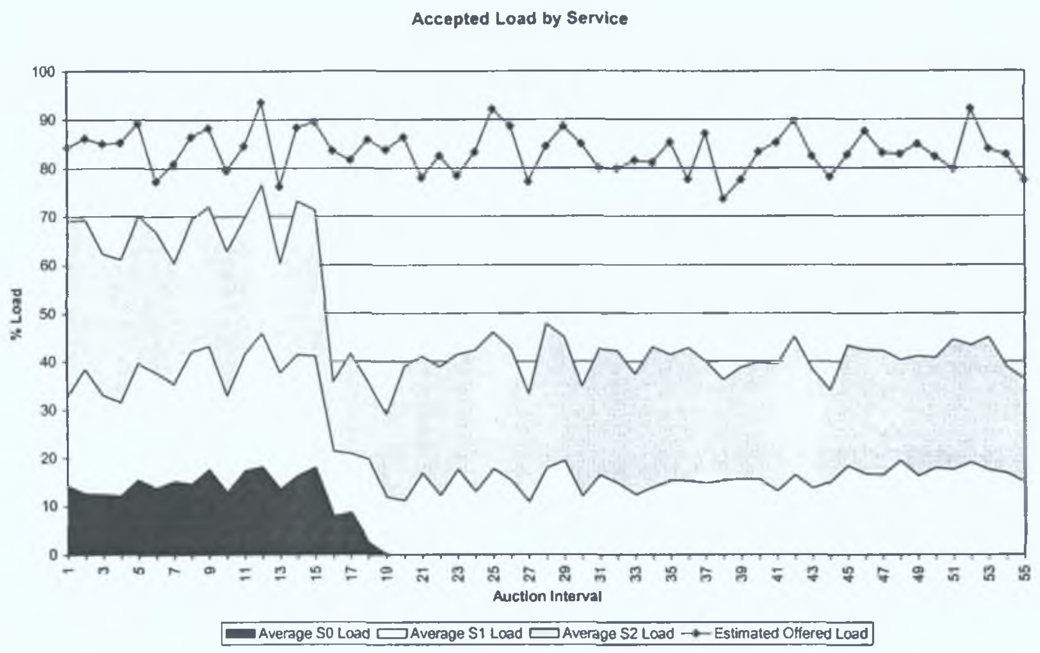


Figure 5.25 – SCP Malfunction

The results of this experiment show that when an SCP malfunctions, the load sent to it diminishes to zero, reducing the overall capacity of the network. The results also shows that the load on the remaining SCF has increased to its maximum (the graph shows average load on the two SCFs). This indicates that the MARINER System attempts to redistribute its share of service traffic to other available SCFs, before beginning to reject incoming requests. The result is a marked improvement over existing IN systems wherein SSF-SCF coupling would result in total loss of all services traffic coming into the coupled SSF. Further, the system continues to protect the network against the excessive offered load, and continues to control and distribute the available capacity in the network.

5.5.2.4 Experiment 4: SSP Malfunction

An SSP malfunction and subsequent shutdown should only manifest itself as a reduction in the load offered to the System.

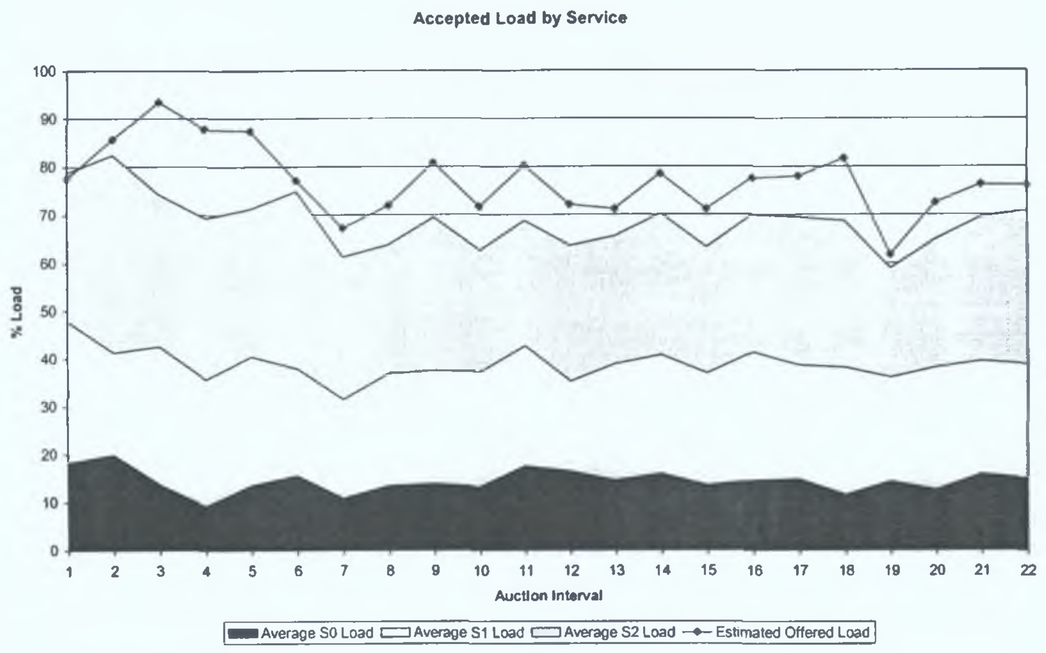


Figure 5.26 – SSP Malfunction

The result shows that if an SSP malfunctions, the overall load offered to the network is reduced. However, the MARINER System continues to operate with the reduced offered load.

5.5.2.5 Experiment 5: resource_data Delay

Figure 5.22 shows that the MARINER System suffers from no adverse effects in the event that a resource_data messages are not available for one or more intervals.

In the event of a delay in the resource_data from a RMA, the capacity of the SCP it represents is not made available to the SSPs for that interval. Further, the portion of requests it received from the SSPs during the last interval is not taken into account during the token allocation process. This would result in the SSPs receiving fewer tokens for the next interval, and hence possible rejecting service requests.

5.5.2.6 Experiment 6: token_allocation Delay

A delay in a token_allocation message from an RMA to an STC has no effect on the MARINER System's ability to operate successfully due to the built in redundancy provided by more than one RMA sending a token allocation message to an STC.

5.5.2.7 Experiment 7: resource_data Message Loss

Figure 5.22 shows that the MARINER System suffers from no adverse effects in the event that resource_data messages are not available for one or more intervals.

In the event of a loss of the resource_data from a RMA, the capacity of the SCP it represents is not made available to the SSPs for that interval. Further, the portion of requests it received from the SSPs during the last interval is not taken into account during the token allocation process. This would result in the SSPs receiving fewer tokens for the next interval, and hence possible rejecting service requests.

5.5.2.8 Experiment 8: token_allocation Message Loss

A loss of a token_allocation message has no effect on the MARINER System's ability to operate successfully due to the built in redundancy provided by the RAA sending the complete token_allocation message to all RMAs, and more than one RMA sending a token_allocation message to an STC.

5.5.2.9 Experiment 9: notification Message Loss

A loss in a notification message from an STC has no effect on the MARINER System's ability to operate successfully due to the built in redundancy provided by the STC broadcasting its notifications to all the RMAs in its vicinity.

5.5.2.10 Experiment 10: token_allocation_ack Message Loss

A loss in a token_allocation_ack message from an STC has no effect on the MARINER System's ability to operate successfully due to the built in redundancy provided by the STC broadcasting its token_allocation_acks to all the RMAs in its vicinity.

5.6 Summary

The criteria used to evaluate MARINER System as a network orientated load control mechanism for the Intelligent Network was set out in § 5.1. With respect to the experiments described in § 5.3 to § 5.5, these criteria may be expressed as the following:

1. Overload Protection: To limit the load at all SCF nodes to 90% of its processing capacity
2. Overload Protection: To rapidly adapt to changes in the offered load.
3. Load Distribution: To distribute the load offered to the network such that the individual SCF loads are as close as possible to the average SCF load
4. Service Differentiation: To continuously maintain the accepted load at the level of the offered load in normal loading conditions and to reject the service requests according to their profit value in excessive loading conditions, so as to maximise the overall network profit at all times
5. Robustness: To maintain a minimum operating performance matching that of existing IN Load Control mechanisms (see § 2.6) in the event of a malfunction or communication errors

The various experimental results described in § 5.3 to § 5.5 demonstrated the degree to which the above criteria had been met by the MARINER System and highlighted areas requiring improvement. A summary of this is listed below:

- § 5.4.2.1 demonstrated that under normal loading conditions, the MARINER System successfully meets criteria 2, 3 and 4 in that the all the offered load is accepted into the IN and evenly distributed among the available SCFs
- § 5.4.2.2 and § 5.4.2.3 showed that under heavy loading conditions, the MARINER System meet criteria 1 through 4. However accepted loads closer to the 90% level would be more desirable, and better usage of notifications is seen as one method of overcoming this limitation.

- § 5.4.2.4 through § 5.4.2.6 demonstrate the sensitivity of the MARINER System to a sudden increase in network-wide and local offered load. The results specifically illustrate the success of the system in achieving criterion 2, while still satisfying criteria 1, 3 and 4. The results also highlight a short lapse is in the recovery time to a sudden decrease in offered load.
- § 5.5.2.1 through § 5.5.2.4 show that the system meets criterion 5 in the event of the loss of any of the IN or system functional entities.
- § 5.5.2.5 through § 5.5.2.10 show that the system meets criterion 5 in the event of any degree of communication loss between its functional entities.

Current and future work on the Trial Platform intends to investigates the following possibilities:

- Investigating more effective use of the notification messages to enable the system to better achieve the 90% resource usage limit in all excessive load scenarios.
- Investigating a more scalable system that utilises a hierarchical approach for the control of large systems i.e. local network RAA's behaving as RMA's in larger networks and sending monitoring data to a central RAA.
- Investigating a more flexible system with STC's incorporated within H.323 Gatekeepers and GSM Switches.

6 CONCLUSION AND FUTURE WORK

6.1 INTRODUCTION

In order to complete the analysis of the performance of the MARINER Load Control System, it is necessary to compare it with one or more other IN load control strategies. The following criteria was used to select the IN Load Control Systems that were used for this comparison:

1. The comparison system must implement one or more load control strategies for Intelligent Networks
2. In order for an accurate comparison to be made, the comparison system must be well defined by publicly available documentation, specifically in the areas of its performance in the areas of overload protection and load control.
3. In order to ensure that the performance of the MARINER System is analysed against a commercially deployed load control system, at least one of the comparison systems must have been deployed on an existing commercial Intelligent Network
4. In order to ensure that the performance of the MARINER System is analysed against similar advanced load control systems, at least one of the comparison systems must utilise adaptive load control strategies, and attempt to maximise generated revenue/profit.

Based on these criteria, the following systems were selected for comparison. The Automatic Call Restriction load control system that is currently deployed in the BT Horizon Intelligent Network was selected due to the fact that it meets criteria 1, 2 and 3. It has been well documented in [Williams94] and [Williams2002]. The Global IN Control Strategy which is an adaptive load control system that seeks to maximise revenue/profit generation, was selected due to the fact that it meets criteria 1, 2 and 4. It is well documented in [Lodge99] and [Lodge2000]. Additionally, the standard Intelligent Network Load Control mechanisms, as described in Chapter 2, were also selected due to the fact these mechanisms have been standardised and feature in most current implementation of Intelligent Networks.

In order to ensure a fair comparison, the criteria used for evaluating the MARINER System, as stated in Section 5.1.1, is used as the comparison criteria.

Sections 6.2 to 6.5 give an overview of each system and specify their behaviour against each of the comparison criteria. Section 6.6 then presents a table, comparing the load control systems. Finally, Section 6.7 draws conclusions from this body of work, and Section 6.8 states the on-going future work that extend from this platform.

6.2 Standard IN Load Control

As described in Chapter 2, standard IN-CS2 load control comprises mainly the Code Gapping and Service Filtering mechanisms. These mechanisms have the following features:

- Standardised – the Code Gapping and Service Filtering mechanisms have been standardised in the IN Capability Set 2.
- Reliable – existing mechanisms have been tried and tested on existing INs, and further developed based on real performance data
- Node-orientated – an overloaded SCF informs the SSF its coupled with to begin blocking incoming requests. The state of the network as a whole is never consulted prior to load shedding.
- Message-orientated – on the activation of either mechanism, the SSF throttles INAP messages required for service execution, and not the service requests themselves.
- Non-prioritised – these mechanisms are incapable of differentiating between services, since they operate on the Functional Plane.
- Static – the current mechanisms utilise static parameters to control traffic load, therefore they cannot provide optimal control in all traffic conditions, with the result that they tend to cause oscillations in resource utilisation.

- Reactive – current mechanisms react to a resource overload after it has commenced, rather than ensuring that traffic is prevented from gaining access to the resource in instances where it would cause one or more resources to overload

6.2.1 Overload Protection

As described in § 2.6, standard IN load control protects the network against prolonged overloads of single nodes through the gapping of incoming messages. This allows the node to process its existing queues, and hence reduce its load. When offered a steady load exceeding the safe maximum network capacity, standard IN load control mechanisms would be able to maintain the average accepted load at the safe maximum. However, due to use of standard gap intervals, the accepted load will oscillate around the safe maximum.

Further, due to the fact that these load control mechanisms require the onset of an overload before sending the gapping requests, they would not be able to react to spiky or rapidly changing offered load, which could lead to at least one interval where the SCP is exposed to an overload.

6.2.2 Load Distribution

In standard INs, SSFs and SCFs are nearly always coupled, forming networks of mated pairs [ETSI_SUB]. Hence, little or no load distribution is implemented.

6.2.3 Service Differentiation

As described in § 2.6, standard IN load control mechanisms operate in the Distributed Functional Plane, hence gapping or quenching messages, irrelevant of the service type they perform. This prevents these mechanisms from being able to differentiate between service types.

6.3 Global IN Control Strategy

The Global IN Control Strategy (GCS) involves the formulation of mathematical optimisation problems whose solution defines the best possible coefficient values to be used by a percentage thinning load throttle residing at SSPs. The optimisation involves the maximisation of generated revenue subject to load constraints on SCPs and SSPs, as well as constraints to ensure that pre-defined weightings (similar to service profit) between service types are reflected in the percentage thinning coefficients.

The strategy consists of two independent optimisation processes, one operating at the SCP and the other at SSPs. At set intervals the SCP optimisation process is invoked and takes as input estimations of IN service request arrival rates at SSPs for the coming interval, SCP target utilisation, service type weights and other service-related information. It outputs percentage thinning coefficients for each IN service type / SSP pairing in the network. These values are transferred to the SSPs, which use them as inputs into their optimisation processes. SSP optimisation may serve to modify the percentage thinning coefficients in light of local loading constraints and estimated arrival rates and processing requirements of non-IN service types. Full details of this process can be found in [Lodge99], [Lodge2000].

6.3.1 Overload Protection

In § 6.3.1 of [Lodge2000], an extensive set of simulation results clearly illustrate the behaviour of the GCS with respect to steady-state Overload Protection. Figure 6.3 shows that when exposed to a steady offered load of 120%, GCS maintains the SCP load at safe maximum threshold. However, some oscillation is apparent around safe maximum due to use of percentage thinning as load throttle

In § 6.3.5 of [Lodge2000], simulation results show the behaviour of the GCS when exposed to spiky traffic, where the offered load rapidly alternates between 60% and 120%. Figure 6.29 shows that in this scenario, the GCS requires up to one interval to adapt the percentage thinning throttle values, leading to a short period where the SCP is exposed to the overload with the onset of the spike and a short period of excessive service rejection after each spike.

Figure 6.29 also shows that when the offered load is within the safe maximum threshold, the SCP load matches it.

6.3.2 Load Distribution

The GCS does not have any load distribution capabilities, and operates specifically to control the load on a single resource.

6.3.3 Service Differentiation

Figures 6.6 and 6.32 in § 6.3 of [Lodge2000] illustrates that GCS is able to differentiate between service to maximise revenue generation in both a steady overload of 120% and spiky traffic, where the offered load rapidly alternates between 60% and 120% of the network capacity.

6.4 AUTOMATIC CALL RESTRICTION

The Automatic Call Restriction (ACR) control uses the rate of call failure in the SCP to detect overload. The control enforces an upper limit to this rate by activation and updating of call restrictions at the SSPs. It also distinguishes between call streams such that restrictions are only applied to the call stream causing an overload (service fairness), before they are applied to other call streams. This control uses leaky bucket monitors at the SCP to monitor the rate of call rejection by call stream, and based on these values, calculates appropriate call gaps, which are communicated to the SSPs.

The ACR control also attempts to control outbound traffic from the SCPs to other network destinations, to control the demand sent to the network, by monitoring the call rejection rates to these destinations. Full details of this process can be found in [Williams94], [Williams2002].

§ 6.3 of [Williams2002] evaluates the performance of ACR using an experiment that simulates an offered SCP load of 100%, which rapidly increases to over 300% due to the failure of another SCP in the simulated network, and then decreases back to 100% when the failed SCP recovers. The result of this experiment is used to evaluate the performance of ACR with respect to the evaluation criteria set out in § 5.1.1 of this paper:

6.4.1 Overload Protection

Figure 7 in § 6.3 of [Williams2002] shows that when the SCP is exposed to a steady offered load of 300%, ACR successfully maintains the SCP load at the safe maximum threshold.

This figure also illustrates that at the onset and the end of the overload, ACR is not able to immediately respond the change in the offered load, leading to under-control and over-control.

With respect to the behaviour of ACR when the offered load is within the safe maximum network capacity, Figure 7 shows that accepted load matches the offered load before and after the overload.

6.4.2 Load Distribution

ACR does not have any load distribution capabilities, and operates specifically to control the load on a single resource. However, it does have the capability of operating in tandem with an external load distribution system.

6.4.3 Service Differentiation

The ACR implements service fairness and hence does not attempt to distinguish between services for the maximisation of network profit.

6.5 The MARINER System

As described in Chapter 4, the MARINER System is a network-orientated load control mechanism developed for the IN by the MARINER Project. It has the following characteristics:

- Standard-compliant – the system was designed in compliance to IN CS-2, but is not itself part of any existing standard.

- Non-tested – the system has only been tested on an emulation of the IN.
- Network Orientated – the system monitors all nodes in its domain and distributes traffic evenly between the available nodes such that traffic load is only shed when the whole network is operating at maximum capacity. In this manner individual node protection is still maintained.
- Proactive – the system uses a network wide view of the IN to discern the onset of an overload, and takes measures to distribute and control the incoming traffic.
- Adaptive - the control parameters of the system continuously adapt to the latest network conditions. This allows it to always have a realistic view of network usage and incoming traffic.
- Service-orientated - the system operates at the application level, controlling and distributing service requests according to the service type and its importance to the operator.

6.5.1 Overload Protection

The experimental results described § 5.4.2.2 through 5.4.2.6 show how the MARINER System protects nodes from overloads by sensing increases in service traffic and proactively distributing the load across the network, so as to avoid the need of load shedding until all capacity within the network has been utilised. It then sheds load by rejecting service requests at the SSFs.

Figures 5.9 and 5.12 illustrate that the MARINER Load Control System is successfully able to protect the network against steady offered loads of 95% and 120%. It is observed that a varying degree of over-control manifests itself in both scenarios. However, it is also noted that configuring the system to use multiple notification messages would remove this effect.

Figures 5.15 and 5.18 show that system is successfully protects the network against sudden surges in offered load, without at any time exposing the protected nodes to an overload. At the onset and end of the spike, a small amount of over-control is observed, but this is rapidly corrected.

Figure 5.6 shows that under normal steady offered load, the MARINER System ensures that the accepted matches the offered load.

6.5.2 Load Distribution

Figures 5.4, 5.7, 5.10, 5.13 and 5.16 illustrate that the MARINER Load Control System is able to successfully distribute the accepted load between the available SCPs for offered loads of both steady and spiky in nature ranging from 35% to 120% of the network capacity. In doing this, it allows for optimum use of all available capacity in the network. This prevents service request rejection and loss of revenue unless all the capacity within the network is being utilised.

Figure 5.25 shows a further advantage of load distribution in the MARINER Load Control System in that it increases the network robustness towards the malfunction or shutdown of a processing node by re-routing its share of traffic to other available nodes.

6.5.3 Service Differentiation

Figures 5.6, 5.9, 5.12, 5.15 and 5.18 clearly illustrate how the MARINER System is able to differentiate between service types in steady and bursty offered loads ranging from 35% to 120% of the network capacity. The figures also show that when forced to reject traffic due to excessive incoming traffic, the MARINER rejects service requests of least priority first. This facility gives network operators using the MARINER System the following advantages:

- The ability to maximise the revenue generated from their network at all times.
- The ability to allow third-party services into their network with the confidence that the capacity allocated to them can be regulated and limited so as to not harm their network, in the event of irresponsible usage by the third parties.
- The ability to have Service Level Agreements automatically enforced by the network.

It should be noted that these results also further emphasize the reasons neither service-fairness or source-fairness is used as an evaluation criterion in this paper.

6.6 Load Control System Comparison

Criterion	**Standard**	**GCS**	**ACR**	**MARINER**
Overload Protection: Staying close to but under safe maximum network capacity processor target utilisation during overload.	*NO* Accepted Load oscillates due to use of standard gap intervals.	*PARTIAL* Some oscillation is apparent around safe maximum due to use of percentage thinning as load throttle	*YES* Accepted Load maintained below safe maximum using variable gap intervals	*YES* Accepted Load slightly below safe maximum. Use of tokens ensures safe maximum not exceeded.
Overload Protection: Immediate reaction to overload onset and end.	*NO* Up to one control interval before gap put in place.	*NO* Up to one control interval before percentage thinning in place.	*NO* Up to one control interval before gapping put in place.	*YES* Immediate reaction due to volume of accepted requests limited by token allocation size.
Load Distribution: Equally between all available SCPs offering required service type	*NO* Mated SSF-SCF messaging excludes load distribition	*NO* Operates specifically to control the load on a single resource.	*NO* Operates specifically to control the load on a single resource.	*YES* Use of token strategy and manipulation of SSF routing tables enables load distribution
Service Differentiation: Ensuring profit maximisation	*NO* Operation at DFP excludes Service Differentiation	*YES* Optimization of percentage thinning coefficients allows for Service Differentiation	*NO* Adherence to service fairness excludes any Service Differentiation	*YES* Tokens generated so as to differentiate between services and maximise profit.

This comparative analysis of the four strategies shows the following:

- Standard IN Load Control is insufficient due to being highly prone to oscillations and not robust to changes in offered load due reliance on standard gap intervals.
- ACR shows that the application of dynamic sets of gap intervals shows a marked improvement by reducing oscillation, but still lacks in the area of robustness to bursty traffic.
- GCS performs better than standard mechanisms with respect to accepted load oscillations and dynamically computes control parameters with the goal of maximising profit whilst protecting the SCP from overload.
- MARINER matches the performance of ACR and GCS in the areas of steady state overload protection and service differentiation respectively, but out-performs all the comparison strategies in robustness to rapid changes in the offered load and load distribution.

6.7 Conclusion

The completion of this assessment of network-orientated load control has shown that it offers the following advantages over existing Intelligent Network Load Control and Overload Protection Systems:

- It protects network nodes in a proactive manner; resulting in an immediate reaction to sudden changes in the offered load and, in an overload, complete utilisation of the network capacity, without endangering the network resources.
- It offers load distribution capabilities to the operator
- It allows the operator to prioritise services, improving their ability to maximize network profit and honor Service Level Agreements.

At the same time, the following limitations of the mechanism have been unveiled:

- The over-protection of network resources when exposed to an offered load slightly over the safe maximum network capacity.

- The lack of a standard manner of implementing network-orientated load control
- The lack of performance data from real Intelligent Networks

Finally, it was shown that the MARINER System, as an implementation of a network-orientated load control system, out performed existing representative implementations of standard, traditional and more advanced Intelligent Network load control systems in the areas of overload protection, load distribution and service differentiation.

In summary, network-orientated load control is a definite enhancement over existing load control mechanisms for Intelligent Networks. However, it needs to be standardized and through those efforts, further tested and validated on real networks.

6.8 Future Work

The following is an overview of the development and enhancement work being explored and implemented on network orientated load control systems.

6.8.1 Multiple Notification Investigation

In response to the tendency of the MARINER System to over-protect the network resources when exposed to traffic loads slightly over the safe maximum network capacity, investigations are being carried out on the use of multiple notification messages from the STC to the RMA, resulting in a reduction of the inaccuracy of single notifications and the RAA being better informed about the traffic situation prior to the auctions.

6.8.2 Standardisation Activities

A submission [ETSI_SUB] has been made to ETSI in order to initiate the standardisation of network orientated load control systems. The response has been encouraging, with more detailed presentations to the Working Groups planned in the months ahead.

6.8.3 Scalability

Further trials on the MARINER System are being designed in order to evaluate the scalability of network orientated load control. In a large network, it is envisioned that hierarchical auctions would be held, where RAAs would participate in auctions, playing the role of RMAs of their local sub-network. Each layer would then have its own RAA. The areas that are being investigated are the optimum number of agents per layer; the efficiency of the tree-like structure; efficient methods of combining the RAA and RMA roles in sub-network RAAs.

6.8.4 Distributed SCF Load Control

Recently, there has been much work in exploring the possibility of splitting the IN SCF functionality into separate CORBA objects distributed across the network. Currently, investigations are being carried out on the possible of using the network-orientated load control to efficiently cope with the traffic demands on these distributed SCFs.

6.8.5 Internet Telephony

The usage of network-orientated load control for Internet Telephony is also being explored. Possible methods of controlling the load on Internet Telephony Gatekeeper and Gateway resources are described in the paper [Wathan1999].

GLOSSARY

CAMEL	Customised Applications for Mobile Network Enhanced Logic
CORBA	Common Object Request Broker Architecture
CS-1	Capability Set 1
CS-2	Capability Set 2
DFP	(INCM) Distributed Functional Plane
ETSI	European Telecommunications Standards Institute
EURESCOM	European Institute for Research and Strategic Studies in Telecommunication
FE	Functional Entity
GFP	(INCM) Global Functional Plane
GSM	Global System for Mobiles
GPRS	General Packet Radio Service
IDL	Interface Definition Language
IN	Intelligent Network
INAP	Intelligent Network Application Protocol
INCM	Intelligent Network Conceptual Model
ITU-T	International Telecommunication Union – Telecommunication Standardisation Sector
MARINER	Multi-Agent Architecture for Distributed IN Load Control and Overload Protection
OO	Object Orientation
PP	(INCM) Physical Plane
RAA	Resource Allocation Agent

RMA	Resource Management Agent
SCF	Service Control Function
SCP	Service Control Point
SIB	Service-Independent Building Block
SP	(INCM) Service Plane
SSF	Service Switching Function
SSP	Service Switching Point
STC	Service Traffic Controller
TIPHON	Telecommunications and Internet Protocol Harmonisation over Networks
VPN	Virtual Private Network

REFERENCES

[Arvidsson97] A. Arvidsson, S. Pettersson and L. Angelin, “Profit Optimal Congestion Control in Intelligent Networks”, in Proceedings of the 15th International Teletraffic Congress, pp. 911-920, Washington D. C., USA, 1997.

[Arvidsson99] A. Arvidsson, B. Jennings, L. Angelin and M. Svensson, “On the use of Agent Technology for IN Load Control”, in Proceedings of the 16th International Teletraffic Congress (ITC-16), vol. 3b, pp. 1093-1105, Edinburgh, Scotland, June 1999.

[CORBA] Object Management Group (OMG), “The Common Object Request Broker (CORBA): Architecture and Specification ”, Revision 2.0, July 1995.

[Dovrolis2000] C. Dovrolis, P. Ramanathann, “Proportional Differentiated Services, Part II: Loss Rate Differentiation and Packet Dropping”, in Proceedings of IEEE/IFIP International Workshop on Quality of Service (IWQoS), pp. 53-61, Pittsburgh PA, U.S.A, June 2000.

[ETSI_SUB] B. Jennings, N. Wathan, R. Brennan and C. Smith, “Network-oriented Load Control for IN: Benefits and Requirements”, Submission to ETSI SPAN on behalf of the ACTS-MARINER project, May 2000.

[Fayn96] I. Faynberg, L. Gabuzda, M. Kaplan, and N. Shah, “Intelligent Network Standards: their Application to Services”, pub. McGraw Hill, New York, U.S.A, 1997

[Folkestad96] A. Folkestad, P. Osland and P. Emstad, “On Load Control for Service Data Points”, in Proceedings of the 4th International Conference on Intelligence in Networks, Bordeaux, France, November 1996.

[Galletti92] M. Galletti, F. Grossini, "Performance Simulation of Congestion Control Mechanisms for Intelligent Networks", in Proceedings of 1992 International Zurich Seminar on Digital Communications, Intelligent Networks and their Applications, Zurich, Switzerland, 1992.

[GRASSHOPPER] IKV++, “Grasshopper Basics and Concepts”, release 1.1 Feb 1999, available (Sept 2000): http://www.grasshopper.de/index.html

[Hac98] A. Hac and L. Gao, "Analysis of Congestion Control Mechanisms in an Intelligent Network", International Journal of Network Management, vol. 8, pp. 18-41, 1998.

[Hnatyshin2001] V. Hnatyshin and A.S. Sethi, "Avoiding Congestion Through Dynamic Load Control", Proc. ITCom-2001, SPIE's International Symposium on The Convergence of Information Technologies and Communications, CO pp. 309-323, Denver, U.S.A, Aug 2001

[Kant95] K. Kant, "Performance of Internal Overload Controls in Large Switches", I Proceedings of the 28th Annual Simulation Conference, pp 228-237, Phoenix, U.S.A, April 1995

[Khorasani01] Mehdi Khorasani, Dr. Lionel Sacks, "Integrity: An Interaction Case Study", in Proceedings of the London Communications Symposium, London, United Kingdom, September 2001.

[Kihl99] Maria Kihl, "Overload control strategies for distributed communication networks", PhD. Thesis, Faculty of Technology, Lund University, Lund, Sweden, March 1999.

[Korner91] Ulf Korner, "Overload Control of SPC Systems" in Proceedings of the 13th International Teletraffic Congress, Copenhagen, Denmark, 1991.

[Korner94] U. Korner, C. Nyberg and B. Wallström, "The Impact of New Services and New Control Architectures on Overload Control", in Proceedings of the 14th International Teletraffic Congress, pp. 275-283, Antibes Juan-les-Pins, France, 1994

[Kwiatkowski94] M. Kwiatkowski, B. Northcote, "Calculating Mean Delays in Intelligent Networks Under Overload", in Proceedings of the Australian Telecommunication Networks and Applications Conference (ATNAC), Melbourne, Australia, December 1994.

[Langlois91] F. Langlois, J. Regnier, "Dynamic Congestion Control in Circuit-Switched Telecommunications Networks", in Proceedings of the 13th International Teletraffic Congress (ITC 13), Copenhagen, Denmark, 1991.

[Lodge97] F. Lodge, D. Botvich, T. Curran, "A fair algorithm for throttling combined IN and non-IN traffic at the SSP of the Intelligent Network", in Proceedings of IEEE Teletraffic Symposium, Manchester, United Kingdom, March 1997.

[Lodge99] F. Lodge, D. Botvich and T. Curran, "Using Revenue Optimisation for the Maximisation of Intelligent Network Performance", in Proceedings of the 16th International Teletraffic Congress, pp. 953-965, Edinburgh, Scotland, June 1999.

[Lodge2000] F. Lodge, "An Investigation into Intelligent Network Congestion Control Techniques", PhD. Thesis, School of Electronic Engineering, Dublin City University, Ireland, 2000.

[MAGEDANZ96] T. Magedanz, R. Popescu-Zeletin, "Intelligent Networks: Basic Technology, Standards and Evolution", International Thomson Computer Press, 1996

[MARINER] ACTS-MARINER Project Consortium, "The European Commission's Advanced Communication, Technologies and Services (ACTS) Multi-Agent Architecture for Distributed Intelligent Network Load Control and Overload Protection (MARINER) Project", available (Sept 2000): http://www.cordis.lu/infowin/acts/rus/projects/ac333.htm

[MARINERD4] ACTS MARINER Project Consortium, "MARINER Deliverable 4: Specification of Final IN Load Control Strategy and Multi-Agent System for deployment on Trial Platform", May 1999, available (Sept 2000): http://www.teltec.dcu.ie/mariner

[MARINERD8] ACTS MARINER Project Consortium, "MARINER Deliverable 8", May 2000, available (Sept 2000): http://www.teltec.dcu.ie/mariner

[MASIF] Object Management Group (OMG), "Mobile Agent System Interoperability Facility", Revision 1.1, 1998

[Mine98] Roberto Minerva, Corrado Moiso, Gabriele Viviani, "The Middleware ate the Verge between Internet and Telecom Services", in Proceedings of the 5th International Conference on Intelligence in Networks, Bordeaux, France, May 1998

[Mohapi2000] S. Mohapi and H.E. Hanrahan, "Value-based service differentiation for distributed NGN service platforms", in Proceedings of the South African Telecommunications Networks and Applications Conference, Drakensberg, South Africa, September 2002

[Nyberg94] H. Nyberg and B. Olin, "On load control of an SCP in the Intelligent Network", in Proceedings of the Australian Telecommunication Network and Applications Conference, Melbourne, Australia, December 1994.

[P8132000] "Technical Development and Support for European ATM Service Introduction", P813 Project Deliverable 5 Recommendations on Traffic-related Implementation Issues Volume 1 of 4, February 2000.

[P916] EURECOM P916 Project Consortium, "Supporting of H.323 by IN", available (Sept 2000): http://www.eurescom.de/public/projects/P900-series/P916/P916.htm.

[Pettersson96] S. Pettersson, "Some Results on Optimal Decisions in Network Oriented Load Control in Signaling Networks", University of Karlskrona/Ronneby Technical Report, ISRN HKR-RES-96/11-SE, Karlskrona, Sweden, 1996

[Q1200] ITU-T, "General Series Intelligent Network Recommendation Structure" (Recommendation Q.1200), ITU-T, 1999

[Q1201] ITU-T, "Principles of Intelligent Network Architecture"(Recommendation Q.1201), ITU-T, 1993

[Q1202] ITU-T, "Intelligent Network – Service Plane Architecture"(Recommendation Q.1202), ITU-T, 1998

[Q1203] ITU-T, "Intelligent Network – Global Functional Plane Architecture" (Recommendation Q.1203), ITU-T, 1998

[Q1204] ITU-T, "Intelligent Network Distributed Functional Plane Architecture" (Recommendation Q.1204), ITU-T, 1993

[Q1205] ITU-T, "Intelligent Network Physical Plane Architecture" (Recommendation Q.1205), ITU-T, 1993

[Q1208] ITU-T, "General Aspects of the Intelligent Network Application Protocol " (Recommendation Q.1208), ITU-T, 1998

[Q1222] ITU-T, "Service Plane for Intelligent Network Capability Set 2" (Recommendation Q.1222), ITU-T, 1998

[Q1223] ITU-T, "Global Functional Plane for Intelligent Network Capability Set 2" (Recommendation Q.1223), ITU-T, 1998

[Q1224] ITU-T, "Distributed Functional Plane for Intelligent Network Capability Set 2" (Recommendation Q.1224), ITU-T, 1998

[Q1228] ITU-T, "Interface Recommendation for Intelligent Network Capability Set 2" (Recommendation Q.1228), ITU-T, 1999

[Q771] ITU-T, "Signalling System No. 7 – Functional Description of Transaction Capabilities" (Recommendation Q.771), ITU-T, 1994.

[Rajaratnam96] M. Rajaratnam, F. Takawira, "Modelling multiple Traffic Streams Subject to Trunk Reservation in Circuit-Switched Networks", in Proceedings of IEEE GLOBECOM 1996, Sydney, Australia, November 1996.

[Rumsewicz96] M. Rumsewicz, "A simple and effective algorithm for the protection of services during SCP overload", in Proceedings of the 4th International Conference on Telecommunications Systems, Nashville, U.S.A, March 1996.

[Sabourin91] T. Sabourin, G. Fiche, M. Ligeour, "Overload Control in a Distributed System", in Proceedings of the 13th International Teletraffic Congress (ITC 13), pp 421-427, Copenhagen, Denmark, 1991.

[TIPHON] ETSI TIPHON Project, "The European Telecommunications Standards Institute Telecommunications and Internet Protocol Harmonization Over Networks Project", available (Sept 2000): http://www.etsi.org.

[Tsolas92] N. Tsolas, G. Abdo, R. Bottheim, "Performance and Overload Considerations when Introducing IN into an Existing Network", in Proceedings of International Zurich Seminar on Digital Communications, Zurich, Switzerland, 1992.

[Vasic99] J. Vasic, "The Internet Integrated Intelligent Network", MSc. Thesis, School of Electronic Engineering, Dublin City University, Ireland, 1999.

[Wathan99] Navin Wathan, Brendan Jennings, Dr. Thomas Curran, "Application of MARINER Agents to Load Control in IP Telephony Networks", in Proceedings of the ACTS CAMELEON Workshop, Karlskrona, Sweden, September 1999.

[Wathan2000] Navin Wathan, Dr. Thomas Curran, "The MARINER Trial Platform: A Model of a Load Control System for Intelligent Networks", in Proceedings of IEEE International Conference On Networks (ICON) 2000, Singapore, September 2000.

[Williams94] P M Williams, 'A novel automatic call restriction scheme for control of focused overloads', in Proceedings of the 11th UK IEEE Teletraffic Symposium, Cambridge, United Kingdom, 1994.

[Williams2002] P M Williams, M J Whitehead, "Realising effective intelligent network overload controls", BT Technology Journal, Vol 20, July 2002.

[Whetten2000] Whetten, B. and G. Taskale, "An Overview of Reliable Multicast Transport Protocol II", IEEE Networks, Vol 14, pp. 37-47, January 2000.

APPENDIX A: MARINER INFORMATION FLOWS

resource_data

Sender	identifier of RMA
Receiver	identifier of RAA
SSPServiceRequest	2-dimensional array of token bids by SSP/service
ScfCapacity	a double holding the SCF processing capacity

token_allocation

Sender	identifier of RAARMA
Receiver	identifier of RMA/STC
Allocation	a three-dimensional array of token allocations, per service per SCP per SSP
IntervalID	integer uniquely identifying the interval for which this token_allocation is valid
IntervalLength	length in milliseconds of the next interval
Deladline	length in milliseconds of next token generation deadline

token_allocation_ack

Sender	identifier of STC
Receiver	identifier of RMA
IntervalID	integer uniquely identifying the interval for which this acknowledgement relates
RelativeTime	(signed) time in milliseconds before/after arrival of `token_allocation` and expiry of Timer T7 (See Figure 4.1)

notification

Sender	identifier of STC/RMA
Receiver	identifier of RMA/RAA
ServiceIdentifier	identifier of service type the notification refers to
RelativeTime	fraction into current interval notification generated
Rejections	number of sessions rejected in current interval prior to notification

late_data_warning

Sender	identifier of RAA
Receiver	identifier of RMA
Duration	time in ms that `resource_data` arrived late

late_alloc_warning

Sender	identifier of RMA
Receiver	identifier of RAA
Duration	time in ms that `token_allocation` arrived late

APPENDIX B: IN MODEL

B.1 SSF

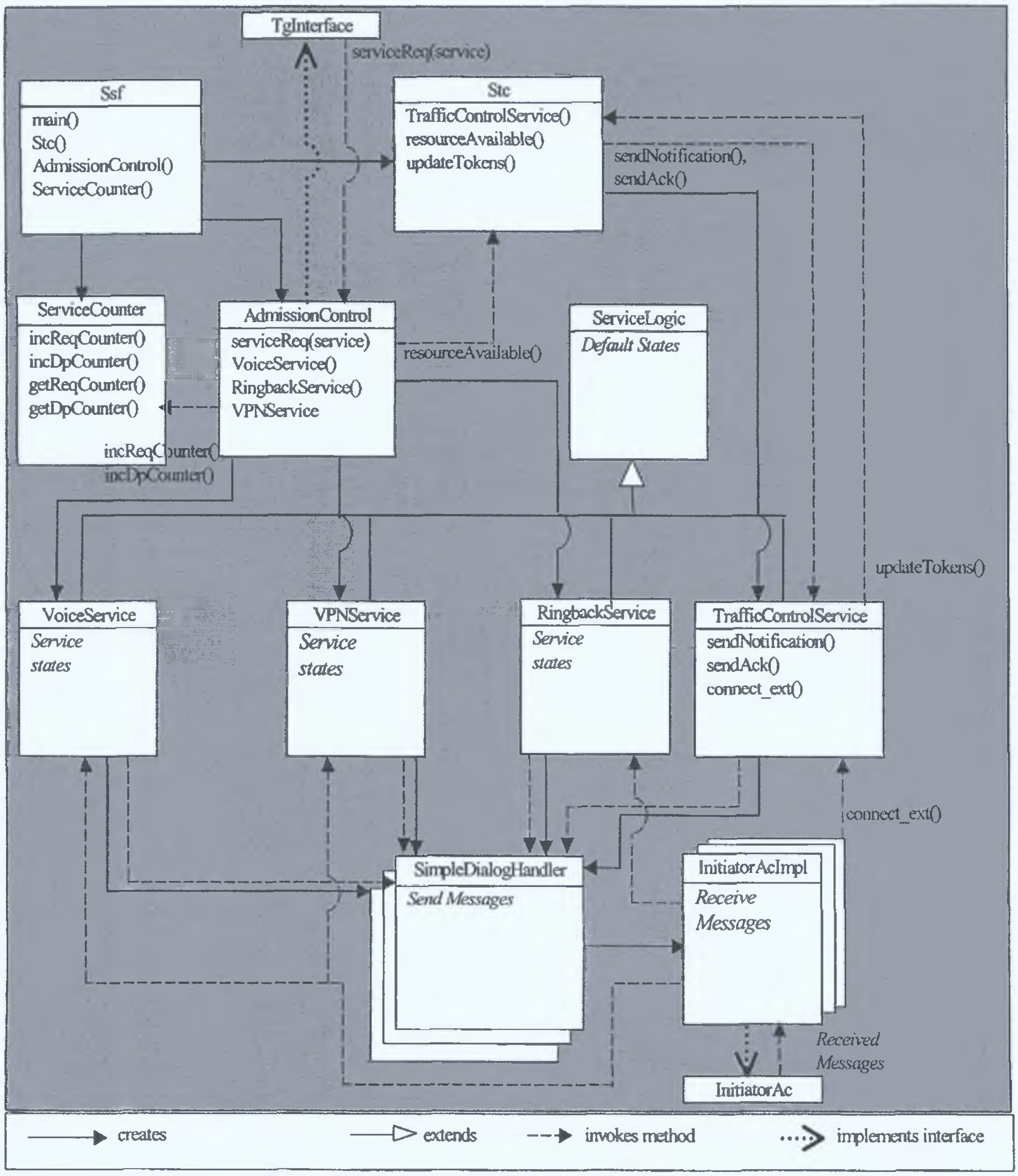


Figure B.1 – The SSF Class Diagram

The SSF classes and their relationships are illustrated in Figure B.1. It operates as described in § 3.2.1. Below are the class descriptions.

B.1.1 Admission Control

The Admission Control class implements the TgInterface. Each time the serviceReq(*in service_key*) method is called, it does the following:

- It verifies the service type being requested
- It requests that the ServiceCounter increment the serviceRequestCounter of the service type by calling incReqCounter(*service_key*).
- It checks that there are resources available to execute the request by calling the resourceAvailable(*service_key*) method in the Stc. It is returned either a nullAddress or a particular scfAddress.
- If a nullAddress is received, it requests that the ServiceCounter increment the serviceDroppedCounter of the service type by calling the incDpCounter(*service_key*).
- If an scfAddress is returned, it creates the ServiceLogic class of the service type

B.1.2 InitiatorAc

The InitiatorAc class is an interface class generated from a CORBA IDL file. It simulates the INAP messages using the TcSignalling.idl interface defined in the OMG IN/CORBA Specification. Below is the InitiatorAc IDL

```
interface InitiatorAc:TcSignaling::TcUser{

        oneway void request_event_report_bcsm();
        oneway void release_call();
        oneway void prompt_and_collect_user_information();
        oneway void connect_to_resource();
        oneway void initiate_call_attempt();
        oneway void connect();
        oneway void continue();
        oneway void connect_ext(in InControlAndMonitor::TokenAllocation
        token_allocation);
};
```

B.1.3 InitiatorAcImpl

The InitiatorAcImpl class implements the InitiatorAc interface. An object of this class is instantiated for every service request by a child of the ServiceLogic class representing the service type requested. Every time a method in this class is called, it calls a method of the same name in the ServiceLogic class e.g.

```
public void release_call() {
        serviceLogic.releaseCall();
}
```

B.1.4 RingbackService

The RingbackService class inherits from the ServiceLogic class and implements the Ssf-side state machine illustrated § B.4.3. It receives messages through the InitiatorAcImpl class and sends messages through the SimpleDialogHandler class.

B.1.5 ServiceCounter

The ServiceCounter class maintains two counter arrays. The reqCounter array keeps count of the number of requests for the different service types. The dpCounter array keeps count of the number of requests rejected by the SSF for the different service types. This class is used by the monitoring system.

B.1.6 ServiceLogic

The ServiceLogic class is the parent class of the service execution classes and implements the default states and error conditions for out of state messages received by the InitiatorAc interface.

B.1.7 SimpleDialogHandler

The SimpleDialogHandler class is used to send messages to particular SCFs. This class is instantiated by the child classes of the ServiceLogic class per service request. On instantiation, it binds to the AcFactory interface of the SCF that is assigned to execute the particular service request. A successful bind process returns a reference to a Responder interface. The SimpleDialogHandler then invokes calls on this interface pertaining to the messages it is instructed to send by the service logic states.

It also instantiates a InitiatorAcImpl object and sends it to the SCF AcFactory during the bind.

B.1.8 Ssf

The Ssf class contains the main() method in the SSF. It is responsible for the following:

- It instantiates the AdmissionControl, ServiceCounter and Stc classes.
- It initialises the CORBA Orb and the Basic Object Adaptor
- It registers the TgInterface to the Interface Repository
- It registers the interface implementation

B.1.9 Stc

The Stc class implements the Service Traffic Controller functionality described in Chapter 4. It does the following:

- It instantiates a TrafficControlService object for each SCF in the network
- It maintains a pool of tokens for each of the service types
- It maintains a timer, set to expire every tokenAllocationInterval
- It restarts the timer, refreshes the pool with a new tokenAllocation and calls the sendAck(*token_allocation_ack*) method in all TrafficControlService objects when the updateTokens(*tokenAllocation*) method is called
- If no tokenAllocation is received before the timer expires, it refreshes the pool with the last allocation

- It subtracts a token from the service type pool when the resourceAvailable(*serviceType*) method is called, and return the address of the SCF to which that token is assigned
- If no token are available in the service type pool, it returns a nullAddress, and calls the sendNotification(*notification*) method in all TrafficControlService objects. Only one notification per service type is called per interval

B.1.10 TgInterface

The TgInterface class is an interface class generated from a CORBA IDL file. It allows service requests into the SSF. Below is its IDL

```
interface TgInterface {
        oneway  void serviceReq (in ServiceKey service_key);
};
```

B.1.11 TrafficControlService

The TrafficControlService class inherits from the ServiceLogic class. It however, does not implement a specific service type state machine, but instead is part of the SSF Service Traffic Control functionality. An object of this class is instantiated for each SCF in the network. It does the following:

- On instantiation, it instantiates a SimpleDialogHandler object
- When the sendNotification(*notification*) method or the sendAck(*token_allocation_ack*) is called, it inserts the notification or acknowledgement as a CORBA Any type, into the extension field of an InitialDp INAP operation and calls the initalDp_ext(*extension*) method of the SimpleDialogHandler.
- When the connect_ext(*extension*) method is called, it extracts the CORBA Any type, verifies that it is a tokenAllocation and calls the updateTokens(*tokenAllocation*) in the Stc

B.1.12 VoiceService

The VoiceService class inherits from the ServiceLogic class and implements the Ssf-side state machine illustrated § B.4.1. It receives messages through the InitiatorAcImpl class and sends messages through the SimpleDialogHandler class.

B.1.13 VPNService

The VPNService class inherits from the ServiceLogic class and implements the Ssf-side state machine illustrated § B.4.2. It receives messages through the InitiatorAcImpl class and sends messages through the SimpleDialogHandler class.

B.2 SCF

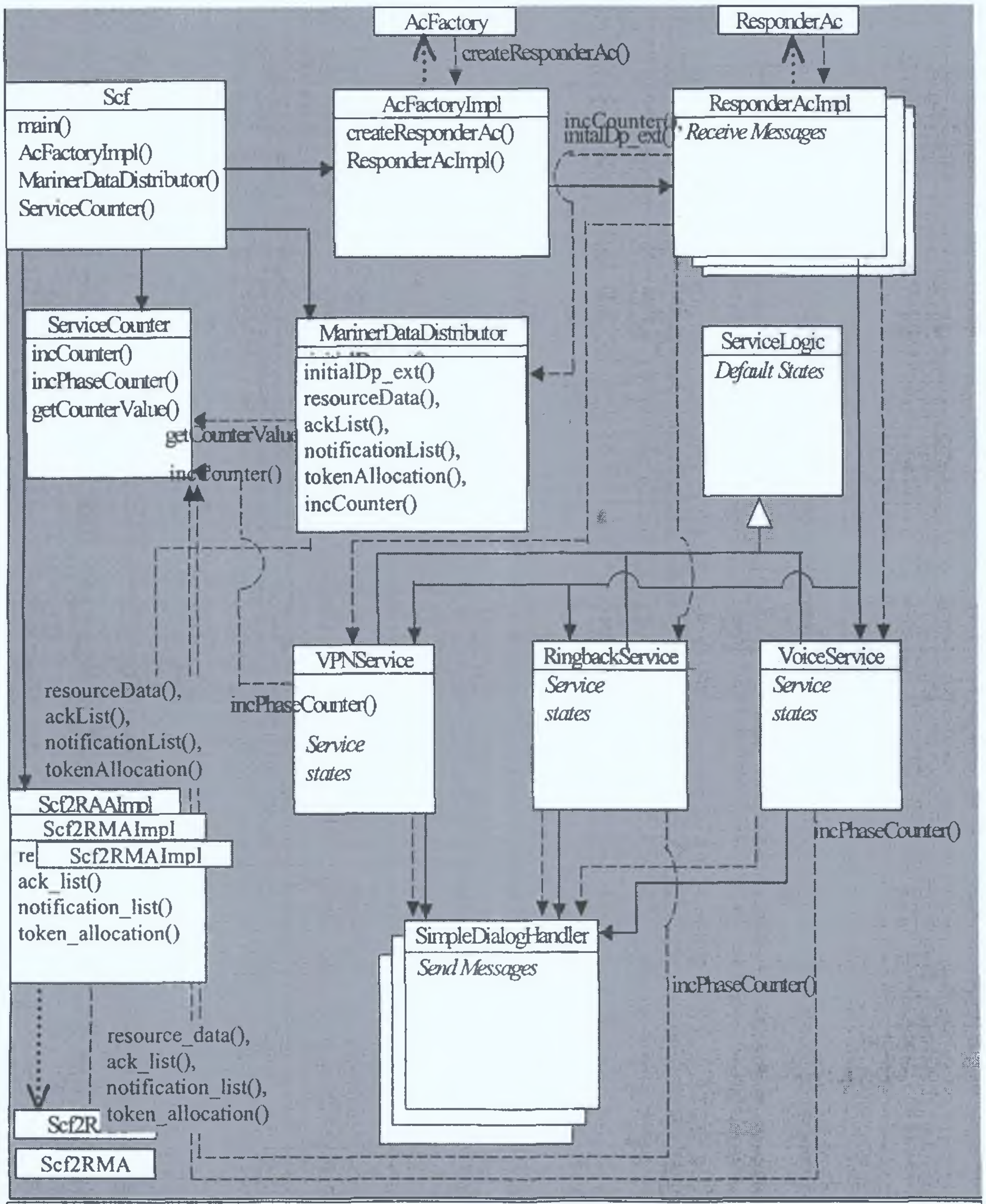

AcFactory
createResponderAc()
ResponderAc
Scf
main()
AcFactoryImpl()
MarinerDataDistributor()
ServiceCounter()
AcFactoryImpl
createResponderAc()
ResponderAcImpl()
incCounter()
initialDp_ext()
ResponderAcImpl
Receive Messages
ServiceCounter
incCounter()
incPhaseCounter()
getCounterValue()
MarinerDataDistributor
initialDp_ext()
resourceData(),
ackList(),
notificationList(),
tokenAllocation(),
incCounter()
ServiceLogic
Default States
getCounterValue()
incCounter()
resourceData(),
ackList(),
notificationList(),
tokenAllocation()
VPNService
incPhaseCounter()
Service states
RingbackService
Service states
VoiceService
Service states
incPhaseCounter()
Scf2RAAImpl
Scf2RMAImpl
Scf2RMAImpl
ack_list()
notification_list()
token_allocation()
SimpleDialogHandler
Send Messages
incPhaseCounter()
resource_data(),
ack_list(),
notification_list(),
token_allocation()
Scf2R
Scf2RMA
creates
extends
invokes method

Figure B.2 – The SCF Class Diagram

The SCF classes and their relationships are illustrated in Figure B.2. It operates as described in § 3.2.2. Below are the class descriptions.

B.2.1 AcFactory

The AcFactory class is an interface class generated from a CORBA IDL file. It allows service requests into the SCF. Below is the AcFactory IDL

```
interface AcFactory {
        ResponderAc create_responder_ac(in InitiatorAc initiator_ac)
                raises (TcSignaling::NoMoreAssociations);
};
```

B.2.2 AcFactoryImpl

The AcFactoryImpl class implements the AcFactory interface. When the create_responder method is called, it instantiates a ResponderAcImpl object and passes it the InitiatorAc reference. It then returns the reference to the ResponderAcImpl object.

B.2.3 MarinerDataDistributor

The MarinerDataDistributor class implements the resource control functionality in the SCF and is the communication bridge between the SSFs and the MARINER System. It does the following:

- When the initialDp_ext(*ssfAddress, extension*) method is called, it verifies that the extension is a recognised MARINER Information Flow e.g. token_allocation_ack, notification and stores the message.
- When the incCounter(*serviceType*) is called, it calls the ServiceCounter inCounter(*serviceType*) method.
- When the tokenAllocation(*tokenAllocation*) method is called, it inserts the token allocation into the extension field of the Connect INAP operation as a CORBA Any

type and sends it to all the SSFs by calling the connect_ext(*extension*) method of their InitiatorAc interfaces

- When the getResourceData() method is called, it calls the getCounterValue() method of the ServiceCounter object to attain the counter values and returns it to the caller.
- When the getAckList() method is called it returns the token_allocation_acks it has received
- When the getNotification() method is called, it returns the notifications it has received

B.2.4 ResponderAc

The ResponderAc class is an interface class generated from a CORBA IDL file. It simulates the INAP messages using the TcSignalling.idl interface defined in the OMG IN/CORBA Specification. Below is the ResponderAc IDL

```
interface ResponderAc:TcSignaling::TcUser{

        oneway void initial_dp(in ServiceKey service_key, in
        InControlAndMonitor::Ss7Address ssf_address);

        oneway void initial_dp_ext(in InControlAndMonitor::Ss7Address
        ssf_address,in any extension);

        oneway void event_report_bcsm();

        oneway void prompt_and_collect_user_information_result();

};
```

B.2.5 ResponderAcImpl

The ResponderAcImpl class implements the ResponderAc interface. On receiving an initialDp(*ssfAddress*, *serviceKey*), it verifies that the service logic for the requested service type is available in the SCF. It returns a no_implement error if the service logic is unavailable. Otherwise, it does the following:

- It calls the incCounter(*serviceKey*) method of the MarinerDataDistributor

- It instantiates the ServiceLogic child object that executes the requested service type

Following that, everytime it receives an INAP operation method call, it calls the corresponding method in the ServiceLogic object.

If it receives an initialDp_ext(*ssfAddress, extension*), it calls the initialDp_ext method in the MarinerDataDistributor class.

B.2.6 RingbackService

The RingbackService class inherits from the ServiceLogic class and implements the Scf-side state machine illustrated § B.4.3. It receives messages through the ResponderAcImpl class and sends messages through the SimpleDialogHandler class.

B.2.7 Scf

The Scf class contains the main() method in the SCF. It is responsible for the following:

- It instantiates the AcFactoryImpl, MarinerDataDistributor, Scf2RMAImpl and ServiceCounter classes.
- It initialises the Orb and the Basic Object Adaptor
- It registers the AcFactory and Scf2RMA interfaces to the Interface Repository
- It registers the interfaces' implementations

B.2.8 Scf2RMA

The Scf2RMA class is an interface class generated from a CORBA IDL file. It allows the RMA to push requests and information flows to the SCF. Below is the Scf2RMA IDL

```
interface Scf2RMA{
        readonly attribute ResourceData resource_data;
        readonly attribute NotificationList notification_list;
        readonly attribute AckList ack_list;
        void auction_result(in AuctionResult anAuctionResult);
};
```

B.2.9 Scf2RMAImpl

The Scf2RMAImpl class implements the Scf2RMA interface. For each method call it receives, it calls the corresponding method in the MarinerDataDistributor class.

B.2.10 ServiceCounter

The ServiceCounter class maintains counters for the number of service requests received for each service type, and the number of service phases executed by the SCF.

- When the incCounter(serviceType) method is called, it increments the service type requested counter.
- When the incPhaseCounter(serviceType, servicePhase) method is called, it increments the service-type-phase counter.
- When the getCounterValue() method is called, it returns the values of all counters.

B.2.11 ServiceLogic

The ServiceLogic class is the parent class of the service execution classes and implements the default states and error conditions for out of state messages received by the ResponderAc interface.

B.2.12 SimpleDialogHandler

The SimpleDialogHandler class is used to send messages to particular SSFs. This class is instantiated by the child classes of the ServiceLogic class per service request. On instantiation, it binds to the InitiatorAc interface of the SSF forwarding the particular service request. The SimpleDialogHandler then invokes calls on this interface pertaining to the messages it is instructed to send by the service logic states.

B.2.13 VoiceService

The VoiceService class inherits from the ServiceLogic class and implements the Scf-side state machine illustrated § B.4.1. It receives messages through the ResponderAcImpl class and sends messages through the SimpleDialogHandler class.

B.2.14 VPNService

The VPNService class inherits from the ServiceLogic class and implements the Scf-side state machine illustrated § B.4.2. It receives messages through the ResponderAcImpl class and sends messages through the SimpleDialogHandler class.

B.3 TRAFFIC GENERATOR

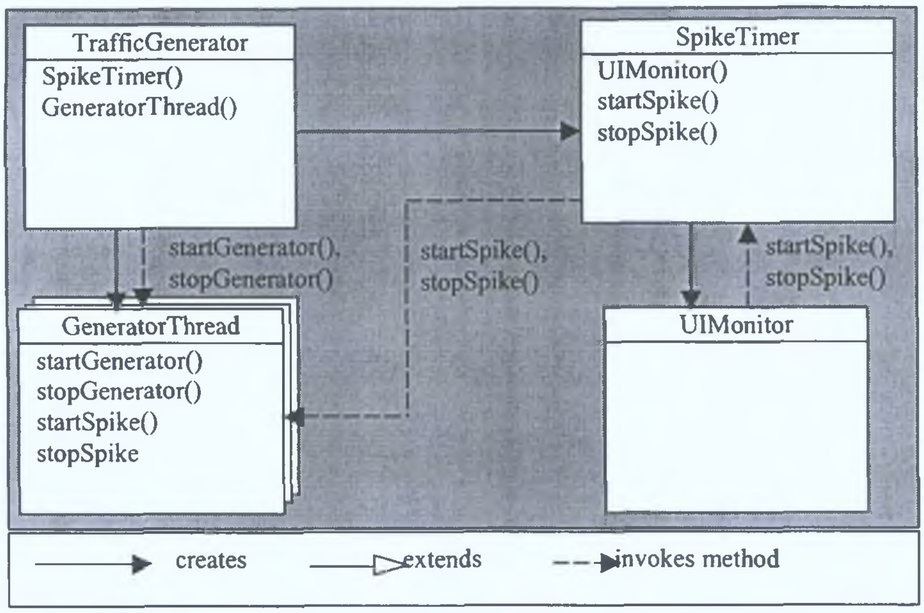


Figure B.3 – The Traffic Generator Class Diagram

The Traffic Generator classes and their relationships are illustrated in Figure B.3. It functions as stated in § 3.2.3. In order to simulate various traffic patterns, these classes read obtain configuration information from a properties file listed below.

```
SERVICES          3
S0_ARRIVAL_RATE   7
S1_ARRIVAL_RATE   7
S2_ARRIVAL_RATE   7
TYPE              no    //Spike - local, global or no
STARTTIME         10    //in minutes
SPIKE_PERIOD      0     //in seconds
MULTIPLIER        8.65
```

Next, are the class descriptions.

B.3.1 GeneratorThread

The GeneratorThread class generates service requests of its assigned service type. It does so by calling the serviceReq(*serviceType*) method on the SSF TgInterface. This is done continuously, with random intervals extracted from a Poisson distribution with a mean arrival rate read from the properties file.

- startGenerator() starts the service request generation
- stopGenerator() stops the service request generation
- startSpike(*multiplier*) increases the Poisson Distribution mean by the multiplier for a period lasting the interval
- stopSpike() returns the Poisson Distribution mean to its original value

B.3.2 UIMonitor

The UIMonitor class monitors the user interface for input. A recognised input leads to either the startSpike() or stopSpike() method being called on the SpikeTimer class. Unrecognised inputs return a text string describing the recognised inputs.

B.3.3 SpikeTimer

The SpikeTimer class simulates sudden increases in service traffic.

Provided there is to be a spike (*Type* is either local or global), it starts a timer for the duration of the *StartTime* and on its expiry calls its own startSpike(M*ultiplier, Service*) method. It also starts another timer for the spike duration. On its expiry, it calls the stopSpike() method.

Its startSpike(M*ultiplier, Service*) method calls the startSpike(*Multiplier*) method in the GeneratorThread object of the stated service type. If called while a traffic increase is in progress it returns an error.

Its stopSpike() method calls the stopSpike() method in the GeneratorThread object.

If the type is local, only one instance of the SpikeTimer will simulate a traffic increase.

The SpikeTimer class also instantiates the UIMonitor class upon its own instantiation.

B.3.4 TrafficGenerator

The TrafficGenerator class contains the main() method of the TrafficGenerator. It does the following:

- It initialised the CORBA Orb and Basic Object Adaptor

- It binds to a SSF TgInterface interface
- It instantiates GeneratorThread objects for each service type stated in the properties file.
- It also instantiates the SpikeTimer object

B.4 SERVICE EXECUTION

Below are the state transition diagrams of the three services modelled by the IN Model.

B.4.1 Restricted User Service

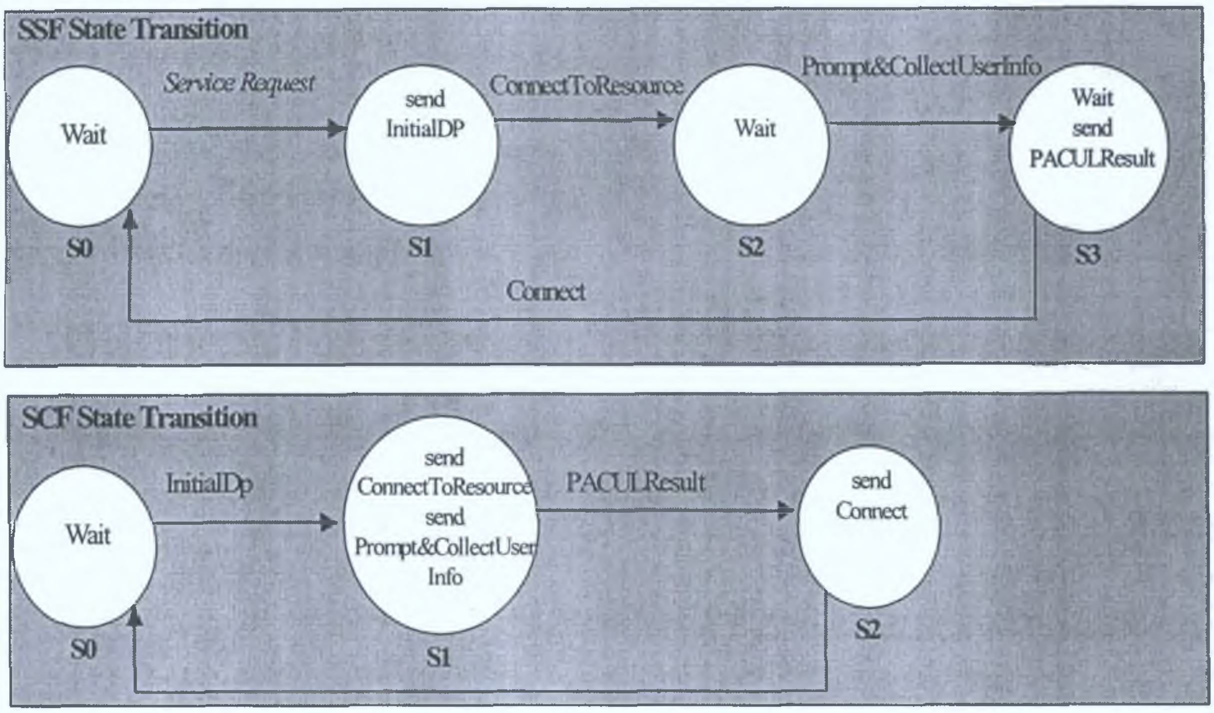


Figure B.4 – The Restricted User Service State Transition Diagram

B.4.2 VPN Service

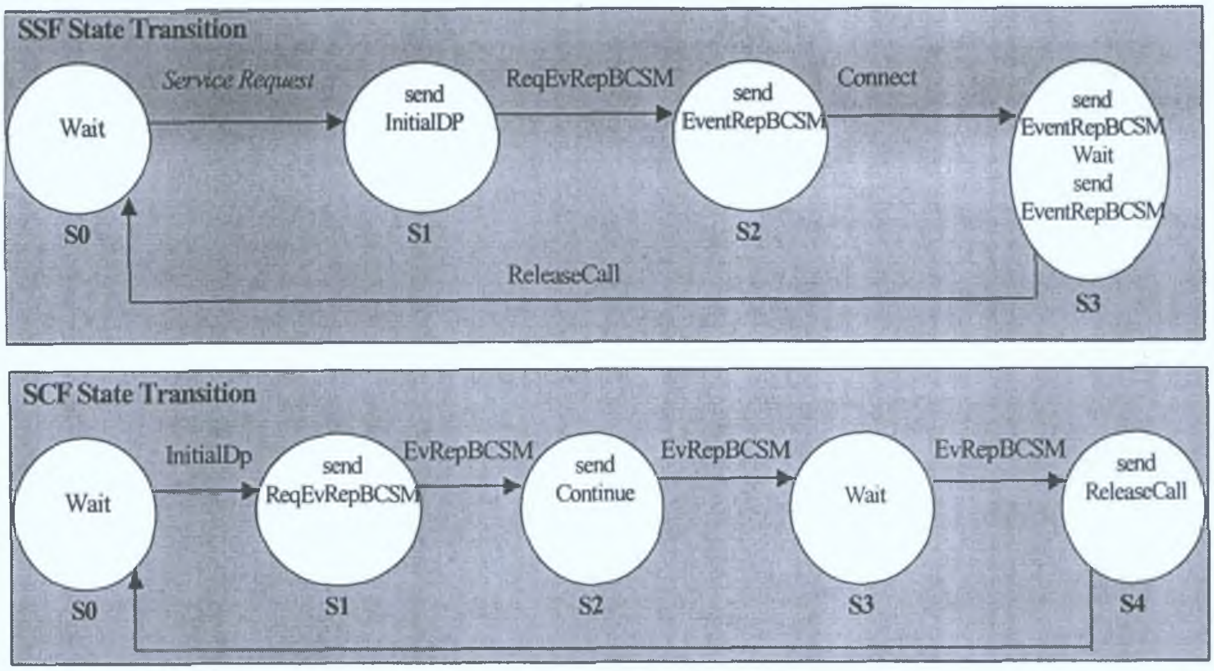


Figure B.5 – The VPN Service State Transition Diagram

B.4.3 Ringback Service

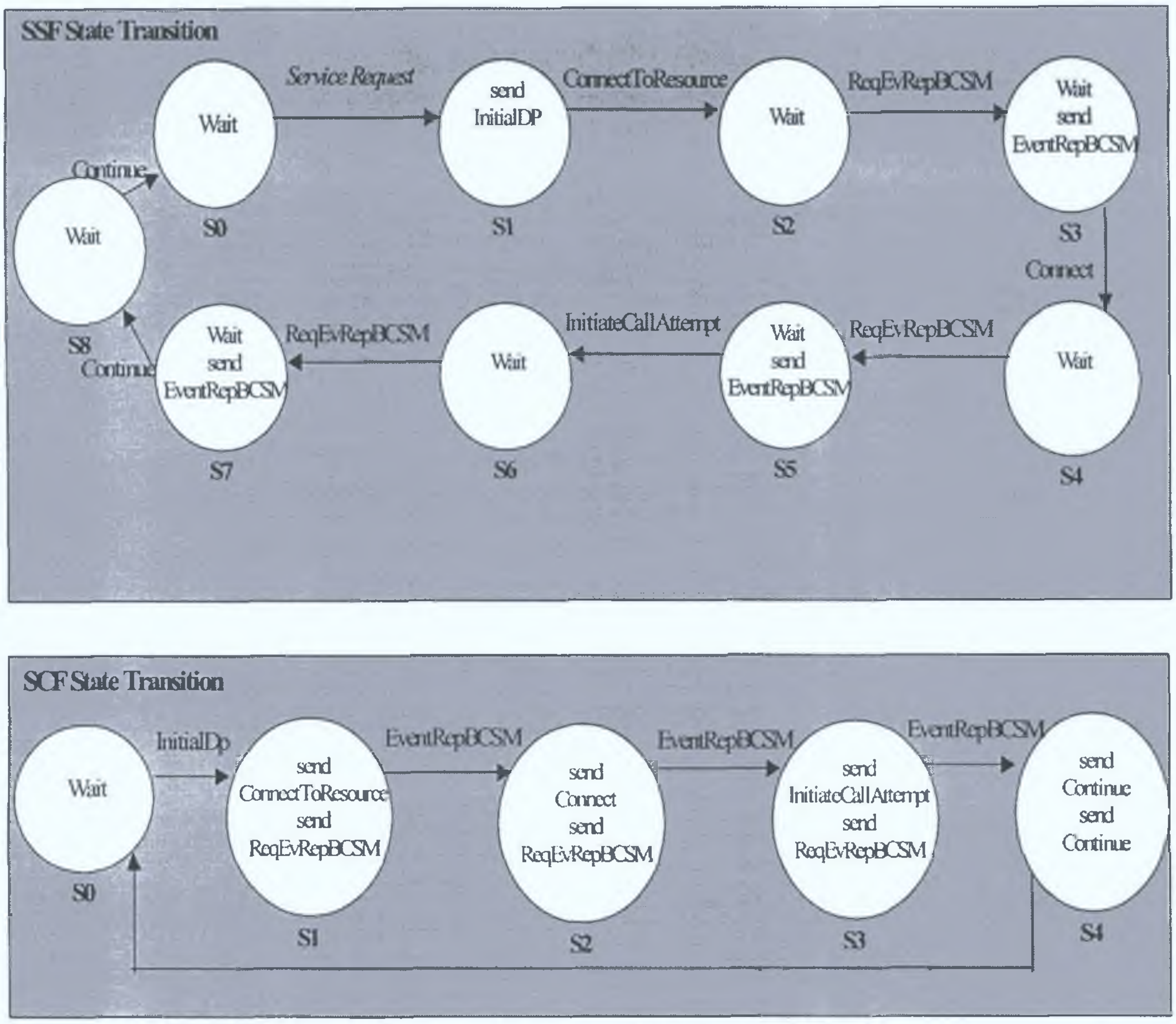


Figure B.6 – The Ringback Service State Transition Diagram

C. APPENDIX C: MARINER SYSTEM

C.1 RAA

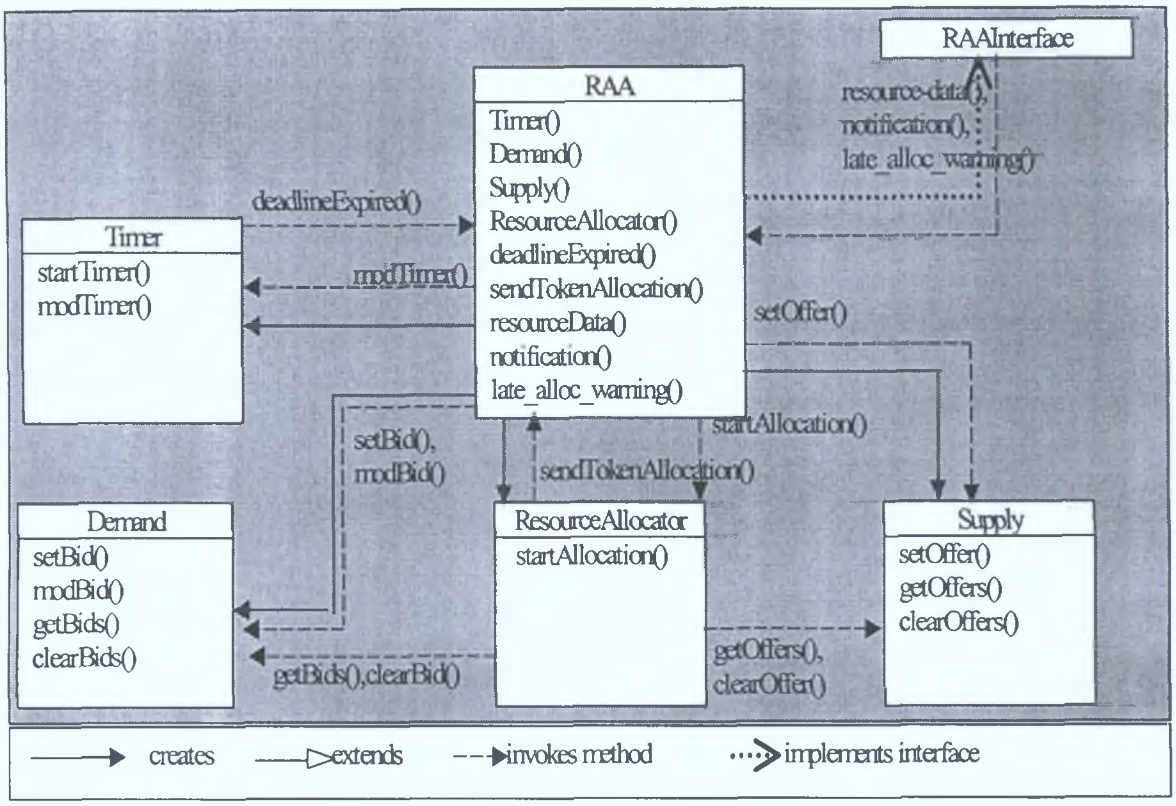


Figure C.1 – The RAA classes

The RAA functions as described in § 4.3.4. Figure C.1 illustrates the RAA classes and their relationships. Below are the class descriptions.

C.1.1 Demand

The Demand class maintains an array of all token requests by SSF and Service Type received in a particular token allocation interval.

- setBid(*tokenRequest, ssf, serviceType*) inserts a new tokenRequest into the array position dictated by ssf and serviceType.
- modBid(*tokenRequest, ssf, serviceType*) modifies a particular array entry.

- getBids() returns the token request array.
- clearBids() clears the array.

C.1.2 RAA

The RAA class contains the main() of the RAA. It also implements the RAAInterface interface. It does the following:

- It instantiates the ResourceAllocator, Timer, Demand and Supply objects.
- It calls the startTimer(token_allocation_interval) method in the Timer object.
- For each resource_data(*resource_data*) method call received, it extracts the SSF token requests, and SCF capacities from resource_data and calls the Demand.setBid(*tokenRequest, ssf, serviceType*) and the Supply.setOffer(*capacity, scf*) respectively.
- When the notification(*notification*) method is called, it calculates the increased tokenRequest from the notification data, and calls the Demand.modBid(*tokenRequest, ssf, serviceType*) method with the new tokenRequest.
- When the late_alloc_warning(*period*) is called, it calls the Timer.modTimer(*-period*) method, to decrease the timer by the period. In subsequent intervals, if no more warnings are received, it will increase token_allocation_interval with increments of 1 second by calling the same method.
- When the deadlineExpired() method is called, it calls the ResourceAllocator.startAllocation() method.
- When the sendTokenAllocation(token_allocation) method is called, it sends the token_allocation to all the RMAs by calling the RMAInterface.token_allocation(token_allocation) method.

C.1.3 RAAInterface

The RAAInterface is an interface class that allows the MARINER Information Flows (See Appendix A) into the RAA. It has following methods:

```
void resource_data(ResourceData resource_data)
void late_alloc_warning(int period)
void notification(Notification notification)
```

C.1.4 ResourceAllocator

The ResourceAllocator class implements the MARINER algorithm. When the startAuction() method is called, it gets the SSF tokenRequests and SCF capacities by calling the Demand.getBids() and Supply.getOffers() methods respectively. It then clears the requests and capacities by calling the clear methods. The algorithm is then run, resulting in a tokenAllocation. The ResourceAllocator then calls the RAA.sendTokenAllocation(tokenAllocation) method.

C.1.5 Supply

The Supply class maintains an array of all resource capacity by SCF received in a particular token allocation interval.

- setOffer(*capacity, scf*) inserts a new capacity into the array position dictated by scf.
- getOffers() returns the capacity array.
- clearOffers() clears the array.

C.1.6 Timer

The Timer class continuously countsdown an interval when the startTimer(*interval*) method is called. Every time it completes the countdown, it calls the RAA.deadlineExpired() method. When the modTimer(*period*) is called, it modifies the countdown interval period.

C.2 RMA

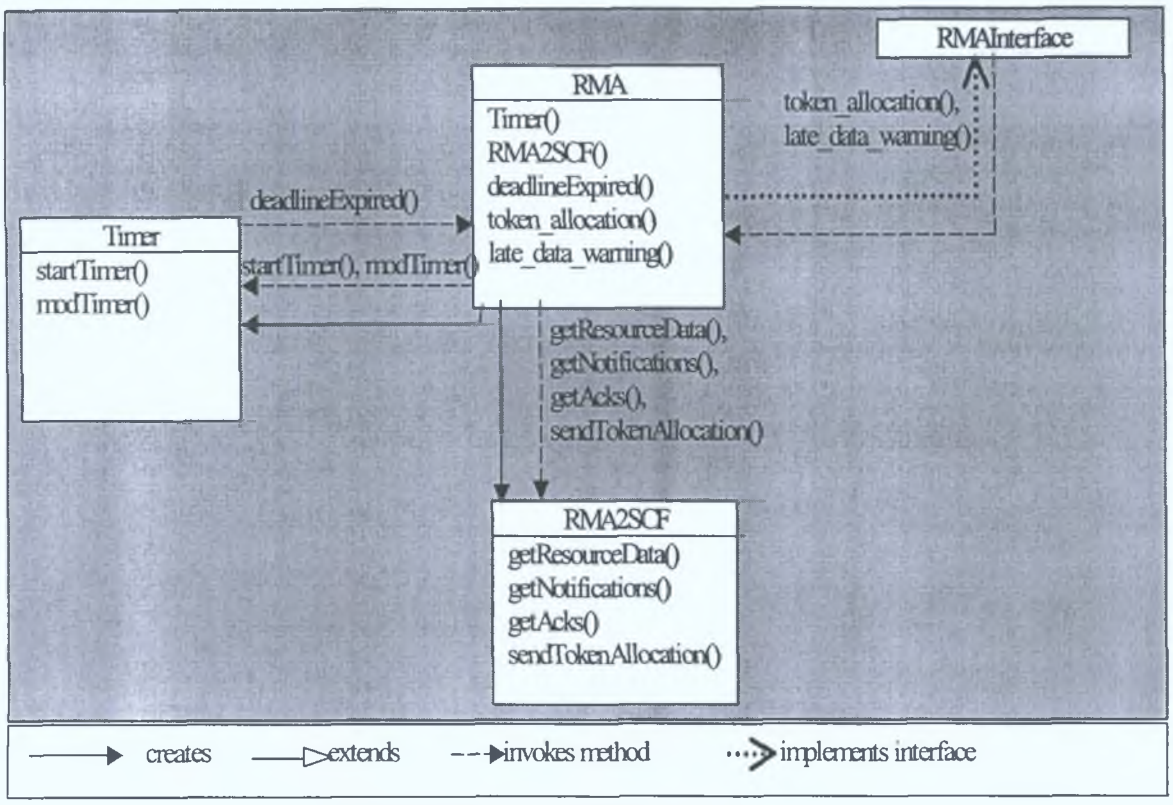


Figure C.2 – The RMA classes

The RMA functions as described in § 4.3.3. Figure C.2 illustrates the RMA classes and their relationships. Below are the class descriptions.

C.1.7 Timer

The Timer class continuously countsdown an interval when the startTimer(*interval*) method is called. Every time it completes the countdown, it calls the RMA.deadlineExpired() method. When the modTimer(*period*) is called, it modifies the countdown interval period.

C.1.8 RMA

The RMA class contains the main() method of the RMA. It also implements the RMAInterface interface. It does the following:

- It instantiates the Timer and RMA2SCF objects
- When the token_allocation(*token_allocation*) method is called, it calls the RMA2SCF.sendTokenAllocation(*token_allocation*) method.
- It calls the startTimer(interval) method in the Timer object.
- When the deadlineExpired method is called, it calls the RMA2SCF.getResourceData(), the RMA2SCF.getNotifications() and the RMA2SCF.getAcks methods.
- When the late_data_warning(*period*) is called, it calls the Timer.modTimer(-*period*) method, to decrease the timer by the period. In subsequent intervals, if no more warnings are received, it will increase the interval with increments of 1 second by calling the same method.

C.1.9 RMAInterface

The RMAInterface is an interface class that allows the MARINER Information Flows (See Appendix A) into the RMA. It has following methods:

```
void token_allocation(TokenAllocation token_allocation)

void late_data_warning(int period)
```

C.1.10 RMA2SCF

The RMA2SCF class is responsible for communication with the SCF. Whenever any method is calld upon it, it calls the corresponding method on the SCF Scf2RMA interface.