Managing High-Availability and Elasticity in a Cluster Environment

Neha Pawar

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By:	**Neha Pawar**
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Signed by the final examining committee:

Dr. R. Jayakumar	Chair
Dr. D. Goswami	Examiner
Dr. J. Paquet	Examiner
Dr. F. Khendek	Supervisor
Dr. M. Toeroe	Co-Supervisor

Approved by Dr. V. Haarslev
Chair of Department or Graduate Program Director

Dr. C. Trueman
Dean of Faculty

Date September 2014

Abstract

Managing High-Availability and Elasticity in a Cluster Environment

Neha Pawar

Cloud computing is becoming popular in the computing industry. Elasticity and availability are two features often associated with cloud computing. Elasticity is defined as the automatic provisioning of resources when needed and de-provisioning of resources when they are not needed. Cloud computing offers the users the option of only paying for what they use and guarantees the availability of virtual infrastructure (i.e. virtual machines). The existing cloud solutions handle both elasticity and availability at the virtual infrastructure level through the manipulation, restart, addition and removal of virtual machines (VMs) as required. These solutions equate the application and its workload to the VMs that run the application. High-availability applications are typically composed of redundant resources, and recover from failures through failover mostly managed by a middleware. For such applications, handling elasticity at the virtual infrastructure level through the addition and removal of VMs is not enough, as the availability management in application level will not make use of additional resources. This requires new solutions that manage both elasticity and availability in application level. In this thesis, we provide a solution to manage the elasticity and availability of applications based on a standard middleware defined by the Service Availability Forum (SA Forum). Our solution manages application level elasticity through the manipulation of the application configuration used by the middleware to ensure service availability. For this purpose we introduce a third party, 'Elasticity Engine' (EE), that manipulates the application configuration used by the SA Forum middleware when a workload changes. This in turn triggers the SA Forum middleware to change the workload distribution in the system while ensuring service availability. We explore the SA Forum middleware configuration attributes that play a role in elasticity management, the constraints applicable to them, as well as their impact on the load distribution. We propose an overall architecture for availability and elasticity management for an SA Forum system. We design the EE architecture and behavior through a set of strategies for elasticity. The proposed EE has been implemented and tested.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ActSUs	SaAmfSGPrefNumStandbySUs
AIS	Application Interface Specification
AMF	Availability Management Framework
API	Application Programming Interface
AS	Application Server
AssSUs	saAmfSGNumPrefAssignedSUs
CCB	Configuration Change Bundle
CLM	Cluster Membership Service
CompMaxActCSIs	saAmfCompNumMaxActiveCSIs
CompMaxStdCSIs	saAmfCompNumMaxStandbyCSIs
CSI	Component Service Instance
DN	Distinguished Name
EE	Elasticity Engine
GUI	Graphical User Interface
HA	High Availability
HPI	Hardware Platform Interface
IM	Information Model
IMM	Information Model Management
InsSUs	saAmfSGNumPrefInserviceSUs
LDAP	Lightweight Directory Access Protocol

MaxStdSIperSU	saAmfSGMaxStandbySIsperSU
OCL	Object Constraint Language
OI-API	Object Implementers API
OM-API	Object Management API
PLM	Platform Management Service
RDN	Relative Distinguished Name
RM	Redundancy Model
SA Forum	Service Availability Forum
SG	Service Group
SI	Service Instance
SIAssgmnts	saAmfSIPrefActiveAssignments
SLA	Service Level Agreement
SMF	Service Management Framework
SU	Service Unit
TIPC	Transparent Inter-Process Communication
UML	Unified Modeling Language
URL	Uniform Resource Locator
VM	Virtual Machine

Chapter 1 - Introduction

This chapter introduces topics discussed throughout this thesis, the motivations behind this thesis and contributions of the thesis. In this chapter we also present the organization of the thesis.

Nowadays, the world depends mostly on computers and the services that computer applications provide. The growth in the use of computers has resulted in high demand and new requirements from the users. The users expect services to be always available and in reach all the time, in other words, the users want services that are highly available. Service availability is defined as the percentage of time the application is running and its services are provided [1].

High Availability (HA) is defined as the availability of a service at least 99.999% [1] of the time. Highly available systems have become a necessity in almost all the domains ranging from banking, telecommunications, and web services to mission critical systems [2]. HA in cloud computing is a big challenge. However, availability is an implicit expectation of cloud systems. Elasticity, on the other hand, is one of the key features of cloud computing that makes cloud computing economically attractive and therefore drives its wide-spreading deployment. Elasticity is defined as the provisioning or de-provisioning of resources according to the workload variations of application services allowing for a "pay-as-you-go" charging model [3].

Current cloud solutions handle both availability and elasticity at the virtual infrastructure level. They manage availability by starting and restarting virtual machines (VMs) when current executing VM fails; and similarly when workload changes VMs are added and removed accordingly. This approach equates the application and its workload to the VMs running the application. It also assumes that the application starts with the VM, it is stateless, and the VMs running the same application share the load.

These assumptions are not necessarily true when we consider applications that provide highly available services such as telecom applications. HA applications generally run in a cluster and their availability is managed by a middleware application. This middleware maintains state-full redundant resources of the application which act as standbys to protect their active peers. The middleware performs error recovery by controlling the life-cycle of the application resources for which it requires a configuration describing the organization of the application.

When we consider elasticity in this context, removing VMs due to decreased workload could be considered by the availability management as a failure of the VM and therefore handled as such. Furthermore, mere addition of new VMs in the case of workload increase will not necessarily lead to the utilization of the new VMs by the application level, potentially causing repeated triggers for elasticity management at the infrastructure level. Repeated triggers for the same workload change may also happen for different VMs due to the availability management performing the switch or a failover at the application level, i.e. in this context the workload cannot be associated with the given VM. We need a new solution that coordinates the elasticity and the availability at an application level.

In this thesis we provide a solution to manage elasticity and availability of applications based on the Availability Management Framework (AMF) [4] of the Service Availability Forum (SA Forum) [5] designed to maintain service availability. The SA Forum has defined a set of middleware Application Programming Interface (API) specifications to facilitate the development of carrier grade and mission critical applications. The SA Forum specifications have been implemented by OpenSAF [6], an open source project.

1.1 Thesis Motivation

As mentioned before the HA applications like telecom applications are composed of redundant resources in cluster and their availability is managed by a middleware. The middleware defined by SA Forum is a proven solution for service availability in the context of cluster computing. Enabling elasticity within the SA Forum's middleware will position SA Forum middleware as a potential solution for managing HA applications in the cloud.

In the SA Forum middleware, AMF is the most important service responsible for the HA of the services of the applications. It maintains the availability of services of application by managing and coordinating redundant resources of these applications.

The redundancy and the logical organization of the applications are described for AMF in a configuration, which is part of the information model maintained by the SA Forum Information Model Management (IMM) [7] service. IMM provides an administrative API that allows the system administration to manipulate the information model, including the AMF configuration. After manipulation, IMM notifies entities such as AMF which implement the modifications.

In an AMF configuration there are two types of entities: entities that represent the application services and entities that are actually capable of providing the services, which represent the resources. AMF assigns each service entity to one or more service provider entity. When the service provider entity fails AMF automatically moves the assignments of the failed service provider entity to another healthy service provider entity. The actual workload the service entities assignment impose on the service provider entities may vary over time, it may potentially increase or decrease within a wide range.

AMF is a proven solution for service availability in the context of cluster computing, however it was not explicitly designed to handle elasticity for cloud computing. AMF allows for the manipulation of its configuration. AMF configuration can be manipulated to trigger AMF actions that increase the resources available for a service entity when its workload increases and vice versa when it decreases. This gives us motivation to present a solution which enables both elasticity and availability within AMF configurations.

1.2 Thesis Contributions

In this thesis, we present how an AMF configuration can be used to trigger AMF actions that increase the resources available for a service entity when its workload increases and decrease resources available for the service entity when its workload decreases. We propose an Elasticity Engine (EE) that enables elasticity in a configuration designed for service availability, therefore achieving both simultaneously. It reacts to workload change variations by modifying the AMF configuration that triggers AMF to dynamically provision or de-provision resources. In this thesis we:

1. Define two types of workload changes in an AMF configuration to characterize the potential changes in workload.
2. Define an overall architecture for HA and elasticity management using the SA Forum middleware.
3. Define the architecture and behavior of the EE through different strategies to increase and decrease workloads including buffer (reserved resources) management to enable elasticity.
4. Implement the EE and perform some experiments.

In our thesis we have focused on AMF managed applications. AMF maintains availability of the applications as long as the AMF configuration remains valid. Thus in our thesis we have assumed that AMF will maintain availability and our solution will enable elasticity within AMF. We also assume that the workload changes of the applications are determined by an external application that is the workload monitor. The workload monitor only signals to our EE when the workload increases beyond or decreases below certain threshold.

1.3 Thesis Organization

The thesis is organized into six chapters. In Chapter 2 we provide the necessary background information on the SA Forum middleware and discuss related work. In Chapter 3, we investigate the elasticity feature in AMF configurations. Chapter 4 presents our overall architecture for HA and elasticity management with the SA Forum middleware. It elaborates on the architecture of the EE and its behavior including the elasticity strategies. Chapter 5 presents our prototype tool and experiments. In Chapter 6 we summarize our work and discuss potential future work.

Chapter 2 - Background and Related Work

In this chapter we introduce the SA Forum specifications, specifically the AMF service and the IMM service, followed by a review of related work.

2.1 SA Forum Specifications

The objective of the SA Forum is to define standard interfaces that facilitate the development of carrier-grade and mission critical applications and systems [5]. It is a consortium formed by telecommunication and computing companies that defines specifications for the standardization of high availability platforms. OpenSAF middleware [6] is an open source implementation of the SA Forum specifications.

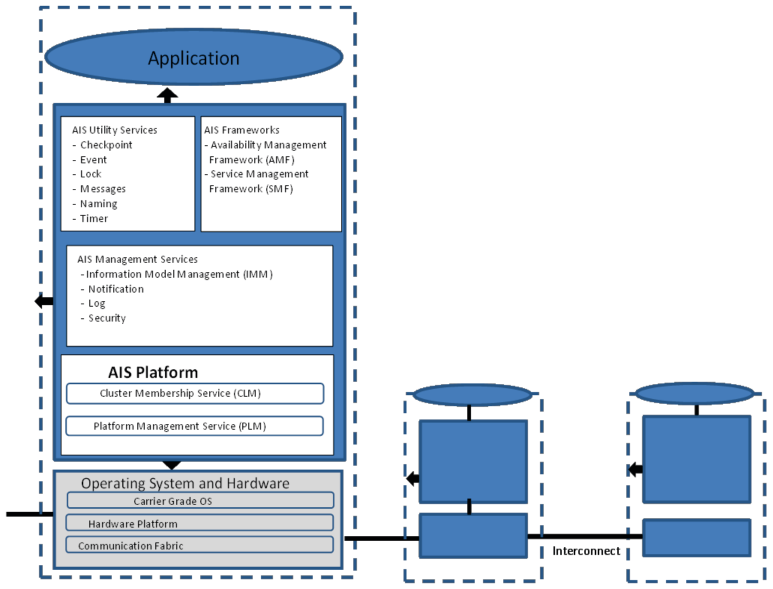


Figure 1 - An overview of the SA Forum services [8]

The SA Forum services are categorized into: the Hardware Platform Interface (HPI) [8] and the Application Interface Specification (AIS) [9]. The main objective of HPI is to provide standardized interfaces to manage hardware platforms. The HPI specifications contain data structures and functional definitions that are used to communicate with other platforms or systems [5] [8]. The main objective of AIS is to provide standardized APIs for middleware functions typically required by HA applications. These specifications consist of different middleware services among which we will be focusing on the AMF [4] service and the IMM [7] service that are more relevant to this thesis. Figure 1 gives an overview of the SA Forum services.

2.2. Availability Management Framework (AMF)

AMF [4] manages the availability of services provided by an application through the management and coordination of its redundant resources, and performing some recovery and repair actions in case of a failure. To do so, AMF requires a configuration of the application that represents the application from AMF perspective and describes the different entities composing it and their relations.

2.2.1 Logical Entities

The AMF specification [4] defines a set of logical entities. These logical entities are shown in Figure 2. We describe the logical entities in this section.

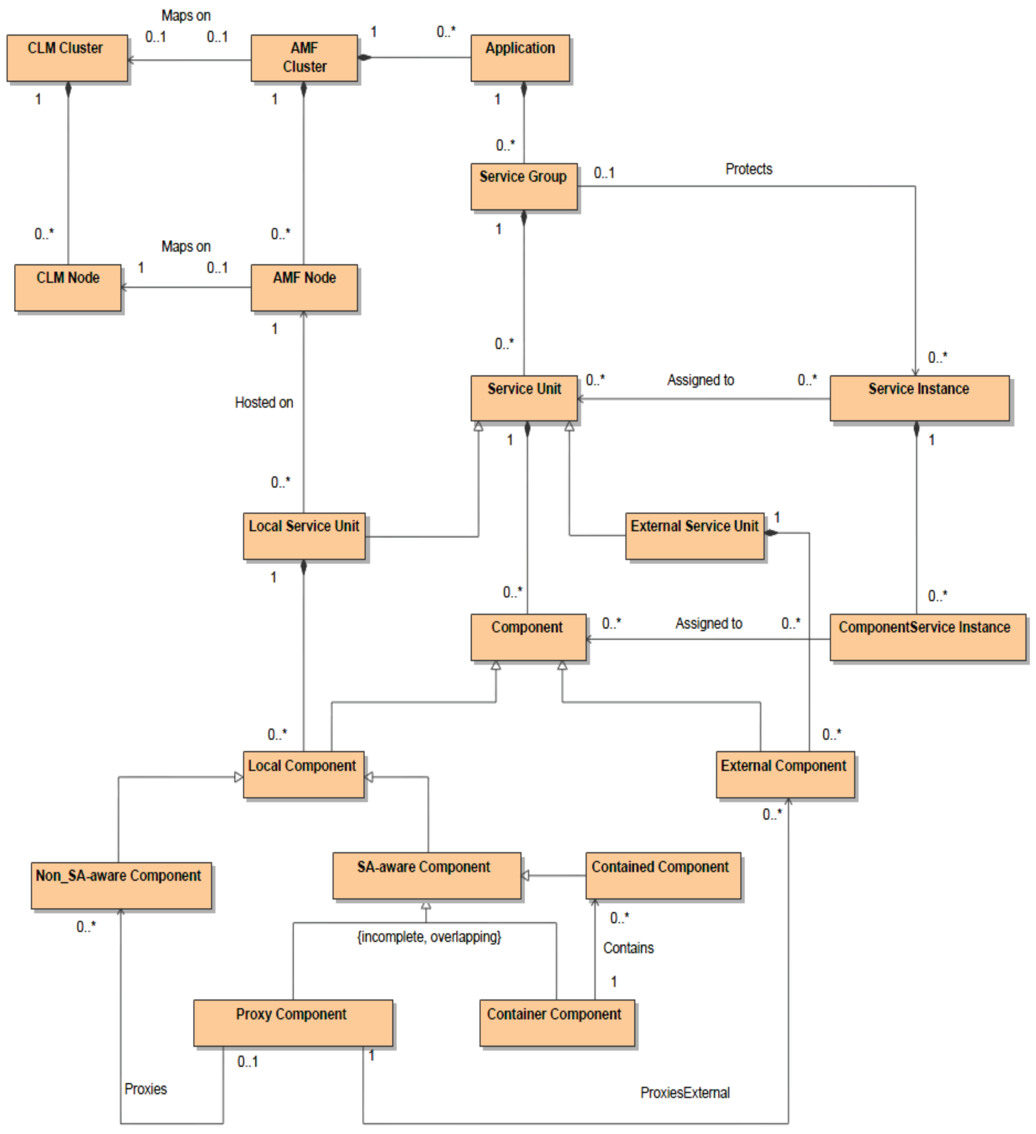


Figure 2 - AMF System Model [4]

- **Component:**

  It is the logical entity that represents a set of resources to AMF. This set of resources can include hardware resources, software resources, or a combination of the two. It is the smallest logical entity on which AMF performs error detection and isolation, recovery and repair [4]. Components are categorized into SA-Aware and Non-SA-Aware.

- ➢ **SA-Aware:**

  This type of component is integrated and controlled by AMF directly. The component registers itself using AMF APIs [4]. It also implements the interfaces and callback functions that provide means to communicate between AMF and the components.

- ➢ **Non-SA-Aware:**

  This type of component cannot directly communicate with AMF. A mediator component is required to link AMF and the Non-SA-Aware components. The mediator is a proxy component. The Non-SA-Aware component is the proxied component and it can communicate with AMF only through a proxy component that is SA-Aware.

- **Component Type:**

  A component type defines the list of attribute values that are shared by components of the same type.

- **Service Unit (SU):**

  It is a logical entity that aggregates a set of components combining their individual functionalities to provide a higher level of service. SUs can contain any number of components, but a particular component can be configured in only one SU.

- **Service Unit Type:**

  A service unit type defines a list of component types and for each of the component types, the number of components that a SU of this type may accommodate. All SUs of the same type share the attribute values defined in the service unit type configuration.

- **Component Service Instance (CSI):**

  CSI represents the workload that AMF can dynamically assign to a component.

- **Component Service Type:**

  A component service type defines the list of attribute names that are shared by all the CSIs of the same type.

- **Service Instance (SI):**

  SI aggregates all CSIs to be assigned to the SU to provide a higher level of service. A SI can contain multiple CSIs, but a particular CSI can be configured in only one SI.

- **Service Type:**

  A service type defines the list of component service types from which its SIs can be built.

- **Service Group (SG):**

  A set of redundant SUs is organized into a SG to protect a particular set of SIs. AMF manages the service availability by assigning active and standby workloads to redundant SUs of each SG. Any SU of the SG must be able to take an assignment for any SI of this set. The redundant SUs collaborate with each other depending on the type of the redundancy model of the SG. AMF defines five redundancy models:

  - **2N Redundancy Model:**

    A SG of 2N redundancy model has at most one SU that handles active assignments and at most one SU that handles standby assignments of all SIs protected by SG. If there are other SUs of the SG, they are spare SUs. Each SI has only one active assignment and one standby assignment. A SU cannot handle active assignments for some SIs and handle standby assignments for some other SIs at the same time (Figure 3).

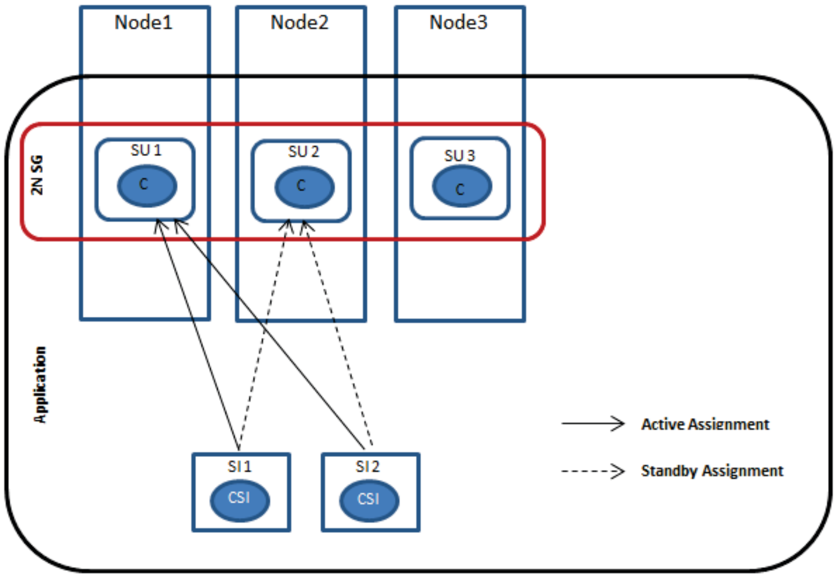


Figure 3 - Example of 2N redundancy model

- **N+M Redundancy Model:**

  A SG of N+M redundancy model allows ‘N’ SUs to handle active assignments and ‘M’ SUs to handle standby assignments for all SIs protected by SG. Each SI will have only one active assignment and one standby assignment. A SU cannot handle active assignments for some SIs and standby assignments for some other SIs at the same time (Figure 4).

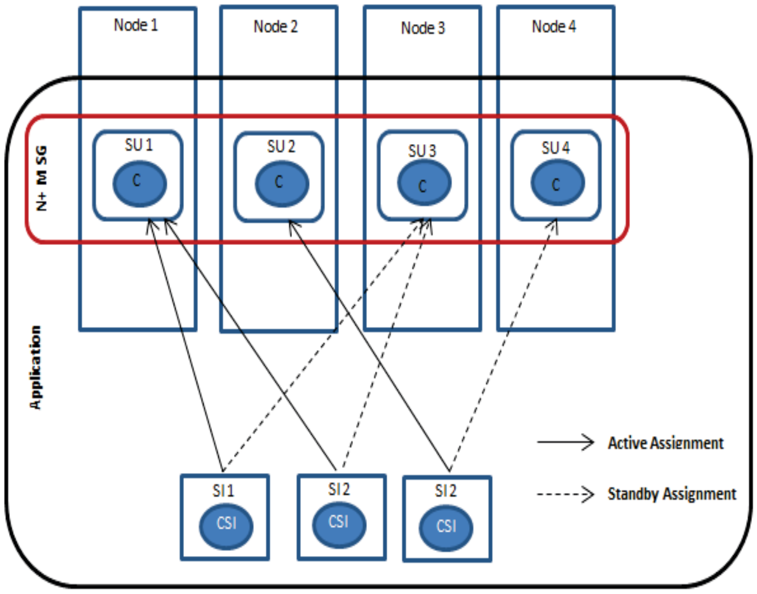


Figure 4 - Example of N+M redundancy model

- **N-way Redundancy Model:**

  A SG of N-way redundancy model allows a SU to handle active and standby assignments of different SIs at the same time. Each SI protected by an SG of N-way redundancy will have only one active assignment and can have one or more standby assignments (Figure 5).

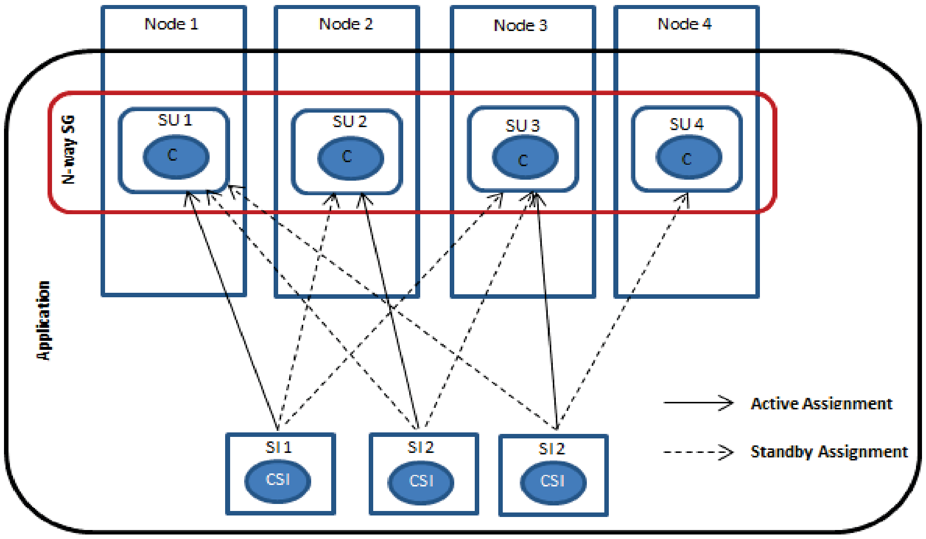


Figure 5 - Example of N-way redundancy model

- **N-way-Active Redundancy Model:**

  A SG of an N-way-Active redundancy model allows an SI to have more than one active assignment and no standby assignments. For each SI multiple SUs are assigned the active HA state for that SI. Each SU is active for each SI assigned to it (Figure 6).

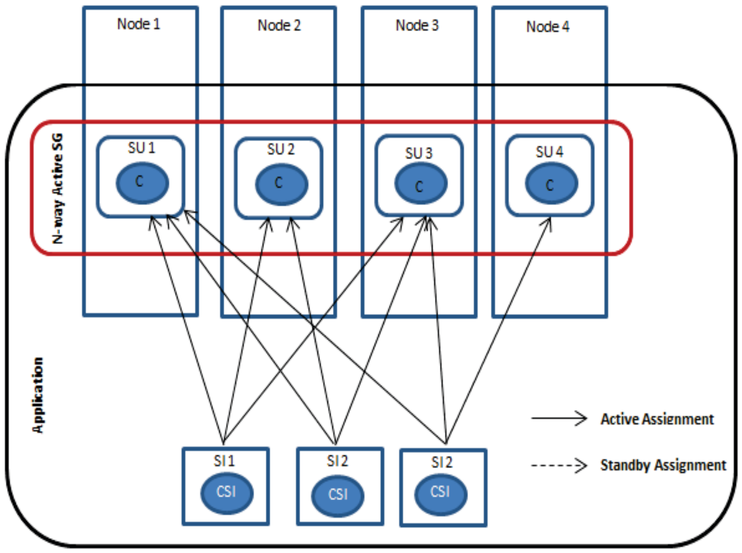


Figure 6 - Example of N-way-Active redundancy model

➢ **No–Redundancy Redundancy Model:**

In a SG of No-Redundancy redundancy model, each SU handles only one SI and each SI has one active assignment and no standby assignments (Figure 7).

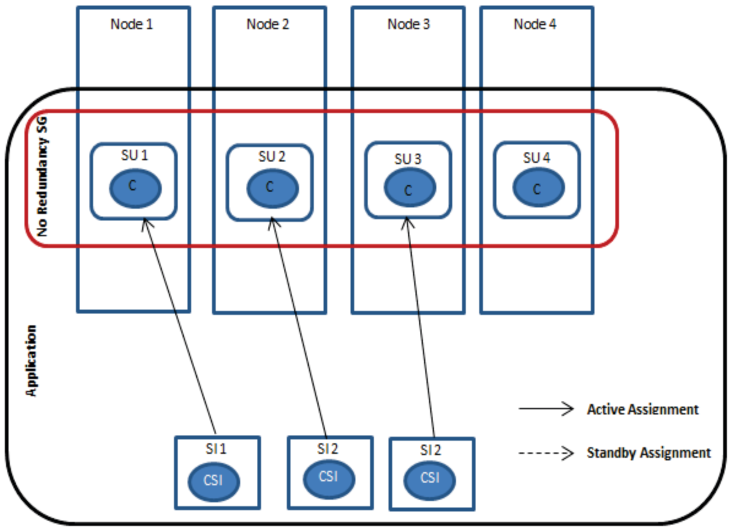


Figure 7 - Example of No-Redundancy redundancy model

- **Service Group Type:**

  A service group type defines a list of SU types that a SG of its SG type can support. All SGs of the same service group type have the same redundancy model and provide similar availability.

- **Application:**

  An application is a logical entity that contains one or more SGs and SIs protected by those SGs.

- **Application Type:**

  An application type defines a list of service group types that an application of its type can be composed of. All of the applications of the same type share the attribute values defined by the application type.

- **AMF Node:**

  AMF Node is the entity on which SUs are deployed.

- **AMF Cluster:**

  The AMF nodes are grouped together to form an AMF Cluster.

- **Protection Group:**

  A protection group for a specific CSI is a group of components to which the CSI has been assigned. The name of a protection group is the name of the CSI that it protects.

2.3 Information Model Management (IMM)

The SA Forum Information Model (IM) is specified using Unified Modeling Language (UML) [9] [7] and describes the various objects that constitute the SA Forum systems. It can be considered as a cluster-wide database for the SA Forum complaint systems. The IMM service manages all of the objects of the SA Forum IM and provides APIs. The IMM APIs allow its users to:

- Configure applications,
- Obtain information about objects and runtime status of the system,
- Perform administrative operations.

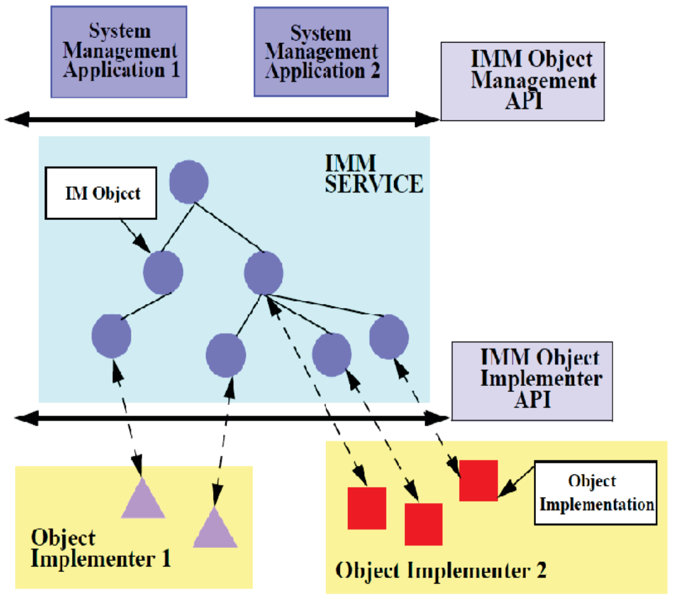

System Management Application 1
System Management Application 2
IMM Object Management API
IM Object
IMM SERVICE
IMM Object Implementer API
Object Implementation
Object Implementer 1
Object Implementer 2

Figure 8 - IMM Service Interface [7]

The users of IMM API are referred as Object Managers (OM) and the API IMM defined for them is called the Object Management API (OM-API).An OM issues administrative operations to create, access, manipulate and manage the configuration objects. IMM notifies the configuration changes made by the OM to the applications that are actually responsible for implementing them, referred to as Object Implementers (OI). The OIs use Object Implementer APIs (OI-APIs) to apply the changes issued by the OM and report back the results in the IM. Thus IMM acts as the mediator between the OMs and the OIs [7] as shown in Figure 8. The IMM objects and attributes are classified into two categories:

- **Configuration Objects and Attributes**

  Configuration objects and attributes carry configuration information defined by the system management applications. They are the means through which the system administrators express their desire about how the system should be deployed. The configuration objects and attributes information is of persistent nature and must survive under any circumstances (e.g. cluster restart). The configuration attributes are read-write attributes from an OM perspective but read-only from an OI perspective [7].

- **Runtime Objects and Attributes**

  The runtime objects and attributes reflect the runtime state of the entities deployed in the system. They do not typically need to be persistent. The runtime object and attribute can only be modified by OIs and are read-only for OMs [7].

2.3.1 Information Model Organization

As mentioned earlier the AMF configuration is accessed through the IMM [7] service. The IM includes all the information that OM and OI require. The configuration information is represented as a tree. It is similar to the naming system in Lightweight Directory Access Protocol (LDAP) [10]. Accordingly, each object is named after the path from its position in the tree to the root of the tree. Each object has a unique first and last name. The first name is the relative distinguished name (RDN) and the last name is the distinguished name (DN).

Each object in the IM has an attribute for the RDN value. For example, in Figure 9, the name of the RDN attribute for SU1 is *"safSu=SU1"*. The DN of an object (also simply called the object name) is the DN of the object's parent in the IM tree hierarchy prefixed with the RDN of the object [7]. For example the DN of SU1 object is *"safSu=SU1, safSg=AmfDemo, safApp=AmfDemo"*. However, in the IM only the RDN of the object is represented and the tree is constructed from DN.

The objects in the AMF configuration are described through attributes. Each type of object has certain attributes and is represented in the IM. Along with the containment relationship that the child objects have with their parents, entities also exhibit other relations. For example, at runtime AMF assigns CSIs to components. In IM such association relations is mapped by selecting the object representing the CSI as the parent, using the DN of the related object i.e. component as the RDN of the association class object. In the example of Figure 9, the CSI with RDN *“safCsi=AmfDemoCsi2”* is assigned to the component with RDN *“safComp=Comp2”*. In IM the runtime object of class ‘*SaAmfCSIAssignment*’ represents the association relation [7]. This runtime object exists with DN *“safCsi=AmfDemoCsi2,safSi=AmfDemo,safApp=AmfDemo”* and RDN *“safComp=Comp2,safSg=AmfDemo,safApp=AmfDemo2”* in the IM. As the DNs are concatenation of RDNs that contain commas, the commas are escaped with the backslash “\” character.

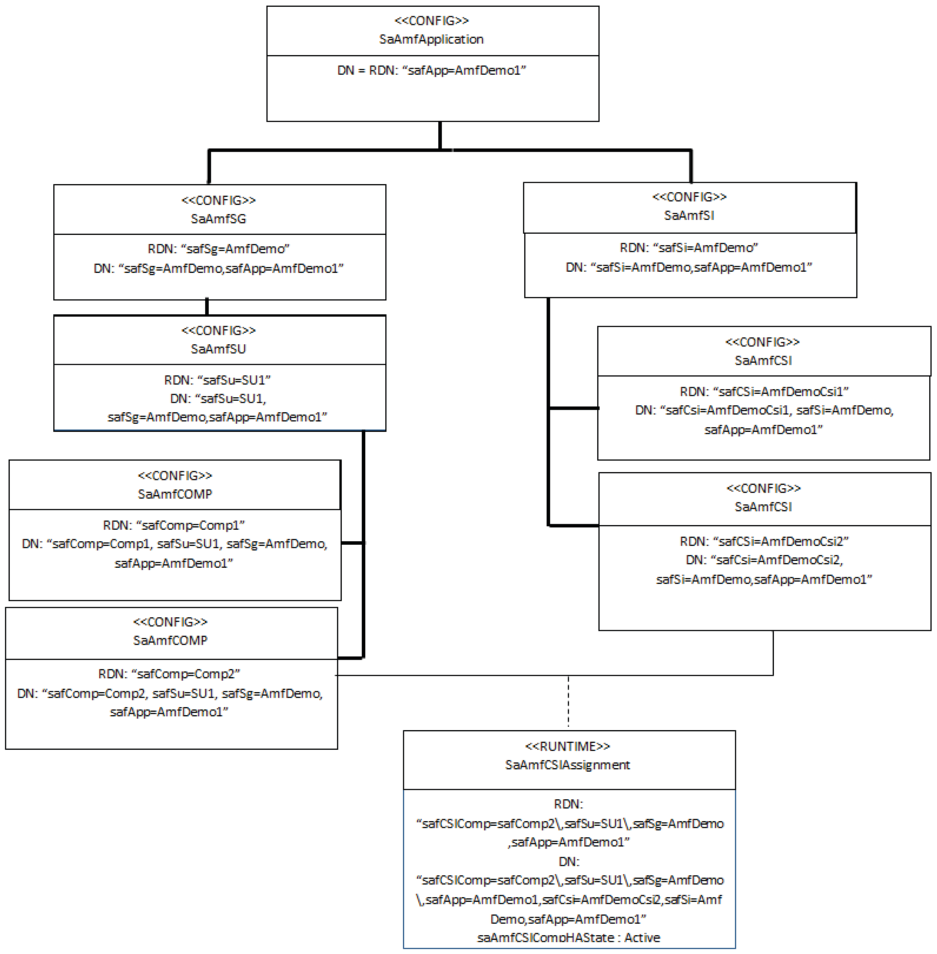

<<CONFIG>>
SaAmfApplication
DN = RDN: “safApp=AmfDemo1”
<<CONFIG>>
SaAmfSG
RDN: “safSg=AmfDemo”
DN: “safSg=AmfDemo,safApp=AmfDemo1”
<<CONFIG>>
SaAmfSI
RDN: “safSi=AmfDemo”
DN: “safSi=AmfDemo,safApp=AmfDemo1”
<<CONFIG>>
SaAmfSU
RDN: “safSu=SU1”
DN: “safSu=SU1, safSg=AmfDemo,safApp=AmfDemo1”
<<CONFIG>>
SaAmfCSI
RDN: “safCSi=AmfDemoCsi1”
DN: “safCsi=AmfDemoCsi1, safSi=AmfDemo, safApp=AmfDemo1”
<<CONFIG>>
SaAmfCOMP
RDN: “safComp=Comp1”
DN: “safComp=Comp1, safSu=SU1, safSg=AmfDemo, safApp=AmfDemo1”
<<CONFIG>>
SaAmfCSI
RDN: “safCSi=AmfDemoCsi2”
DN: “safCsi=AmfDemoCsi2, safSi=AmfDemo,safApp=AmfDemo1”
<<CONFIG>>
SaAmfCOMP
RDN: “safComp=Comp2”
DN: “safComp=Comp2, safSu=SU1, safSg=AmfDemo, safApp=AmfDemo1”
<<RUNTIME>>
SaAmfCSIAssignment
RDN: “safCSIComp=safComp2\,safSu=SU1\,safSg=AmfDemo,safApp=AmfDemo1”
DN: “safCSIComp=safComp2\,safSu=SU1\,safSg=AmfDemo\,safApp=AmfDemo1,safCsi=AmfDemoCsi2,safSi=AmfDemo,safApp=AmfDemo1”
saAmfCSICompHAState : Active

Figure 9 - Example of the Information Model

2.3.2 Object Management

The OM such as the system administrator or a management application use the IMM service to configure and control the system [7]. They create a set of configuration objects describing the entities the system should consist of. They may also modify the set of objects and the different object attributes to manage the system. Through the IMM service, the following set of object management operations can be performed:

- **Object Search**

  Only OMs can read the IM to search for objects and attributes. Other applications can temporally register as OMs with IMM to search for object information present in the IM. The OM specifies search criteria such as a specific attribute name or the attribute name with its value. Depending on the search criteria specified, IMM returns the objects that best match in the IM. The OM can also specify the scope within which they want IMM to search for the objects. IMM may return only the object name, or the object name with some specified attributes or all the attributes with their value.

- **Object Access**

  OM can directly access an object and its attributes if they are familiar with the object hierarchy. If the specified object with the attributes exists in the IM, it will return the object with the required values to OM [7].

- **Administrative Ownership**

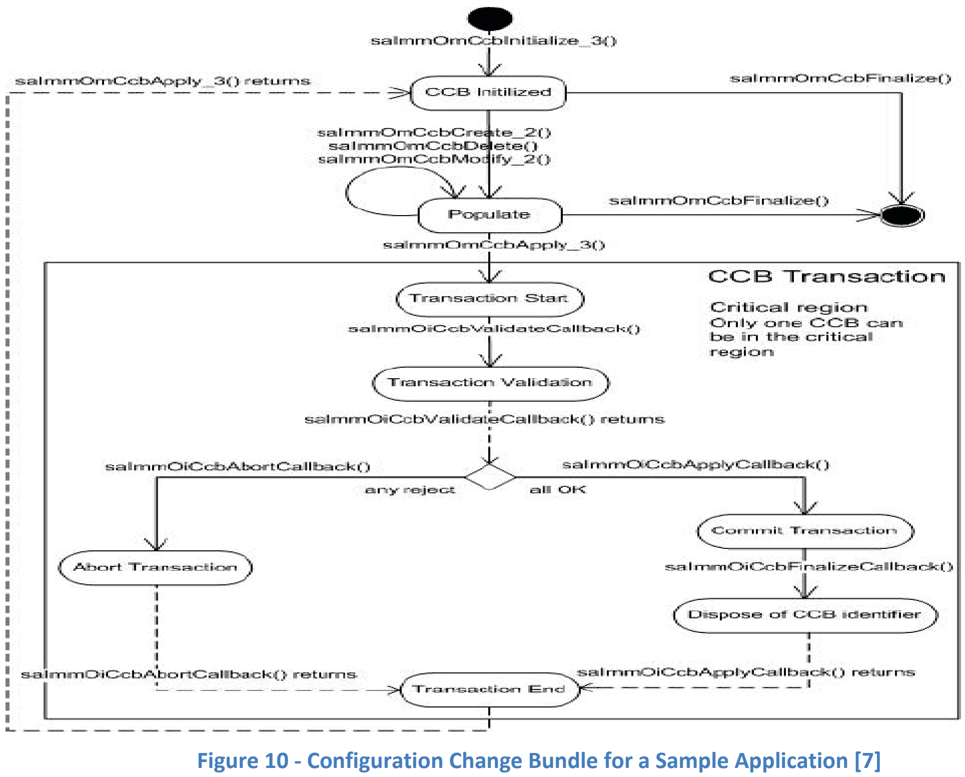
  From IMM's point of view, OM has access to the entire IM at any time. Hence it is possible that two different OMs may simultaneously modify the attributes of the same object. IMM implements the administrative ownership to avoid the possibility of different OMs modifying the same object simultaneously. So, before any OM creates, deletes or modifies an object, it needs to gain administrative ownership. An OM acquires administrative ownership by requesting IMM to set the name provided by it as the administrative owner of the object. IMM checks if any of the objects requested already has administrative owner, if no such owner exists it sets the requesting OM as the administrative owner of the object. Once the request is granted the OM is registered as the administrative owner. It can modify or issue administrative operations on the object. Hence it is important that OMs release the administrative ownership once they are done. IMM only allows an OM with administrative ownership to modify the objects, however other OMs can read object attributes even while the objects are being modified [7].

- **Configuration Change Bundle**

  To create, delete or manipulate configuration objects the OMs have to obtain relevant administrative ownership and construct a Configuration Change Bundle (CCB) transaction. A CCB is a session of subsequent CCB transactions. Each of these CCB transactions is a set of configuration changes that need to be applied automatically.

  When an OM initializes a CCB, IMM creates an empty container for such transaction and returns a handle identifying this session to the OM. The OM can add any number of configuration changes such as create new objects, delete some existing ones or modify the attributes of some others to this CCB. The only requirement is that all of the targeted configuration objects in the CCB request must have the same administrative ownership [7].

  Once CCB is populated by an OM, it is submitted to IMM for implementation. The major task of IMM in CCB implementation is to coordinate the changes and ensure the consistency of the IM. However, IMM does not know the semantics of the different configuration objects and their attributes. Hence, it applies the CCB through a series of interactions with the OIs of the targeted configuration objects. IMM calls the OIs to validate the CCB. The CCB validator validates the CCB and responds back to the validation call with either a callback to apply the CCB or abort the CCB. If the validator replies with abort, all the changes requested are aborted. If the validator responds with apply the CCB, this CCB is forwarded to an OI. The OI will apply all the changes requested in the CCB and reply to the CCB implementation call. The OI either implements all of the change requests in the CCB or it does not implement any change requests. Figure 10 illustrates the CCB implementation process.



saImmOmCcbInitialize_3()
saImmOmCcbApply_3() returns
CCB Initilized
saImmOmCcbFinalize()
saImmOmCcbCreate_2()
saImmOmCcbDelete()
saImmOmCcbModify_2()
Populate
saImmOmCcbFinalize()
saImmOmCcbApply_3()
CCB Transaction
Transaction Start
Critical region
Only one CCB can be in the critical region
saImmOiCcbValidateCallback()
Transaction Validation
saImmOiCcbValidateCallback() returns
saImmOiCcbAbortCallback()
saImmOiCcbApplyCallback()
any reject
all OK
Commit Transaction
Abort Transaction
saImmOiCcbFinalizeCallback()
Dispose of CCB identifier
saImmOiCcbAbortCallback() returns
saImmOiCcbApplyCallback() returns
Transaction End

Figure 10 - Configuration Change Bundle for a Sample Application [7]

2.3.3 Object Implementer Management

An OI implements the configuration objects and manipulates the configuration object's attributes and entities according to the change request made by OM through the CCB. The OIs are the applications that actually implement the configuration, hence they play three important roles: the CCB applier, the CCB validator and the runtime owner roles [7].

As a runtime owner, an OI creates, deletes and performs administrative operations on objects and updates the runtime information of objects and attributes in the IM. OM obtains the runtime status of the AMF configuration from accessing the runtime attributes in the IM.

An OM creates configuration change requests through the CCB and submits it to IMM. In order to assure consistency and coordination of configuration changes IMM needs to consult the object validators and appliers. An OI that takes the role of the CCB validator, checks the type and constraints of an attribute or an object as defined for the OI. IMM checks if the class and the attributes are valid with respect to the IM. This type of validation is called the local validation. After the local validation for all the changes requested, the OI carries out global validation, which includes dependencies between the objects and attributes and the consistency of the IM after the implementation of CCB. Finally OIs confirm that there are enough resources and all the required OIs are present to carry out the CCB implementation. If IMM receives a confirmation from all of the OIs that the CBB is valid, IMM will again call the OIs in the CCB applier role to deploy the CCB. The appliers are aware of the changes in the validation phase itself; hence they are prepared to implement the CCB. Once the CCB is applied the OI writes back in the IM to inform the status of the CCB. If the CCB could not be applied all the CCB appliers are informed that the transaction has been cancelled and should not be processed further.

- **Object Implementer Registration**

  We have already seen the roles that OI plays in maintaining the configuration in the IM. OI processes are the processes that have the best knowledge of the IM and of the changes in the IM. If an application process wants to have the privileges of being notified of configuration changes like the creation of new SIs, etc. It is possible for the process to register itself as an OI of the object.

The process needs to first select an OI name and register with IMM. This will create a link between the process and the OI name. The OI name is already set at the class level and IMM automatically creates a link between the object and the OI name that is set for the class. Hence all the objects of the same class will have the same OI. Thus, a process that wants to act as an OI of any particular object has to register itself with the same name as that of the object's OI name. IMM informs all the processes that are registered as the OI about any updates and administrative operations requested on the object.

2.4 Related Work

In this section we will review work of other researchers on availability and elasticity in cloud computing and also cluster computing environments. Most of the related work in cloud and cluster computing environments handle either elasticity or availability but not both simultaneously. Moreover, some work are actually more about scalability than elasticity as distinguished in [3].

OpenStack [11] is the most popular cloud controller and it consists of several related projects among which the Heat [12] and Ceilometer [13] projects are of particular interest to us. Heat [17] [18] claims to provide auto-scaling (i.e. elasticity) and HA features within OpenStack. It can automatically increase or decrease the number of VMs according to workload changes based on some policies defined in the configuration. It can also restart services in the case of failures. Ceilometer [14] provides metering service and informs Heat when workload changes occur. Heat provisions or de-provisions the resources using a rather straight forward policy such as adding one VM if the CPU or memory utilization is greater than 50% and removing a VM if the utilization falls below 10%. Heat also reacts to application failures by restarting the appropriate resources. But this reaction may take up to a minute, which is significant when considering HA in terms of the five 9's. Moreover, Heat provides availability and elasticity at virtual infrastructure levels only.

The work in [15] [16] [17] focuses on elastic resource provisioning in clusters. The main goal of this work is to provision resources to service requests as they arrive in queue and release the resources on completion. The solution presented in this work maintains a job queue and elastically provisions resources in a cluster according to the size of the queue maintained. The author in [15], designed an elastic site manager and define policies to achieve elastic provisioning of resources which also manage sudden workload increases by reserving adequate resources. Murphy et al. [16] dynamically increase and decrease virtual organization clusters in terms of the number of VMs, when the number of jobs in the queue change. The goal of the work in [17] is to dynamically increase and decrease resources on workload changes but the main focus of the author is to assign relevant tasks to appropriate resources and priority is given to load balancing rather than allocating resources to application services. The drawbacks of this work are that the solutions presented in the work require the service requests to be maintained in the queue which is an overhead and the authors of this work assume very specific design architecture of the application. Furthermore, the solution presented in [15] [16] [17], only focus on elastic provision of virtual infrastructure resources (like VMs).

The work in [19] [20] focuses on on-demand infrastructure resource provisioning. Zhang et al [18] focuses on providing infrastructure resources on-demand by first trying to improve resource utilization of the loaded application, and then allocating more resources if required. Yang et al. [19] use a profile-based approach to capture the expert's knowledge of just-in-time scaling (i.e. elasticity) applications. Other researchers have proposed workload predictions for more efficient elasticity handling [20].

In [21], the goal is to assure service scalability in service-oriented computing. The author proposes two approaches to assure scalability: service replication and migration, to increase resources allocated to a service. Thus, the work is more focused on scalability rather than elasticity as distinguished in [3].

The work in [22] [23], mainly focus on dynamic scaling of web applications. The goal of the author is to dynamically provision and de-provisions VMs according to the workload change. They use load balancer to distribute web application loads across resources (VMs). In this work they focus on the automatic scalability of virtual resources and dynamic distribution of web services using a load balancer. The work does not handle availability and elasticity at an application level.

In this sub-section, we presented literature work from different perspectives that can be directly or indirectly related to our work. Most of the literature focusses either on availability or elasticity but does not provide a solution for elasticity and availability together. Some solutions, like OpenStack, provide a solution for elasticity and availability but at the virtual infrastructure level only.

Chapter 3 - Elasticity in Availability Management Framework

In this chapter, we discuss the attributes in the AMF configuration that play a role in elasticity management, the constraints applicable to them as well as their impact on load distribution.

3.1 Elasticity Related Attributes in an AMF Configuration

An AMF configuration consists of the description of entities such as components, SUs, SGs, SIs, CSIs with their respective types, nodes and their relations. These entities are described in the AMF configuration with the help of objects and their attributes of the classes defined by the AMF specification [4]. The attributes are either configuration (read-only or writable) or runtime attributes [4]. The OMs (e.g. configuration designers, system administrators, management applications, etc.) set the configuration attributes, while the runtime attributes are set by AMF at runtime. AMF receives the changes in configuration attributes, evaluates the system state and implements the configuration changes while maintaining service availability. We can force AMF to change the SI-to-SU assignment by modifying the values of writable configuration attributes and as a result re-distribute the workload generally within a given SG and a cluster.

We illustrate with an example, the service side and service provider side attributes of the AMF configuration, which can be modified to achieve elasticity in an AMF configuration. Figure 11 shows, a highly available web application. An SG of the N-way-Active redundancy model type protects the web application service hosted on four nodes. The SG consists of four SUs, namely SU1, SU2, SU3 and SU4 hosted on four nodes. Each SU consists of two components ‘http-server’ and ‘application server’ (AS) that collaborate closely to provide the web application service. There are two SIs, SI1 and SI2 that define the web service workload. Each SI consists of two CSIs, the http-CSI and the AS-CSI.

- *saAmfSGAutoAdjust:SaBoolT = SA_TRUE*

  This attribute indicates to AMF that it must transfer back a SI assignment to the most preferred SU in an SG whenever a highest-ranked SU is available in the SG. This attribute is important to enable elasticity in AMF. It needs to be set to SA_TRUE if not set. In the example of the web service application this attribute is set to SA_TRUE.

- *saAmfSGNumPrefInserviceSUs = 4*

  This attribute denotes the number of SUs of the SG that are ready to accept a SI assignment. The components of the in-service SUs have all the required software and services installed to handle the SI assignments. In the example of web service application this attribute is set to four. The attribute should not be set to more than the number of SUs actually configured in the AMF configuration or set to less that the number of SUs required for SI assignments.

- *saAmfSGNumPrefAssignedSUs = 3*

  This attribute denotes the number of SUs that AMF can use for assigning SIs. The constraining attributes provide an upper bound and lower bound range within which the value can be set for this attribute. The attribute value of ‘*saAmfSGNumPrefInserviceSUs’* constrains the value of the attribute *‘saAmfSGNumPrefAssignedSUs’* by not allowing the *‘saAmfSGNumPrefAssignedSUs’* attribute value to be set to lower than ‘four’ in our example.

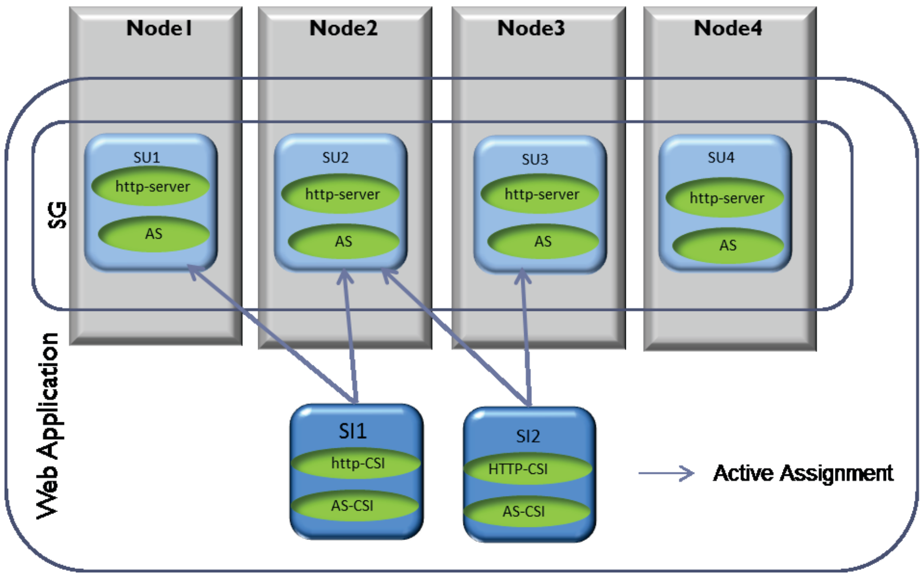


Figure 11 - Example of Web Service Application

- *saAmfSGMaxActiveSIsperSU =2*

  This attribute specifies the maximum number of active SIs that can be simultaneously assigned to a SU. The value of the attribute can be increased up to the value set for the configuration attribute *'saAmfCtDefNumMaxActiveCSIs'* [4]. This attribute of AMF defines the maximum number of CSIs (of a particular service type) that the components of the SG can handle simultaneously.

- *saAmfSIPrefActiveAssignments*

  This attribute is only applicable to a SG with an N-way-Active redundancy model. It specifies the number of SUs that need to be assigned to the SI. For the example, *'SI1.saAmfSIPrefActiveAssignment=2'* and *'SI2.saAmfSIPrefActiveAssignment=2'*.The value of this attribute must not be less than 'two' to maintain service availability.

In the example, if the workload of SI1 increases, we can increase the attribute value of '*saAmfSGNumPrefAssignedSUs'* of the SG and the SI1's attribute value of *'saAmfSIPrefActiveAssignments',* which will force AMF to assign more SUs to SI1. If the workload of SI1 decreases, we can decrease the SI1's attribute value of *'saAmfSIPrefActiveAssignments'*, which will force AMF to free the SUs assigned to SI1. We can change the AMF configuration attributes to force AMF to increase or decrease resources when the workloads of services change.

The AMF configuration attributes from the service side and service provider side that can be modified for elasticity are referred to as elasticity attributes in the rest of this thesis. When the elasticity attributes are modified, AMF applies the changes in the system while maintaining HA. To maintain HA of the services the AMF configuration needs to be valid throughout the modifications. Therefore to apply valid changes to the AMF configuration all of the dependencies among entities need to be checked and whether system will be able to provide and protect the needed services after the elasticity attribute changes need to be determined. There are various configuration attributes at various levels of the AMF configuration that constrain the elasticity attributes. The AMF domain model [24] captures all of these constraints and expresses it with the help of Object Constraint Language (OCL) [25]. Table 1 and Table 2 list all of the elasticity attributes and the constraints on them.

Table 1 - AMF Elasticity Related Attributes of Service Provider Side Entities

Attribute Names	Description	Constraints
saAmfSURank	*It is used to specify the order in which SUs are selected for instantiation. The rank can also be used to determine the order in which an SU is selected for SI assignments, when no other configuration attribute defines it.*	*N/A*
saAmfSGAutoAdjust	*If set to SA_TRUE, AMF should auto-adjust the assignments of the SG's SU to the preferred configuration, according to the SU ranks.*	*N/A*
saAmfSGNumPrefInserviceSUs	*It denotes the number of SG's SU that are ready to accept SI assignment. The components of the in-service SUs have all the required software and services*	*1. The value should not be increased to more than the configured number of SUs.* *2. The attribute value should be greater than or equal to two in the case of the 2N redundancy model.* *3. The value of saAmfSGNumPrefInserviceSUs*

Attribute Names	Description	Constraints
	installed to handle the SI assignments.	*(InsSUs) must be greater than or equal to value of saAmfSGNumPrefAssignedSUs (AssSUs) in the case of N-way and N-way-Active redundancy models. We use the following equation to confirm the same:* $\boldsymbol{InsSUs \geq AssSUs}$ *4. It must be greater than or equal to the sum of saAmfSGPrefNumActiveSUs (ActSUs) and saAmfSGPrefNumStandbySUs (StdSUs) in the case of N+M redundancy model. We use the following equation to confirm the same:* $\boldsymbol{InsSUs \geq ActSUs + StdSUs}$
saAmfSGNumPrefActiveSUs	*This configuration attribute is only applicable to the N+M redundancy model. It represents the preferred number of "active" SUs in the SG. It denotes that AMF should try to keep this number of SUs active.*	*1. The value must not decrease to less than one.* *2. Its value must not be modified to a value greater than the number of in-service SUs. We use the following equation to confirm the same:* $\boldsymbol{InsSUs \geq ActSUs + StdSUs}$
saAmfSGNumPrefStandbySUs	*This configuration attribute is only applicable to the N+M redundancy model. It represents the preferred number of "standby" SUs in the SG. It denotes that AMF should try to keep this number of SUs standby.*	*1. The value must not be set to less than one (Note that it might have been set to zero in the initial configuration, in which case it should remain zero).* *2. While modifying the value of this attribute, it is necessary to maintain the following equation.* $\boldsymbol{InsSUs \geq ActSUs + StdSUs}$
saAmfSGNumPrefAssignedSUs	*This attribute is only applicable for the N-way, and the N-way-Active redundancy model. It represents the preferred number of SUs with assignments in the SG.*	*1. While decreasing the value of the attribute it should not be decreased to less than the number of SUs required to protect the preferred number of active and standby assignments of each of the SIs that the SG needs to protect.* *2. While manipulating the value, it should not be set to more than the preferred in-service SUs. We use the following equation to confirm the same* $\boldsymbol{InsSUs \geq AssSUs}$
saAmfSGMaxActiveSIsperSU	*It specifies the maximum number of SIs that can be assigned as active to an SU of the SG. This attribute is only applicable to N+M, N-way, and N-way-Active redundancy models.*	*1. saAmfCompNumMaxActiveCSIs* [4] *(CompMaxActCSIs) attribute denotes number of active CSIs that can be supported by the components of a SG. saAmfSGMaxActiveSIsperSU (MaxActSIperSU) attribute's value should not be increased to more than the CompMaxActCSIs. We use the following equation to confirm the same* $\boldsymbol{MaxActSIperSU \leq No.of\ Components\ per\ SU \times \frac{CompMaxActCSIs}{No.of\ CSIs\ \text{per SI}}}$ *2. Before decreasing the value of this attribute we check if there is enough active capacity to support the required active assignments by the following equation* $\boldsymbol{MaxActSIperSU \times ActSUs \geq Required\ active\ assignments}$

Attribute Names	Description	Constraints
saAmfSGMaxStandbySIsperSU	*This attribute specifies the maximum number of SIs that can be assigned as standby to a SU of the SG. This attribute is only applicable to N+M and N-way redundancy models*	*1. saAmfCompNumMaxStandbyCSIs* [4] *(CompMaxStdCSIs) attribute denotes the number of standby CSIs that can be supported by the components of a SG. saAmfSGMaxStandbySIsperSU (MaxStdSIperSU) attribute's value should not be increased to more than the CompMaxStdCSIs. We use the following equation to confirm the same* $\boldsymbol{MaxStdSIperSU \leq No.of\ Components\ per\ SUs \times \frac{CompMaxStdCSIs}{No.of\ CSIs\ \text{per SI}}}$ *2. Before decreasing the value of this attribute we check if there is enough standby capacity to support required standby assignments by using the following equation* $\boldsymbol{MaxStdSIperSU \times StdSUs \geq Required\ standby\ assignments}$
saAmfNodeCapacity	*This attribute specifies the capacity of the node to configure SUs and SIs*	*N/A*

The service side attributes are listed in Table 2.

Table 2- AMF elasticity related attributes of service side entities

Attribute Names	Description	Constraints
saAmfSIRank	*SI rank is used to specify the order in which SIs are selected for the assignment.*	*N/A*
saAmfSIPrefActiveAssignments	*This attribute represents the preferred number of active assignments per SI in the N-way-Active redundancy model. It is not applicable for the other redundancy models.*	*1. The attribute value should not be decreased to less than two.* *2. saAmfSIPrefActiveAssignments (SIAssgmnts) attribute value may be increased, only if the SI needing capacity is not assigned yet to all the SUs in the SG. We check the same by the following equation:* $\boldsymbol{SIAssgmnts \leq AssSUs}$ *And if the SG has enough capacity. We confirm the same by the following equation.* $\boldsymbol{SIAssgmnts \leq MaxActSIperSU \times AssSUs}$
saAmfSIPrefStandbyAssignments	*This attribute represents the preferred number of standby assignments per SI in the N-way redundancy model. It is not applicable for the other redundancy models.*	*1. The attribute value should not be decreased to less than two.*
saAmfSIActiveWeight	*SI weight for active assignments of this SI.*	*N/A*
saAmfSIStandbyWeight	*SI weight for standby assignments of this SI.*	*N/A*
saAmfSIRankedSU	*This is used to specify the ranked list of SUs per SI; It is applicable for the SGs with N-way and N-way-Active redundancy models.*	*N/A*

The aforementioned attributes are writable configuration attributes. We can manipulate the values of these attributes to force AMF to change the SI-to-SU assignments, which will re-distribute the workload within a given SG or cluster in general. This, in turn, increases and decreases resources to different SIs representing workloads in the system. Therefore, we can achieve our objective of managing elasticity within AMF by selecting an appropriate combination of the AMF configuration modifications that change the resources depending on the workload changes.

3.2 Types of workload changes in an AMF Configuration

Now that we have determined the elasticity attributes and their constraints, we will define the two types of workload changes in an AMF configuration. The two types of workload changes characterize the potential changes in the workload of an AMF configuration. In an AMF configuration a workload is represented by SIs that consists of CSIs. The workload may increase or decrease due to change in the user's requests. This change in workload triggers elasticity action; hence it is mandatory to characterize the potential changes in workload. The section describes the two types of workload changes: Single-SI and Multiple-SI type workload changes.

3.2.1 Single-SI Type workload changes

When the workload change maps to the single SI pre-existing in the AMF configuration, we define it as a Single-SI change. For example, if the SI is defined as a Uniform Resource Locator (URL) through which users access a given service, any increase of user requests will still be represented in the AMF configuration by the same SI. We can say that the workload imposed by the single SI has increased as shown in Figure 12(A). Similarly, any decrease of user requests will still be represented in the AMF configuration by the same SI, so we can say that the workload of this single SI has decreased as shown in Figure 12(B). We assume that changes in the workload associated with a single SI are detected by a workload monitor.

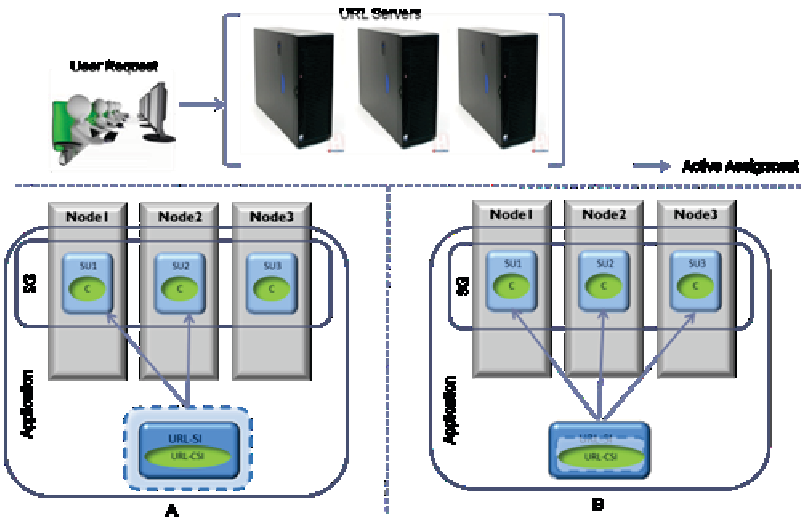


Figure 12 - Example for Single-SI type workload changes

3.2.2 Multiple-SI type workload changes

When the change in the workload manifests as an increase or a decrease in the number of SIs in the AMF configuration, we define it as Multiple-SI change. For example, if an SI is defined as the VLC media player [26], any increase in the number of requests for the VLC will map to a new SI in the AMF configuration as shown in Figure 13(A). Also, any decrease in VLC requests will result in decreasing the number of SIs as shown in Figure 13(B). Multiple-SI type workload change is associated to a configuration change performed through IMM.

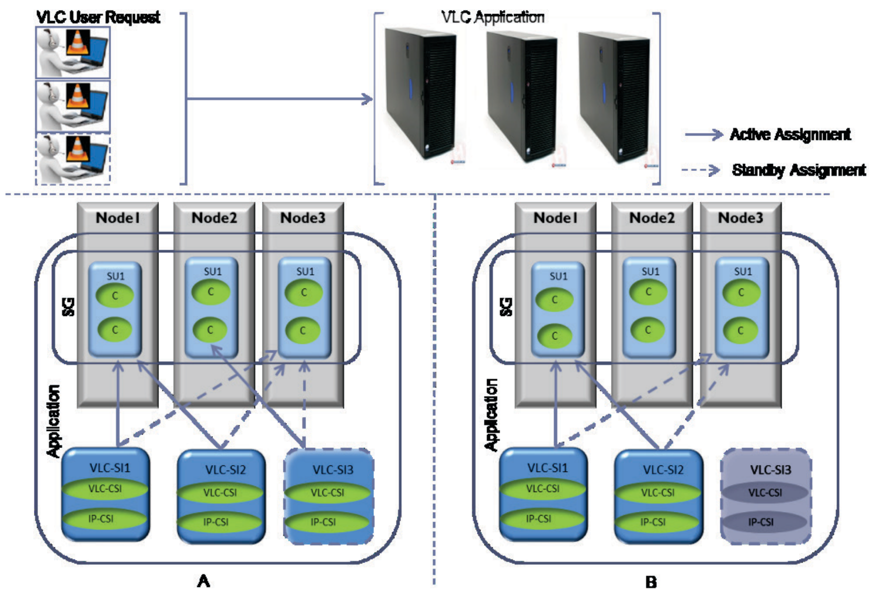


Figure 13 - Example of Multiple-SI type workload changes

3.3 Summary

In this chapter we determined the AMF configuration attributes related to elasticity and the attributes constraining them. Our goal is to enable elasticity and availability in the AMF configuration. We enable elasticity in the AMF configuration by manipulating the AMF configuration attributes related to elasticity. To guarantee availability we need to check the constraints before modifying the AMF configuration attributes. To characterize the potential workload changes in an AMF configuration, we also defined ‘Single-SI’ and ‘Multiple-SI’ type of workload changes. The Single-SI type of workload changes in an AMF configuration are detected by the workload monitor. The Multiple-SI type of workload changes are declared by the IMM service. We will enable elasticity in the AMF configuration in the case of Single-SI or Multiple-SI type of workload changes.

Chapter 4 - Overall Architecture and Elasticity Engine

In this chapter, we present our solution for managing elasticity and availability with the SA Forum middleware. We elaborate on EE architecture and its behavior through the elasticity strategies.

4.1 Overall architecture for HA and elasticity management

AMF is responsible for maintaining the availability of the system. AMF receives the configuration changes from IMM and acts accordingly [4]. A monitor(s) is required to detect the application workload changes and inform the EE about any significant change (e.g. exceeding a given threshold). The workload changes detected by the monitor are associated with the same SI, i.e. they are of type 'Single-SI' workload change. The workload in the AMF configuration may also change due to an increase or decrease in the number of SIs i.e. Multiple-SI type workload change. The number of SIs can be changed by modifying the AMF configuration through the IMM service. In this case, the EE expects a notification from IMM.

When the EE receives a signal that the workload has increased or decreased from the monitor or IMM, it reads the configuration in the IM using the IMM service to calculate the configuration changes necessary to adjust the system. It then writes the CCBs into IMM, and AMF in turn receives these changes (i.e. CCBs) from IMM and implements them by rearranging the SI-to-SU assignments as necessary. Once AMF implements the CCB, AMF updates the runtime attributes of the configuration objects. The EE also informs the system manager or cloud manager to increase the number of nodes in the cluster and install required software on them to keep the system ready for further workload changes. Figure 18 shows the overall architecture for HA and elasticity management with AMF.

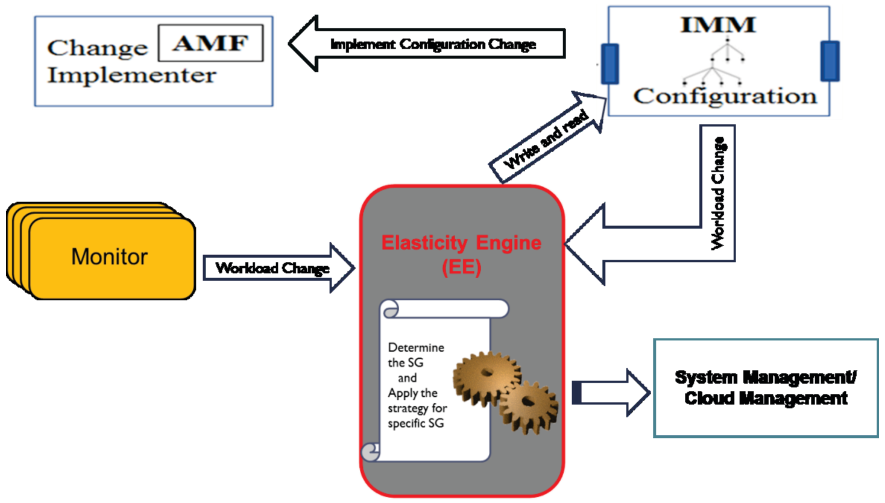

Change AMF Implementer
Implement Configuration Change
IMM Configuration
Write and read
Workload Change
Monitor
Workload Change
Elasticity Engine (EE)
Determine the SG and Apply the strategy for specific SG
System Management/ Cloud Management

Figure 14 - Overall Architecture for HA and Elasticity Management with AMF

4.2 The Elasticity Engine Architecture

The EE is composed of the "*Elasticity Controller*", the "*Redundancy Model (RM) Adjustors*" and the "*Buffer Manager"* as shown in Figure 15. At a high level of abstraction the operation of the EE consists of the following steps:

1. The EE receives the indication that the workload has changed in two ways:
    a. The workload monitor(s) monitors the actual workload associated with an SI and signals the need of an adjustment if there is a significant change in the workload (for example, an increase or decrease in the incoming traffic exceeds some threshold).
    b. The workload in the AMF configuration may also change due to the addition or removal of services, that is, in the case of an increase or decrease in the number of SIs in the AMF configuration, the EE receives the information about these changes from IMM.

2. After receiving the workload change signals, the EE Controller reads the AMF configuration in the IM to determine the SG protecting the SI that has changed in workload. Depending on the SG's redundancy model the EE Controller calls the RM Adjustor.
3. The RM Adjustor reads the AMF configuration attributes of the SG in the IM using IMM and calculates the configuration changes (i.e. CCBs) required to adjust the SG's configuration to the received workload changes. The configuration changes accommodate any additional workload or release any resources in excess while maintaining availability. The RM Adjustor creates and applies CCBs according to the various strategies defined in the next section.
4. To speed up future adjustments some nodes may be reserved for the SG, therefore the RM Adjustor calls the Buffer Manager to reserve nodes or free up allocated nodes through additional CCBs. Depending on the outcome of the adjustments the EE Controller may take one or more of the following actions:
    - If the adjustments of the given SG are insufficient: The EE Controller will do similar configuration adjustments of other SGs which have similar redundancy model and are sharing nodes with the SG requiring capacity.
    - Towards the administrator or cloud manager: The EE Controller will inform to add or remove nodes in the cluster, if the cluster size is insufficient or if some nodes are freed up, and/or
    - Towards the administrator or software management: The EE Controller will inform the installation of required software on additional nodes within the cluster if new nodes are needed to be able to cope with the workload increase.

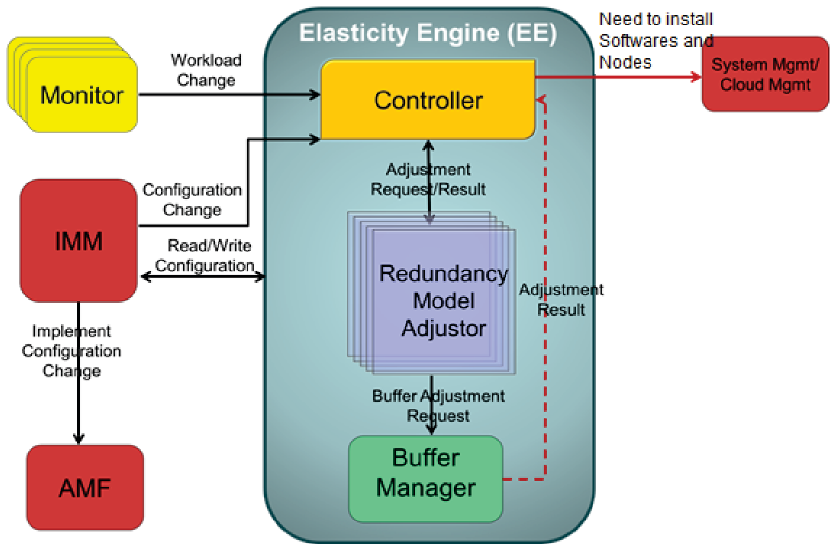


Figure 15 - The Architecture of Elasticity Engine

The sequence diagram in Figure 16 shows the EE's sequence of actions to handle workload changes.

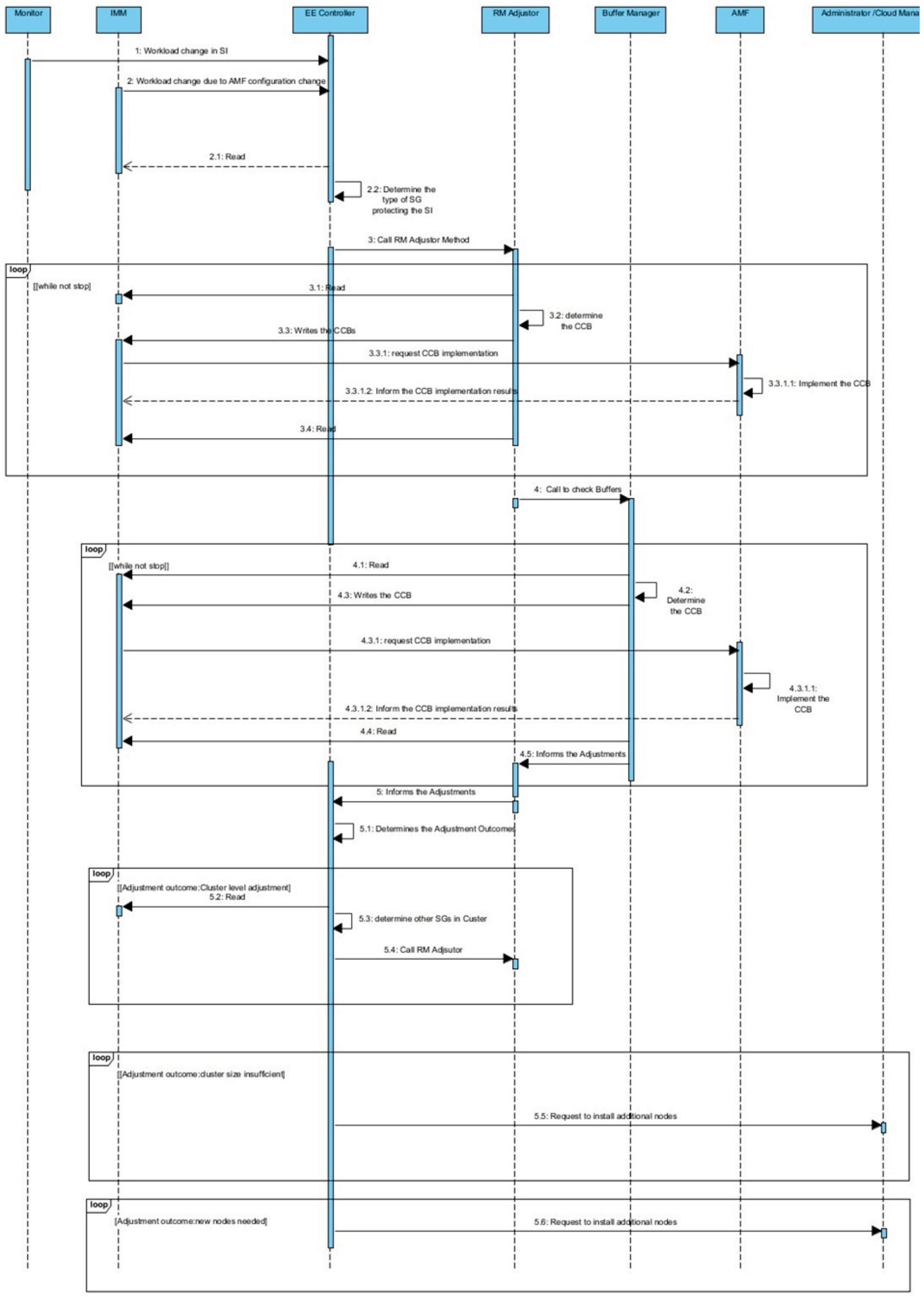

Monitor
IMM
EE Controller
RM Adjustor
Buffer Manager
AMF
Administrator /Cloud Mana
1: Workload change in SI
2: Workload change due to AMF configuration change
2.1: Read
2.2: Determine the type of SG protecting the SI
3: Call RM Adjustor Method
loop
[[while not stop]
3.1: Read
3.2: determine the CCB
3.3: Writes the CCBs
3.3.1: request CCB implementation
3.3.1.1: Implement the CCB
3.3.1.2: Inform the CCB implementation results
3.4: Read
4: Call to check Buffers
loop
[[while not stop]]
4.1: Read
4.2: Determine the CCB
4.3: Writes the CCB
4.3.1: request CCB implementation
4.3.1.1: Implement the CCB
4.3.1.2: Inform the CCB implementation results
4.4: Read
4.5: Informs the Adjustments
5: Informs the Adjustments
5.1: Determines the Adjustment Outcome
loop
[[Adjustment outcome:Cluster level adjustment]
5.2: Read
5.3: determine other SGs in Custer
5.4: Call RM Adjsutor
loop
[[Adjustment outcome:cluster size insufficient]
5.5: Request to install additional nodes
loop
[Adjustment outcome:new nodes needed]
5.6: Request to install additional nodes

Figure 16 – Elasticity Engine's Sequence Diagram

4.3 Elasticity Engine Strategies

The EE handles workload changes depending on the redundancy model of the SG protecting the SI in the AMF configuration. It first tries to adjust the workload changes at the SG level by adjusting the configuration of the SG protecting the affected SI. If the SG level adjustments is not possible it tries to adjust workload changes at the cluster level where it tries to adjust the configuration for other SGs and SIs in the cluster sharing nodes with the SG protecting the affected SI. The EE's RM Adjustors handle the workload changes. Each of the RM Adjustor uses a combination of the following strategies. The combination of the strategies depends on the redundancy model type of the SG and the execution state of the system while applying the strategies.

4.3.1 Workload increase

If the monitor reports an increase in the workload of an SI (i.e. Single-SI type workload changes), the EE will try to increase the capacity assigned to the SI. If the workload increase is due to a new SI (i.e. Multiple-SI type workload changes), the EE checks if the new SI is not already assigned before increasing the capacity in the SG for the new SI. However, the strategies used to handle the workload increase are the same. We define three main strategies to handle the workload increase:

- **Spreading the SI workload**

  In this strategy we handle a service workload increase by spreading it over more nodes. The EE uses this strategy when an SG protecting the SI is an 'N-way-Active' redundancy model. The EE will handle the increase of the workload of an SI by increasing the number of assignments of the SI in the SG protecting it. Thus, the workload increase of the SI is handled by spreading it across more SUs. Figure 17 shows the workload of the SI before (A) and after (B) the adjustment. The orange portion indicates the capacity used by SIs protected by SG1, the green portion denotes the capacity used by SI1 and the blue portion indicates the capacity used by SI2 protected by SG2. The light blue portion indicates the increase in workload (A) of SI1. The SG2 is of the N-way-Active redundancy model and its SUs are configured on all of the nodes in the figure. According to the strategy the assignment of SI2 protected by SG2 is incremented from two to three, thus, the SI2's workload is distributed on an additional Node3 and the workload increase is handled.

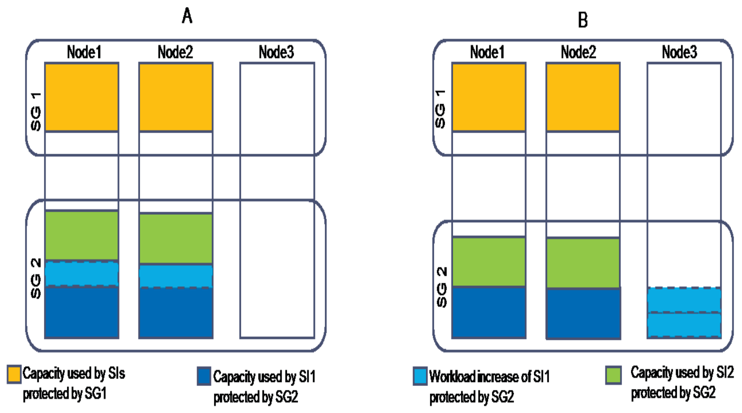
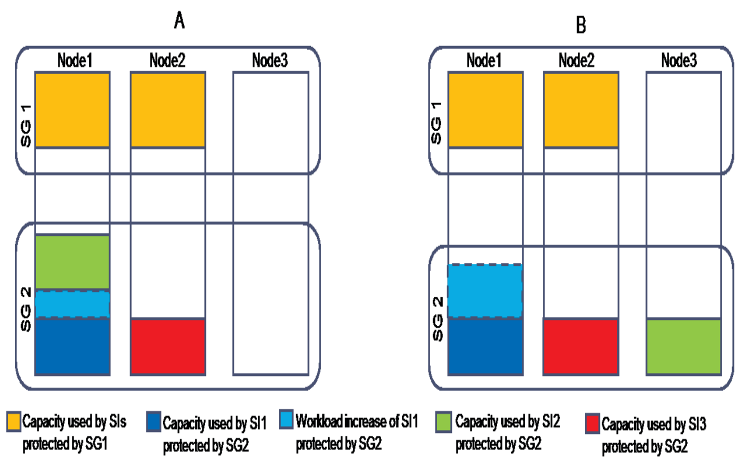

A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload increase of SI1 protected by SG2
Capacity used by SI2 protected by SG2

Figure 17 - Spreading the SI workload

❖ Distributing the SIs over more SUs

In this strategy we handle workload increase by distributing the services configured on the loaded node over more number of nodes. At the SG level the EE may handle the increase of the workload of an SI by distributing the SIs to more SUs within the SG, therefore giving more capacity to each SI including the one experiencing the increase. This strategy cannot be applied to the 2N and the No-Redundancy redundancy models. In Figure 18, the capacity used by SIs protected by SG1 is indicated in orange. The green indicates the portion used by SI1, the blue indicates the portion used by SI2 and the red portion indicates the capacity used by the SI3 of SG2. The SUs of SG2 are configured on all the nodes. In Figure 18(A) the light blue portion indicates an increase in workload of SI1 protected by SG2. According to this strategy EE decreases the number of SIs that can be assigned to a SU from two to one and the number of assigned (or active) SUs from two to three. This will force AMF to move SI2 protected by SG2 to Node3.

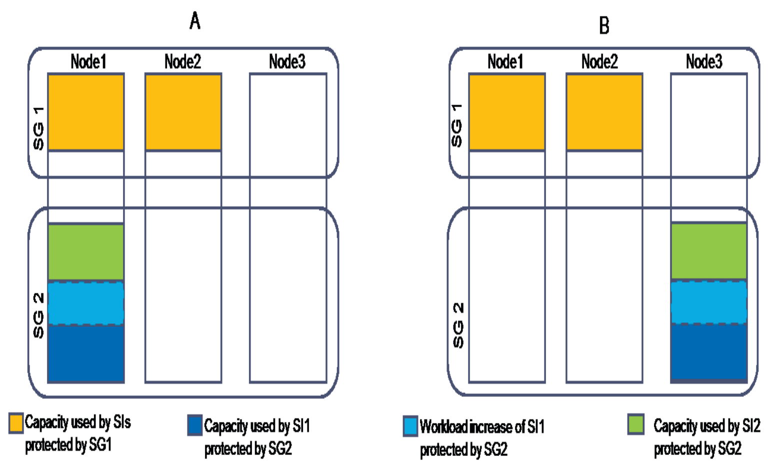


A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload increase of SI1 protected by SG2
Capacity used by SI2 protected by SG2
Capacity used by SI3 protected by SG2

Figure 18 - Distributing the SIs over more SUs

❖ **Prioritizing the SU on the least loaded node**

In this strategy we handle the service workload increase by re-assigning the services from loaded node to least loaded node. The EE may handle an increase in the workload of an SI by swapping the rank of the SU currently active for the SI with rank of the SU on the least loaded node. This will cause AMF to move the SIs of the currently active SU to a node having more capacity. The EE uses this strategy when a SG protecting the SI experiencing workload increase, is of a 2N or No-Redundancy redundancy model. We can apply the strategy to other redundancy models as well however it may contradict other considerations guiding the ranks, such as balancing SIs within SG. In Figure 19(A), Node1 is used to serve SIs protected by SG1 indicated by orange. Capacity used by SI1 and SI2 protected by SG2 is indicated by green and blue colors respectively. The light blue portion in Figure 19(A) indicates a workload increase in SG2. Since the SUs of SG1 and SG2 are configured on all of the nodes, the SG2's SU on Node3 can be prioritized. This will force AMF to move the assignments to Node3 as shown in Figure 19(B).



A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload increase of SI1 protected by SG2
Capacity used by SI2 protected by SG2

Figure 19 - Prioritizing the SU on the least loaded node

4.3.2 Workload decrease

The EE handles a workload decrease by freeing SUs of the SG, which indirectly may free the nodes that host these SUs. The EE will first try to free up some capacities of the SG protecting the SI and may then try at the cluster level with other SGs. The EE applies workload decrease strategies according to the redundancy model type of the SG that protects the SI and the current execution state of the system. These strategies are opposite to the strategies that handle workload increase.

- **Merging the SI workload** In this strategy we handle the service workload decrease by spreading it over less nodes. At the SG level the EE may handle the decrease of the workload of an SI by decreasing the number of SI assignments and therefore distributing the SI's workload to smaller number of SUs within the SG. The EE uses this strategy when an SG protecting the SI is of an N-way-Active redundancy model. Figure 20 shows the workload of the SI before (A) and after (B) the adjustment. The orange portion indicates the capacity used by SIs protected by SG1, the green portion denotes the capacity used by SI1 and the blue portion indicates the capacity used by SI2 protected by SG2. The light blue portion indicates the decrease in workload of SI2 (A). The SG2 is of an N-way-Active redundancy model type and its SUs are configured on all of the nodes in the figure. According to the strategy the assignments of SI2 protected by SG2 is decremented from three to two, thus its load is distributed on only two nodes.

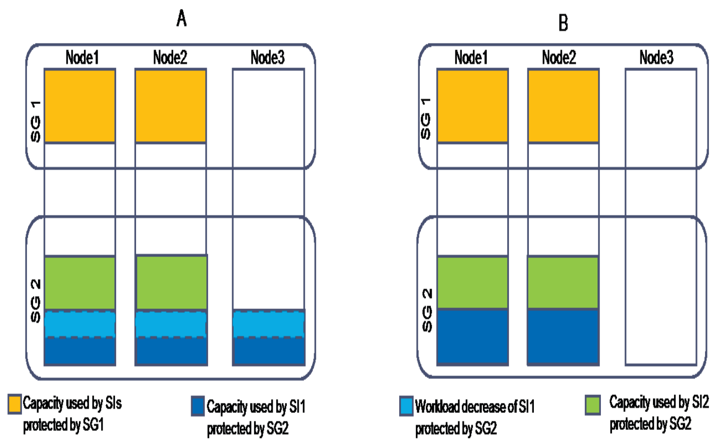

A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload decrease of SI1 protected by SG2
Capacity used by SI2 protected by SG2

Figure 20 - Merging the SI workload

❖ **Re-grouping the SIs to less SUs of the SG**

In this strategy we handle the workload decrease by distributing the services over less nodes. In other words, at the SG level the EE may handle a decrease in workload of an SI by redistributing the SIs to lower number of SUs within the SG, therefore reducing the capacity provided to the SIs including the one experiencing the decrease. Accordingly, each SI protected by the SG should allow for such a decrease. This strategy cannot be applied to the 2N and the No-Redundancy redundancy models. In Figure 21, the orange portion indicates the capacity used by SIs of SG1. The blue portion indicates the capacity used by SI1, the green portion indicates the capacity used by SI2 and the red portion indicates the capacity used by SI3 protected by SG2. The light blue portion indicates the workload decrease in SI1 of SG2. According to this strategy the EE increases the number of SIs that can be assigned to a SU from one to two and reduces the number of assigned (or active) SUs from three to two This will force AMF to move SI2 to Node1 as shown in Figure 21(B).

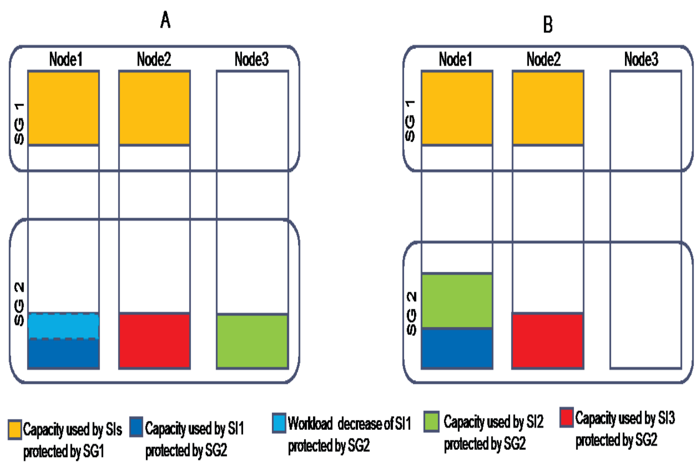

A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload decrease of SI1 protected by SG2
Capacity used by SI2 protected by SG2
Capacity used by SI3 protected by SG2

Figure 21 - Re-grouping the SIs to less SUs of the SG

- **Prioritizing the nodes that serve other SIs**

In this strategy we handle the workload decrease by re-assigning the services to another node handling some services in order to free the current node. The EE may handle a decrease in the workload of an SI by swapping the rank of a SU currently active for the SI with the rank of a SU on a node that has other assignments as well. As a result AMF will move the assignments of the current active SU to the already loaded node as shown in Figure 22. The EE uses this strategy primarily when an SG protecting the SI experiencing a workload decrease is of a 2N or No-Redundancy redundancy model. In Figure 22, the orange portion indicates the capacity used by SIs protected by SG1. The blue portion indicates the capacity used by SI1 and green indicates the portion of capacity used by SI2. The SI1 and SI2 are protected by SG2. The light blue portion indicates the workload decrease of SI1 indicated in Figure 22(A). Since SUs of SG2 are configured on all the nodes in the figure, the SU on Node1 can be prioritized according to this strategy. This will force AMF to move the assignments of SI1 and SI2 to Node1 as shown in Figure 21(B).

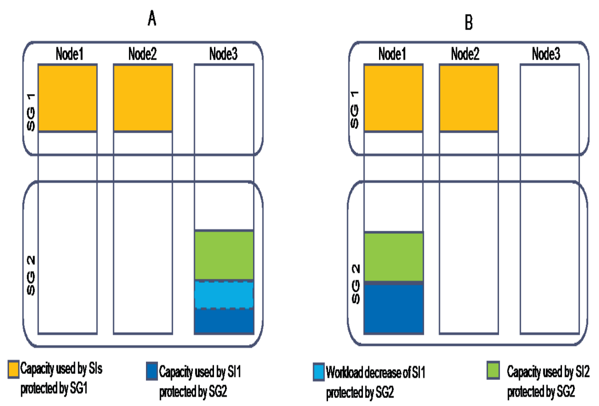

A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload decrease of SI1 protected by SG2
Capacity used by SI2 protected by SG2

Figure 22 - Prioritizing the nodes that serve other SIs

4.3.3 Buffer management

In the AMF configuration, only a subset of the configured SUs in an SG are in-service SUs and AMF can only use the number of assigned SUs among the in-service SUs for SI assignments. In-service SUs are those instantiated and ready to serve the SI assignments but not necessarily assigned yet. The un-instantiated spare SUs in an SG are those that are configured in the SG but not in service; however they can easily be instantiated. To increase the resources to handle a workload increase, the EE increases the number of assigned SUs (those on which AMF can distribute the SI assignments) and decreases the number of assigned SUs, if the workload decreases. The EE can use these different subsets to prepare AMF for sudden workload increases by reserving additional SUs at different levels as buffers. In other words, in this strategy we reserve enough nodes in the cluster to keep the system ready to handle sudden workload changes. These SUs are reserved in two types of Buffers: The 'in-service-SU-buffer' and the 'un-instantiated-SU-buffer'.

The 'in-service-SU-buffer' is the number of instantiated SUs ready for service but not used for assignments yet. They may be added quickly to the pool of SUs used for assignments or in the case of failure they replace a failed SU. The in-service-SU-buffer is the difference between the number of in-service SUs and the number of assigned SUs (or the sum of active and standby SUs) of an SG. These SUs may use some resources, as they may be instantiated.

The 'un-instantiated-SU-buffer' indicates that the SUs in the buffer are ready for instantiation as they have all the necessary software installed. These SUs have been configured in the SG but are not instantiated by AMF; hence they do not consume resources. The un-instantiated-SU-buffer is the difference between the number of configured SUs and in-service SUs of an SG.

The size of the in-service-SU-buffer and the un-instantiated-SU-buffer is configurable. The number of SUs in an in-service-SU-buffer is set according to the time required for the adjustments, the time required to handle the increase in workload by an SG and the time required to instantiate a SU in the un-instantiated-SU-buffer. The number of SUs in the un-instantiated-SU-buffer is set according to the time required to install the required software on a node and/or increase the number of nodes in the cluster. When the EE changes the number of assigned SUs (or the number of active and standby SUs) it also adjusts the other configuration attributes in an SG to maintain the required number of SUs in the buffers.

- **Reservation of Resources**

  When the EE increases the number of assigned SUs of the SG, it also prepares for any sudden workload increase by bringing into service some additional SUs to maintain the size of in-service-SU-buffer. The EE can increase the number of in-service SUs only if there are additional SUs configured in an SG. Therefore the EE also ensures that there are some un-instantiated spare SUs configured in the SG to maintain the un-instantiated-SU-buffer. Otherwise the EE tries to configure new SUs. This is possible if there are nodes in the node group configured for the SG that are not hosting any SUs and have the required software installed on them. Otherwise, the EE signals to the system administrator or cloud manager to configure new nodes with the required software installed on them.

- **Freeing Reserved Resources**

In the case of a decrease in the workload, the EE tries to free resources by decreasing the number of assigned SUs. If this is successful the EE also decreases the number of in-service SUs while maintaining the in-service-SU-buffer. It may also decrease the number of configured SUs if the un-instantiated-SU-buffer is maintained. However this is not absolutely necessary.

Figure 23 indicates the buffer management action of the EE. In Figure 23(A), the SUs of the SG can be hosted on all of the seven nodes, amongst which only six nodes have the SUs configured. The in-service SUs are five amongst which dark blue colored nodes host the assigned SUs while the light blue colored nodes host the spare in-service instantiated SUs. We take the size of the in-service-SU-buffer to be two SUs and the un-instantiated-SU-Buffer to be one SU. In Figure 23(B), the EE's action of resource reservation is indicated. When the number of assigned SUs hosted on the nodes (dark blue colored nodes) increase, the EE calculates the difference between the assigned SU and the in-service SUs and increases the number of in-service units to six. Consequently, it also configures a new SU on Node7. Figure 24(C) indicates the EE's action to free the reserved resources. When the number of assigned SUs hosted on the nodes (dark blue colored nodes) decrease, the EE calculates the difference between the assigned SUs and in-service SUs and decrease the in-service SUs to five.

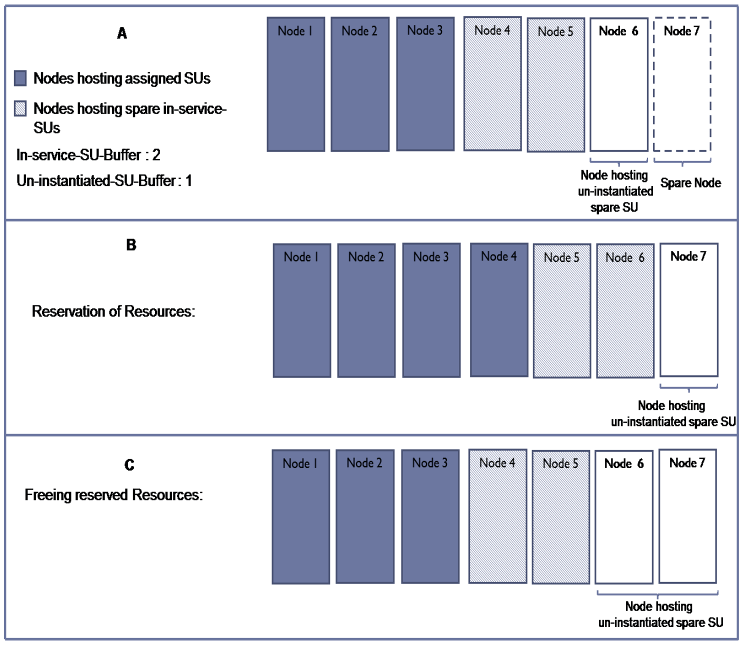

A
Nodes hosting assigned SUs
Nodes hosting spare in-service-SUs
In-service-SU-Buffer : 2
Un-instantiated-SU-Buffer : 1
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6
Node 7
Node hosting un-instantiated spare SU
Spare Node
B
Reservation of Resources:
Node hosting un-instantiated spare SU
C
Freeing reserved Resources:
Node hosting un-instantiated spare SU

Figure 23 - Buffer Manager

4.3.4 Cluster Level Adjustments

The services configured on the nodes in the cluster share resources. Hence, if we cannot handle the workload change of a service within the group of nodes it is hosted, we may handle its workload change by adjusting the workload of other services in the cluster. This adjustment will result in the same effect for the service experiencing workload changes because the services are hosted on the same nodes and share the node resources.

If the EE action for the configuration adjustment is unsuccessful at the SG level the EE tries to adjust other SGs in the cluster. For this purpose the EE looks for similar SG sharing resources with the one experiencing the workload change. If there is such an SG, the EE initiates the same adjustment for an SI protected by this SG. The SI is also selected based on similarities. This adjustment indirectly will result in the same effect for the original SG because the two SGs are hosted on the same node and share the node resources. Hence either of the SGs can take the node resources or release them.

Figure 24 shows two SGs of 2N redundancy models. Assuming that SG2 is configured only on two nodes (Node1 and Node2) and SG1 is configured on all three nodes (Node1, Node2 and Node3). The orange portion indicates the capacity used by SIs protected by SG1 and the blue portion indicates the capacity used by SIs protected by SG2. The light blue portion indicates the increase in workload of SG2. In such a scenario, the EE cannot adjust at the SG level as shown in Figure 24(A). It uses the cluster level adjustment to handle workload changes. The EE prioritizes the SG1's SU on Node3 forcing AMF to move the assignment of SI protected by SG1 to Node3.

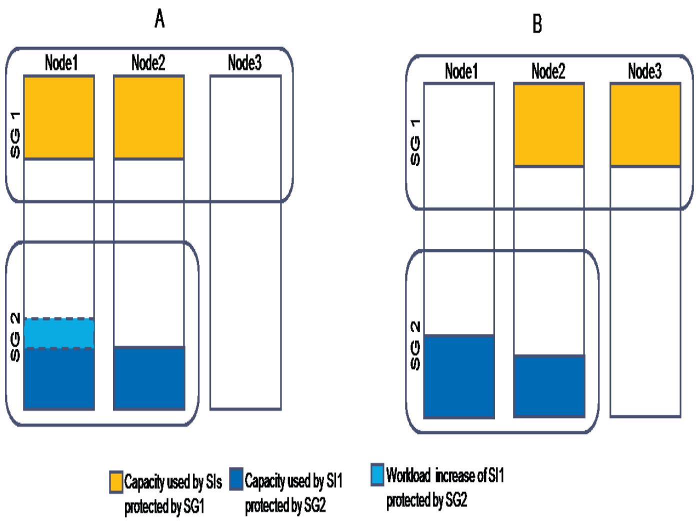

A
B
Node1
Node2
Node3
SG 1
SG 2
Capacity used by SIs protected by SG1
Capacity used by SI1 protected by SG2
Workload increase of SI1 protected by SG2

Figure 24 - Cluster Level Adjustments

4.4 Elasticity Engine Algorithms

This section covers the detailed algorithms for the strategies discussed in the previous section.

4.4.1 Workload increase algorithms

The EE applies the combination of the strategies to handle workload increases depending on the redundancy model type of an SG and the current execution state of the system. The redundancy model type of an SG determines the configuration attributes that the EE can adjust to handle workload changes. Typically, these algorithms define the step by step procedure with the configuration attributes that the EE's RM Adjustor follows to handle workload changes.

- **Spreading the SI workload**

  This algorithm defines the steps followed by the EE's RM Adjustor to handle workload increase of an SI protected by a SG of an N-way-Active redundancy model type (see Figure 25).

  1. The RM Adjustor initializes two variables: 'SI1' with the name of the SI whose workload has increased and 'SG1' with the name of the SG protecting this SI.
  2. The EE's RM Adjustor checks if the preferred number of active assignments attribute of SI1 (*saAmfSIPrefActiveAssignments*) is less than the number of preferred assigned SUs of SG1 (*saAmfSGNumPrefAssignedSUs*).
  3. If the preferred number of active assignments of SI1 is less than the number of preferred assigned SUs of SG1, the RM Adjustor checks if there is enough capacity configured in SG1 to handle a new assignment of SI1.
     a. If there is capacity, the RM Adjustor increases the preferred number of active assignments of SI1. This will force AMF to assign SI1 to one more SU i.e. the workload represented by SI1 spreads to more SUs.
     b. If there is no capacity configured, the RM Adjustor checks if it can be configured based on the capabilities of the components of the SUs. If so, it increases the number of assignments each SU can take on and returns to Step 3 otherwise it follows with Step 4.
  4. If preferred number of active assignments of SI1 and the number of preferred assigned SUs of SG1 are equal, that is, SI1 is already assigned to each assigned SU in SG1 then

the RM Adjustor tries to increase the number of preferred assigned SUs if there are spare in-service SUs.

5. If the RM Adjustor has increased the number of preferred assigned SUs in SG1 (*saAmfSGNumPrefAssignedSUs*) it calls the Buffer Manager to reserve resources for further workload increases and returns to Step 2.
6. If there are no in-service SUs i.e. SG1 is using all the nodes on which it can be hosted, the RM Adjustor reports to the Elasticity Controller that it was not successful and the adjustments need to be tried at the cluster level.

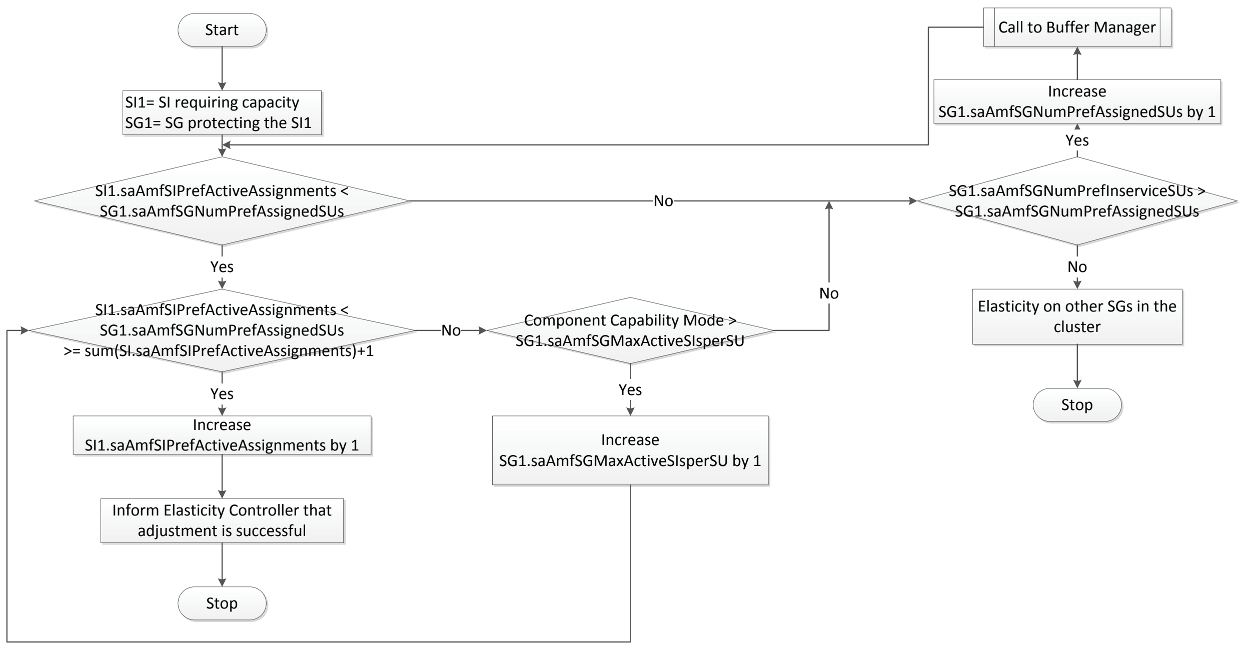

Start
SI1= SI requiring capacity
SG1= SG protecting the SI1
SI1.saAmfSIPrefActiveAssignments < SG1.saAmfSGNumPrefAssignedSUs
No
Yes
SI1.saAmfSIPrefActiveAssignments < SG1.saAmfSGNumPrefAssignedSUs >= sum(SI.saAmfSIPrefActiveAssignments)+1
No
Component Capability Mode > SG1.saAmfSGMaxActiveSIsperSU
No
Yes
Increase SI1.saAmfSIPrefActiveAssignments by 1
Inform Elasticity Controller that adjustment is successful
Stop
Increase SG1.saAmfSGMaxActiveSIsperSU by 1
Call to Buffer Manager
Increase SG1.saAmfSGNumPrefAssignedSUs by 1
Yes
SG1.saAmfSGNumPrefInserviceSUs > SG1.saAmfSGNumPrefAssignedSUs
No
Elasticity on other SGs in the cluster
Stop

Figure 25 - Flow-chart: Spreading the SI's workload (N-way-Active Redundancy Model)

- Distributing the SIs over more SUs of SG

The EE follows the procedure defined in the following algorithm to handle workload increases in the N-way-Active, the N+M and the N-way redundancy models (see Figure 26).

1. The EE's RM Adjustor initializes five variables:

   'SI1' with the name of the SI whose workload has increased,

   'SU1' with the name of the SU currently assigned active for the SI1, ‘SG1’ with the name of the SG protecting this SI1,

‘ActiveSUs’ pointing to the preferred number of active SUs if SG1 is of N+M redundancy model and to the preferred number of assigned SUs if SG1 is of the N-way redundancy model, and

‘StandbySUs’ pointing to the preferred number of standby SUs if SG1 is of N+M redundancy model and to the preferred number of assigned SUs if SG1 is of a N-way redundancy model.

2. The RM Adjustor checks if it can decrease the maximum number of active assignments on the SUs of SG1 (*saAmfSGMaxActiveSIsperSU*) without losing any SI assignments. If yes, it tries to do so until the number of current active assignments assigned to SU1 decreases. If it is successful it proceeds to Step 5 to handle the standby side in a similar manner.
3. If the RM Adjustor cannot decrease the maximum number of active assignments per SU without losing SI assignments, it will then check to increase the SG1’s capacity by increasing the value of the attribute ActiveSUs points to.
4. If the RM Adjustor is successful in increasing the number of active SUs, it invokes the Buffer Manager and then returns to Step 2. Otherwise it reports to the Elasticity Controller that the adjustments need to be made at the cluster level.
5. The RM Adjustor reinitializes ‘SU1’ with the name of the SU currently assigned standby for SI1 if the SG1 is of an N+M redundancy model and the highest ranking SU if SG1 is of the N-way redundancy model.
6. It checks if it can decrease the maximum number of standby assignments on the SUs of SG1 (*saAmfSGMaxStandbySIsperSU*) without losing any SI assignments. If yes, it tries

to do so until the number of current standby assignments assigned to SU1 decreases. If successful it reports to the Elasticity Controller about the success of the adjustments.

7. If the RM Adjustor cannot decrease the maximum number of standby assignments per SU without losing an assignment, it will then try to increase the SG1's standby capacity by increasing the value of the attribute StandbySUs points to.
8. If the RM Adjustor is successful in increasing the number of standby SUs it invokes the Buffer Manager and then returns to Step 6 otherwise it reports to the Elasticity Controller that further adjustments are needed at the cluster level.

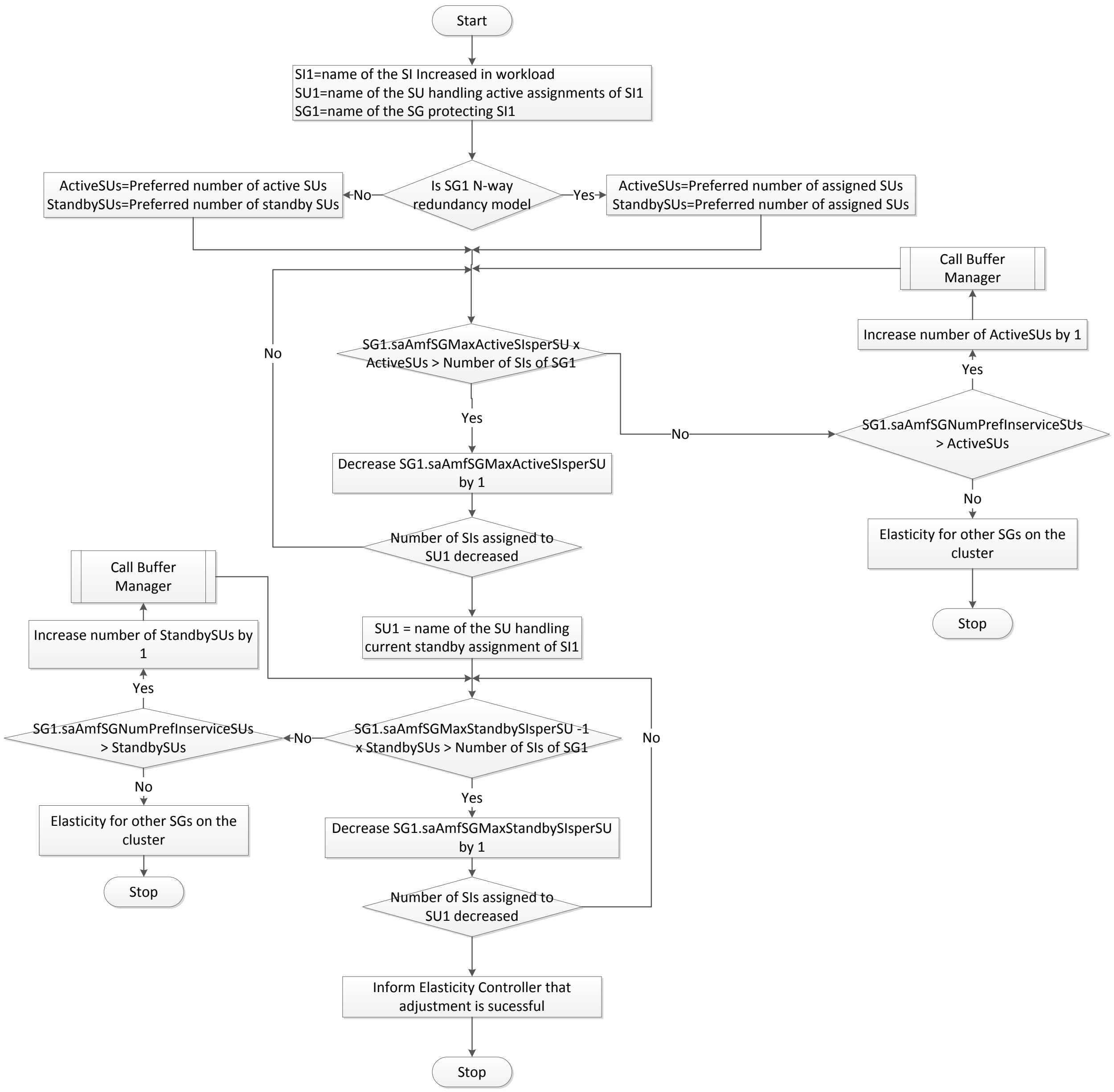

Start
SI1=name of the SI Increased in workload
SU1=name of the SU handling active assignments of SI1
SG1=name of the SG protecting SI1
Is SG1 N-way redundancy model
No
Yes
ActiveSUs=Preferred number of active SUs
StandbySUs=Preferred number of standby SUs
ActiveSUs=Preferred number of assigned SUs
StandbySUs=Preferred number of assigned SUs
Call Buffer Manager
Increase number of ActiveSUs by 1
Yes
SG1.saAmfSGMaxActiveSIsperSU x ActiveSUs > Number of SIs of SG1
No
Yes
SG1.saAmfSGNumPrefInserviceSUs > ActiveSUs
No
Decrease SG1.saAmfSGMaxActiveSIsperSU by 1
Elasticity for other SGs on the cluster
Number of SIs assigned to SU1 decreased
Stop
Call Buffer Manager
Increase number of StandbySUs by 1
SU1 = name of the SU handling current standby assignment of SI1
Yes
SG1.saAmfSGNumPrefInserviceSUs > StandbySUs
SG1.saAmfSGMaxStandbySIsperSU -1 x StandbySUs > Number of SIs of SG1
No
No
Yes
Elasticity for other SGs on the cluster
Decrease SG1.saAmfSGMaxStandbySIsperSU by 1
Stop
Number of SIs assigned to SU1 decreased
Inform Elasticity Controller that adjustment is sucessful
Stop

Figure 26 - Flow-chart: Distributing SIs over More SUs (N+M & N-way Redundancy Models)

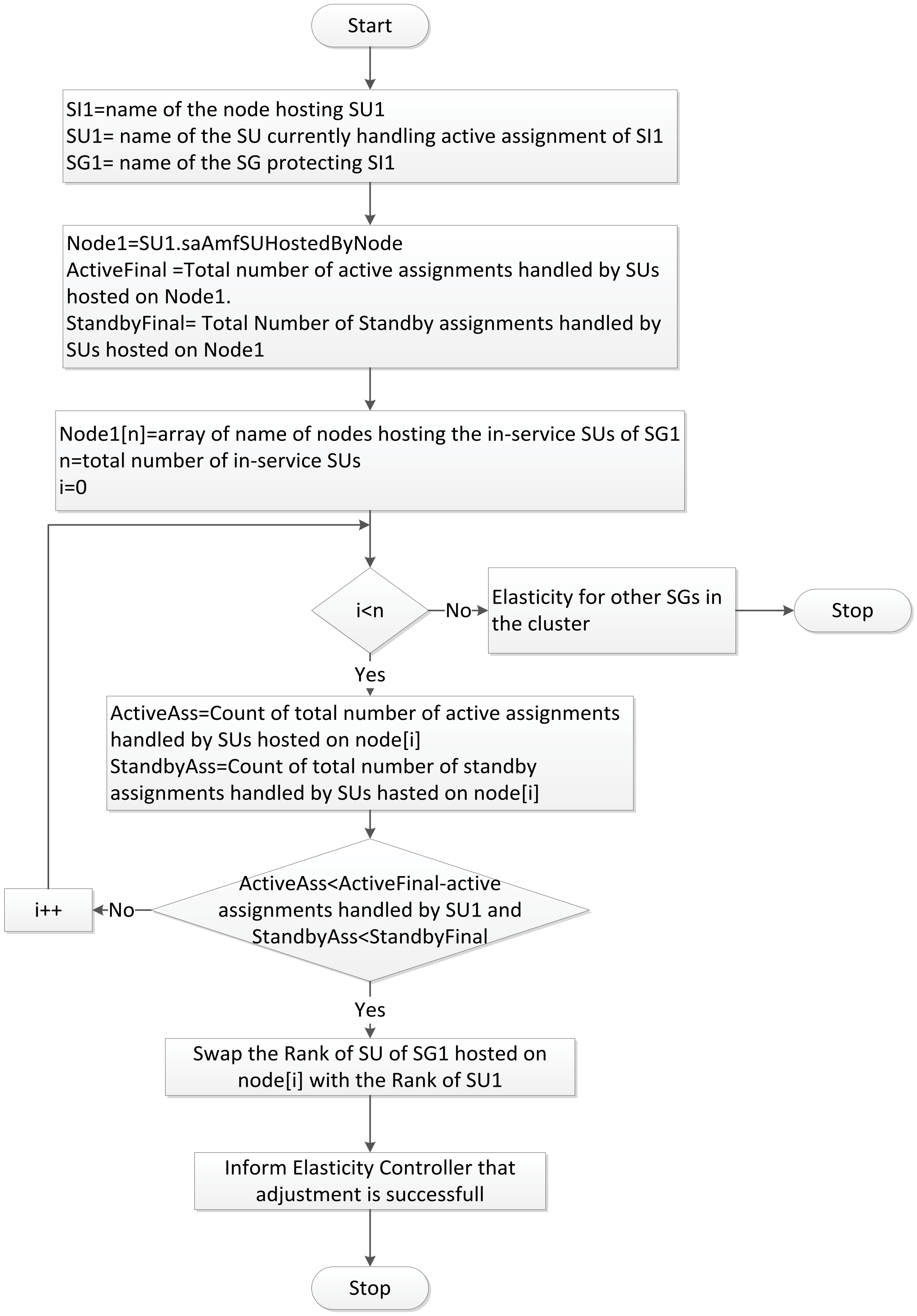
- **Prioritizing the SU on the least loaded node**

  The algorithm defines the steps followed by the EE to handle workload increases in the 2N and No-Redundancy redundancy model (see Figure 27).

  1. The EE's RM Adjustor initializes 'SI1' with the name of the SI whose workload has increased,

‘SU1’ with the name of the SU currently assigned active for the SI, ‘SG1’ with the name of the SG protecting this SI.

2. It finds the node hosting the SU1 and initializes ‘ActiveFinal’ with the sum of active assignments handled by each SU hosted on the node and ‘StandbyFinal’ with the sum of standby assignments handled by each SU hosted on the node.
3. It finds all the in-service SUs of SG1 and initializes an array ‘node1’ with the names of nodes hosting them.



Start
SI1=name of the node hosting SU1
SU1= name of the SU currently handling active assignment of SI1
SG1= name of the SG protecting SI1
Node1=SU1.saAmfSUHostedByNode
ActiveFinal =Total number of active assignments handled by SUs hosted on Node1.
StandbyFinal= Total Number of Standby assignments handled by SUs hosted on Node1
Node1[n]=array of name of nodes hosting the in-service SUs of SG1
n=total number of in-service SUs
i=0
i<n
No
Elasticity for other SGs in the cluster
Stop
Yes
ActiveAss=Count of total number of active assignments handled by SUs hosted on node[i]
StandbyAss=Count of total number of standby assignments handled by SUs hasted on node[i]
ActiveAss<ActiveFinal-active assignments handled by SU1 and StandbyAss<StandbyFinal
No
i++
Yes
Swap the Rank of SU of SG1 hosted on node[i] with the Rank of SU1
Inform Elasticity Controller that adjustment is successfull
Stop

Figure 27 - Flowchart: Prioritizing SU on the Least Loaded Node (2N & No Redundancy Models)

4. For each node in the array ‘node1’
    a. The RM Adjustor counts the total number of active assignments and the total number of standby assignments handled by the SUs hosted on the node.
    b. It compares if the total number of active assignments is less than the value of activeFinal minus the current number of active assignments handled by SU1 and the total number of standby assignments handled by the node is less than the value of standbyFinal.
5. If there is such a node, the RM Adjustor selects the one with the least assignments; it creates a CCB to swap the rank of the SU of the SG1 hosted on this node with the rank of SU1. In addition, if the SG is not configured to auto adjust, it initiates the SG adjust administrative operation.
6. If there is no node with lesser assignments than the node hosting SU1, the RM Adjustor reports to the Elasticity Controller that further adjustments are needed at the cluster level

4.4.2 Workload decrease algorithms

The EE follows the steps defined in the following algorithms to handle workload decreases in the SG depending on the redundancy model type.

- **Merging the SI workload**

  The steps defined in this algorithm are applicable to an SG of an N-way-Active redundancy model (see Figure 28). The EE’s Controller determines the redundancy model type of the SG protecting the SI decreased in workload and calls the RM Adjustor.

1. The RM Adjustor initializes ‘SI1’ with the name of the SI whose workload has decreased and ‘SG1’ with the name of the SG protecting SI1.

2. The RM Adjustor checks if SI1's '*saAmfSIPrefActiveAssignments*' attribute value is less than three and goes to the next step. If it is not less than three, it decreases it by one and goes ahead.
3. The RM Adjustor checks two conditions before decreasing the '*saAmfSGNumPrefAssignedSUs*' of SG1.

   (1) The product of '*saAmfSGNumPrefAssignedSUs-1*' and '*saAmfSGMaxActiveSIsperSU*' value of SG1 is greater than or equal to the sum of '*saAmfSIPrefActiveAssignments*' of each SI protected by SG1.

   (2) The value of '*saAmfSGNumPrefAssignedSUs*-1' is greater than the value of '*saAmfSIPrefActiveAssignments*' of each SI of SG1.

   a. If one of the two conditions is not satisfied the RM Adjustor goes to Step 4.

   b. If both the conditions are satisfied the RM Adjustor decreases the value '*saAmfSGNumPrefAssignedSUs*' attribute by one. The RM adjustor calls the Buffer Manager and reports to the Elasticity Controller that the adjustment was successful.

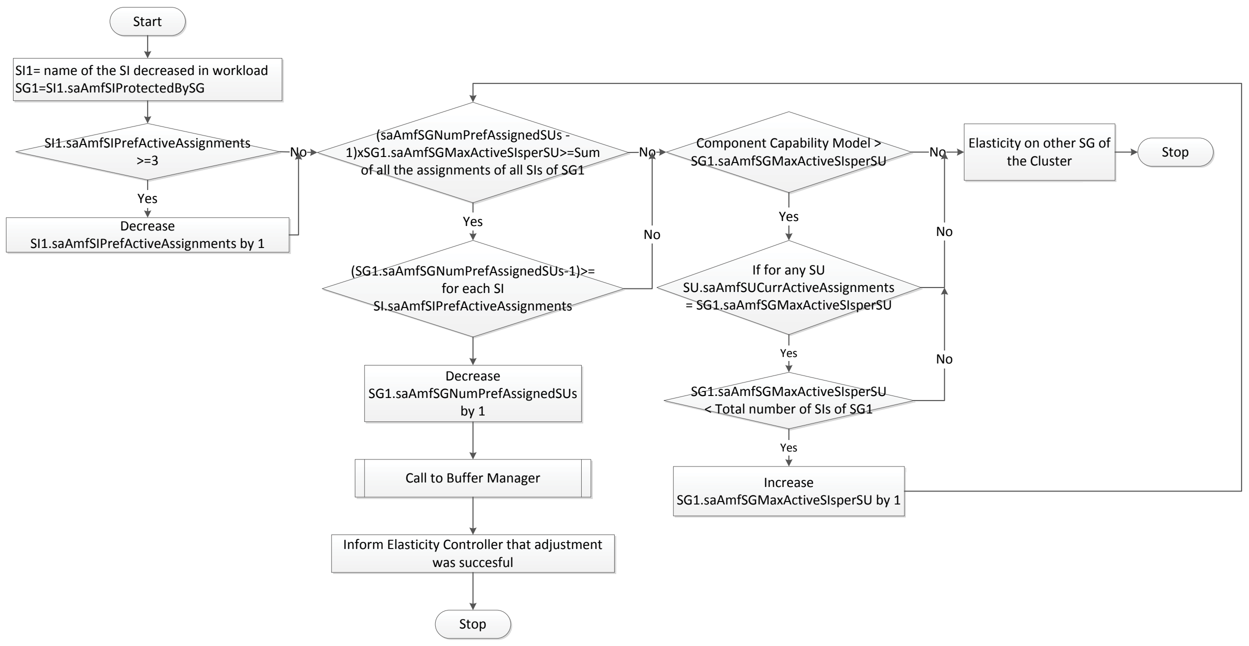

Start
SI1= name of the SI decreased in workload
SG1=SI1.saAmfSIProtectedBySG
SI1.saAmfSIPrefActiveAssignments >=3
Yes
Decrease SI1.saAmfSIPrefActiveAssignments by 1
No
(saAmfSGNumPrefAssignedSUs - 1)xSG1.saAmfSGMaxActiveSIsperSU>=Sum of all the assignments of all SIs of SG1
Yes
(SG1.saAmfSGNumPrefAssignedSUs-1)>= for each SI SI.saAmfSIPrefActiveAssignments
Decrease SG1.saAmfSGNumPrefAssignedSUs by 1
Call to Buffer Manager
Inform Elasticity Controller that adjustment was succesful
Stop
No
No
Component Capability Model > SG1.saAmfSGMaxActiveSIsperSU
Yes
If for any SU SU.saAmfSUCurrActiveAssignments = SG1.saAmfSGMaxActiveSIsperSU
Yes
SG1.saAmfSGMaxActiveSIsperSU < Total number of SIs of SG1
Yes
Increase SG1.saAmfSGMaxActiveSIsperSU by 1
No
No
No
Elasticity on other SG of the Cluster
Stop

Figure 28 - Flowchart: Merging the SI Workload (N-way-Active Redundancy Model)

4. The RM Adjustor checks the following three conditions to increase '*saAmfSGMaxActiveSIsperSU*' of SG1. After increasing '*saAmfSGMaxActiveSIsperSU'* it goes to Step 3.
   a. The component compatibility model should be greater than the value of '*saAmfSGMaxActiveSIsperSU*' attribute of SG1. If not it goes to Step 5.
   b. The current number of active assignments of SIs for at least one of the SUs of SG1 must be equal to the value '*saAmfSGMaxActiveSIsperSU*' attribute of SG1. If not it goes to Step 5.
   c. The value of '*saAmfSGMaxActiveSIsperSU*' attribute of SG1 must be less than the total number of SIs protected by the SG1. If not it goes to Step 5.
5. The RM Adjustor informs the Elasticity Controller to try other SGs in the cluster.

- **Re-grouping the SIs on less SUs of the SG**

The algorithm defines the steps followed by the EE's RM Adjustor to handle the workload decrease of the SI protected by the N+M or the N-way redundancy models (see Figure 29).

1. The EE's RM Adjustor initializes

   'SI1' with the name of the SI whose workload has increased,

   'SU1' with the name of the SU currently assigned active for SI1,

   'SG1' with the name of the SG protecting SI1,

   'ActiveSUs' pointing to the preferred number of active SUs if the SG1 is of the N+M redundancy model and to the preferred number of assigned SUs if SG1 is of the N-way redundancy model, and

   'StandbySUs' indicating the preferred number of standby SUs if SG1 is of the N+M redundancy model and to the preferred number of assigned SUs if SG1 is of the N-way redundancy model.

2. The EE's RM Adjustor checks if it can decrease the number of SUs of SG by one without the loss of required active assignments.
3. If it causes the loss of an active assignment, the RM Adjustor will check the component capability model of the components of the SG to see if the value of the component capability model is greater than the maximum active SIs per SU of the SG and also whether the present node capacity is not assigned to the SIs. If all of these conditions are satisfied the EE will increase the value of maximum active SIs per SU.
4. If the RM Adjustor can decrease the number of SUs without affecting the active assignments it also checks for the required standby assignments of the SG.
5. If it causes loss of standby assignments, the RM Adjustor will check the component capability model of the components of the SG to see if the value of the component capability model is greater than the maximum standby SIs per SU of the SG and also the RM Adjustor checks whether the present node capacity is not assigned to the SIs. The RM Adjustor creates a CCB to increase the value of maximum standby SIs per SU.
6. If the RM Adjustor can decrease the number of SUs of the SG without loss of both required active and standby assignments, it decreases the number of SUs.
7. If the RM Adjustor is not able to free capacity in the SG, it will report to the Elasticity Controller to try to free the capacity at the cluster level.

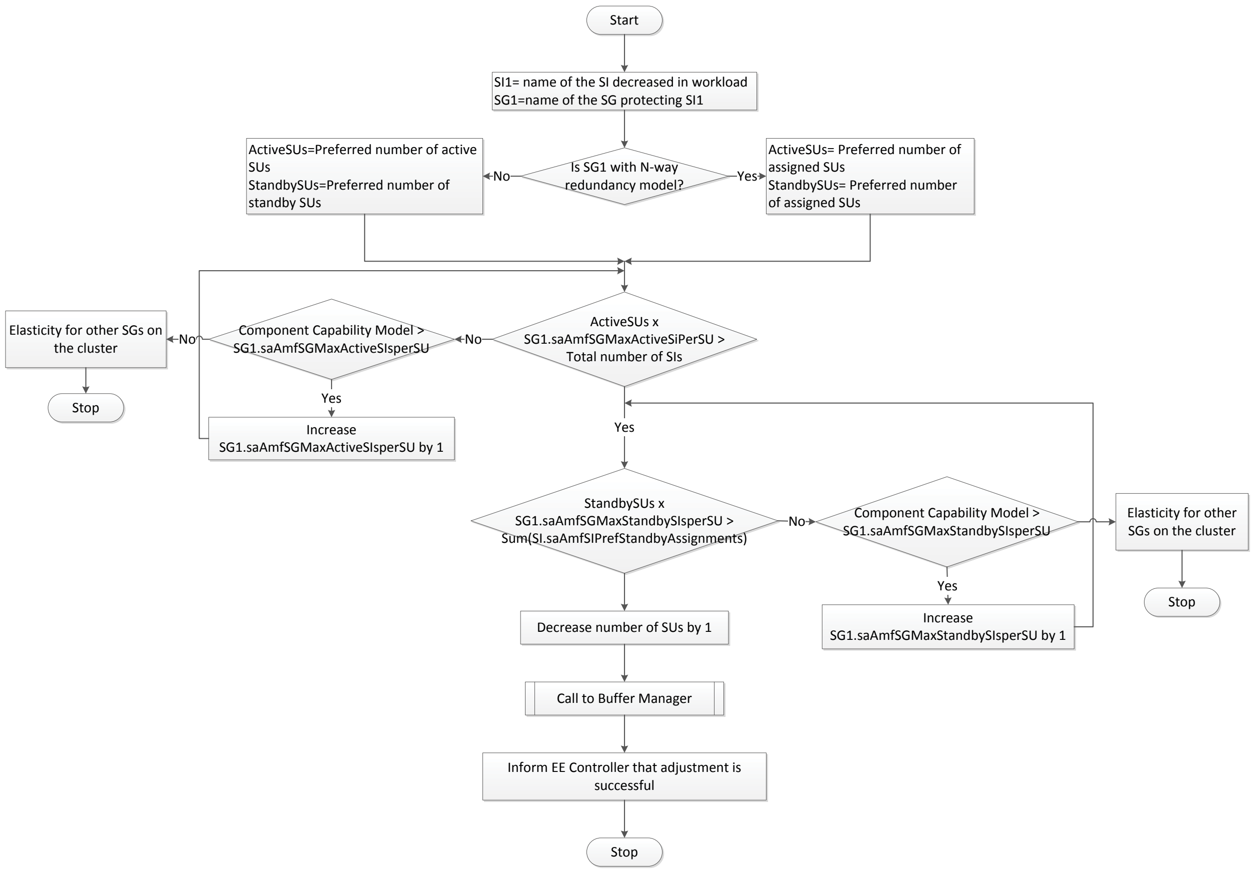

Start
SI1= name of the SI decreased in workload
SG1=name of the SG protecting SI1
Is SG1 with N-way redundancy model?
No
Yes
ActiveSUs=Preferred number of active SUs
StandbySUs=Preferred number of standby SUs
ActiveSUs= Preferred number of assigned SUs
StandbySUs= Preferred number of assigned SUs
ActiveSUs x SG1.saAmfSGMaxActiveSiPerSU > Total number of SIs
Component Capability Model > SG1.saAmfSGMaxActiveSIsperSU
Elasticity for other SGs on the cluster
Stop
Increase SG1.saAmfSGMaxActiveSIsperSU by 1
StandbySUs x SG1.saAmfSGMaxStandbySIsperSU > Sum(SI.saAmfSIPrefStandbyAssignments)
Component Capability Model > SG1.saAmfSGMaxStandbySIsperSU
Increase SG1.saAmfSGMaxStandbySIsperSU by 1
Elasticity for other SGs on the cluster
Decrease number of SUs by 1
Call to Buffer Manager
Inform EE Controller that adjustment is successful
Stop

Figure 29 - Flowchart: Re-grouping the SIs on Less SUs (N+M & N-way Redundancy Models)

- **Prioritizing the nodes that serve other SIs**

  The EE's RM Adjustor uses the steps defined in this algorithm to handle workload decreases of SI protected by the 2N or No-Redundancy Redundancy Models (see Figure 30).

  1. The EE's RM Adjustor initializes 'SI1' with the name of the SI whose workload has decreased, 'SU1' with the name of the SU currently assigned active for the SI1 and 'SG1' with the name of the SG protecting this SI1.
  2. The RM Adjustor finds the name of node hosting the SU1 and initializes 'Node1'. It then searches for other SUs hosted on Node1 and finds out if they are handling any assignments. If any of the SUs are handling active assignments, it reports to the Elasticity Controller for cluster level adjustments. If no SUs are hosted on Node1 that

handle any assignments other than SU1 the RM Adjustor must find other in-service SU of SG1 i.e. on a more loaded node then Node1.

3. It finds all the spare in-service SUs of SG1 and initializes an array ‘node1’ with the names of nodes hosting them.
4. For each node in the ‘node1’:
   a. The RM Adjustor searches for SUs hosted on the node other than the SUs of SG1 and finds out if any of these SUs are handling any assignments. If the RM Adjustor finds any such node it goes to Step 5 or else it informs the EE Controller for elasticity action at the cluster level.
5. If there is a node whose hosted SUs are serving SI, it creates a CCB that swaps the rank of the in-service SU of SG1 with the rank of SU1 and reports to the EE Controller that the adjustment is successful.

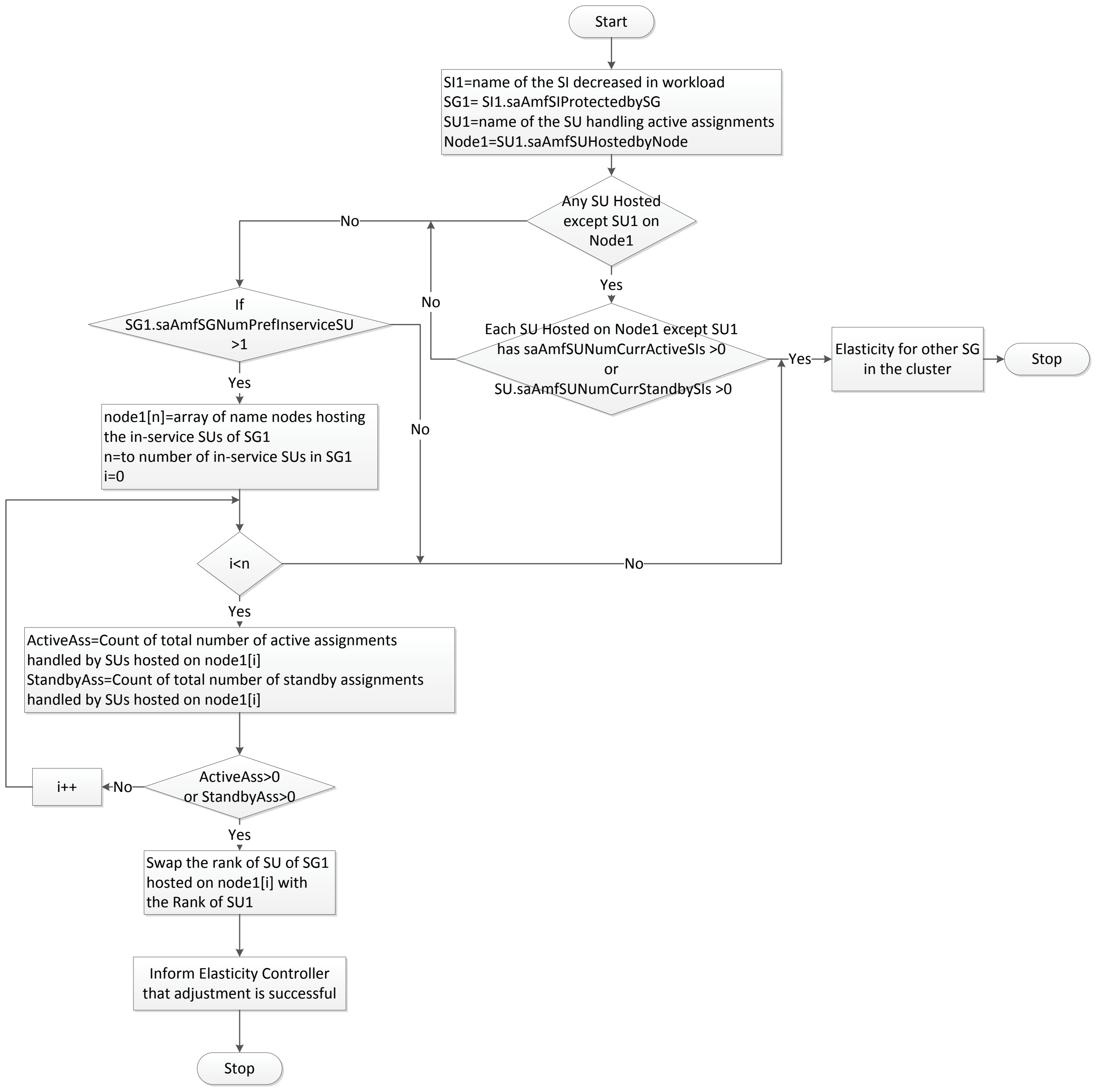

Start
SI1=name of the SI decreased in workload
SG1= SI1.saAmfSIProtectedbySG
SU1=name of the SU handling active assignments
Node1=SU1.saAmfSUHostedbyNode
Any SU Hosted except SU1 on Node1
No
Yes
If SG1.saAmfSGNumPrefInserviceSU >1
No
Each SU Hosted on Node1 except SU1 has saAmfSUNumCurrActiveSIs >0 or SU.saAmfSUNumCurrStandbySIs >0
Yes
Elasticity for other SG in the cluster
Stop
Yes
node1[n]=array of name nodes hosting the in-service SUs of SG1
n=to number of in-service SUs in SG1
i=0
No
i<n
No
Yes
ActiveAss=Count of total number of active assignments handled by SUs hosted on node1[i]
StandbyAss=Count of total number of standby assignments handled by SUs hosted on node1[i]
i++
No
ActiveAss>0 or StandbyAss>0
Yes
Swap the rank of SU of SG1 hosted on node1[i] with the Rank of SU1
Inform Elasticity Controller that adjustment is successful
Stop

Figure 30 - Flowchart: Prioritizing Nodes that Serve other SIs (2N & No Redundancy Models)

4.4.3 Buffer Management algorithms

For the redundancy models where the assignments can be distributed over multiple SUs, changes in the workload are often handled by changing the number of SUs used for the distribution. Bringing into service new SUs requires some time because new nodes may need to be added, the new nodes need the software to be installed and the instantiation of the software may take time. We implement the following algorithm to maintain the ‘in-service-SU-buffer’ and the ‘un-instantiated-SU-buffer’.

- **Reservation of resources**

  When the RM Adjustor increases the number of SUs used for an SI assignment that is reflected by different attributes depending on the redundancy model, it invokes the Buffer Manager to adjust the number of SUs of the SG if possible. The Buffer Manager follows the steps defined in this algorithm to manage the buffers (see Figure 31).

  1. The Buffer Manager initializes ‘SG1’ with the name of the SG to be adjusted and initializes ‘No_Assigned’ with the sum of the preferred number of active SUs and the preferred number of standby SUs if SG1 is of a N+M redundancy model or else ‘No_Assigned’ is initialized with the preferred number of the assigned SUs in SG1.
  2. It initializes ‘Diff1’ by the difference between the value of number of in-service SUs of SG1 and value of No_Assigned.
  3. If Diff1 is greater than or equal to the in-service-SU-buffer, this means that there are enough in- service SUs then it goes to Step 4 or else it follows Step 5.
  4. It initializes ‘Diff2’ by the difference between the number of configured SUs and the number of in-service SUs of SG1. If Diff2 is greater than or equal to the un-instantiated SU-buffer, this means that there are enough reserved resources and no adjustments are needed. If Diff2 is less than the un-instantiated-SU-buffer it follows Step 6.
  5. The Buffer Manager increments the number of in-service SUs if there are spare instantiated SUs in SG1 and goes to Step 3 or else it informs the RM Adjustor to request the EE Controller to indicate the system administrators or the Cloud management the need to configure nodes.

6. The Buffer Manager checks to see if there are spare nodes in the node group of SG1 to configure additional SUs. If the number of nodes in the node group of SG1 is greater than the number of configured SUs then additional SUs can be configured therefore the Buffer Manager configures a new SU.
7. If the number of SUs in SG1 is equal to the number of nodes in the node group of SG1 that means any new node would require software installation therefore the Buffer Manager informs the RM Adjustor to report the EE Controller to request the system administrator or cloud manager to configure new nodes.

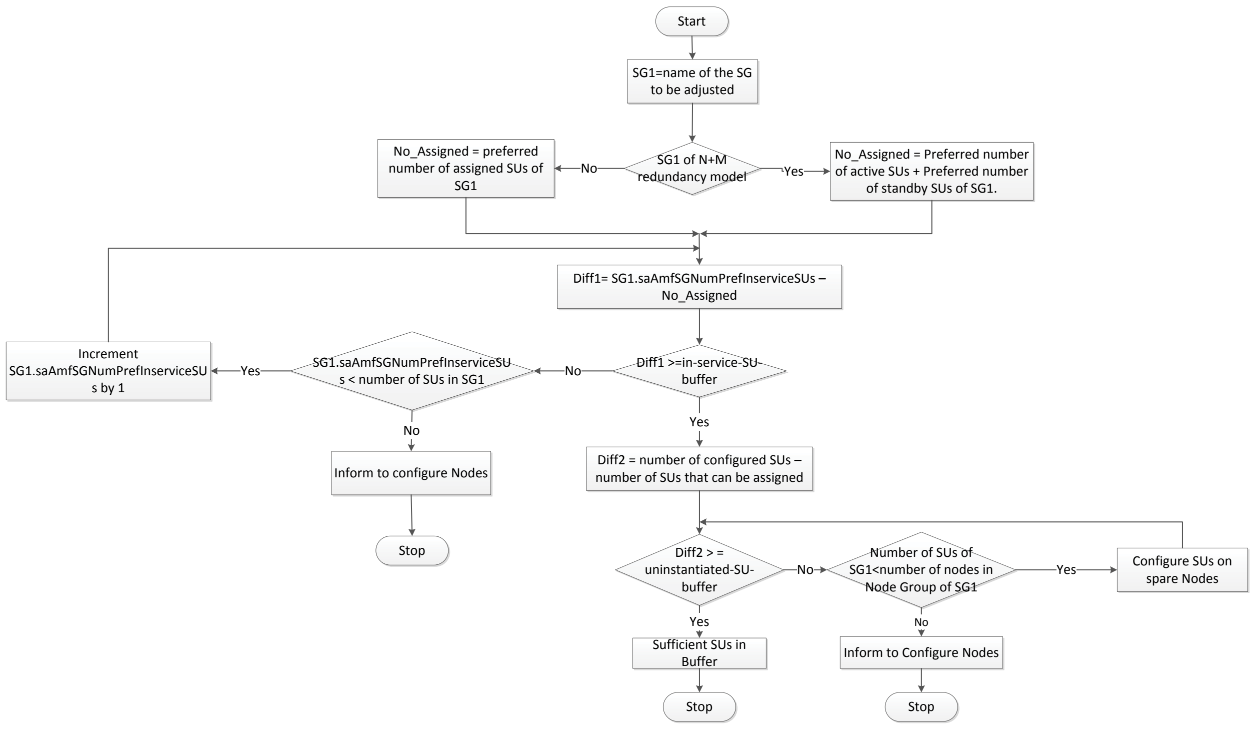

Start
SG1=name of the SG to be adjusted
SG1 of N+M redundancy model
No
Yes
No_Assigned = preferred number of assigned SUs of SG1
No_Assigned = Preferred number of active SUs + Preferred number of standby SUs of SG1.
Diff1= SG1.saAmfSGNumPrefInserviceSUs – No_Assigned
Diff1 >=in-service-SU-buffer
SG1.saAmfSGNumPrefInserviceSUs < number of SUs in SG1
Increment SG1.saAmfSGNumPrefInserviceSUs by 1
Inform to configure Nodes
Stop
Diff2 = number of configured SUs – number of SUs that can be assigned
Diff2 > = uninstantiated-SU-buffer
Number of SUs of SG1<number of nodes in Node Group of SG1
Configure SUs on spare Nodes
Sufficient SUs in Buffer
Inform to Configure Nodes
Stop
Stop

Figure 31 - Flowchart: Buffer Manager (Reservation of Resources)

- **Freeing Reserved Resources**

When the RM Adjustor decreases the number of SUs used for an assignment, it invokes the Buffer Manager to release resources in excess if possible. Note that since un-instantiated SUs do not use resources, the ‘un-instantiated-SU-buffer’ is not adjusted (See Figure 32).

1. The Buffer Manager initializes ‘SG1’ with the name of the SG to be adjusted.

2. If SG1 is of an N+M redundancy model, it initializes ‘Diff’ by the difference between the number of in-service SUs of SG1 and the sum of the preferred number of active and standby SUs of SG1. If SG1 is not an N+M redundancy model then it initializes ‘Diff’ by calculating the difference between number of in-service SUs and the number of preferred assigned SUs of SG1.
3. The Buffer Manager compares if the value of Diff is greater than in-service-SU-buffer. If yes, it decrements the number of in-service SUs of the SG1 by one and returns to Step 2.
4. The Buffer Manager reports to the RM Adjustor that there are enough SUs of SG1 in the buffer when the value of Diff is not greater than the in-service-SU-buffer.

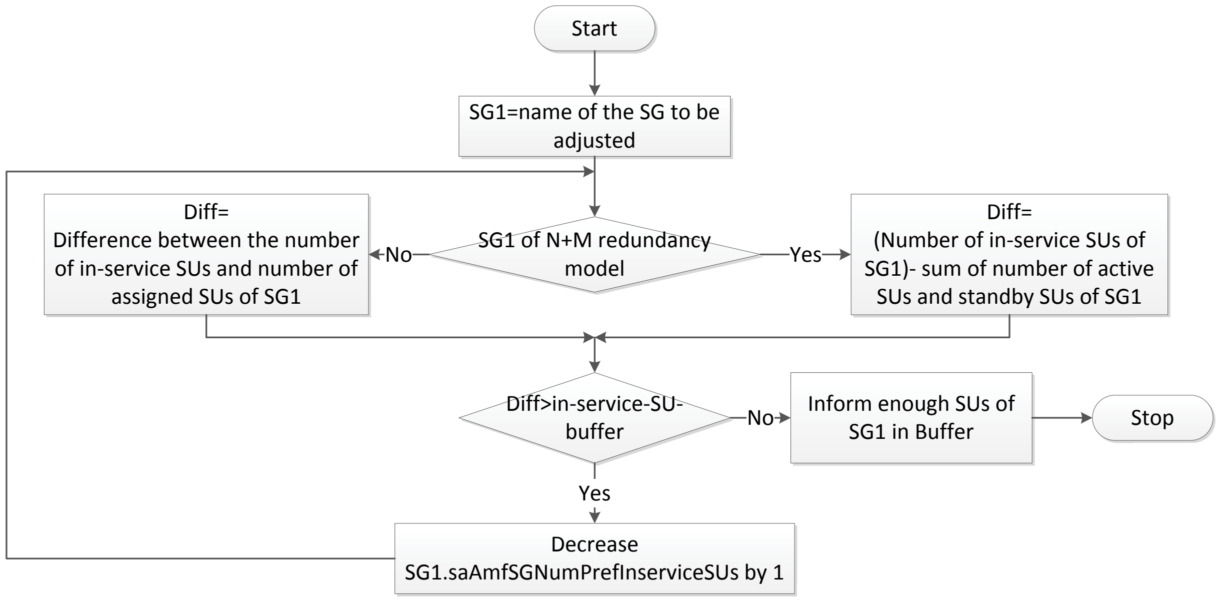

Start
SG1=name of the SG to be adjusted
Diff= Difference between the number of in-service SUs and number of assigned SUs of SG1
No
SG1 of N+M redundancy model
Yes
Diff= (Number of in-service SUs of SG1)- sum of number of active SUs and standby SUs of SG1
Diff>in-service-SU-buffer
No
Inform enough SUs of SG1 in Buffer
Stop
Yes
Decrease SG1.saAmfSGNumPrefInserviceSUs by 1

Figure 32 - Flowchart: Buffer Manager (Freeing Reserved Resources)

4.5 Summary

In the chapter, we proposed our solution to manage elasticity and HA with the SA Forum middleware. The solution uses the elasticity related configuration attributes and the availability constraints described in Chapter 3. The EE dynamically responds to workload changes according to the strategies discussed in this chapter. It manipulates the AMF configuration attributes that forces AMF to adjust the amount of resources along with managing HA. The illustration of the strategies for manipulation of the AMF configuration attributes to handle workload changes is given in the Appendix.

We have seen in the Related Work section, the cloud controller namely OpenStack [11] and Heat [12] focus on providing both availability and elasticity at the virtual infrastructure level. The HA applications usually run in a cluster and their availability is managed by a middleware through the coordination of redundant resources. In this context, managing elasticity at a virtual infrastructure level will result in contradictions between the cloud controller and the middleware. Our solution manages elasticity within AMF of the SA Forum, which is designed to manage service availability. Thus, we can assume that AMF will maintain the availability of application services in AMF configuration as long as the AMF configuration remains valid with respect to the availability constraints. Our solution adjusts the resources by obeying the availability constraints while manipulating the AMF configuration attributes. Therefore, our solution with AMF manages the elasticity and the availability of the application services.

The EE strategies proposed assume the workload change of a single SI to adjust the resources in AMF configuration. They do not handle multiple simultaneous SI workload changes. The EE strategies can be further developed to handle multiple simultaneous SI workload changes. In the next chapter, we present our prototype tool and experiments.

Chapter 5 - A Prototype of the Elasticity Engine

Based on the EE strategies discussed in Chapter 4, we developed a prototype tool as proof of our concept. The prototype tool is an application developed in ‘C’ [27]. In this chapter, we describe the tool and discuss a case study.

5.1 The EE Prototype Architecture

The monitor(s) detect the workload changes represented by an SI in the AMF configuration and notify the EE. As the workload monitor is still under development by another student in the research group, we provide the workload increase and decrease through a Graphical User Interface (GUI). The AMF configuration is rendered in a GUI of EE prototype. The user clicks on the SI name of the AMF configuration on the GUI of the EE prototype to indicate the SI workload changes. The EE prototype may also get workload change notifications from the IMM service [7] when the SI is added or deleted in the AMF configuration. When the EE prototype receives a notification, of workload change it reads the AMF configuration to access the redundancy model of the SG and configuration attributes. The EE prototype applies a combination of the strategies discussed in Chapter 4 depending on the redundancy model of the SG and the state of the system. The EE prototype writes configuration changes (i.e. CCBs) in the IMM service. This forces AMF to increase or decrease the resources allocated to the impacted SI. The EE prototype may also inform the system administrators or cloud managers to increase the number of nodes in the AMF configuration to speed up further adjustments. Figure 33 shows the architecture of the EE Prototype tool.

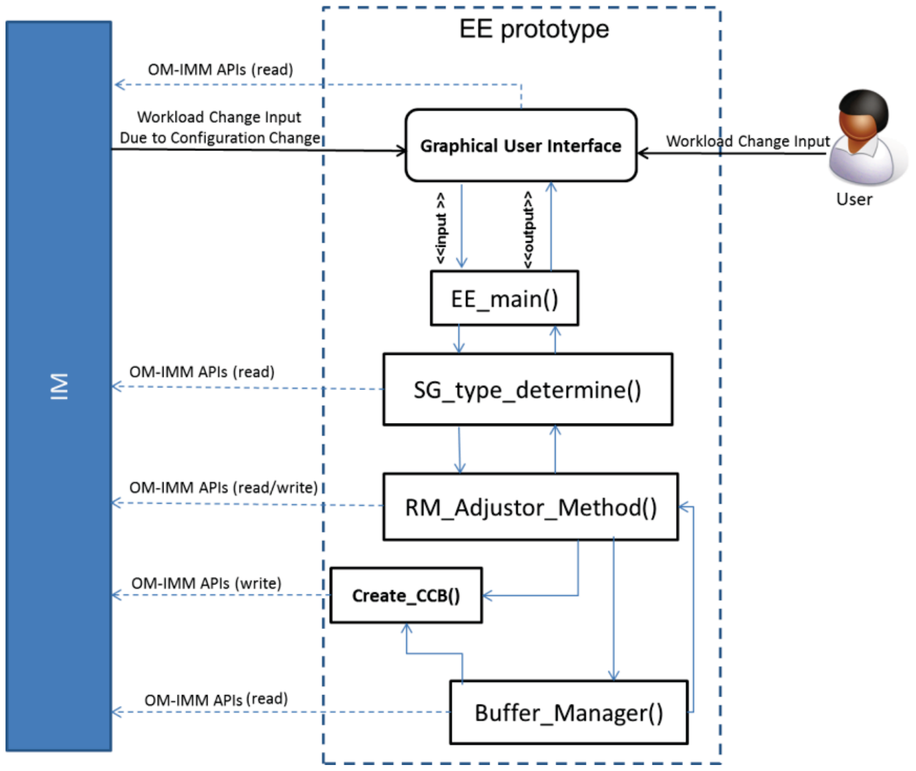
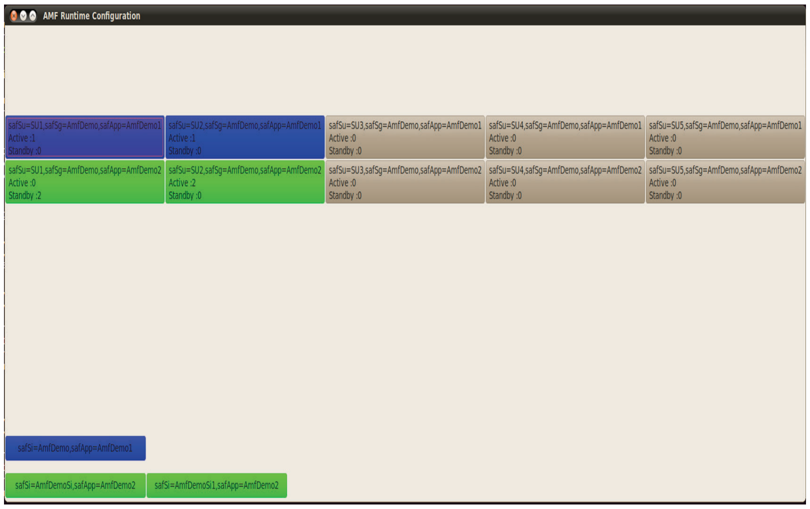


Figure 33 - EE Prototype Tool Architecture

Graphical User Interface: the GUI renders graphical outputs and takes inputs from the user and forwards workload change inputs from the user to the 'EE_main( )'. The GUI uses the IMM APIs [7] to read the AMF configuration in the IM to show the configured SIs and SUs with their names, and indicate the SI-to-SU assignments with identical colors in GUI as shown in Figure 34. The user clicks on the SI name to indicate the workload change. The user right-clicks to indicate workload increase and left-clicks to indicate a workload decrease of the SI. The GUI forwards this input to the 'EE_main( )'. In addition, when a new SI is created or an SI is deleted, the GUI is informed to render the information and the information is forwarded to the 'EE_main( )'. After the EE adjusts the workload changes, the GUI displays the output of the EE action.


AMF Runtime Configuration

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0

safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0

safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0

safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0

safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :2

safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2
Active :2
Standby :0

safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :0

safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :0

safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :0

safSi=AmfDemo,safApp=AmfDemo1

safSi=AmfDemoSi,safApp=AmfDemo2

safSi=AmfDemoSi1,safApp=AmfDemo2

Figure 34 – A GUI for rendering an AMF configuration

EE_main( ):the ‘EE_main( )’ determines what type of workload change occurs. It is a ‘Single-SI’ type workload change if the input is from the user and it is a ‘Multiple-SI’ type workload change if the input is from the IMM service. The ‘EE_main( )’ then calls the ‘SG_type_determine( )’ and passes the name of the impacted SI, elasticity action and workload change type as parameters. The ‘EE_main( )’ also forwards the output of the EE action to the GUI after receiving a reply from the ‘SG_type_determine( )’ call.

SG_type_determine( ):upon receiving a call with the parameters ‘SG_type_determine( )’ uses OM-IMM APIs [7] to read the name of the SG that is protecting the impacted SI and it’s redundancy model type. The ‘SG_type_determine( )’ decides which ‘RM_Adjustor_Method( )’ to call depending on the redundancy model type of SG, the elasticity action and the workload change type. After receiving the ‘RM_Adjustor_Method( )’ reply, the ‘SG_type_determine( )’ will carry out one or more of the following actions:

- ✓ Cluster level adjustment: it will determine other similar types of SGs in the cluster to call the ‘RM_Adjustor_Method( )’ for them.
- ✓ Elasticity action Successful: if the EE adjustment was successful it indicates the ‘EE_main( )’ to inform GUI to display “Elasticity Action is Successful”.

- ✓ Configure nodes in the cluster: the ‘SG_type_determine( )’ indicates the ‘EE_main ( )’ to inform GUI to display “Configure Nodes in Cluster” to inform system management or cloud management.

RM_Adjustor_Method( ):each of the ‘RM_Adjustor_Method( )’actually implements the EE algorithms defined in Section 4.4 of the previous chapter. The ‘RM_Adjustor_Method( )’ reads the configuration attribute values of the SG protecting the impacted SI and the execution state of the system from the IM (using OM-IMM APIs) to determine the CCBs (i.e. configuration changes). Subsequently, it calls ‘Create_CCB( )’ and passes necessary information to write CCBs to IMM. This method also calls ‘Buffer_Manager( )’ to manage the number of SUs in SG according to the ‘in-service-SUs-buffer’ and ‘un-instantiated-SU-buffer’.

Create_CCB( ):the ‘Create_CCB( )’ function uses the OM-IMM APIs [7] to write the CCBs in IMM. After the CCB implementation, it returns to the calling function.

Buffer_Manager( ):the ‘Buffer_Manager( )’ implements the algorithms defined in Section 4.4 of Chapter 4. The ‘Buffer_Manager( )’ reads the IM using the IMM APIs [7] to check the number of SUs in the SG. If the number of SUs in the SG are not enough according to the ‘in-service-SU-buffer’ and un-instantiated-SU-buffer’, it calculates CCBs and calls the ‘Create_CCB( )’ to write the CCBs in IMM.

5.2 Experiment Test-bed Set-up

For experimentation we use OpenSAF 4.3 [6] middleware as it is an open source middleware that implements the SA Forum [8] specifications. The EE prototype tool is deployed on a VM in the VMware player [28] on a Host with Intel® Core™ i7 -2600 CPU 340 GHz, RAM 16GB and 64-bit Windows operating system [29]. The VM Player is free for personal use and also allows us to create up to 17 virtual processors, 8TB virtual disks and 64 GB memory per

VM [28] which is enough for the experimentation. We create five VMs with the Ubuntu 10.04 operating system [30] and install OpenSAF 4.3 [6] on each of them.

For the communication between cluster nodes we use Transparent Inter-Process Communication protocol (TIPC) [31]. The VMs in the cluster are isolated from any external network to allow only internal communication between the VMs through TIPC. Since the five VMs in the cluster closely communicate with each other we can run the EE prototype tool on any one of the VMs.

5.3 A Case Study

In this section we discuss a case study used, to experiment with the EE prototype tool. The case study is a system consisting of two applications. The system configuration is shown in Figure 35. The application '*safApp=AmfDemo1*' consists of one SI '*safSi=AmfDemo,safApp=AmfDemo1*' protected by SG '*safSg=AmfDemo,safApp=AmfDemo1'* with a N-way-Active redundancy model. The application '*safApp=AmfDemo2*' consists of two SIs namely '*safSi=AmfDemoSi,safApp=AmfDemo2*' and '*safSi=AmfDemoSi1,safApp=AmfDemo2*' protected by SG '*safSg=AmfDemo,safApp=AmfDemo2'* with a N+M redundancy model. The two SGs consist of five SUs configured on separate AMF nodes. Each AMF node corresponds to a VM in the VM player.

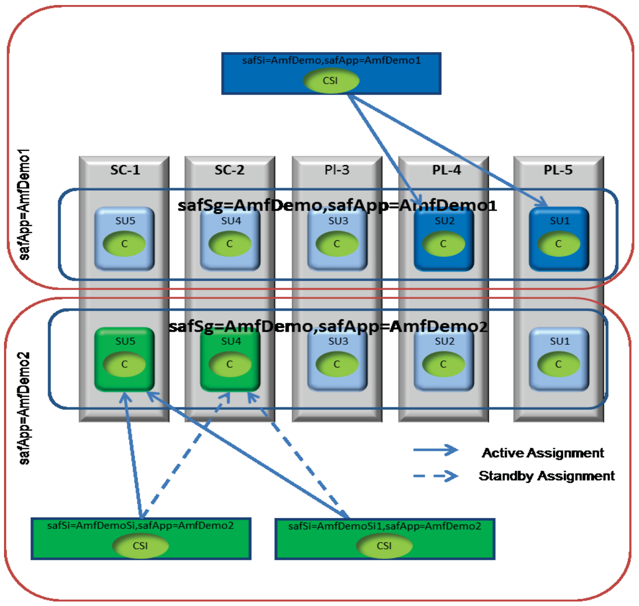

safSi=AmfDemo,safApp=AmfDemo1
CSI
safApp=AmfDemo1
SC-1
SC-2
Pl-3
PL-4
PL-5
safSg=AmfDemo,safApp=AmfDemo1
SU5
SU4
SU3
SU2
SU1
C
safApp=AmfDemo2
safSg=AmfDemo,safApp=AmfDemo2
Active Assignment
Standby Assignment
safSi=AmfDemoSi,safApp=AmfDemo2
safSi=AmfDemoSi1,safApp=AmfDemo2

Figure 35 – System Configuration for the Case Study

5.4 Experiments with the EE Prototype Tool

In this section we test the behavior of the EE when the workload of the applications represented by the SI increases or decreases.

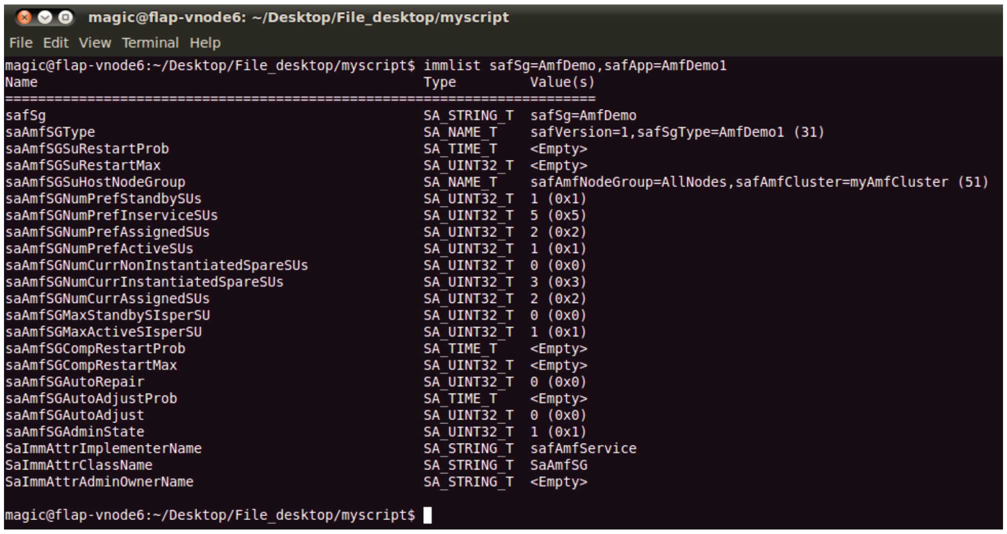
5.4.1 Workload increase

In this subsection we test the EE prototype for a workload increase with two test cases: when the workload of the SI protected by an SG with an N-way-Active redundancy model increases, and when the workload of the SI protected by an SG with an N+M redundancy model increases.

❖ **Test case: Workload increase for the SG with an N-way-Active redundancy model**

The prototype tool reads the initial system configuration and displays it on the GUI as shown in Figure 34. It displays the SUs of the two SGs and the SIs representing application's workloads. The SIs and the assigned SUs of *'safApp=AmfDemo1'* application are in blue. The SIs and the assigned SUs of the *'safApp=AmfDemo2'* application are in green. The GUI also displays the current number of active assignments and standby assignments each SU handles (see Figure 34).

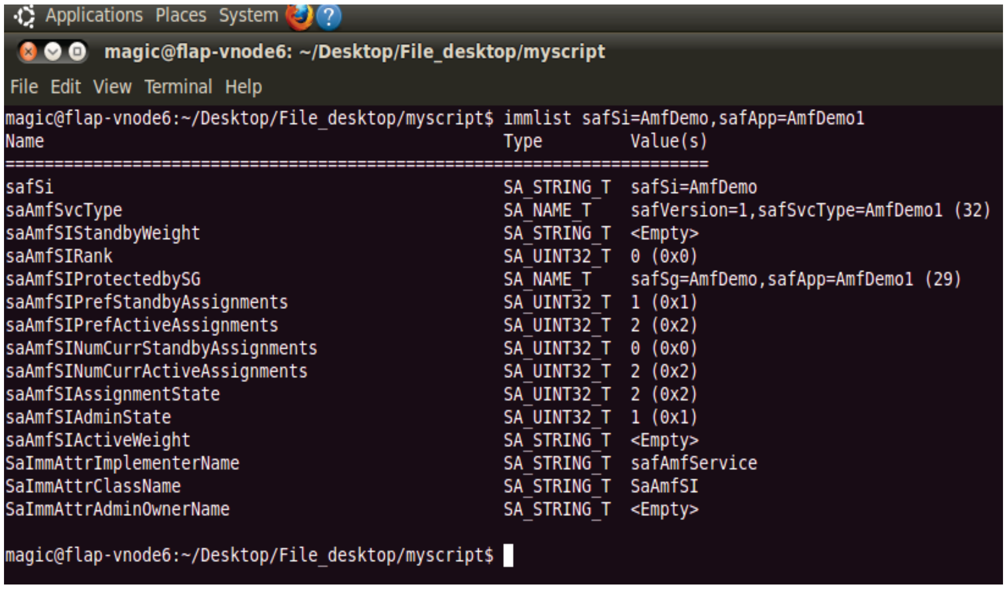
Figure 36 gives '*safSg=AmfDemo,safApp=AmfDemo1*' SG object's configuration attribute values and Figure 37 gives '*safSi=AmfDemo,safApp=AmfDemo1*' SI object's configuration attribute values. We run 'immlist' command in OpenSAF [8] [6] to list these attribute values.


magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo1
Name                                               Type         Value(s)
========================================================================
safSg                                              SA_STRING_T  safSg=AmfDemo
saAmfSGType                                        SA_NAME_T    safVersion=1,safSgType=AmfDemo1 (31)
saAmfSGSuRestartProb                               SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                             SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                           SA_UINT32_T  1 (0x1)
saAmfSGNumPrefInserviceSUs                         SA_UINT32_T  5 (0x5)
saAmfSGNumPrefAssignedSUs                          SA_UINT32_T  2 (0x2)
saAmfSGNumPrefActiveSUs                            SA_UINT32_T  1 (0x1)
saAmfSGNumCurrNonInstantiatedSpareSUs              SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                 SA_UINT32_T  3 (0x3)
saAmfSGNumCurrAssignedSUs                          SA_UINT32_T  2 (0x2)
saAmfSGMaxStandbySIsperSU                          SA_UINT32_T  0 (0x0)
saAmfSGMaxActiveSIsperSU                           SA_UINT32_T  1 (0x1)
saAmfSGCompRestartProb                             SA_TIME_T    <Empty>
saAmfSGCompRestartMax                              SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                  SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                              SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                  SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                  SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$ 
```

Figure 36 - 'safSg=AmfDemo,safApp=AmfDemo1' SG object before the EE action

Figure 36 shows that '*safSg=AmfDemo,safApp=AmfDemo1*' SG consists of five in-service SUs (indicated by '*saAmfSGNumPrefInserviceSUs*'), two assigned SUs (indicated by '*saAmfSGNumPrefAssignedSUs*') and maximum active SIs per SU is one (indicated by '*saAmfSGMaxActiveSIsperSU*'). Figure 37 shows that '*safSi=AmfDemo,safApp=AmfDemo1*' SI is assigned to two SUs (indicated by '*saAmfSIPrefActiveAssignments*').

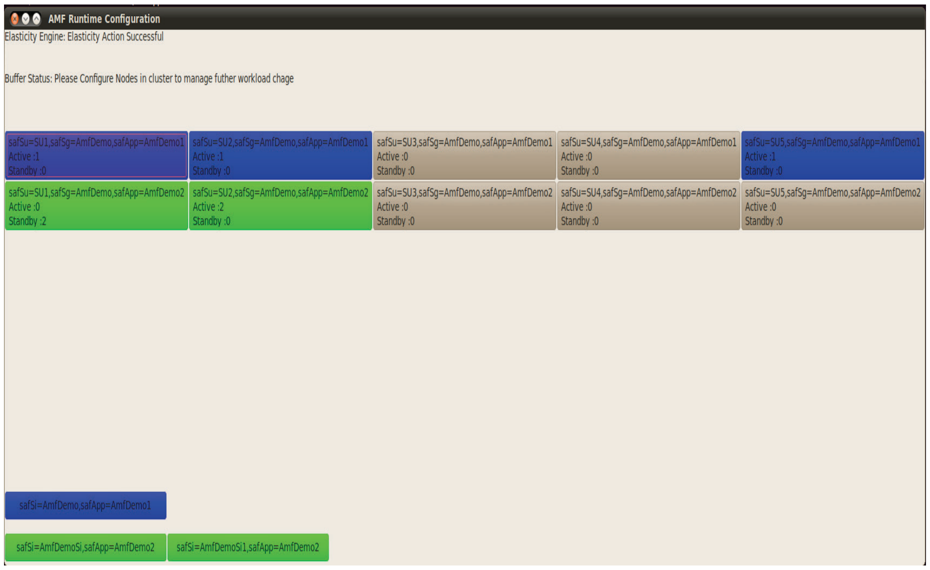

Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSi=AmfDemo,safApp=AmfDemo1
Name                                               Type         Value(s)
========================================================================
safSi                                              SA_STRING_T  safSi=AmfDemo
saAmfSvcType                                       SA_NAME_T    safVersion=1,safSvcType=AmfDemo1 (32)
saAmfSIStandbyWeight                               SA_STRING_T  <Empty>
saAmfSIRank                                        SA_UINT32_T  0 (0x0)
saAmfSIProtectedbySG                               SA_NAME_T    safSg=AmfDemo,safApp=AmfDemo1 (29)
saAmfSIPrefStandbyAssignments                      SA_UINT32_T  1 (0x1)
saAmfSIPrefActiveAssignments                       SA_UINT32_T  2 (0x2)
saAmfSINumCurrStandbyAssignments                   SA_UINT32_T  0 (0x0)
saAmfSINumCurrActiveAssignments                    SA_UINT32_T  2 (0x2)
saAmfSIAssignmentState                             SA_UINT32_T  2 (0x2)
saAmfSIAdminState                                  SA_UINT32_T  1 (0x1)
saAmfSIActiveWeight                                SA_STRING_T  <Empty>
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSI
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 37 - 'safSi=AmfDemo,safApp=AmfDemo1' SI object before the EE action

To test the EE's behavior for workload increases in the SG with an N-way-Active redundancy model, we right-click on '*safSi=AmfDemo,safApp=AmfDemo1'* SI on the GUI shown in Figure 34. The right-click event of the GUI calls the 'EE_main( )' and passes the SI name and the workload increase as parameters.

The 'EE_main( )' determine this as a workload increase with the workload change of type Single-SI. The 'SG_type_determine( )' uses IMM APIs [7] to read the IM. It determines that the SI is protected by SG with an N-way-Active redundancy model and calls the specific 'RM_Adjustor_Method( )' to adjust resources. This 'RM_Adjustor_Method( )' uses the 'Spreading the SI workload' strategy explained in Chapter 4. Before increasing capacity it checks if the SI's *'saAmfSIPrefActiveAssignments'* attribute value is less than the SG's '*saAmfSGNumPrefAssignedSUs'* attribute value and if it is not less, the 'RM_Adjustor_Method( )'checks if it can increase the number of assigned SUs. The number of in-service SUs for the SG is five (see Figure 36); hence it calls 'Create_CCB( )' to write a CCB in IMM to increase the assigned SUs to three. The 'RM_Adjustor_Method( )' then gives a call to the 'Buffer_Manager( )' because the number of assigned SUs of the SG has changed. The ‘Buffer_Manager( )’ reads the IM and determines that the number of in-service SUs are not enough and informs the controller to increase the ‘number of nodes for future workload increases’ and returns to the ‘RM_Adjustor_Method( )’. Subsequently, the ‘RM_Adjustor_Method( )’ reads that the active assignments of the SI are two (see Figure 37) and the assigned SUs are three (see Figure 39) and checks to see if the SG has capacity before it calls the ‘Create_CCB( )’ to write a CCB in IMM to increase the SI active assignments to three in the IM. It checks by calculating whether the active capacity *(i.e. ‘saAmfSGMaxActiveSIsperSU* x *saAmfSGNumPrefAssignedSUs’*) is greater than the sum of the active SI assignments. Thus after the CCB implementation the system configuration has capacity to handle three active assignments of the SI, hence the ‘RM_Adjustor_Method( )’ calls the ‘Create_CCB( )’ to write a CCB in IMM to increase the SI assignment to three. This CCB forces AMF to assign the SI active assignment to the unassigned SU. The ‘RM_Adjustor_Method( )’ returns ‘Elasticity action is successful’ to the calling function. Figure 38 gives the output of the EE when the SI is clicked to indicate a workload increase. Figure 39 and Figure 40 show the SG and SI object’s attributes after the EE action.


AMF Runtime Configuration

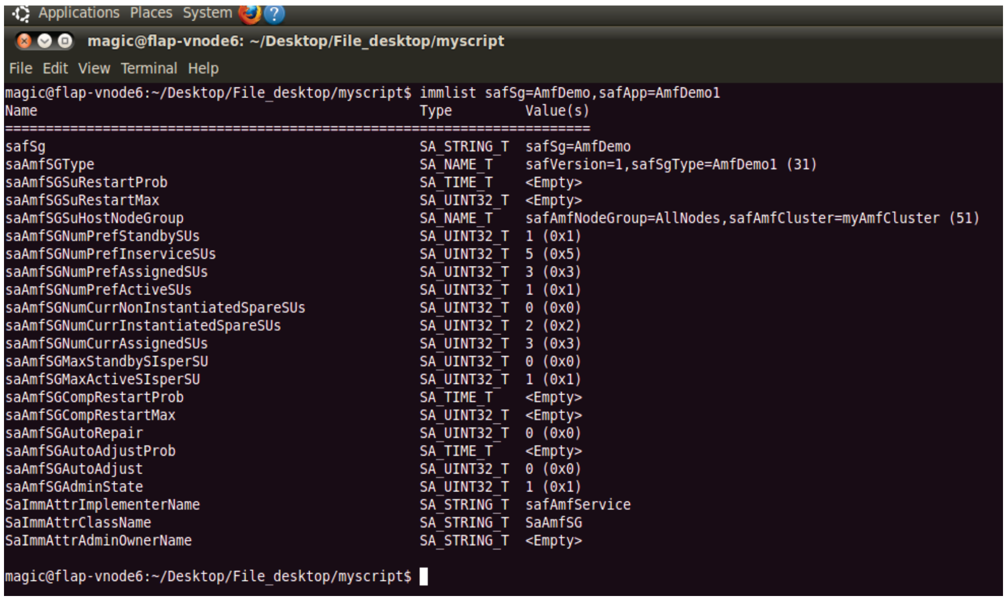
Elasticity Engine: Elasticity Action Successful

Buffer Status: Please Configure Nodes in cluster to manage futher workload chage

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0	safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0	safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1 Active :0 Standby :0	safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1 Active :0 Standby :0	safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :2	safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2 Active :2 Standby :0	safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :0	safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :0	safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :0

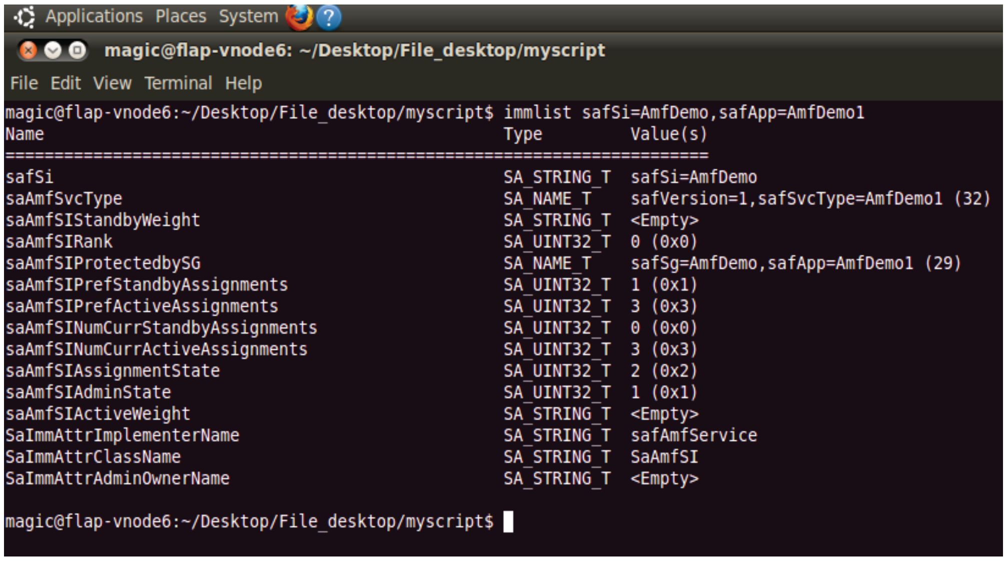
safSi=AmfDemo,safApp=AmfDemo1
safSi=AmfDemoSi,safApp=AmfDemo2
safSi=AmfDemoSi1,safApp=AmfDemo2

Figure 38 - System Configuration after EE and AMF actions for the workload increase in a SG with N-way-Active redundancy model


Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo1
Name                                                Type         Value(s)
========================================================================
safSg                                               SA_STRING_T  safSg=AmfDemo
saAmfSGType                                         SA_NAME_T    safVersion=1,safSgType=AmfDemo1 (31)
saAmfSGSuRestartProb                                SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                 SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                              SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                            SA_UINT32_T  1 (0x1)
saAmfSGNumPrefInserviceSUs                          SA_UINT32_T  5 (0x5)
saAmfSGNumPrefAssignedSUs                           SA_UINT32_T  3 (0x3)
saAmfSGNumPrefActiveSUs                             SA_UINT32_T  1 (0x1)
saAmfSGNumCurrNonInstantiatedSpareSUs               SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                  SA_UINT32_T  2 (0x2)
saAmfSGNumCurrAssignedSUs                           SA_UINT32_T  3 (0x3)
saAmfSGMaxStandbySIsperSU                           SA_UINT32_T  0 (0x0)
saAmfSGMaxActiveSIsperSU                            SA_UINT32_T  1 (0x1)
saAmfSGCompRestartProb                              SA_TIME_T    <Empty>
saAmfSGCompRestartMax                               SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                   SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                               SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                   SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                   SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                            SA_STRING_T  safAmfService
SaImmAttrClassName                                  SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                             SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 39 - 'safSg=AmfDemo,safApp=AmfDemo1' SG object after the EE action


Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

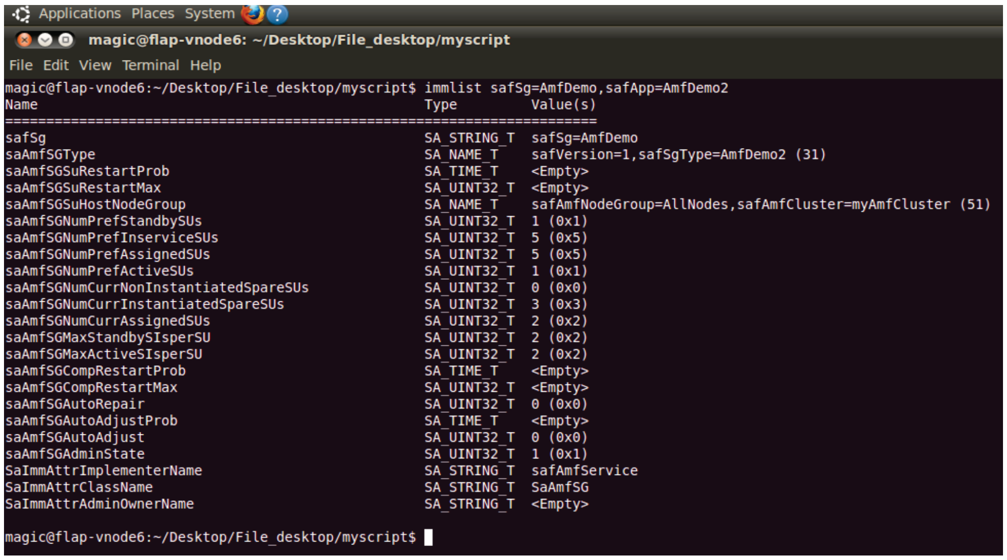
```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSi=AmfDemo,safApp=AmfDemo1
Name                                                Type         Value(s)
========================================================================
safSi                                               SA_STRING_T  safSi=AmfDemo
saAmfSvcType                                        SA_NAME_T    safVersion=1,safSvcType=AmfDemo1 (32)
saAmfSIStandbyWeight                                SA_STRING_T  <Empty>
saAmfSIRank                                         SA_UINT32_T  0 (0x0)
saAmfSIProtectedbySG                                SA_NAME_T    safSg=AmfDemo,safApp=AmfDemo1 (29)
saAmfSIPrefStandbyAssignments                       SA_UINT32_T  1 (0x1)
saAmfSIPrefActiveAssignments                        SA_UINT32_T  3 (0x3)
saAmfSINumCurrStandbyAssignments                    SA_UINT32_T  0 (0x0)
saAmfSINumCurrActiveAssignments                     SA_UINT32_T  3 (0x3)
saAmfSIAssignmentState                              SA_UINT32_T  2 (0x2)
saAmfSIAdminState                                   SA_UINT32_T  1 (0x1)
saAmfSIActiveWeight                                 SA_STRING_T  <Empty>
SaImmAttrImplementerName                            SA_STRING_T  safAmfService
SaImmAttrClassName                                  SA_STRING_T  SaAmfSI
SaImmAttrAdminOwnerName                             SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 40 - 'safSi=AmfDemo,safApp=AmfDemo1' SI object after the EE action

❖ **Test case: Workload increase for the SG with an N+M redundancy model**

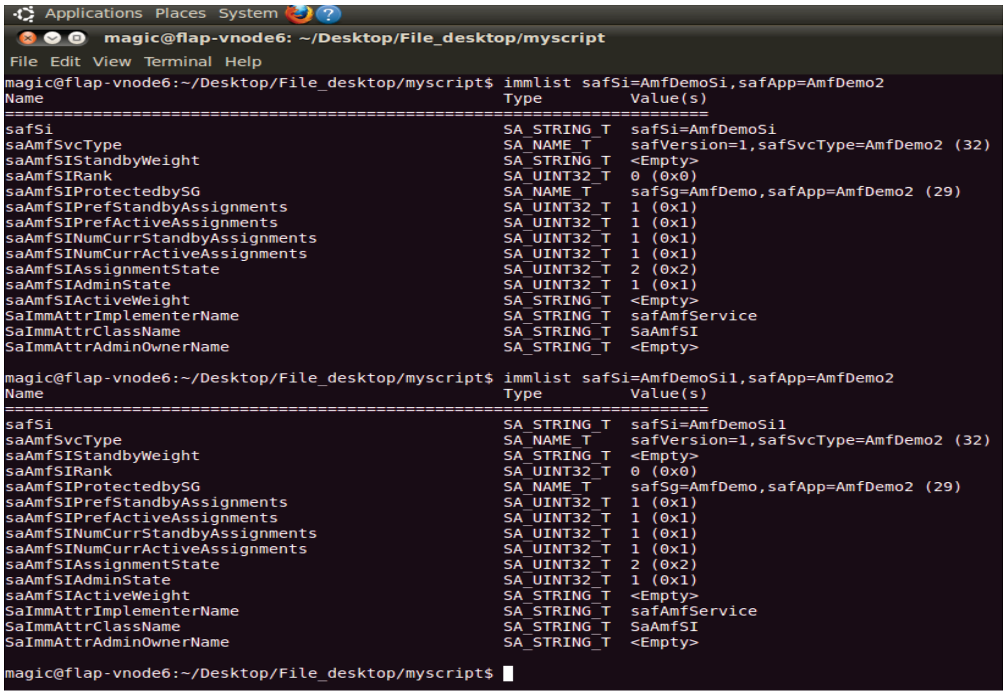
To test this case we use the system configuration results of the previous test case. Figure 38 shows the system configuration to test the behavior of the EE when the workload of SI protected by SG using N+M redundancy model increases.

The list of configuration attribute values of the *'safSg=AmfDemo,safApp=AmfDemo2'* SG object with the N+M redundancy model is shown in Figure 41. The SG has one active SU (indicated by the *'saAmfSGNumPrefActiveSUs'* attribute) and one standby SU (indicated by the *'saAmfSGNumPrefStandbySUs'* attribute). Its maximum active SIs per SU and maximum standby SIs per SU is two (indicated by *'saAmfSGMaxActiveSIsperSU'* and *'saAmfSGMaxStandbySIsperSU'*). Figure 42 shows the attributes of the two SIs protected by *'safSg=AmfDemo,safApp=AmfDemo2'* SG.


Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo2
Name                                               Type         Value(s)
========================================================================
safSg                                              SA_STRING_T  safSg=AmfDemo
saAmfSGType                                        SA_NAME_T    safVersion=1,safSgType=AmfDemo2 (31)
saAmfSGSuRestartProb                               SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                             SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                           SA_UINT32_T  1 (0x1)
saAmfSGNumPrefInserviceSUs                         SA_UINT32_T  5 (0x5)
saAmfSGNumPrefAssignedSUs                          SA_UINT32_T  5 (0x5)
saAmfSGNumPrefActiveSUs                            SA_UINT32_T  1 (0x1)
saAmfSGNumCurrNonInstantiatedSpareSUs              SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                 SA_UINT32_T  3 (0x3)
saAmfSGNumCurrAssignedSUs                          SA_UINT32_T  2 (0x2)
saAmfSGMaxStandbySIsperSU                          SA_UINT32_T  2 (0x2)
saAmfSGMaxActiveSIsperSU                           SA_UINT32_T  2 (0x2)
saAmfSGCompRestartProb                             SA_TIME_T    <Empty>
saAmfSGCompRestartMax                              SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                  SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                              SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                  SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                  SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$ █
```

Figure 41 - 'safSg=AmfDemo,safApp=AmfDemo2' SG object before the EE action


Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

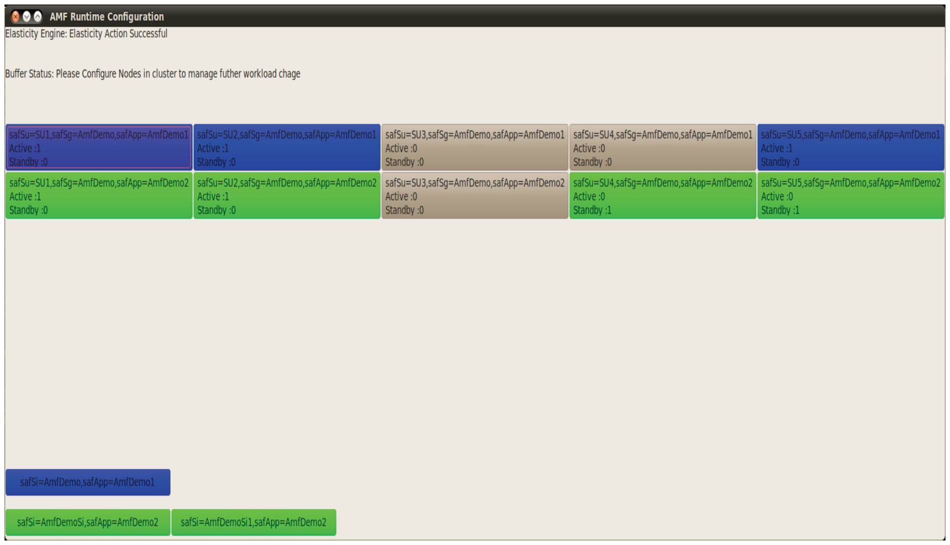
```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSi=AmfDemoSi,safApp=AmfDemo2
Name                                               Type         Value(s)
========================================================================
safSi                                              SA_STRING_T  safSi=AmfDemoSi
saAmfSvcType                                       SA_NAME_T    safVersion=1,safSvcType=AmfDemo2 (32)
saAmfSIStandbyWeight                               SA_STRING_T  <Empty>
saAmfSIRank                                        SA_UINT32_T  0 (0x0)
saAmfSIProtectedbySG                               SA_NAME_T    safSg=AmfDemo,safApp=AmfDemo2 (29)
saAmfSIPrefStandbyAssignments                      SA_UINT32_T  1 (0x1)
saAmfSIPrefActiveAssignments                       SA_UINT32_T  1 (0x1)
saAmfSINumCurrStandbyAssignments                   SA_UINT32_T  1 (0x1)
saAmfSINumCurrActiveAssignments                    SA_UINT32_T  1 (0x1)
saAmfSIAssignmentState                             SA_UINT32_T  2 (0x2)
saAmfSIAdminState                                  SA_UINT32_T  1 (0x1)
saAmfSIActiveWeight                                SA_STRING_T  <Empty>
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSI
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSi=AmfDemoSi1,safApp=AmfDemo2
Name                                               Type         Value(s)
========================================================================
safSi                                              SA_STRING_T  safSi=AmfDemoSi1
saAmfSvcType                                       SA_NAME_T    safVersion=1,safSvcType=AmfDemo2 (32)
saAmfSIStandbyWeight                               SA_STRING_T  <Empty>
saAmfSIRank                                        SA_UINT32_T  0 (0x0)
saAmfSIProtectedbySG                               SA_NAME_T    safSg=AmfDemo,safApp=AmfDemo2 (29)
saAmfSIPrefStandbyAssignments                      SA_UINT32_T  1 (0x1)
saAmfSIPrefActiveAssignments                       SA_UINT32_T  1 (0x1)
saAmfSINumCurrStandbyAssignments                   SA_UINT32_T  1 (0x1)
saAmfSINumCurrActiveAssignments                    SA_UINT32_T  1 (0x1)
saAmfSIAssignmentState                             SA_UINT32_T  2 (0x2)
saAmfSIAdminState                                  SA_UINT32_T  1 (0x1)
saAmfSIActiveWeight                                SA_STRING_T  <Empty>
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSI
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$ █
```

Figure 42 - 'safSi=AmfDemoSi,safApp=AmfDemo2' and 'safSi=AmfDemoSi1,safApp=AmfDemo2' object before the EE action

To test the EE’s behavior for a workload increase for the SG with an N+M redundancy model, we right-click on the name of *‘safSi=AmfDemoSi,safApp=AmfDemo2’* SI on the GUI shown in Figure 38. The right-click event of the GUI calls the ‘EE_main( )’ and passes the SI name and the workload increase as parameters.

The ‘EE_main( )’ determines the workload of the SI is increased and is of the Single-SI type. The ‘SG_type_determine( )’ uses the IMM APIs [7] to read the *‘safSi=AmfDemoSi,safApp=AmfDemo2’* SI attributes in the IM and finds that the *‘safSg=AmfDemo,safApp=AmfDemo2’* SG is protecting this SI (see Figure 42). It determines the redundancy model type of the SG is N+M redundancy model and calls the ‘RM_Adjustor_Method( )’. The ‘RM_Adjustor_Method( )’ follows the strategy of ‘Distributing the SIs over more SUs’ explained in Chapter 4. The ‘RM_Adjustor_Method( )’ checks if any SI assignments will be lost if it decreases the number of active SI assignments each SU of the SG can handle (i.e *‘saAmfSGMaxActiveSIsperSU’*) to distribute the workload to more SIs. In the current system configuration, it calculates the available active capacity excluding the capacity that will be lost after decreasing the SG’s ‘*saAmfSGMaxActiveSIsperSU’* attribute value by multiplying attribute values of *‘saAmfSGMaxActiveSIsperSU-1’* and ‘*saAmfSGNumPrefActiveSUs’* of the SG which gives one (see Figure 41) but the capacity required is two (see Figure 42). Hence, the ‘RM_Adjustor_Method( )’ cannot decrease the SG’s *‘saAmfSGMaxActiveSIsperSU’* attribute value by one. The ‘RM_Adjustor_Method( )’ tries to increase the number of active SUs if there are spare in-service SUs available of the SG. The SG has three spare in-service SUs (see Figure 41) hence the ‘RM_Adjustor_Method( )’ increases the number of ‘*saAmfSGNumPrefActiveSUs’* by one by calling the ‘Create_CCB( )’ and calls the

‘Buffer_Manager( )’. The ‘Buffer_Manager( )’ determines that the number of SUs are not enough hence it returns, ‘Configure Nodes in the cluster for future workload increase’ to the calling method. The ‘RM_Adjustor_Method( )’ again checks if any SI assignments will be lost if it decreases the number of SIs each SU can handle of the SG. The available active capacity will be two after decreasing the attribute ‘*saAmfSGMaxActiveSIsperSU*’ value to one of the SG. Hence, the ‘RM_Adjustor_Method( )’ calls the ‘Create_CCB( )’ to initialize a CCB in IMM to decrease the value of ‘*saAmfSGMaxActiveSIsperSU*’ by one. For the standby assignments of the SI, the ‘RM_Adjustor_Method( )’ checks if any SI assignments will be lost if it decreases the number of standby SI assignments each SU can handle (i.e. *‘saAmfSGMaxStandbySIsperSU’*) of the SG. It calculates the available standby capacity excluding the capacity that will be lost after decreasing the ‘s*aAmfSGMaxStandbySIsperSU’* by multiplying ‘*saAmfSGMaxStandbySIsperSU-1’* and ‘*saAmfSGNumPrefStandbySUs’* attribute values of the SG. For the above example, it is one and the required capacity is two (see Figure 41). Hence, the ‘RM_Adjustor_Method( )’ cannot decrease the ‘*saAmfSGMaxStandbySIsperSU’* by one of the SG. It tries to increase the number of standby SUs, if there are spare in-service SUs available. This SG has two spare in-service SU (see Figure 44) hence the ‘RM_Adjustor_Method( )’ increases the number of *‘saAmfSGNumPrefStandbySUs’* by one of the SG. Then the ‘RM_Adjustor_Method( )’ calls the ‘Create_CCB( )’ to initialize a CCB in IMM to decrease the ‘*saAmfSGMaxStandbySIsperSU’* by one of SG. This forces AMF to distribute the standby SI assignments on more SUs. The ‘RM_Adjustor_Method( )’ compares to find, if the active and standby assignments handled by the SUs have reduced after applying the CCBs. The assignments of the SUs of the SG have reduced as shown in Figure 43, hence it reports that the ‘Elasticity Action is Successful’. Figure 43 gives the output of the EE, when we click the SI to indicate the workload increase. Figure 44 and Figure 45 show the SG object’s attributes after the EE action.



Elasticity Engine: Elasticity Action Successful

Buffer Status: Please Configure Nodes in cluster to manage futher workload chage

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0

safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0

safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0

safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0

safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2
Active :1
Standby :0

safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2
Active :1
Standby :0

safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :0

safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :1

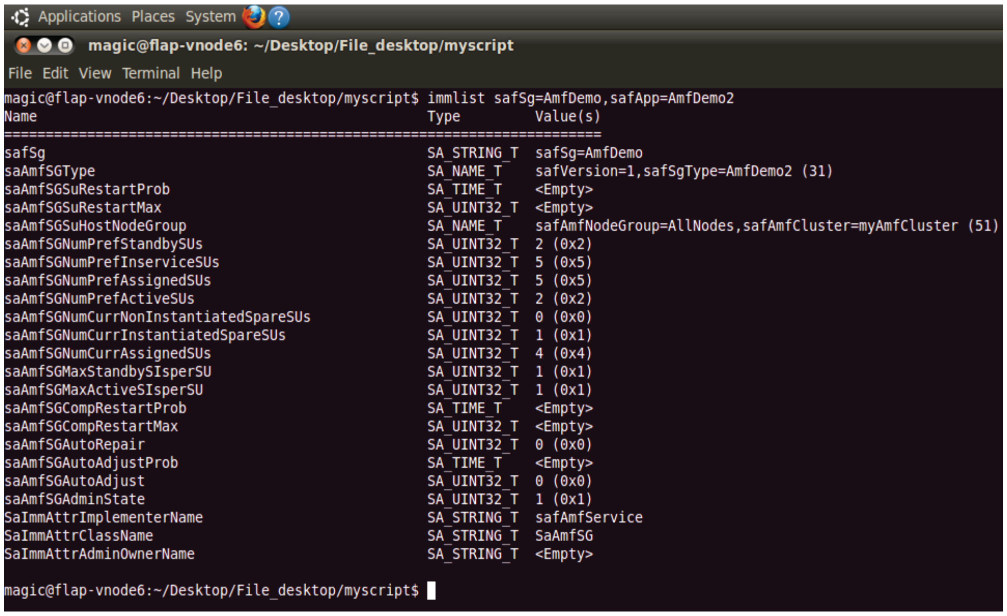
safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :1

safSi=AmfDemo,safApp=AmfDemo1

safSi=AmfDemoSi,safApp=AmfDemo2

safSi=AmfDemoSi1,safApp=AmfDemo2

Figure 43 - System Configuration after EE and AMF actions for workload increase in a SG with N+M redundancy model


Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo2
Name                                                Type         Value(s)
========================================================================
safSg                                               SA_STRING_T  safSg=AmfDemo
saAmfSGType                                         SA_NAME_T    safVersion=1,safSgType=AmfDemo2 (31)
saAmfSGSuRestartProb                                SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                 SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                              SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                            SA_UINT32_T  2 (0x2)
saAmfSGNumPrefInserviceSUs                          SA_UINT32_T  5 (0x5)
saAmfSGNumPrefAssignedSUs                           SA_UINT32_T  5 (0x5)
saAmfSGNumPrefActiveSUs                             SA_UINT32_T  2 (0x2)
saAmfSGNumCurrNonInstantiatedSpareSUs               SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                  SA_UINT32_T  1 (0x1)
saAmfSGNumCurrAssignedSUs                           SA_UINT32_T  4 (0x4)
saAmfSGMaxStandbySIsperSU                           SA_UINT32_T  1 (0x1)
saAmfSGMaxActiveSIsperSU                            SA_UINT32_T  1 (0x1)
saAmfSGCompRestartProb                              SA_TIME_T    <Empty>
saAmfSGCompRestartMax                               SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                   SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                               SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                   SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                   SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                            SA_STRING_T  safAmfService
SaImmAttrClassName                                  SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                             SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$ █
```

Figure 44 - ‘safSg=AmfDemo,safApp=AmfDemo2’ SG object after the EE action

5.4.2 Workload decrease

In this subsection, we test the EE prototype tool for a workload decrease with two test cases: when the workload of the SI protected by an SG with an N-way-Active redundancy model decreases, and when the workload of the SI protected by an SG with an N+M redundancy model decreases.

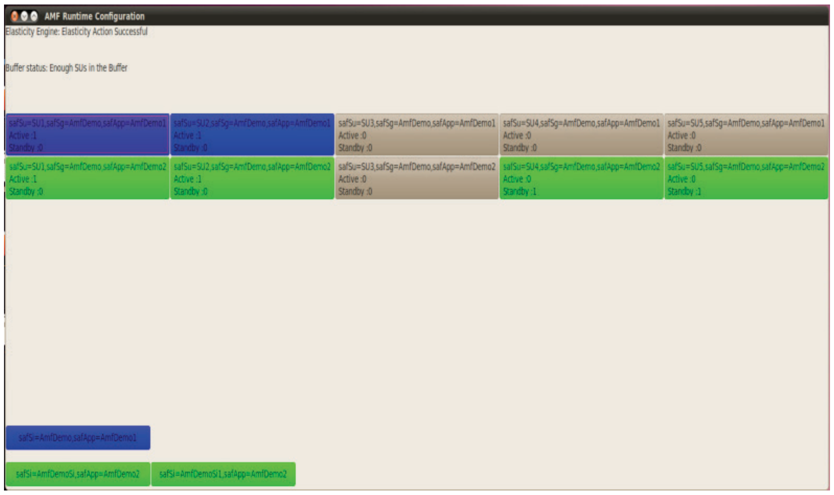
- ❖ **Test case: Workload decrease for an SG with an N-way-Active redundancy model**

  We use the system configuration results of the previous test case as shown in Figure 43 to test the workload decrease for an SG with an N-way-Active redundancy model.

  The list of configuration attribute values of *'safSg=AmfDemo,safApp=AmfDemo1'* SG object with an N-way-Active redundancy model is shown in Figure 39. The SG has three assigned SUs (indicated by the *'saAmfSGNumPrefAssignedSUs'* attribute) and five in-service SUs (indicated by the *'saAmfSGNumPrefInserviceSUs'* attribute). Its maximum active SIs per SU (i.e. *'saAmfSGMaxActiveSIsperSU'*) is one. Figure 40 shows the *'safSi=AmfDemo,safApp=AmfDemo1'* SI object's attributes. The SI is assigned to three SUs (indicated by *'saAmfSIPrefActiveAssignments'*).

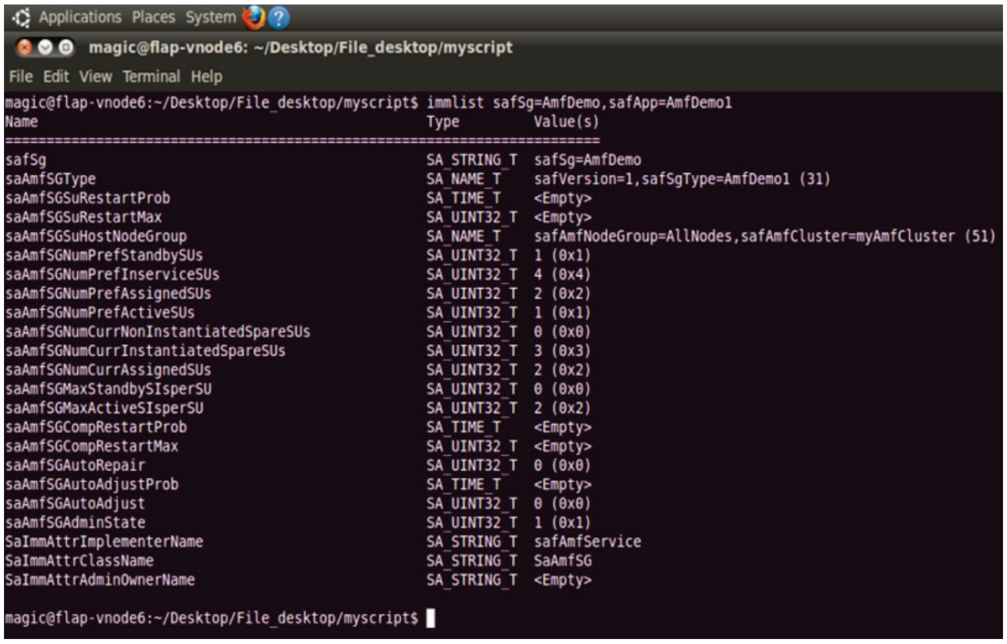
  To test the EE's behavior for workload decreases for the SG with an N-way-Active redundancy model, we left-click on the name of *'safSi=AmfDemo,safApp=AmfDemo1'* SI on the GUI shown in Figure 43. The left-click event of the GUI calls the 'EE_main( )' and passes the SI name and the workload decrease as parameters.

  The 'EE_main( )' determines a workload decrease and the workload change of type Single-SI. The 'SG_type_determine( )' uses IMM APIs [7] to read the IM. It determines that the SI is protected by *'safSg=AmfDemo,safApp=AmfDemo1'* SG with an N-way active redundancy model (see Figure 40). The 'SG_type_determine( )' accordingly calls the 'RM_Adjustor_Method( )' to handle the workload decrease in the SG. The 'RM_Adjustor_Method( )' follows the strategy of the 'Merging the SI workload' explained in Chapter 4. This 'RM_Adjustor_Method( )' reads the IM to determine that the SI object has three active assignments (see Figure 40). Since the SI has decreased in workload, it no longer requires three active assignments. The ‘RM_Adjustor_Method( )’ calls the ‘Create_CCB( )’ to initialize a CCB in IMM to decrease SI assignments to two. The ‘RM_Adjustor_Method( )’ then checks to free the assigned SUs of the SG. The ‘RM_Adjustor_Method( )’ reads the SG attributes to compare the capacity available (three active assignments) and the capacity required (two active assignments) as shown in Figure 39 and Figure 47 . Since there is enough capacity it calls the ‘Create_CCB( )’ to write a CCB in IMM to decrease the number of SUs to two of the SG in the IM. The ‘RM_Adjustor_Method( )’ then calls the ‘Buffer_Manager( )’ to free reserved resources. The ‘Buffer_Manager( )’ checks the difference between assigned and in-service SUs to determine if it is greater than the value of ‘in-service-SU-buffer’ to free the reserved resources. The ‘Buffer_Manager( )’ calls the ‘Create_CCB( )’ to initialize a CCB in IMM to decrease in-service SUs to four. The ‘RM_Adjustor_Method( )’ reports that ‘the Elasticity action is Successful’ to the calling function. Figure 45 gives the output of the EE action when the SI is clicked to indicate workload decrease of the N-way-Active redundancy model. Figure 46 and Figure 47 shows the SG and SI object’s attributes respectively after the EE action.



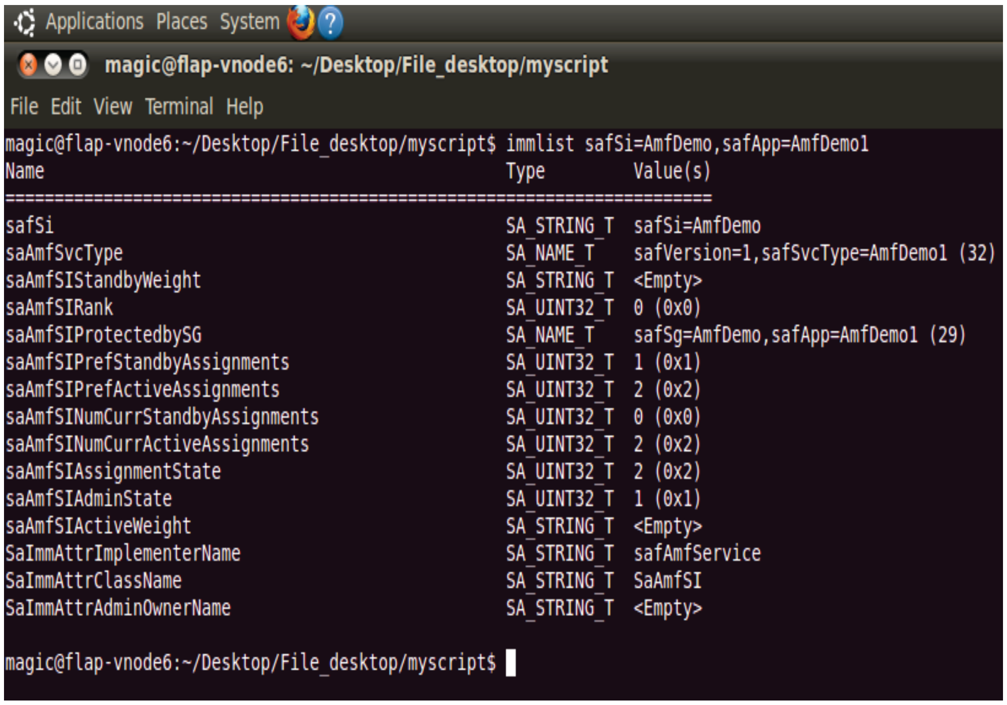
```
Elasticity Engine: Elasticity Action Successful

Buffer status: Enough SUs in the Buffer

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1   safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1   safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1   safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1   safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1
Active :1                                 Active :1                                 Active :0                                 Active :0                                 Active :0
Standby :0                                Standby :0                                Standby :0                                Standby :0                                Standby :0
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2   safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2   safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2   safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2   safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2
Active :1                                 Active :1                                 Active :0                                 Active :0                                 Active :0
Standby :0                                Standby :0                                Standby :0                                Standby :1                                Standby :1

safSi=AmfDemo,safApp=AmfDemo1

safSi=AmfDemoSi,safApp=AmfDemo2   safSi=AmfDemoSi1,safApp=AmfDemo2
```

Figure 45 - System Configuration after EE and AMF actions for a workload decrease in a SG with the N-way- Active redundancy model



```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo1
Name                                                Type         Value(s)
========================================================================
safSg                                               SA_STRING_T  safSg=AmfDemo
saAmfSGType                                         SA_NAME_T    safVersion=1,safSgType=AmfDemo1 (31)
saAmfSGSuRestartProb                                SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                 SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                              SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                            SA_UINT32_T  1 (0x1)
saAmfSGNumPrefInserviceSUs                          SA_UINT32_T  4 (0x4)
saAmfSGNumPrefAssignedSUs                           SA_UINT32_T  2 (0x2)
saAmfSGNumPrefActiveSUs                             SA_UINT32_T  1 (0x1)
saAmfSGNumCurrNonInstantiatedSpareSUs               SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                  SA_UINT32_T  3 (0x3)
saAmfSGNumCurrAssignedSUs                           SA_UINT32_T  2 (0x2)
saAmfSGMaxStandbySIsperSU                           SA_UINT32_T  0 (0x0)
saAmfSGMaxActiveSIsperSU                            SA_UINT32_T  2 (0x2)
saAmfSGCompRestartProb                              SA_TIME_T    <Empty>
saAmfSGCompRestartMax                               SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                   SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                               SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                   SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                   SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                            SA_STRING_T  safAmfService
SaImmAttrClassName                                  SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                             SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 46 - 'safSg=AmfDemo,safApp=AmfDemo1' SG object after the EE action



```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSi=AmfDemo,safApp=AmfDemo1
Name                                                Type         Value(s)
========================================================================
safSi                                               SA_STRING_T  safSi=AmfDemo
saAmfSvcType                                        SA_NAME_T    safVersion=1,safSvcType=AmfDemo1 (32)
saAmfSIStandbyWeight                                SA_STRING_T  <Empty>
saAmfSIRank                                         SA_UINT32_T  0 (0x0)
saAmfSIProtectedbySG                                SA_NAME_T    safSg=AmfDemo,safApp=AmfDemo1 (29)
saAmfSIPrefStandbyAssignments                       SA_UINT32_T  1 (0x1)
saAmfSIPrefActiveAssignments                        SA_UINT32_T  2 (0x2)
saAmfSINumCurrStandbyAssignments                    SA_UINT32_T  0 (0x0)
saAmfSINumCurrActiveAssignments                     SA_UINT32_T  2 (0x2)
saAmfSIAssignmentState                              SA_UINT32_T  2 (0x2)
saAmfSIAdminState                                   SA_UINT32_T  1 (0x1)
saAmfSIActiveWeight                                 SA_STRING_T  <Empty>
SaImmAttrImplementerName                            SA_STRING_T  safAmfService
SaImmAttrClassName                                  SA_STRING_T  SaAmfSI
SaImmAttrAdminOwnerName                             SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 47 - 'safSi=AmfDemo,safApp=AmfDemo1' SG object after the EE action

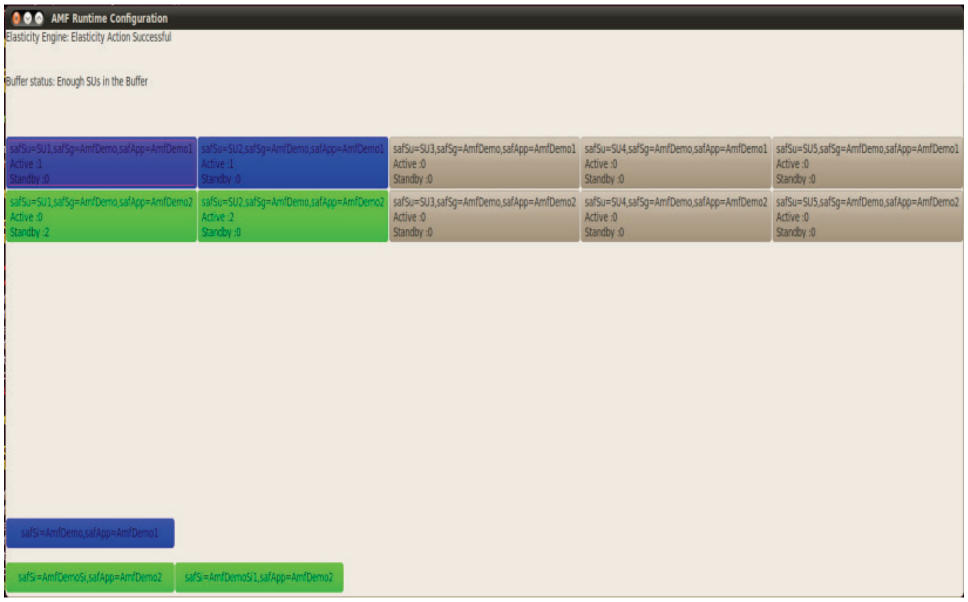
- **Test case: Workload decrease for the SG with an N+M redundancy model**

We use the system configuration results of the previous test case as shown in Figure 45 to test the workload decrease for an SG with an N+M redundancy model.

The list of configuration attribute values of '*safSg=AmfDemo,safApp=AmfDemo2'* SG object with the N+M redundancy model is shown in Figure 44. The SG has five in-service SUs (indicated by the *'saAmfSGNumPrefInserviceSUs'* attribute), two active SUs (indicated by *'saAmfSGNumPrefActiveSUs'*) and two standby SUs (indicated by *'saAmfSGNumPrefStandbySUs'*). Its maximum active SIs per SU (i.e '*saAmfSGMaxActiveSIsperSU'*) is one and its maximum standby SIs per SU is one (*'saAmfSGMaxStandbySIsperSU'*). Figure 42 shows SIs protected by *'safSg=AmfDemo,safApp=AmfDemo2'* SG with an N+M redundancy model.

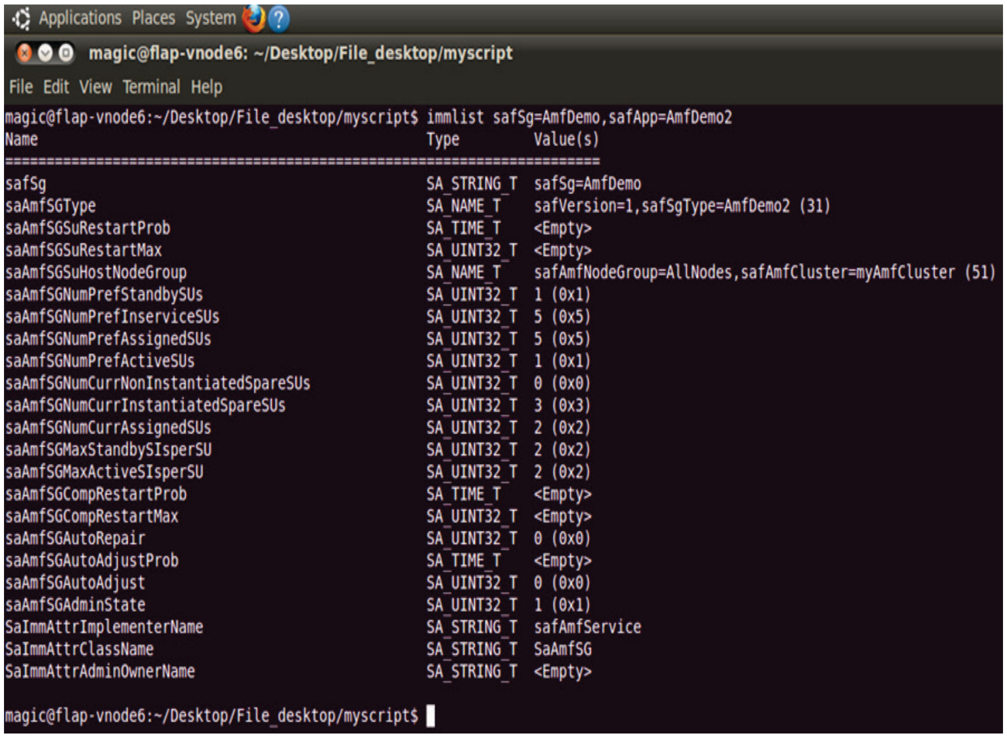
We left-click on *'safSi=AmfDemoSi,safApp=AmfDemo2'* on the GUI shown in Figure 45 to test the EE behavior when there is a decrease in workload represented by an SI protected by the SG with an N+M redundancy model. The left-click event of the GUI calls the 'EE_main( )' and passes the SI name and the workload decrease as parameters.

The 'EE_main( )' determines a workload decrease and the workload change of type Single-SI. The 'SG_type_determine( )' uses IMM APIs [7] to read the IM. It determines that *'safSi=AmfDemoSi,safApp=AmfDemo2'* is protected by *'safSg=AmfDemo,safApp=AmfDemo2'* SG (see Figure 45) with an N+M redundancy model and accordingly calls the 'RM_Adjustor_Method( )'. This 'RM_Adjustor_Method( )' uses 'Re-grouping the SIs on less SUs of the SG' strategy explained in Chapter 4. According to the strategy, it checks if it can decrease the number of SUs without losing active assignments by multiplying SG's *'saAmfSGMaxActiveSIsperSU'* and '*saAmfSGNumPrefActiveSUs*-1' attribute values. The calculated active capacity is one (see Figure 44) which is not enough for the two SIs. It then checks the required constraining attributes (i.e. '*saAmfCompNumMaxActiveCSIs'* [4]) to increase the maximum number of SIs that can be assigned to each SU in the SG (i.e. the *‘saAmfSGMaxActiveSIsperSU’* attribute). The component capability model allows to increase the *‘saAmfSGMaxActiveSIsperSU’* by one hence it calls ‘Create_CCB( )’ to write a CCB in IMM to increase it to two. The ‘RM_Adjustor_Method( )’ then tries to decrease the number of active SUs of the SG. The available active capacity in the SG is four and the required active capacity is two active SI assignments. The ‘RM_Adjustor_Method( )’ calls the ‘Create_CCB( )’ to write the CCB in IMM to increase decrease the number of active SUs to one. The ‘RM_Adjustor_Method( )’ then tries to decrease the standby SUs. It calculates the available capacity after decreasing one standby SU of the SG will be one standby assignment (see Figure 44) but the required capacity is two standby SI assignments. The ‘RM_Adjustor_Method( )’ will try to increase the maximum standby SIs per SU of the SG (i.e. *‘saAmfSGMaxStandbySIsperSU’*) by checking if the component capability model allows (i.e. ‘*saAmfCompNumMaxStandbyCSI’* [4]) to increase it by one. It calls the ‘Create_CCB( )’ to write a (see Figure 44 and Figure 43) CCB in IMM to increase the number of maximum standby SI assignments per SU of the SG. The ‘RM_Adjustor_Method( )’ then checks if it can decrease the number of standby SUs. The available standby capacity is four standby assignments and required standby capacity is two standby SI assignments. It then calls the ‘Create_CCB( )’ to write a CCB in IMM to decrease the number of standby SUs by one of the SG and calls the ‘Buffer_Manager( )’ to free any in-service SUs. Figure 48 gives the output of the EE when SI is clicked to indicate workload decrease. Figure 49 shows the SG object’s attribute values.



```
Elasticity Engine: Elasticity Action Successful

Buffer status: Enough SUs in the Buffer

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1  safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1  safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1  safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1  safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1
Active :1                                Active :1                                Active :0                                Active :0                                Active :0
Standby :0                               Standby :0                               Standby :0                               Standby :0                               Standby :0
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2  safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2  safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2  safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2  safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2
Active :0                                Active :2                                Active :0                                Active :0                                Active :0
Standby :2                               Standby :0                               Standby :0                               Standby :0                               Standby :0

safSi=AmfDemo,safApp=AmfDemo1

safSi=AmfDemoSi,safApp=AmfDemo2  safSi=AmfDemoSi1,safApp=AmfDemo2
```

Figure 48 - System Configuration after EE and AMF actions for workload decrease in an SG with N+M redundancy model

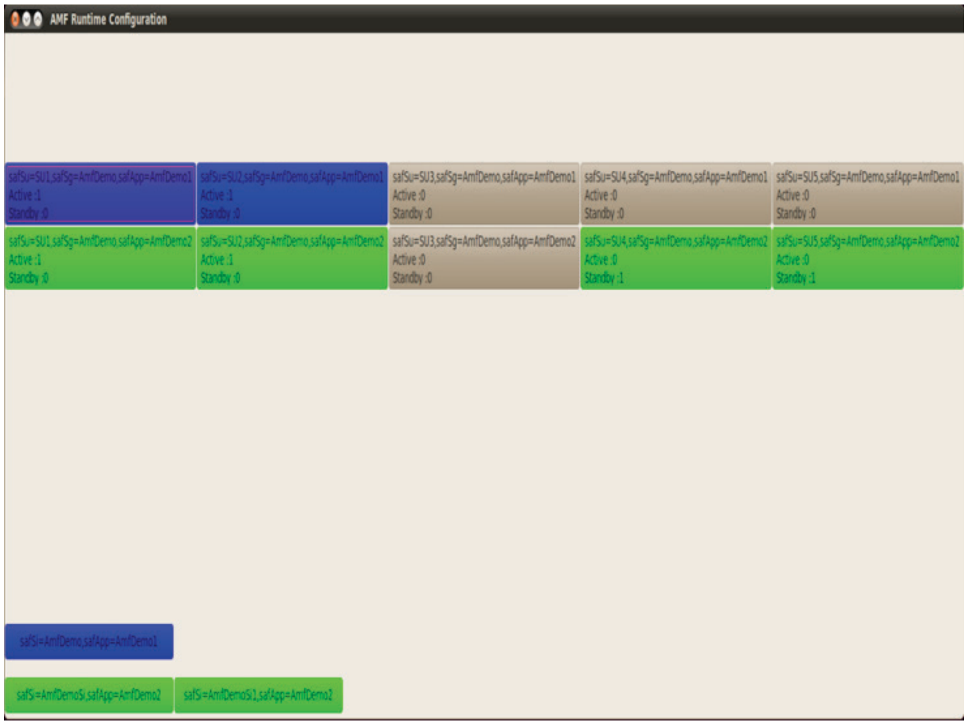

Applications Places System
magic@flap-vnode6: ~/Desktop/File_desktop/myscript
File Edit View Terminal Help

```
magic@flap-vnode6:~/Desktop/File_desktop/myscript$ immlist safSg=AmfDemo,safApp=AmfDemo2
Name                                               Type         Value(s)
========================================================================
safSg                                              SA_STRING_T  safSg=AmfDemo
saAmfSGType                                        SA_NAME_T    safVersion=1,safSgType=AmfDemo2 (31)
saAmfSGSuRestartProb                               SA_TIME_T    <Empty>
saAmfSGSuRestartMax                                SA_UINT32_T  <Empty>
saAmfSGSuHostNodeGroup                             SA_NAME_T    safAmfNodeGroup=AllNodes,safAmfCluster=myAmfCluster (51)
saAmfSGNumPrefStandbySUs                           SA_UINT32_T  1 (0x1)
saAmfSGNumPrefInserviceSUs                         SA_UINT32_T  5 (0x5)
saAmfSGNumPrefAssignedSUs                          SA_UINT32_T  5 (0x5)
saAmfSGNumPrefActiveSUs                            SA_UINT32_T  1 (0x1)
saAmfSGNumCurrNonInstantiatedSpareSUs              SA_UINT32_T  0 (0x0)
saAmfSGNumCurrInstantiatedSpareSUs                 SA_UINT32_T  3 (0x3)
saAmfSGNumCurrAssignedSUs                          SA_UINT32_T  2 (0x2)
saAmfSGMaxStandbySIsperSU                          SA_UINT32_T  2 (0x2)
saAmfSGMaxActiveSIsperSU                           SA_UINT32_T  2 (0x2)
saAmfSGCompRestartProb                             SA_TIME_T    <Empty>
saAmfSGCompRestartMax                              SA_UINT32_T  <Empty>
saAmfSGAutoRepair                                  SA_UINT32_T  0 (0x0)
saAmfSGAutoAdjustProb                              SA_TIME_T    <Empty>
saAmfSGAutoAdjust                                  SA_UINT32_T  0 (0x0)
saAmfSGAdminState                                  SA_UINT32_T  1 (0x1)
SaImmAttrImplementerName                           SA_STRING_T  safAmfService
SaImmAttrClassName                                 SA_STRING_T  SaAmfSG
SaImmAttrAdminOwnerName                            SA_STRING_T  <Empty>

magic@flap-vnode6:~/Desktop/File_desktop/myscript$
```

Figure 49 - ‘safSg=AmfDemo,safApp=AmfDemo2’ SG after the EE action

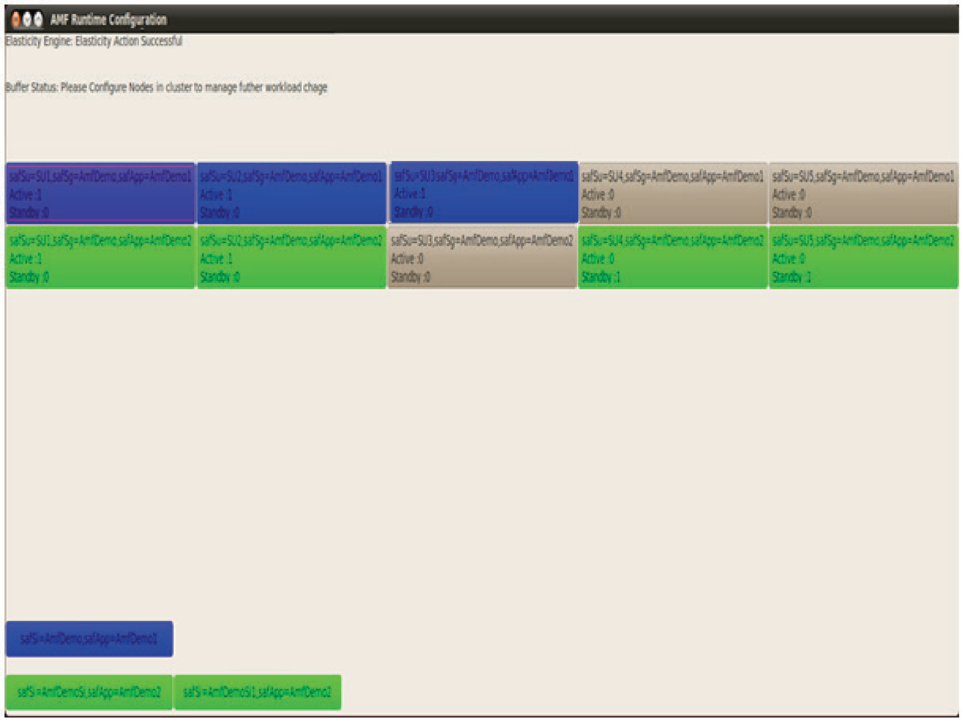
5.4.3 Cluster Level Adjustments

In this section we will execute the EE to test ‘Cluster level Adjustment’ when workload changes for a SI that is protected by one of the SGs in the cluster.


AMF Runtime Configuration
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0
safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1
Active :1
Standby :0
safSu=SU3,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0
safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0
safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1
Active :0
Standby :0
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2
Active :1
Standby :0
safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2
Active :1
Standby :0
safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :0
safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :1
safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2
Active :0
Standby :1
safSi=AmfDemo,safApp=AmfDemo1
safSi=AmfDemoSi,safApp=AmfDemo2
safSi=AmfDemoSi1,safApp=AmfDemo2
Figure 50 - System Configuration to test Cluster Level Adjustments

When we execute the EE, it reads the configured AMF configuration and displays it on the GUI. Figure 50 shows the system configuration. The *'safSg=AmfDemo,safApp=AmfDemo1'* and *'safSg=AmfDemo,safApp=AmfDemo2'* are configured on the same five nodes. They share resources with each other. The *'safSg=AmfDemo,safApp=AmfDemo2'* SG is using four SUs configured on the nodes as shown in Figure 50. If there is any change in the workload represented by the SI protected by the *'safSg=AmfDemo,safApp=AmfDemo2'* SG the EE will adjust the SI-to-SU assignments on the other SG at the cluster level to handle the workload change. We demonstrate the same behavior of the EE in this test case.

We right-click '*safSi=AmfDemoSi,safApp=AmfDemo2'* SI on the GUI shown in Figure 50 to indicate a workload increase. The right-click event of the GUI calls the 'EE_main( )' and passes the SI name and workload increase as parameters. The 'EE_main( )' determines a workload increase and the workload change type is Single-SI. The 'SG_type_determine( )' uses the IMM APIs [7] to read the IM. It finds that the SI is protected by ‘*safSg=AmfDemo,safApp=AmfDemo2’* SG with the N+M redundancy model and calls the ‘RM_Adjustor_Method( )’. This ‘RM_Adjustor_Method( )’ uses the ‘Distribute the SIs over more SUs’ strategy explained in Chapter 4. This ‘RM_Adjustor_Method( )’ cannot handle the workload increase in *‘safSg=AmfDemo,safApp=AmfDemo2’* SG because all the SIs of the SG are distributes and the ‘RM_Adjustor_Method( )’ cannot spread the SIs any more (see Figure 50). This ‘RM_Adjsutor_Method( )’ reports the ‘SG_type_determine( )’ that the adjustment needs to be done at the cluster level. The ‘SG_type_determine( )’ uses the ‘Cluster level adjustment’ strategy explained in Chapter 4 to increase the resources allocated to *‘safSi=AmfDemoSi,safApp=AmfDemo2’* SI. According to the ‘Cluster level adjustment’ strategy, the ‘SG_type_determine( )’ reads the IM using the IMM APIs to determine other SGs in the cluster that are sharing resources with *‘safSg=AmfDemo,safApp=AmfDemo2’*. It finds that the SUs of *‘safSg=AmfDemo,safApp=AmfDemo1’* are also configured on the same group of nodes in the cluster (see Figure 50). It determines that *‘safSg=AmfDemo,safApp=AmfDemo1’* is of N-way-Active redundancy model and calls the ‘RM_Adjustor_Method( )’ accordingly. This ‘RM_Adjustor_Method( )’ determines the required configuration changes to spread the workload of *‘safSi=AmfDemo,safApp=AmfDemo1’* from two SUs namely *‘safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1’* & ‘*safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1’* to three SUs. It calls the ‘Create_CCB( )’ to write the CCBs in IMM. This gives the impacted SI (*safSi=AmfDemoSi,safApp=AmfDemo2*) more capacity to use on nodes. The EE displays that the ‘EE action was successful’ on the GUI as shown in Figure 51.



Elasticity Engine: Elasticity Action Successful

Buffer Status: Please Configure Nodes in cluster to manage futher workload chage

safSu=SU1,safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0	safSu=SU2,safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0	safSu=SU3safSg=AmfDemo,safApp=AmfDemo1 Active :1 Standby :0	safSu=SU4,safSg=AmfDemo,safApp=AmfDemo1 Active :0 Standby :0	safSu=SU5,safSg=AmfDemo,safApp=AmfDemo1 Active :0 Standby :0
safSu=SU1,safSg=AmfDemo,safApp=AmfDemo2 Active :1 Standby :0	safSu=SU2,safSg=AmfDemo,safApp=AmfDemo2 Active :1 Standby :0	safSu=SU3,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :0	safSu=SU4,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :1	safSu=SU5,safSg=AmfDemo,safApp=AmfDemo2 Active :0 Standby :1

safSi =AmfDemo,safApp=AmfDemo1

safSi =AmfDemoSi,safApp=AmfDemo2 safSi =AmfDemoSi1,safApp=AmfDemo2

Figure 51 - System Configuration after EE and AMF action for Cluster Level Adjustments

5.5 Summary

In this chapter we described the EE prototype and tested the EE strategies. We briefly demonstrated its usage through a simple case study. Further testing of the EE is required as future work. Moreover, more realistic case studies should be considered.

Chapter 6 - Conclusion and Future Work

6.1 Conclusion

The objective of this thesis was to propose a solution to manage elasticity and availability in the application level. Elasticity is a key requirement in cloud computing and generally cloud services are believed to be "available" all the time. In the thesis we reviewed the facts that existing cloud solutions such as OpenStack [11] and Heat [12] handle elasticity and availability at the level of VMs. These solutions equate the application and its workload to the VMs running the applications. HA applications are typically composed of redundant resources in a cluster managed by a middleware. The management of elasticity and HA of such applications in the cloud at the virtual infrastructure level will result in contradictions between the cloud controllers and the middleware. In this thesis, we proposed an EE that manages application level elasticity within AMF designed to manage service availability.

We defined 'Single-SI' and 'Multiple-SI' types of workload changes in an AMF configuration to characterize the potential changes in workloads and determined the AMF configuration attributes related to elasticity and the attributes constraining them. We presented the overall architecture for HA and elasticity management using the SA Forum middleware. Further, we proposed the architecture of the EE that consists of the Controller, the RM Adjustor and Buffer Manager. We also presented the working components of each part of the EE. AMF allows the manipulation of its configuration. The EE proposed in this thesis manipulates the AMF configuration that forces AMF to increase the resources or decrease resources in the configuration. Thus AMF and OpenSAF as a middleware can be a promising solution for managing application availability in the cloud; however the integration of the EE with cloud orchestration needs further work.

In the thesis, we have defined strategies to handle the workload increase and decrease in an AMF configuration. We also defined a buffer management strategy for reserving or freeing resources in an AMF configuration to handle future workload changes and a cluster level adjustment strategy to adjust resources in the cluster to handle the workload changes. The EE follows one or more of the proposed strategies according to the redundancy model of the SG protecting the impacted SI and the execution status of the system to manipulate the AMF configuration. Finally, we developed the EE prototype that implements the proposed strategies and architecture, and tested it.

6.2 Future Work

The solution presented in this thesis has been prototyped and tested using OpenSAF [6]. However, as the workload monitor is under development the workload increase and decrease is provided through a user interface. The workload monitor requires further research by itself as low level monitoring of processes and threads in the nodes of cluster need to be mapped into the AMF configuration and SI-workload. Measuring the real workload and comparing it with actual resource capacities available in the nodes will also provide more refined selection of elasticity strategies.

The EE strategies used so far have not been tested for multiple simultaneous SI workload changes. In future work, the EE can be extended to handle this issue. The strategies we propose are more focused to provision resources but policies that consider the Service Level Agreements (SLAs) and pricing of resources could be considered as future extension. Also, efficient workload prediction policies could be incorporated so that the EE can handle changes more efficiently.

Reference

[1] M. Toeroe and T. Francis, *Service Availability: Principles and Practice*. Wiley, 2012.

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Appendix

A number of examples are provided to illustrate configuration changes in response to a workload change made by the EE as explained in Chapter 4. Figure 52 shows an example of configuration of an SG with a 2N redundancy model.

I. Workload changes of an SG with a 2N redundancy model

- Workload increase of type Single-SI

  Configuration:

Attribute Names	SG1	SG2
Ordered List of SUs in SG	{SU1, SU2, SU3}	{SU1, SU2, SU3}
Ordered List of SIs	{SI1, SI2}	{SI1, SI2}
saAmfSGMaxActiveSIsperSU	2	2
saAmfSGMaxStandbySIsperSU	2	2
saAmfSGAutoAdjust	SA_TRUE	SA_TRUE
component capability model	2_active_or 2_standby	2_active_or 2_standby

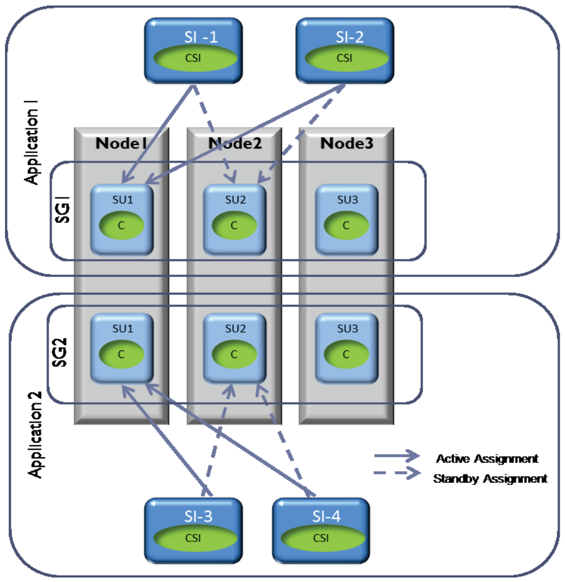

Figure 52 - System Configuration of SGs with a 2N redundancy model before CCB implementation

In the system configuration shown in Figure 52, assume that the workload represented by SI-3 increases. The EE's Elasticity Controller receives a workload increase signal of SI-3 and determines that SI-3 is protected by SG2 with a 2N redundancy model. The EE's Elasticity Controller will accordingly call the RM Adjustor method to adjust the workload increase.

The EE's RM Adjustor method uses the strategy of 'Prioritizing the SU on the least loaded node' as explained in Chapter 4. The RM Adjustor reads the name of SU to which SI-3 is currently assigned. It then accesses the SU's attribute '*saAmfSUHostedByNode'* in the IM using IMM APIs. The RM Adjustor then calculates the total number of active and standby SI assignments currently handled by SUs hosted on each node hosting the in-service SUs of SG2. For the system configuration shown in Figure 52 SI-3 is assigned to SU1 of SG2. The SG2's SU1 is hosted on node 'Node1'. This 'Node1' also hosts SU1 of SG1 and the total numbers of active assignments are three and standby assignments are 0. Similarly the RM Adjustor counts the total number of assignments handled by the SUs hosted by each node hosting the in-service SUs of SG2. The RM Adjustor then compares the assignments to get the node that will have the least number of assignments after the assignments of current active SU1 of SG2 are assigned to it. For the system configuration shown in Figure 52, Node3 has the least number of assignments i.e. zero and will handle only two active assignments after the in-service SU3 of SG2 is ranked higher. The least loaded node will have the maximum free capacity which the loaded SI can use. The RM Adjustor creates CCBs to swap the ranks of SU3 with

SU1 of SG2. Figure 53 shows the system configuration of the SGs after the EE and AMF actions.

CCBs: saAmfSURank (SU1) of SG2: 3

saAmfSURank (SU3) of SG2: 1

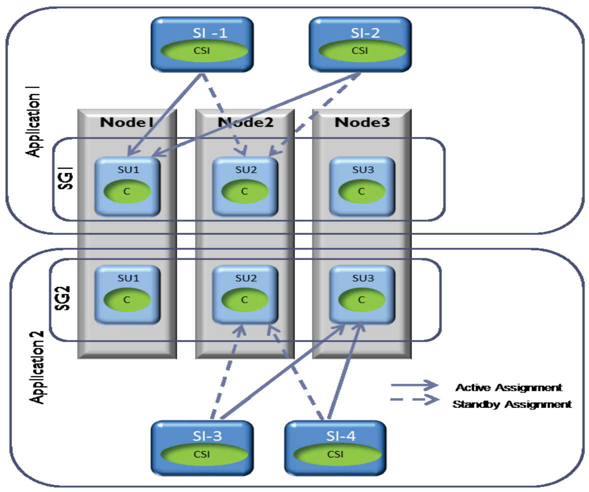

Figure 53 - System Configuration of SGs with a 2N redundancy model after CCB implementation (workload increase)

- Workload decrease of type Single-SI

To illustrate this scenario we use the system configuration shown in Figure 53 which is the system configuration result of the previous scenario.

Configuration:

Attribute Names	SG1	SG2
Ordered List of SUs in SG	{SU1, SU2, SU3}	{SU3, SU2, SU1}
Ordered List of SIs	{SI1, SI2}	{SI-1, SI-2}
saAmfSGMaxActiveSIsperSU	2	2
saAmfSGMaxStandbySIsperSU	2	2
saAmfSGAutoAdjust	SA_TRUE	SA_TRUE
component capability model	2_active_or 2_standby	2_active_or 2_standby

Assume that the workload represented by SI-3 decreases in the system configuration shown in Figure 53. The EE's Elasticity Controller receives the workload decrease signal for SI-3 and determines that SI-3 is protected by SG2 with a 2N redundancy model. The EE's Elasticity Controller will accordingly call the EE's RM Adjustor method to adjust workload decrease.

The EE's RM Adjustor method uses the strategy of 'Prioritizing the SU on the node serving other SIs' explained in Chapter 4. The RM Adjustor reads the name of the SU to which SI-3 is assigned and determines the hosting node of this SU. The RM Adjustor then counts the total number of active and standby SI assignments currently assigned to the SUs hosted on the node. For the system configuration shown in Figure 53, SI-3 is assigned to SG2's SU3. The SU3 is hosted on 'Node3'. This 'Node3' does not host any other SU that handle any assignments. The RM Adjustor counts the total number of assignments handled by the SUs hosted by each node hosting the in-service SUs of SG2. The RM Adjustor then compares the assignments to get the node that is hosting SUs that handle some assignments. For the system configuration shown in Figure 53, Node1 has some assignments, thus Node3 can be freed. The RM Adjustor creates CCBs to swap the rank of SU3 with SU1 of SG2. And informs the Elasticity action is Successful.

CCBs: saAmfSURank (SU1) of SG2: 1

saAmfSURank (SU3) of SG2: 3

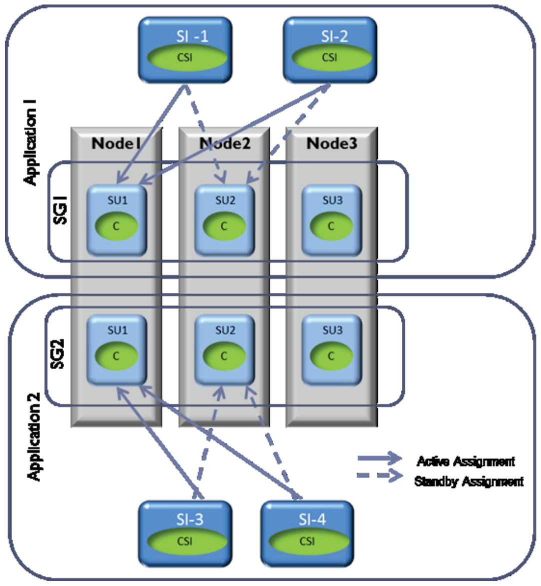

Figure 54 - System Configuration of SGs with a 2N redundancy model after CCB implementation (workload decrease)

II. Workload changes of an SG with a N-way redundancy model

- Workload increase of type Single-SI

Configuration:

Attribute Names	SG1
Ordered List of SUs in SG	{SU1, SU2, SU3,SU4}
Ordered List of SIs	{SI-1, SI-2, SI-3}
saAmfSGNumPrefInserviceSUs	4
saAmfSGNumPrefAssignedSUs	4
saAmfSGMaxActiveSIsperSU	2
saAmfSGMaxStandbySIsperSU	2
saAmfSGAutoAdjust	SA_TRUE
component capability model	2_active_and_2_standby

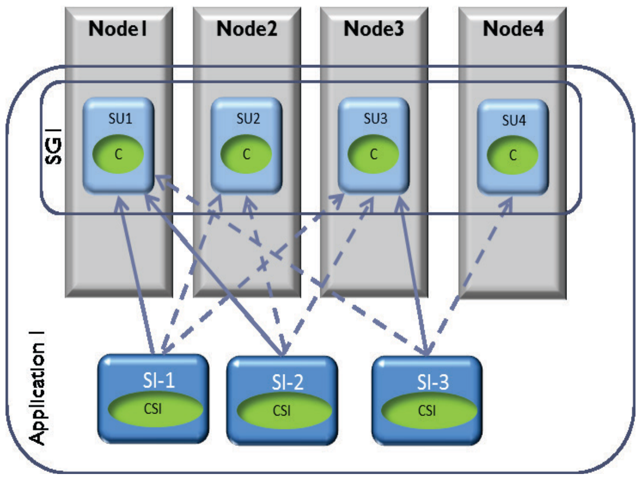

Figure 55 - System Configuration of SG with N-way redundancy model before CCB implementation (Single-SI)

In the system configuration shown in Figure 55, assume that the workload represented by SI-1 increases. The EE's Elasticity Controller will determine that SI-1 is protected by SG1 with an N-way redundancy model. It will call the EE's RM Adjustor method to adjust workload increase.

The EE's RM Adjustor follows the strategy of 'Distributing the SIs over more SUs' as explained in Chapter 4. According to the strategy, the RM Adjustor finds the SU currently handling active SI-1 assignment and saves the number of SI assignments that the current assigned SU handles. It checks if any SI assignments will be lost if it decreases the number of SIs that can be assigned to each SU. For the system configuration shown in Figure 55, it calculates the available active capacity excluding the capacity that will be lost after decreasing the value of *'saAmfSGMaxActiveSIsperSU'* by multiplying value of *'saAmfSGMaxActiveSIsperSU-1'* attribute and the value of *'saAmfSGNumPrefActiveSUs'* attribute of SG1. For the system configuration shown in Figure 55, it is four and the required active capacity is three. Hence, the RM Adjustor decreases the *'saAmfSGMaxActiveSIsperSU'* by one. The RM Adjustor checks if the number of SIs sharing capacity with SI-1 has decreased. It confirms that previously there were two active SI assignments and one standby assignment (see Figure 55) but after the CCB there are only one active and one standby assignment sharing capacity with SI-1 (see Figure 56). For the standby assignment of SI-1, the RM Adjustor checks if any SI assignment will be lost if it decreases the number of SI that can be assigned to each SU (i.e. '*saAmfSGMaxStandbySIsperSU'*). It calculates the available standby capacity excluding the capacity that will be lost after decreasing the *'saAmfSGMaxStandbySIsperSU'* by multiplying '*saAmfSGMaxStandbySIsperSU-1'* and the '*saAmfSGNumPrefStandbySUs'* of SG1. For the system configuration shown in Figure 55, the available capacity after decreasing the '*saAmfSGMaxStandbySIsperSU'* is four and the required standby capacity is six. Hence the RM Adjustor cannot decrease the SG1's *'saAmfSGMaxStandbySIsperSU'* attribute value by one. It tries to increase the number of assigned SUs. But there are no spare in-service SUs. The RM Adjustor method will request the Elasticity Controller to adjust workload at the cluster level. Since there are no SGs in the cluster for the example shown in Figure 55, the Elasticity Controller informs system administrator to increase the number of nodes in cluster.

CCB: saAmfSGMaxActiveSIsperSU = 1

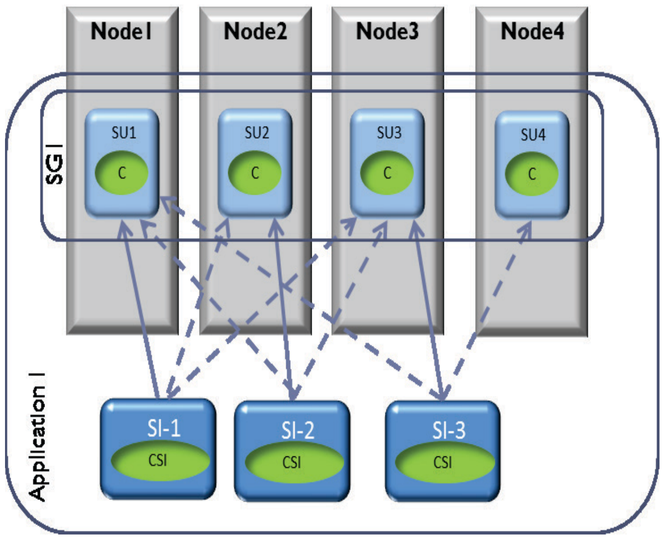

Figure 56 - System Configuration of SG with N-way redundancy model after CCB implementation (workload increase)

- Workload decrease of type Single-SI

To illustrate this scenario we use the system configuration shown in Figure 56, which is the system configuration result of the previous scenario.

Configuration:

Attribute Names	SG1
Ordered List of SUs in SG	{SU1, SU2, SU3,SU4}
Ordered List of SIs	{SI-1, SI-2, SI-3}
saAmfSGNumPrefInserviceSUs	4
saAmfSGNumPrefAssignedSUs	4
saAmfSGMaxActiveSIsperSU	1
saAmfSGMaxStandbySIsperSU	2
saAmfSGAutoAdjust	SA_TRUE
component capability model	2_active_and_2_standby

In the system configuration shown in Figure 56, assume that the workload represented by SI-1 decreases. The Elasticity Controller of the EE reads the IM to find that SI-1 is protected by a SG with an N-way redundancy model and calls the RM Adjustor method to adjust workload decrease.

The RM Adjustor method checks to see if it can decrease the number of SUs without the loss of active or standby assignments. It calculates the required active and standby capacity. For the system configuration shown in Figure 56, the required active capacity is three and the required standby is six. The RM Adjustor calculates the available active capacity after decreasing the number of SUs by multiplying the attribute values of *'saAmfSGNumPrefAssignedSUs-1'* and *'saAmfSGMaxActiveSIsperSU'* of the SG1 in Figure 56, which is three. The RM Adjustor calculates the available standby capacity after decreasing the number of SUs by multiplying the attribute values of *'saAmfSGNumPrefAssignedSUs-1'* and *'saAmfSGMaxStandbySIsperSU'* of the SG1 shown in Figure 56, which is six. The RM Adjustor determines that available capacity after the decreasing number of assigned SUs in SG1 is enough for the required capacity. The RM Adjustor writes a CCB to decrease the number of assigned SUs and calls the buffer manager to checks the buffers). Figure 57 shows the system configuration after the CCB implementation.

CCB: saAmfSGNumPrefAssignedSUs: 3

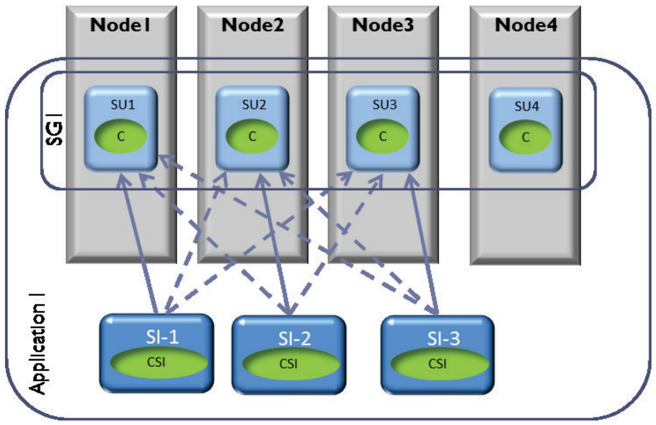

Figure 57 - System Configuration of SG with the N-way redundancy model with CCB implementation (workload decrease)

- Workload increase of type Multiple-SI

The workload increase of type Multiple-SI in a SG is due to the creation of a new SI. A new SI-4 is added to the system configuration shown in Figure 58 through IMM.

Configuration:

Attribute Names	SG1
Ordered List of SUs in SG	{SU1, SU2, SU3,SU4}
Ordered List of SIs	{SI-1, SI-2, SI-3, SI-4}
saAmfSGNumPrefInserviceSUs	4
saAmfSGNumPrefAssignedSUs	4
saAmfSGMaxActiveSIsperSU	1
saAmfSGMaxStandbySIsperSU	2
saAmfSGAutoAdjust	SA_TRUE
component capability model	2_active_and_2_standby

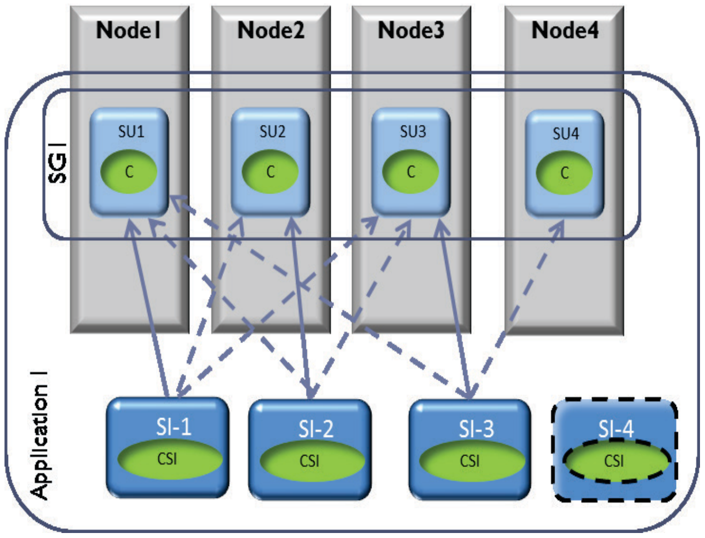

Figure 58 - System Configuration of SG with N-way redundancy model before CCB implementation (Multiple-SI workload increase)

When the EE's Elasticity Controller gets a callback from the IMM service informing a creation of a new SI-4 in the system configuration, it accesses SI-4 and determines that SG1 with an N-way redundancy model is protecting it. The Elasticity Controller will call the EE's RM Adjustor method to adjust workload increase.

The RM Adjustor will first confirm if this new SI-4 of SG1 has already been assigned by AMF. It calculates the required active capacity including the SI-4 which is four and the available capacity i.e. the product of *'saAmfSGMaxActiveSIsperSU'* and *'saAmfSGNumPrefAssignedSUs'* which is four as shown in Figure 58. Therefore, AMF has already assigned the SI-4's active assignments. Similarly it checks for the standby capacity. The required standby capacity including the new SI-4 is eight and the available capacity is also eight. After determining if SI-4 is already assigned, The RM Adjustor informs the Elasticity Controller that the adjustment is Successful (see Figure 59). If there was not enough capacity for SI-4, the EE would use similar adjustments as used in the workload increase of type Single-SI to assign SI-4 discussed in Chapter 4.

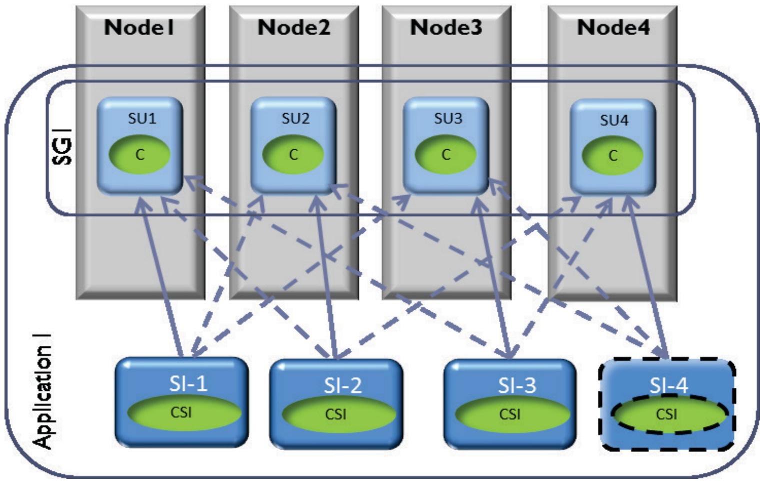

Figure 59 - System Configuration of SG with N-way redundancy model after CCB implementation (Multiple-SI workload increase)

- Workload decrease of type Multiple-SI

The workload decrease of type Multiple-SI in a SG is due to the deletion of an SI.SI-4 is deleted in the system configuration shown in Figure 60 through the IMM service.

Configuration:

Attribute Names	SG1
Ordered List of SUs in SG	{SU1, SU2, SU3,SU4}
Ordered List of SIs	{SI-1, SI-2, SI-3, SI-4}
saAmfSGNumPrefInserviceSUs	4
saAmfSGNumPrefAssignedSUs	4
saAmfSGMaxActiveSIsperSU	1
saAmfSGMaxStandbySIsperSU	2
saAmfSGAutoAdjust	SA_TRUE
component capability model	2_active_and_2_standby

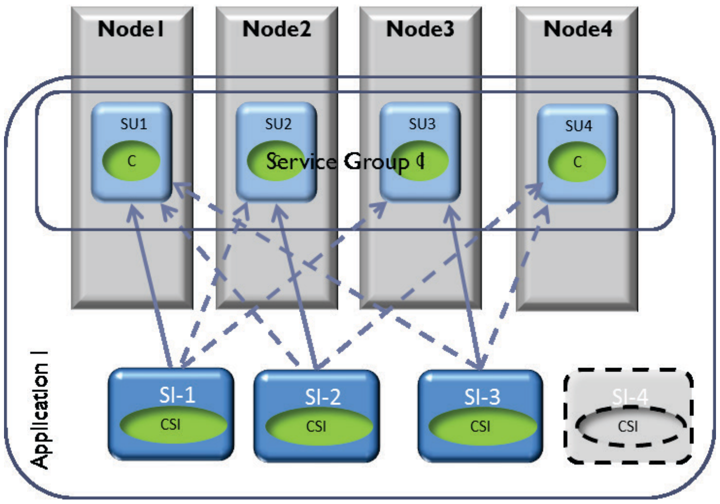

Figure 60 - System Configuration of SG with N-way redundancy model before CCB implementation (Multiple-SI workload decrease)

When the EE’s Elasticity Controller gets a callback from the IMM service informing the deletion of SI-4, it determines that the workload decrease is in SG1 with an N-way-Active redundancy model. It calls the RM Adjustor to adjust the workload decrease.

The RM Adjustor method uses ‘Re-grouping the SIs on less SUs of the SG’ strategy explained in Chapter 4.The RM Adjustor checks three conditions before decreasing the number of assigned SUs. It checks to see if the number of SUs left after subtracting the SUs that it plans to decrease is enough for the SIs protected by the SG. The RM Adjustor checks to see if the value *'saAmfSGNumPrefAssignedSUs-1'* of SG is greater than or equal to *'saAmfSIPrefStandbyAssignments'* plus one of each SI protected by SG. For the system configuration shown in Figure 60, the number of SUs is three after decreasing the number of assigned SUs in SG which is greater than each of the SI's number of standby assignments plus one. The RM Adjustor checks if the active capacity is enough for the SIs by comparing the number of SIs protected by SG with the product of the values of *'saAmfSGMaxActiveSIsperSU'* and *'saAmfSGNumPrefAssignedSUs-1'* attributes of SG. For the system configuration shown in Figure 60, the active capacity is three. After confirming that the active and standby capacity is enough for the SI assignments the RM Adjustor creates a CCB to decrease the number of assigned SUs and calls the buffer manager.

CCB: saAmfSGNumPrefAssignedSUs: 3

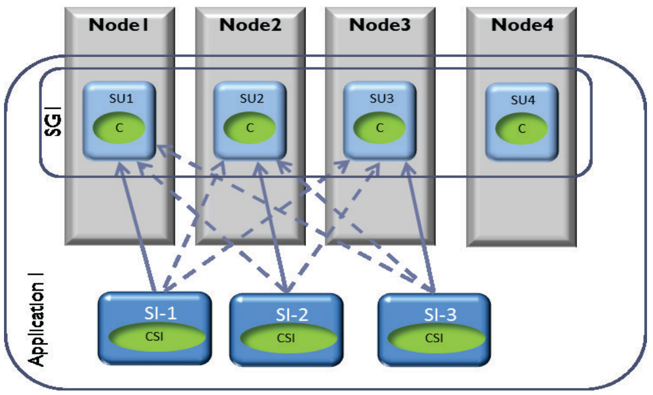

Figure 61 – System Configuration of SG with the N-way redundancy model after CCB implementation (Multiple-SI workload decrease)

We have presented the EE's actions for a SG with the 2N and N-way redundancy models for workload increase and decrease scenarios in the Appendix. The No-Redundancy redundancy model is similar to the 2N redundancy model except that the EE does not consider standby assignments while handling elasticity. The workload change scenarios for a SG with N+M redundancy and the N-way-Active redundancy model are previously illustrated in Chapter 5, thus after the investigations we can conclude the following:

Table 3 - Investigation Scenarios

	Single-SI		Multiple-SI	
Redundancy Model	Increase	Decrease	Increase	Decrease
2N	✓	✓	×	×
N+M	✓	✓	✓	✓
N-way	✓	✓	✓	✓
N-way Active	✓	✓	✓	✓
No Redundancy	✓	✓	×	×

A check mark denotes that an elasticity action is possible in the particular scenario and cross mark denotes that the elasticity action is not considered, since the redundancy model is not very flexible in the scenario.