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CONTRIBUTION TO THE COORDINATED VIRTUAL NETWORK EMBEDDING PROBLEM IN NETWORK VIRTUALIZATION

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Antoni Dalmases Trilla

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Advisor: Xavier Hesselbach Serra

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Abstract

Network virtualization has been widely proposed as an alternative to the implementation of new physical networks with specific characteristics. Network virtualization is based on assigning virtual networks with different demands on the same substrate network. However, this implementation involves the problem of how to allocate these virtual networks efficiently depending on pre-established constraints such as energy consumption or throughput.

This thesis is the continuation of another one in which the network behavior was studied when, for a fixed number of virtual networks, the demand of each one was increasing. The new proposed scenario is based on raising the number of virtual network requests for only one low load to obtain better results.

To this end, the simulation environment used in the previous work is analyzed and the new approach is simulated. The results of proposed scenario demonstrate better performances in terms of efficiency, i.e. the substrate network resources are better assigned than in the previous work.

Resum

La virtualització de xarxa ha estat àmpliament proposada com una alternativa a la implementació de noves xarxes físiques amb característiques específiques. La virtualització de xarxa es basa en assignar xarxes virtuals amb diferents demandes en la mateixa xarxa substrat. No obstant això, aquesta implementació implica el problema de com assignar aquestes xarxes virtuals de forma eficient depenent d'unes restriccions preestablertes com el consum d'energia o el *throughput*.

Aquesta tesi és la continuació d'una altra en la qual es va estudiar el comportament de la xarxa quan, per un nombre fix de xarxes virtuals, la demanda de cadascuna d'elles anava augmentant. El nou escenari proposat es basa en l'augment del nombre de sol·licituds de xarxes virtuals per a una sola càrrega baixa per obtenir millors resultats.

Amb aquesta finalitat, s'analitza l'entorn de simulació utilitzat en el treball anterior i es simula el nou enfocament. Els resultats de l'escenari proposat demostren un millor rendiment en termes d'eficiència, és a dir, els recursos de la xarxa substrat són millor assignats que en el treball anterior.

Resumen

La virtualización de red ha sido ampliamente propuesta como una alternativa a la implementación de nuevas redes físicas con características específicas. La virtualización de red se basa en asignar redes virtuales con diferentes demandas en la misma red sustrato. Sin embargo, esta implementación implica el problema de cómo asignar estas redes virtuales de forma eficiente dependiendo de unas restricciones preestablecidas como el consumo de energía o el *throughput*.

Esta tesis es la continuación de otra en la que se estudió el comportamiento de la red cuando, per un número fijo de redes virtuales, la demanda de cada una de ellas iba aumentando. El nuevo escenario propuesto se basa en el aumento del número de solicitudes de redes virtuales por a una sola carga baja para obtener mejores resultados.

Con esta finalidad, se analiza el entorno de simulación utilizado en el trabajo anterior y se simula el nuevo enfoque. Los resultados del escenario propuesto demuestran un mejor rendimiento en términos de eficiencia, es decir, los recursos de la red sustrato son mejor asignados que en el trabajo anterior.

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1. Introduction

Since its inception, the Internet has proven its worth by supporting myriads of distributed applications and heterogeneous networking technologies. However, due to the existence of multiple stakeholders with conflicting goals and policies, alterations to the present architecture, even necessary ones, have now become almost impossible to achieve. Like many successful technologies, the Internet is suffering the adverse effects of inertia [1]. The significant capital investment and competing interests of its major stakeholders creates a barrier to the introduction of disruptive technologies.

Network Virtualization (NV) has been propounded as a fundamental diversifying attribute of the future inter-networking paradigm that will allow multiple heterogeneous network architectures to coexist on a shared substrate. NV provides flexibility, promotes diversity, promises security and increases manageability. Therefore, it aims to overcome the resistance of the current Internet to architectural change providing innovation and enabling a new business model by decoupling the network services from the underlying infrastructure.

In NV, the primary entity is the Virtual Network (VN), a combination of virtual nodes connected through virtual links. The topology formed by the VN is virtualized to the Substrate Network (SN), i.e. the underlying physical network. Multiple VN topologies with widely varying characteristics can be created and co-hosted on the same physical hardware. The procedure to virtualize VNs to the SN, referred to as the Virtual Network Embedding (VNE), has the problem of how to do the optimal mapping, subjected by several constraints as embedding cost, energy-efficiency, packet loss rate, throughput, etc.

Nowadays, this problem is one of the most recurrent themes in the cloud computing area. Researchers are developing algorithms and methods to obtain better performances in NV. In that sense, it is very important to find optimal solutions, or at least better results than current ones. For example, a low percentage of improvement in performance could mean huge savings in companies that maintain the physical network.

This thesis is a continuation of a previous master thesis [2] in which a procedure to resolve the VNE problem was explained and a scenario was presented. The main objective is to solve the VNE problem using a different approach. It is divided in step-by-step objectives to accomplish the general purpose:

1. Study the cloud computing terminology and NV in order to understand the main problem in embedding networks
2. Analyze the framework used to resolve the VNE problem and make an user guide of the simulation environment
3. Study the previous work and methodologies
4. Determine metrics for comparing different scenarios
5. Validate the results of previous work
6. Propose a new scenario in order to improve the previous results
7. Run simulations with the new scenario to validate its better results

The thesis is divided in six chapters. In the first chapter, an introduction of the project is briefly presented. There is a context of current Internet technologies, the motivation of the thesis and its objectives.

The second chapter summarizes the theoretical fundaments of the investigation, beginning with the cloud computing and NV that will help to understand the basis of the project. Then, the framework used to execute the simulations is presented.

In the third chapter, there is a user guide of the simulation environment. An introduction to the software used is presented and two ways to run simulations are described: by a graphical interface or directly by using the framework.

The fourth chapter explains the simulation context: what has been done until now and what is intended to prove. There, a new approach in NV is studied as a better way than what has already been done in previous work.

The fifth chapter shows the results of all simulations: the validations of the previous work, the new evaluations resulting from the new approach, and the results of a scenario based on a low load.

Finally, the sixth chapter includes the conclusions of the project and some ideas for further work.

2. Required background knowledge

This chapter consists in exposing the main required background knowledge in order to understand all the work. First, there is a brief introduction of cloud computing and several examples. Next, the virtualization concept applied to a network is explained. Then, the VNE problem is presented as the main challenge when mapping VNs. In the following section, the framework used in this thesis is explained as a form to resolve the problem. Finally, there is a brief introduction to the simulation environment used.

2.1. Cloud computing

Scientific and business applications have an increasing demand for fast and scalable execution environments to deliver results for ever increasing problem sizes or concurrent requests in a requested time frame. For this reason, companies and institutions prefer to rent modern resource capabilities from specialized hosting companies instead of buying their own hardware [3].

According to the National Institute of Standards and Technology (NIST) [4], cloud computing is a model for enabling on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction. Cloud computing is hinting at a future in which users will not compute on local computers, but on centralized facilities operated by third-party compute and storage utilities [5]. The main services can be divided in three groups: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS).

Cloud computing is often described as a stack, depending on the services that a user or a company want [6][7]. Figure 1 shows a comparison between the traditional model and new approaches of cloud computing, in which there are the management levels that the consumer has in each case. In the traditional model the user must manage the whole infrastructure, whereas in the cloud computing models there is a part of stack that is not managed by the user but the vendor.

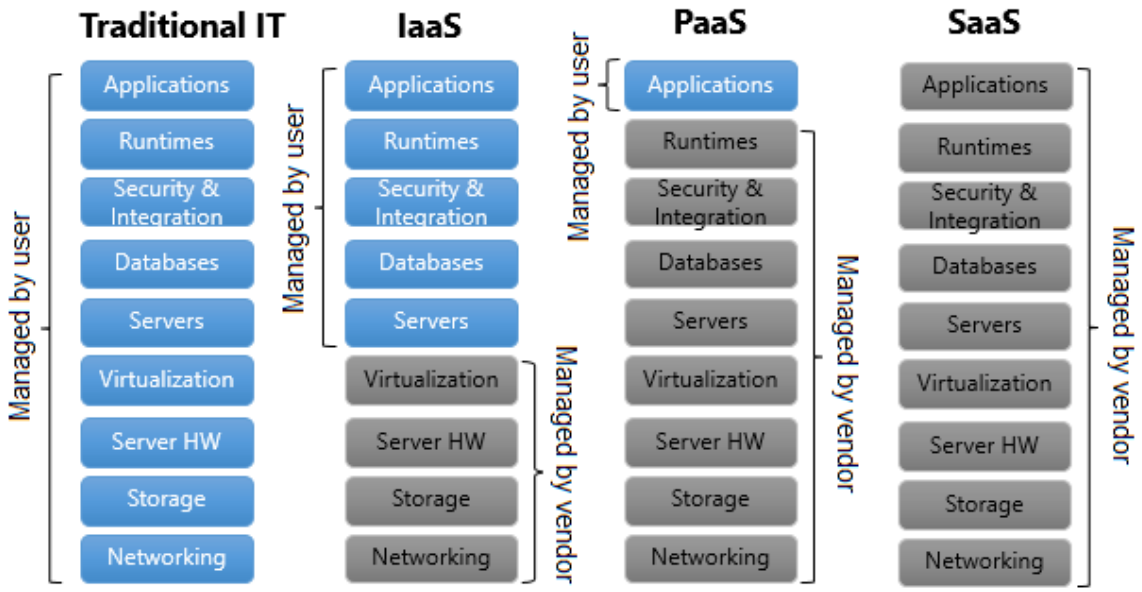

Figure 1. Traditional and cloud computing models

2.1.1. Infrastructure as a Service

IaaS [8] provides generic functionality for hosting and provisioning of access to raw computing infrastructure and its operating middleware software. IaaS are typically provided by data centers that rent modern hardware facilities to customers, who are freed from the burden of their maintenance and deprecation. Resources are allocated according to user needs; hence the highest utilization and optimization levels can be achieved.

Amazon Web Services, considered as a pioneer in this field, is a division of Amazon specialized in the provision of web-based storage and computing services to web developers.

2.1.2. Platform as a Service

PaaS provides all facilities to support the complete life cycle of building and delivering web applications and services (including design, development, testing, deployment, and hosting), with no need for software downloads and installations.

An example of this relatively new concept is Microsoft Azure Web Sites, which allows publishing web apps running on multiple frameworks and written in different programming languages.

2.1.3. Software as a Service

SaaS [9][10] is at the top end of the cloud computing stack, which is seen as a replacement to traditional software. SaaS can lower expenses associated with software acquisition and maintenance. Users get access to a specific application service hosted in the cloud using the Internet.

A well-known example of the SaaS is Google Docs, which is offered freely by Google as an alternative to on-site office productivity applications such as Microsoft Office. As a suite of software applications, it includes word processing, spreadsheet, presentation, drawing, etc. In addition, it facilitates group or organizational collaboration by allowing multiple users to edit the same document.

2.2. Network virtualization

An essential part of cloud computing approach is the Network Virtualization (NV) [11]. It is based on creating a logical software-based view of the networking resources (nodes and links). The physical networking devices are simply responsible for the forwarding of packets, while the virtual network (software) provides an intelligent abstraction that makes easier to deploy and manage network services and underlying network resources. The business model decouples Internet Service Providers (ISPs) into two new roles: the Infrastructure Provider (InP) and the Service Provider (SP).

InPs deploy and manage the Substrate Network (SN), i.e., the underlying physical network. They offer their resources to different SPs that create and deploy virtual networks to offer end-to-end services to end users. A Virtual Network (VN) is a collection of virtual nodes connected together by a set of virtual links to form a virtual topology, which is essentially a subset of the underlying physical topology. Each virtual node is hosted on a particular physical node, whereas a virtual link spans over a path in the physical network and includes a portion of the network resources along the path. Each

VN is operated and managed by a single SP, even though the SN might be aggregated from multiple InPs.

2.3. Virtual Network Embedding

In this context, VNs must be allocated in the SN like the example in Figure 2, in which two VNs managed by different SPs are mapped in a SN composed by two different InPs. This process is usually called Virtual Network Embedding (VNE) [12] and consists of two major components: the mapping of the virtual nodes (with computational capacity requirement) to the substrate nodes, and the mapping of the virtual links (with bandwidth capacity requirement) to the substrate links.

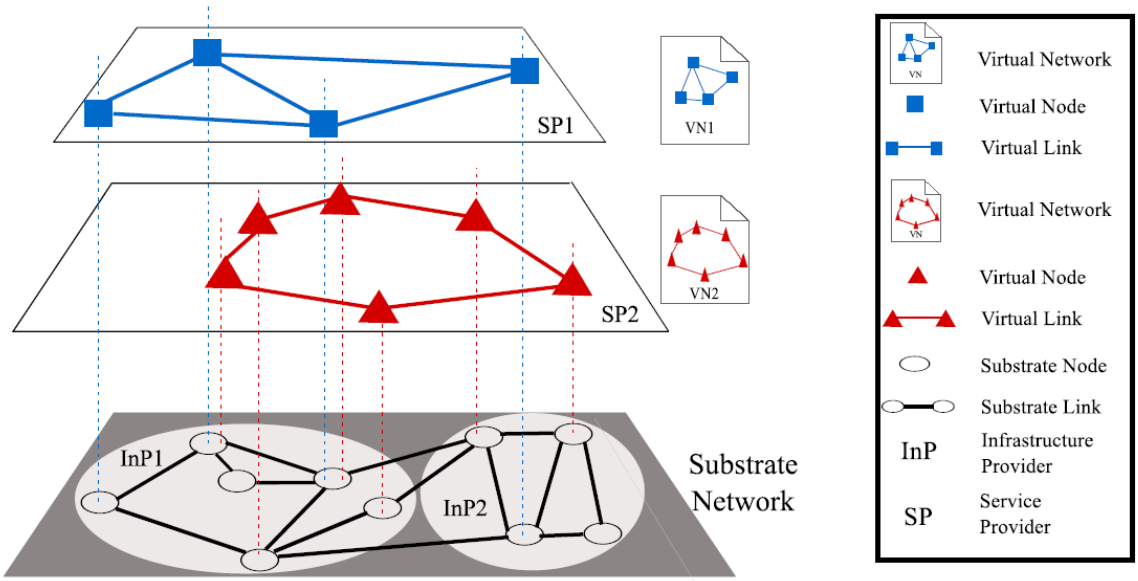

Figure 2. NV environment

The problem of embedding virtual networks in a SN, referred to as the VNE problem [13], is the main resource allocation challenge in NV. It deals with the efficient mapping of a set of Virtual Network Requests (VNRs). A VNR is a set of virtual nodes that must be mapped to a set of substrate nodes with sufficient resources to accomplish the requirements, and set of virtual links to be mapped to a set of paths in the substrate network. The embedding can be optimized with regard to performance (e.g. CPU capacity, link BW), energy-efficiency (e.g. power usage of a node), security (e.g. node reliability, link encryption), or other parameters.

Algorithms solving the VNE problem come in two forms: offline algorithms and online algorithms. Offline algorithms take a given set of VNRs together with the description of a SN and compute a near optimal embedding for these requests. While this approach achieves good results with regard to optimality, it does not consider a dynamic arrival process of the VNRs. On the other hand, online algorithms take and allocate VNRs as they arrive. This approach is better suited to deal with high dynamicity, but it tends to have worse optimal solutions.

The framework used to run simulations in this thesis works with offline algorithms. At first sight, it may seem an inapplicable and unrealistic approach because all VNRs are needed before the embedding process starts. However, offline approaches can be used as a complement to online ones. A possible implementation would be by using an online

algorithm to map VNRs as they arrive and, at certain time, the offline algorithm would be used with the existing VNs to reallocate them in the SN, so it would achieve better performances. In conclusion, the fact of using online and offline approaches together improves the results of using them separately because it takes into account dynamic arrival VNRs and it offers better optimal solutions than only online models.

2.4. Paths Algebra

Paths Algebra (PA) [14] is a mathematical framework for solving the VNE problem using a combination of linear and non-linear metrics. Such metrics can be used depending on the optimization goal.

2.4.1. Paths Algebra formulation

A network is represented by a directed graph $G = (V, A)$, where V is the set of vertices (nodes) and A the set of arcs (links). Consider the path represented in the Figure 3, which can be represented by $V = \{1, 2, 3, 4\}$ and $A = \{a, b, c\}$.

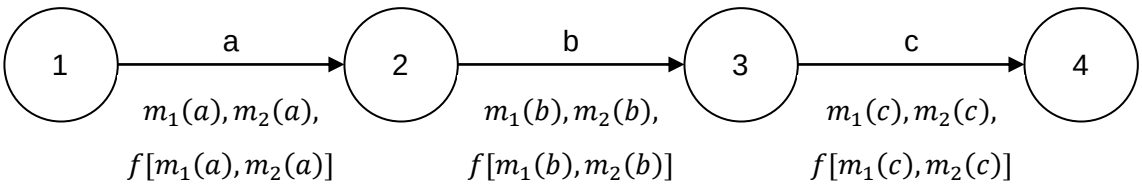

Figure 3. Example of a simple path

PA uses M as the set of m adopted routing metrics and F as the set of k metrics combination function. Each arc in this example is characterized by $(m_1(x), m_2(x), f[m_1(x), m_2(x)])$, where $m_1(x)$ and $m_2(x)$ are the values of metrics on the arc and $f[m_1(x), m_2(x)])$ is a function of combination metrics. $C(p_{a,c})$ is the set of combined-metrics of all edges and it can be reproduced by

$$C(p_{a,c}) = \begin{bmatrix} C_a \\ C_b \\ C_c \end{bmatrix} = \begin{bmatrix} m_1(a) & m_2(a) & f[m_1(a), m_2(a)] \\ m_1(b) & m_2(b) & f[m_1(b), m_2(b)] \\ m_1(c) & m_2(c) & f[m_1(c), m_2(c)] \end{bmatrix}$$

A synthesis $S[\cdot]$ is a set of binary operations applied to the values of the links combined-metrics along a path to obtain a resulting value that characterizes this path as far as the constraint imposed by the combined-metric is concerned. Four syntheses may be used: minimization, maximization, addition and multiplication. The synthesis to be used is metric dependent, e.g. the addition of links delay is chosen to evaluate the path delay, while the minimization of links is used to determine the path spare.

PA ranks all eligible paths from best to worst. The framework also introduces the concept of Hidden Hops, which make reference to the intermediate nodes of a directed path in the SN that is mapping a specific virtual link of a VNR. Note that the virtual links will also consume resources of all Hidden Hops on the paths.

In this type of algorithm each node decides on the best next hop to forward a packet independently from the decision of any other node. This may create a loop when, for example, a source node s has to reach destination node d, but two intermediated nodes x and y decide that the next hop is the other node. Loop Avoidance by the Destination (LADN) [15] is an implementation used by PA to avoid these loops in hop-by-hop routing algorithm. It is composed of four stages:

1. SEARCHPATH: it discovers all paths between each pair of SN nodes
2. SORTPATH: it selects only cycle-free paths
3. EVALUATEPATH: it characterizes each path based on the defined link parameters
4. ORDERPATH: it orders the paths according to the defined metrics and priorities

2.5. ALEVIN

Algorithms for Embedding Virtual Networks (ALEVIN) is a modular framework proposed by Virtual Network Resource Embedding Algorithms (VNREAL) project [16], a research on NV that creates a framework for VNE algorithms, allowing researchers to evaluate and compare solutions according to a wide set of criteria.

The aim taken by VNREAL is to provide an environment in which a large number of both SN and VNs can be created and embedded by using previously implemented VNE algorithms. The embedding is rated afterwards by user-defined metrics to compare different algorithms. ALEVIN is an implementation of these criteria.

2.5.1. Topology generation

Waxman model [17] is used by ALEVIN to generate the SN and all VNs. It has been widely used to generate random topologies for VNE simulations.

The nodes of a network are uniformly distributed in a plane and the model computes the probability of creating an edge between two nodes u and v with the following probability function

$$P(u,v) = \alpha e^{\frac{-d(u,v)}{\beta L}}$$

where $d(u,v)$ is the Euclidean distance between u and v, $0 < \alpha \leq 1$ is the average out-degree (the number of arcs incident from a node), $0 < \beta \leq 1$ is the average edge length and L is the maximum Euclidean distance between any two nodes.

A random number between 0 and 1 is generated and the edge is created if it is smaller than $P(u,v)$. A rise in the parameter α increases the probability of edges between any nodes in the graph, while an increase in β yields a larger ratio of long edges to short edges.

3. ALEVIN framework

ALEVIN is a Java-coded framework that handles several types of virtual embedding algorithms and arbitrary parameters for resources and demands. Such modularity allows researchers to add new algorithms and metrics. It works together with MATLAB, which contains the PA algorithm required to perform the embedding process. ALEVIN provides two ways to perform simulations:

- Graphical User Interface (GUI) [18] enables to visualize and handle the SN and arbitrary VNs as directed graphs
- Java-coded environment enables to create scenarios in order to do massive simulations. It does not have GUI, so the parameters are defined inside a Java-programmed code

ALEVIN can only work with static networks (offline algorithm), so a SN and VNRs must be defined previously. Neither the SN nor the VNRs can be modified when the embedding process is started, so it is mandatory to do another one if a new VNR is defined.

In the following sections the simulation environment is presented, and two ways to perform the simulations are described. The first one uses the GUI, and the second one describes the code-level application to perform scenarios, which is the method used to obtain the results of this thesis.

3.1. Simulation environment

ALEVIN tools needed for running simulation are available in an Ubuntu image, which is executed by virtualization software like *VMware Player*. The first step is to insert a new virtual machine. Select the *Home* tag, then *Open a Virtual Machine* and find the Ubuntu image (Ubuntu.vmx). Once the virtual machine has been inserted (Figure 4), click *Play virtual machine* to open it. The Figure 5 shows Ubuntu Operating System environment inside the virtual machine.

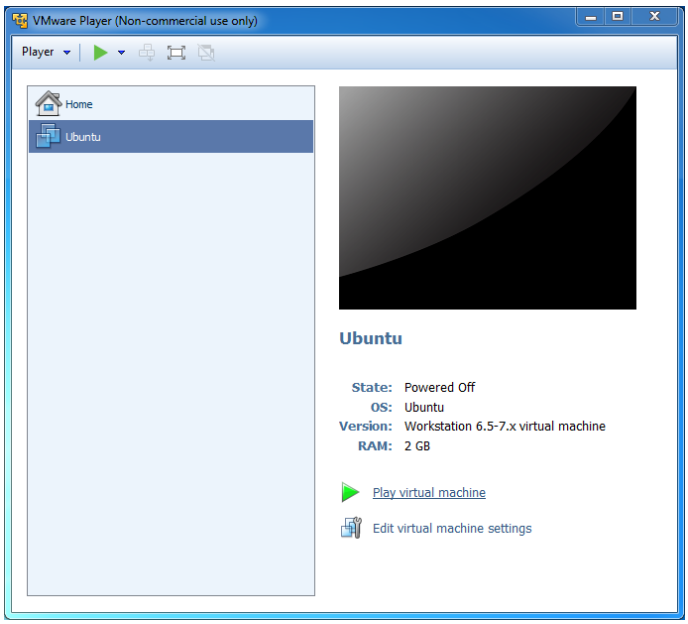

Figure 4. VMware Player

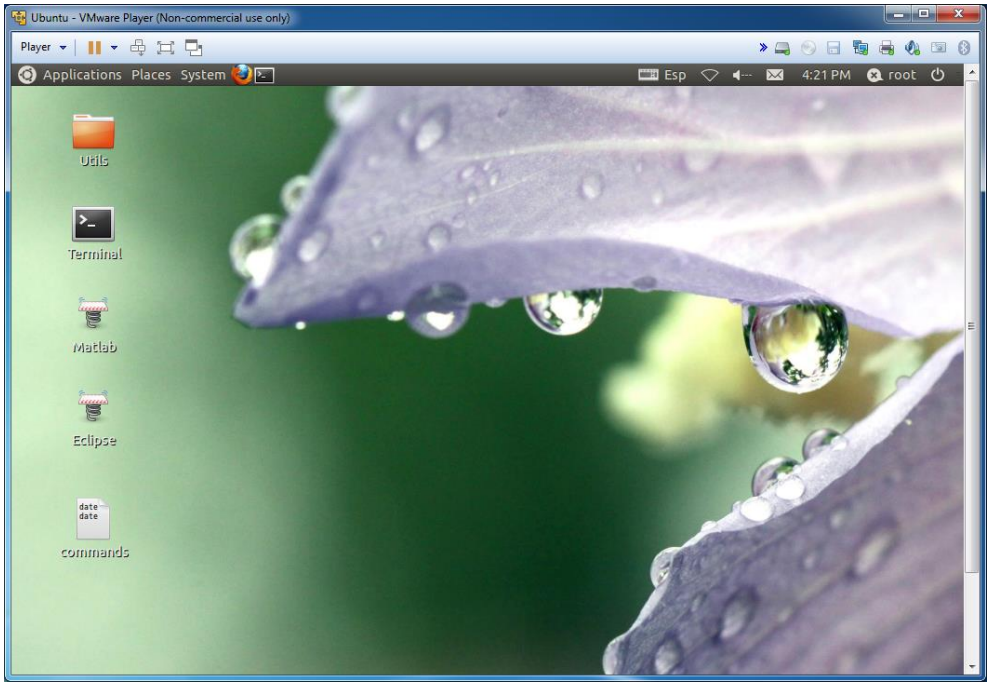

Figure 5. Ubuntu Operating System environment inside the virtual machine

The simulation process begins by opening Eclipse, which contains the ALEVIN project. Eclipse is an Integrated Development Environment (IDE) mainly programmed in Java and used to develop projects in several programming languages. With this structure, a Java programmer can easily modify the code or add new functionalities to the application. On the other hand, a user who does not dominate the Java programming language can still follow this guide to generate simulations.

3.2. Graphical User Interface

The graphical interface is opened by running the *Main* class located in *vnreal* package (Figure 6).

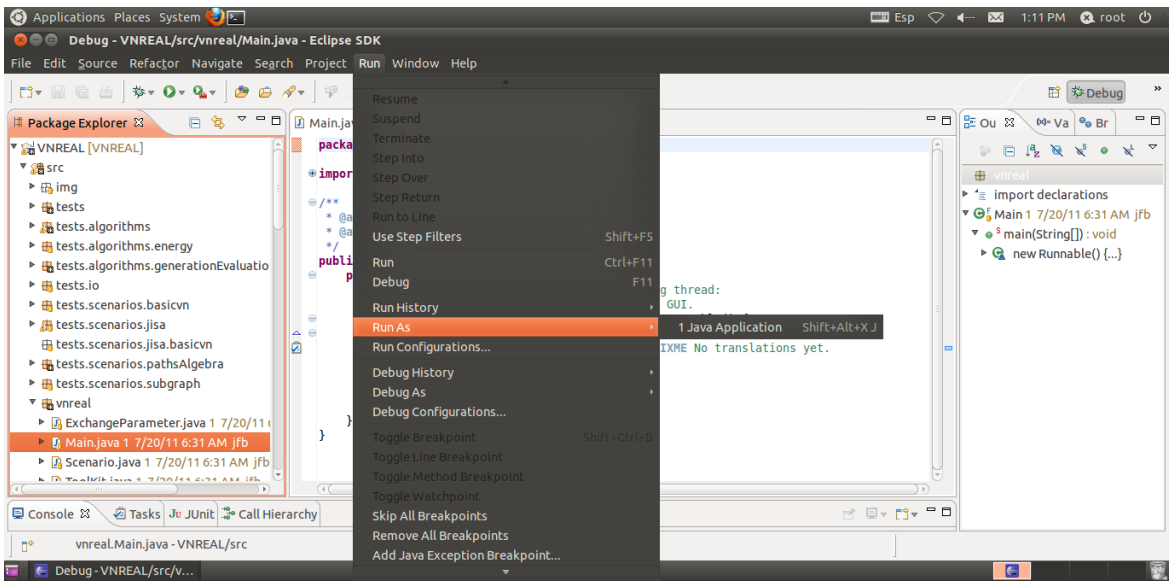

Figure 6. Running the GUI application

The window of the GUI is divided in three boxes:

- Main box: graphical representation of the SN and all VNs
- Right box: list of nodes and links, and their connections
- Box below: all messages about adding nodes, links, constraints, and running simulations

There are two forms to generate networks: manually and automatically.

3.2.1. Manual generation

In the manual generation, nodes, links and constraints are added one by one.

Click on *File / New empty scenario/layers* and insert the number of virtual networks. The main box is divided into one SN box and the number of VN boxes. Nodes and links can be inserted following these steps:

- Node: right-click on the appropriate place and choose *Create node*
- Link: select the desired nodes clicking the *Shift* key at the same time, right-click and select one of the two options (source and destination) depending on the desired direction of the link

In both cases (Figure 7), it is necessary to add a resource (SN) or a demand (VN).

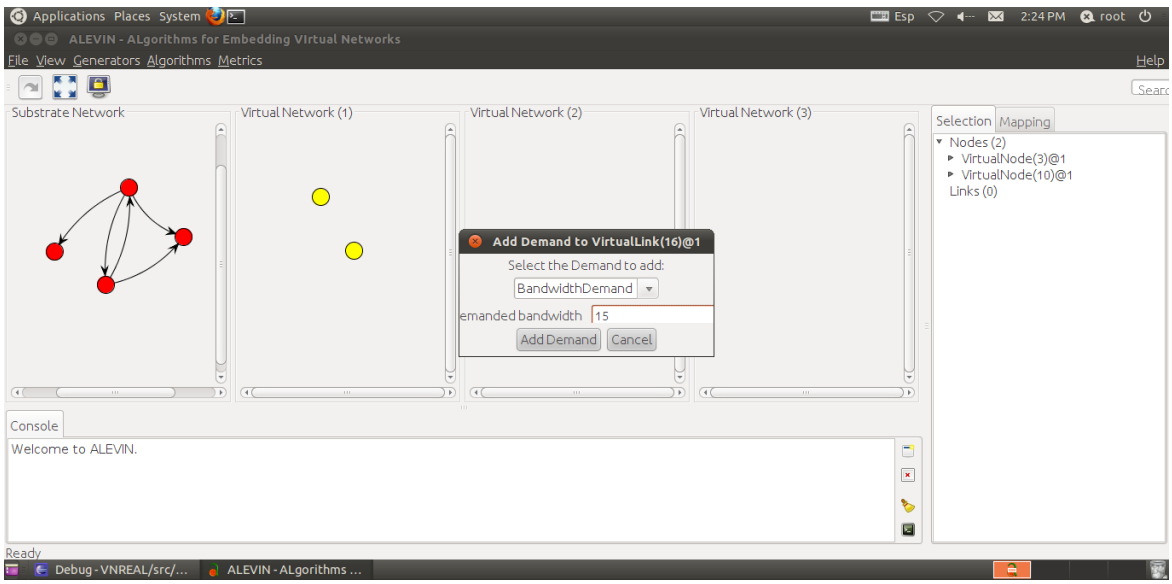

Figure 7. Adding a VN demand

3.2.2. Automatic generation

In the automatic generation, nodes, links and constraints are generated by the software.

Click on *Generators / Scenario Wizard* to add all necessary parameters for the generation (Figure 8 on left). Next, click on *Generators / Generate constraints* to add maximum values of parameters to SN resources and VN demands (Figure 8 on right).

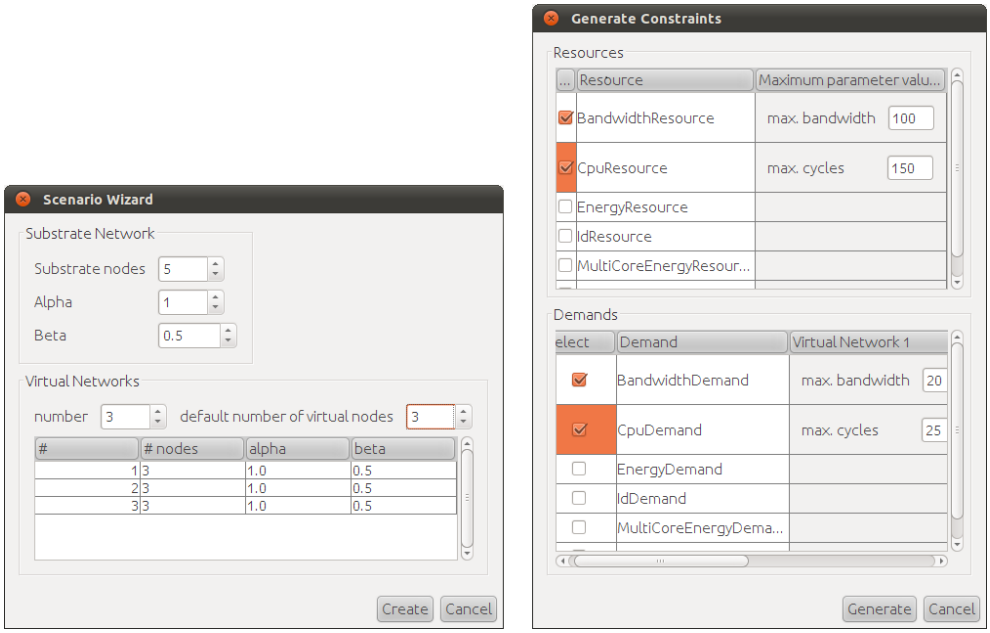

Figure 8. Generate scenario and Generate constraints

It generates all constraints randomly. The specific value of a constraint is showed in the *Selection* box on right when a node or link is selected.

3.2.3. Mapping and results

The next step is to choose the mapping algorithm from the *Algorithms* menu. The progress is shown in a pop-up window and when the algorithm finishes the *Console* box displays a message. The information of VN embedding is in the *Mapping* box. The results, which are values of several metrics, can be viewed in the *Metrics* menu.

3.3. Java-coded environment

As said, the ALEVIN framework allows running massive simulations. It has no GUI, so it includes the modification of several network parameters defined in Java-classes.

3.3.1. Execution of simulations

The class *AbstractLoadScenarioForPathsAlgebra* contains the parameters that must be modified in order to generate a simulation. It is located in *tests.scenarios.pathsAlgebra* package (Figure 9). The following parameters can be modified depending on the desired type of scenario:

- *numScenarios*: number of scenarios evaluated in a single simulation
- *numRunsPerScenario*: number of runs per each scenario
- *numSNodesArray*: number of nodes in the SN
- *numVNetsArray*: number of VN
- *numVNodesPerVNetArray*: number of nodes in the VN
- *rhoArray*: mean load of the SN
- *maxCPUresArray*: maximum CPU of SN nodes
- *maxBWresArray*: maximum BW of SN links
- *alphaArray*: alpha parameter of topology generation
- *betaArray*: beta parameter of topology generation

Note that the *rhoArray* is the percentage of SN resources demanded by all VNRs, e.g. if the number of VNRs is 10 and this parameter is 0.1, the mean demands of VNRs is the 10% of SN resources. For the same value of *rhoArray*, if the number of VNRs is 20, the mean demands will be also the 10%, so the demands of each VNR will be lower.

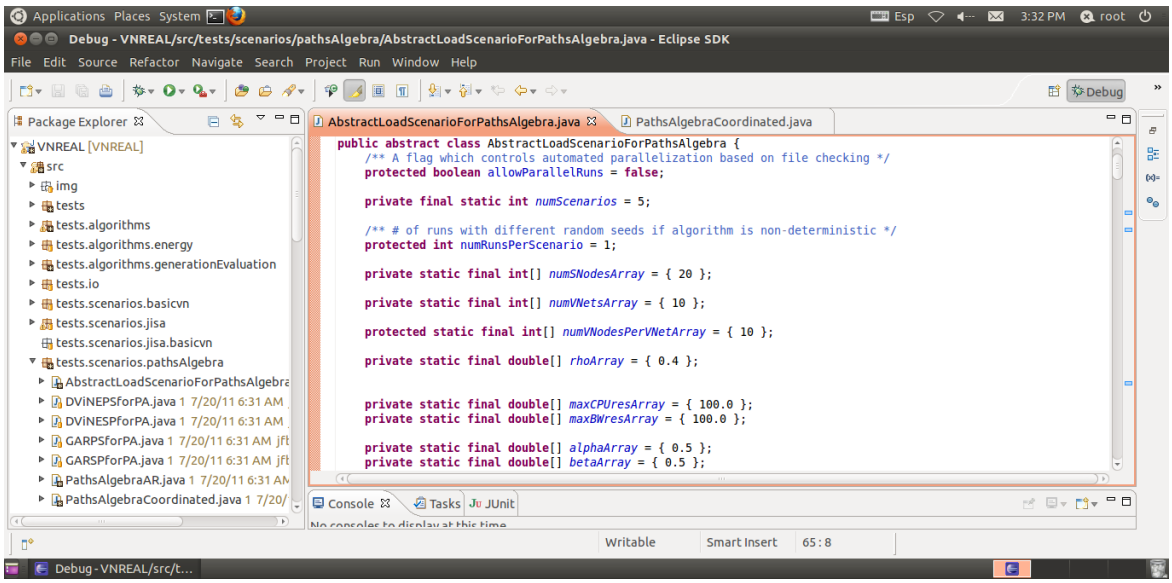

Figure 9. Simulation parameters

The generation of scenarios can be deterministic or random. The procedure used by ALEVIN to obtain one type of scenario or the other is by using a pseudorandom process [19]. A pseudorandom process is a process that appears to be totally random but it is not. To get a process with random output, the input should be random (not controlled by the user) like the current time, the current cycles of the CPU, the temperature of the processor, etc. On the other hand, in a deterministic process, given the same inputs, it produces the same outputs.

In the case of scenario generation, two lines must be modified. To set a random generation, the line *UniformStream.setSeed(System.currentTimeMillis());* must be inserted in both places (Figure 10), where *System.currentTimeMillis()* is the input. On the contrary, the deterministic generation is set by changing this input by a specific number.

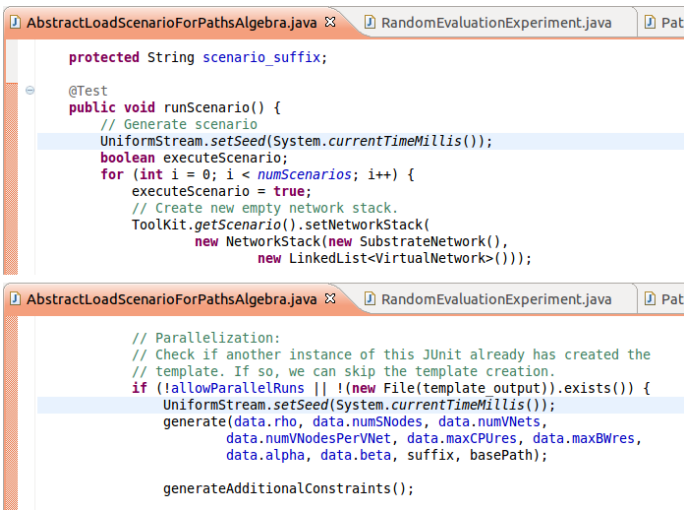

Figure 10. Deterministic and random scenario generation

Finally, an approach to resolve the VNE problem must be selected. ALEVIN has two algorithms:

- PA Coordinated (class *PathsAlgebraCoordinated*): it realizes a coordinated node and link mapping [20]. It is the approach used in this thesis
- PA Available Resources (class *PathsAlgebraAR*): it realizes the link mapping and then the node mapping [21]

Both classes are located in the previously mentioned package. They can be executed by running the corresponding *JUnit Test* (Figure 11).

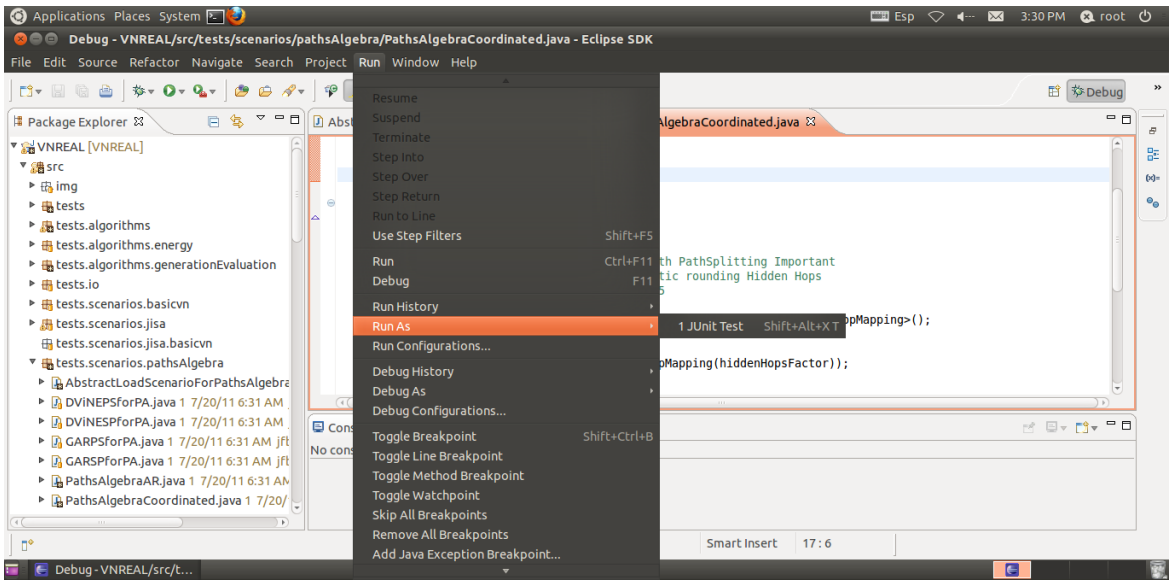

Figure 11. Running the PA Coordinated simulation

3.3.2. Generated files

The files are generated into two different folders. It is recommendable to empty them before the simulation execution in order not to mix different simulation files, with the exception of six scripts with extension *.sh* that must not be deleted from the first folder. The following are the most important generated files.

Files generated in */home/jfb/PathsAlgebra/Files/*:

- Information about the SN:
  - *substrateNetwork.dat*: adjacency matrix. The dimension of this matrix is nxn, where n is the number of nodes. Rows are source nodes and columns are destination nodes. For each pair of nodes the value is 1 if there is a link between them and 0 otherwise
  - *substrateMetric1.dat*: similar to adjacency matrix, but there is the value of BW between two nodes
  - *substrate*Metric2.dat: CPU values of each node
- Information about VNs:
  - *virtualHidden_x*: Hidden Hops demand
  - *virtualMetric1_x*: BW demands of the virtual request
  - *virtualMetric2_x*: CPU demands of the virtual request
  - *virtualRequest_x*: adjacency matrix of a virtual request

- Information about embedding:
    - *Virtual_to_Real_x*: virtual nodes of VN mapped into SN

Depending on the type of PA simulation (Coordinated or Available Resources), the following files are generated in */root/PathsAlgebraCoordinated/* or */root/PathsAlgebraAR/*:

- *README_x*: file with information about the resources of the scenario
- *Scenario-template_x.xml*: file with the scenario before the mapping
- *Scenario-mapped_x.xml*: file with the scenario after the mapping

The last two files can be opened in the GUI by clicking *File / Import* and selecting the desired XML-file. They can be processed into the graphical interface as explained.

3.3.3. Evaluation of Paths Algebra

The framework has a class called *RandomEvaluationExperiment* to evaluate several metrics which is located in the *tests.algorithms.generationEvaluation* package.

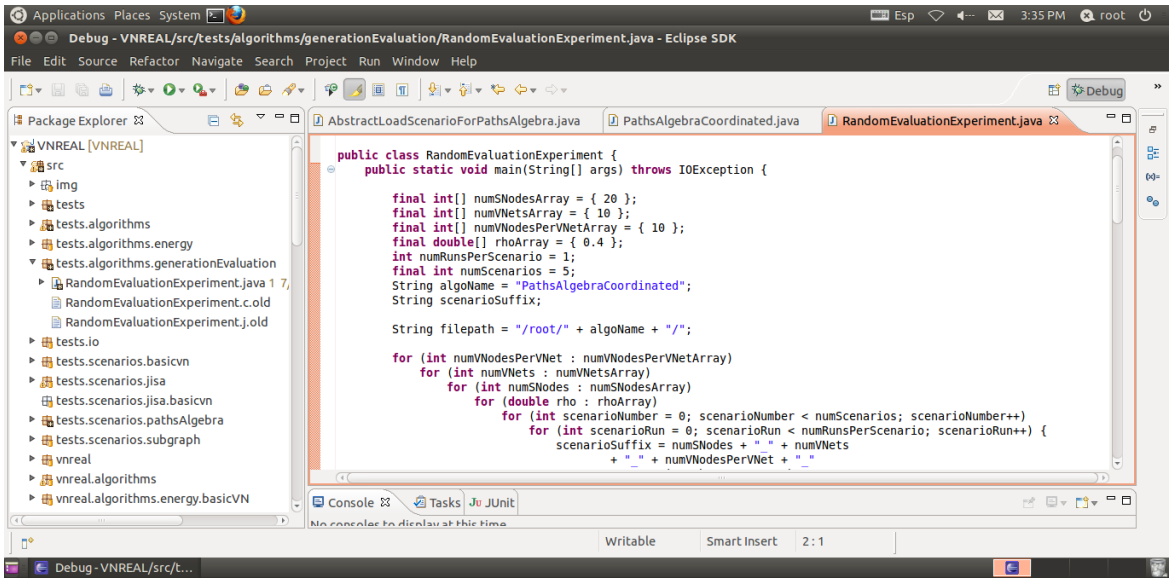

Figure 12. Evaluation class

The results are generated using *Scenario-mapped_x.xml* files, so the parameters (Figure 12) must be consistent with the values defined in the class that contains the simulation parameters, explained previously. As said, the modularity of PA allows several metrics that can be added in this file in order to be evaluated. Each metric is defined in a different class, all of them located in the *vnreal.evaluations.metrics* package, which can be added in the evaluation file as shown in Figure 13.

The execution of the evaluation (*Run* menu) generates one evaluation file per scenario. The files have a *.csv* extension that can be opened with a spreadsheet application like Microsoft Excel or OpenOffice Calc.

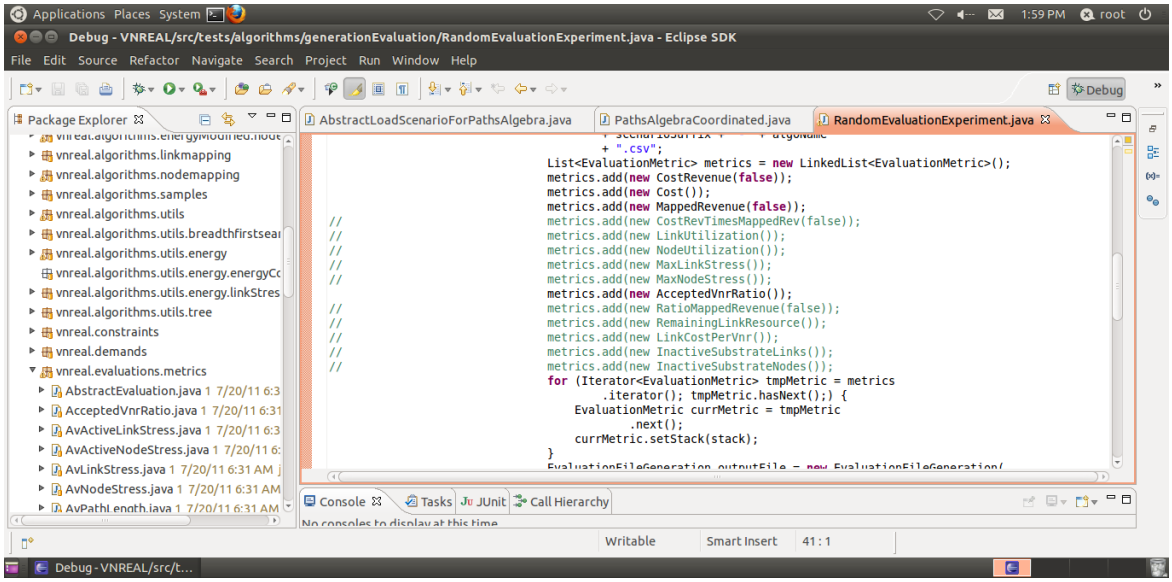

Figure 13. Evaluation metrics

4. Simulation context

This chapter consists in exposing the context of the simulations done. In the last two sections, the metrics used to evaluate results and an example of how to calculate these metrics are explained.

4.1. Scenario of previous work

The previous work [2] proposed the use of new linear and non-linear parameters such as packet loss rate, availability, and energy consumption. The author used some constraints in order to maximize or minimize them, so several types of scenarios were analyzed. However, these metrics are not dealt with in this thesis, nor the constraints defined there, only the general simulation is studied.

Table 1 shows the parameters chosen for running the simulations. These values are widely used in the field of simulating VNE approaches, so they can be evaluated and compared with other methodologies.

Parameter	**Java parameter**	**Value**
Nodes in the SN	*numSNodesArray*	20
Number of VNRs	*numVNetsArray*	10
Nodes in each VN	*numVNodesPerVNetArray*	10
Loads	*rhoArray*	0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99
Number of scenarios	*numScenarios*	20

Table 1. Parameters of previous work

VNs require more resources (CPU and BW) of the SN when the load is increased. From this assumption, a statement can be easily proven: the higher the load, the lower the number of mapped VNs.

Using the same PA approach (Coordinated node and link mapping) together with the parameters of previous work, new simulations are executed in order to validate their results. Results from new simulations are expected to be similar, but not exactly the same because of the randomness when generating scenarios. Thus, if the graphics follow the same tendency, some premises will be verified:

1. Both simulations will have been done with the same parameters and using the same PA method
2. Results of this approach will be more truthful because these simulations will have a higher number of tested scenarios
3. New approaches can be tested and compared with previous work

4.2. Proposed scenario

The new proposed scenario is based on increasing the number of VNRs for only one low load to get better performances. In order to understand how to achieve better results with this method, the VNE problem can be explained as the Knapsack problem [22]: given a set of items, each with a mass and a value, determine the items to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible. This concept can be extrapolated to the VNE problem with the following changes in the naming:

- Set of items: set of VNRs
- Mass of each item: demands (CPU and BW) of each VNR
- Total weight of knapsack: total resources of the SN
- Value: one or more metrics that must be minimized or maximized

By using this comparison, the difference between both approaches can be easily understood. In the previous work, the author studied the behavior of the knapsack (SN) when the items (VNRs) had higher weights (demands). On the other hand, the proposed scenario in this thesis maintains the demands and runs simulations by changing the number of VNRs. Extrapolated from the Knapsack problem; it can be seen as putting small items into the knapsack, in principle with less effort than when introducing larger items.

Figure 14 shows both behaviors. Considering the size of VNs is equal (from a statistical point of view), the SN on the left can only map a single VN, leaving many resources unassigned, while on the right there are smaller VNs that fill the resources offered by the SN more efficiently.

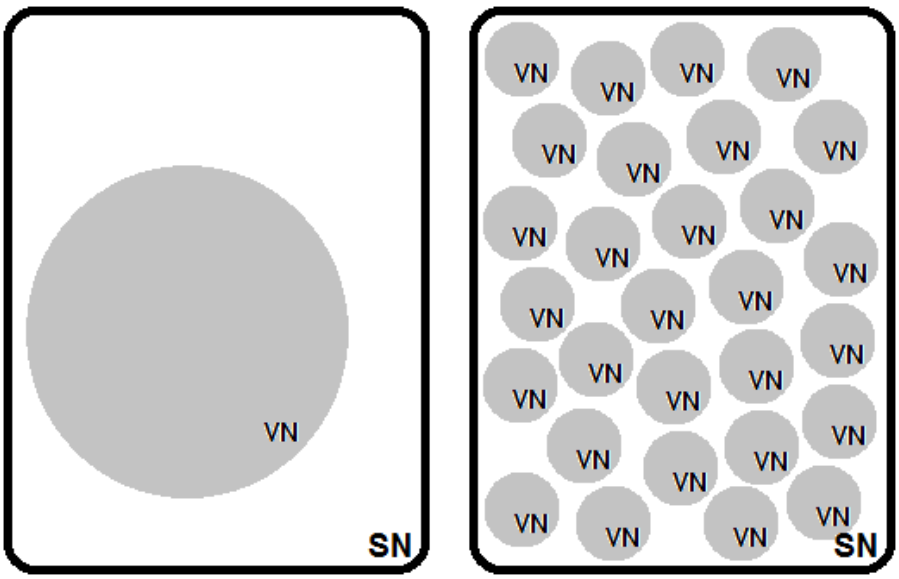

Figure 14. Comparing the VNE problem with the Knapsack problem

The fact of assigning smaller VNs is also regarded as more realistic by the business model, as InPs do not often have clients whose demands fill almost all resources of the infrastructure, so the second approach is better suited to the current specifications. Table 2 shows the parameters used in new simulations.

Parameter	Java parameter	Value
Nodes in the SN	*numSNodesArray*	20
Number of VNRs	*numVNetsArray*	10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99
Nodes in each VN	*numVNodesPerVNetArray*	10
Loads	*rhoArray*	0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99
Number of scenarios	*numScenarios*	20

Table 2. Parameters of proposed scenario

Note that to increase the load by raising the number of VNs, two parameters must be modified: *rhoArray* and *numVNetsArray*. The first indicates the total load of the SN, whereas the second is the number of VNRs. The simulations are done by using each pair of these values, i.e. in the first simulation there are 10 VNRs and a load of 0.1; in the second, 20 VNRs and 0.2, and so on. Using these values the demand of a VN in each simulation is always equal because for all cases the load of each one is 0.01, obtained by dividing the total load by the number of VNRs.

4.3. Low load scenario

The low load scenario is based on raising the number of VNRs but maintaining the load. Table 3 shows the parameters used in this approach.

Parameter	Java parameter	Value
Nodes in the SN	*numSNodesArray*	20
Number of VNRs	*numVNetsArray*	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Nodes in each VN	*numVNodesPerVNetArray*	10
Load	*rhoArray*	0.1
Number of scenarios	*numScenarios*	20

Table 3. Parameters of low load scenario

This scenario was not included in the objectives, but its behavior is interesting to know. The fact of raising only the number of VNRs for the same load implies that the mapped VNs will only fill a 10% of the SN, so each one will have less demands. For that reason, this approach cannot be compared with the previous scenarios.

Almost all results of this approach are expected to remain constant for all VNRs because of the constant load.

4.4. Metrics

There are several metrics used in the literature [12][14][23], most of them also used by ALEVIN. They are used to compare the first two approaches in order to know which the best one is. The following metrics are given directly by evaluation files:

- Cost is the amount of substrate resources that are used to map VNs. The Cost is determined by summing up all resources of the SN that have been reserved for the VNRs
- Revenue is the sum of virtual resources that are requested by the mapped VNs
- Cost/Revenue is a relation used to compare algorithms with respect to their embedding results. The higher the value, the more resources are needed to embed the VNs, so the perfect embedding is achieved when the division equals 1
- Acceptance Ratio is the percentage of VNs that have been completely embedded

These are also used to generate other proposed metrics that will serve to compare both approaches more precisely:

- Number of mapped VNs measures the number of VNs that have been completely embedded. It is given by the Acceptance Ratio multiplied by the number of initial VNRs
- Cost per mapped VN measures the mean Cost to map a single VN. It is calculated by dividing the total Cost of the embedding by the number of mapped VNs
- Revenue per mapped VN measures the mean Revenue of all mapped VNs. It is calculated in the same way as the previous metric, but using the Revenue

The Cost and the Revenue are calculated by summing CPU (cycles per second) and BW (bits per second), so a standardization conversion is necessary in order to sum both in the SN and in the VNs. The conversion factor equals to 1 is used in the literature [24], as well as by ALEVIN evaluation.

4.5. Numerical example

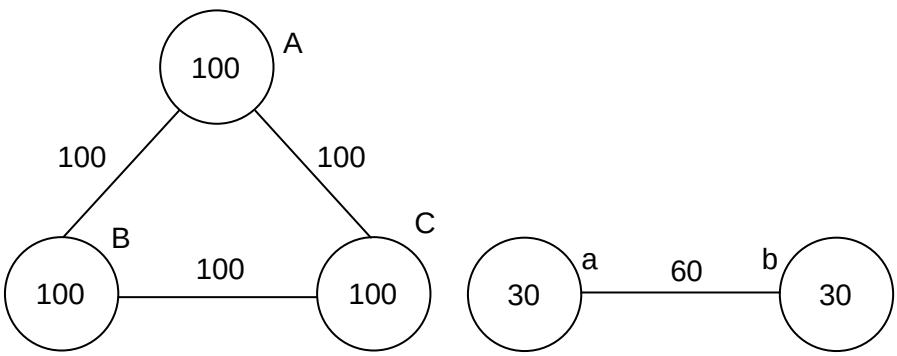

Figure 15. Example of a SN (on left) and a VN (on right)

A numerical example is presented in order to understand how the metrics are calculated. Given the SN and the VN of the Figure 15 in which the numbers inside the nodes are the CPU and the numbers over the links are the BW (bidirectional), the VN is mapped to the SN according the following schema.

$VNode(a) \rightarrow SNode(B)$

$VNode(b) \rightarrow SNode(C)$

$VLink(a \rightarrow b) \rightarrow SLink(B \rightarrow C)$

The available resources after the mapping are shown in the Figure 16.

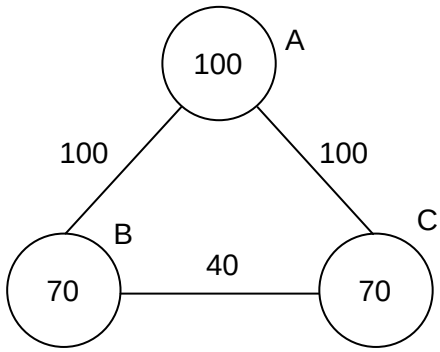

Figure 16. Available resources of the SN after the first mapping

This mapping has the following Cost and Revenue values (for the Cost metric, $CPU(X)$ and $BW(X \rightarrow Y)$ refers to the SN resources used to map the VN):

$Cost_1 = CPU(B) + CPU(C) + BW(B \rightarrow C) = 30 + 60 + 30 = 120$

$Revenue_1 = CPU(a) + CPU(b) + BW(a \rightarrow b) = 30 + 60 + 30 = 120$

$$\frac{Cost_1}{Revenue_1} = \frac{120}{120} = 1$$

Consider a new VN with the same demands to be mapped in the SN using the same substrate nodes as the first embedding. As the substrate link $SLink(B \rightarrow C)$ does not have sufficient capacity, the algorithm must map the virtual link using the other path of the SN. The VN is mapped to the SN according to the following scheme:

$VNode(a') \rightarrow SNode(B)$

$VNode(b') \rightarrow SNode(C)$

$VLink(a' \rightarrow b') \rightarrow SLink(B \rightarrow A \rightarrow C)$

Figure 17 shows the available resources after the second mapping. Note that the substrate node A is a Hidden Hop and also consumes resources for forwarding packets.

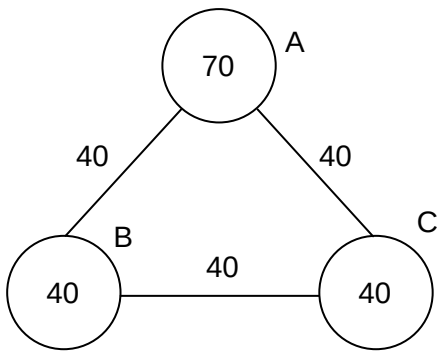

Figure 17. Available resources of the SN after the second mapping

The second mapping has the following Cost and Revenue values:

$Cost_2 = CPU(B) + CPU(A) + CPU(C) + BW(B \rightarrow A) + BW(A \rightarrow C)$
$= 30 + 30 + 30 + 60 + 60 = 210$

$$Revenue_2 = CPU(a') + CPU(b') + BW(a' \rightarrow b') = 30 + 60 + 30 = 120$$

$$\frac{Cost_2}{Revenue_2} = \frac{210}{120} = 1{,}75$$

The previous metrics are particular for each mapping. The general metrics are calculated when the embedding process finishes. For this scenario, the following values are obtained:

$$Cost = Cost_1 + Cost_2 = 120 + 210 = 330$$

$$Revenue = Revenue_1 + Revenue_2 = 120 + 120 = 240$$

$$\frac{Cost}{Revenue} = \frac{330}{240} = 1{,}375$$

$$Acceptance\ Ratio = 100\%$$

$$Mapped\ VNs = 2$$

$$Cost\ per\ mapped\ VN = \frac{Cost}{Mapped\ VNs} = \frac{330}{2} = 165$$

$$Revenue\ per\ mapped\ VN = \frac{Revenue}{Mapped\ VNs} = \frac{240}{2} = 120$$

5. Results

In this chapter there are the tables that contain the mean values of all simulations and the corresponding graphics. First, there is the old approach extracted from previous work, then the results of new approach, and finally the results of the low load scenario. The numerical results of each simulation are in the Appendix.

5.1. Validation of previous work

In this section there are the results of the previous work (Table 4) in which only the Cost/Revenue and the Acceptance Ratio were added to the document, and the new values of the validations obtained in this thesis (Table 5). As said, the randomness in the scenario generation implies different values compared to the previous ones.

Load	VNRs	C/R	Acc. Ratio
0,1	10	1,75	85,00
0,2	10	1,79	60,50
0,3	10	1,82	42,50
0,4	10	1,85	30,00
0,5	10	1,86	23,50
0,6	10	1,92	17,50
0,7	10	1,95	14,00
0,8	10	1,93	11,00
0,9	10	1,93	8,50
0,95	10	1,93	7,00
0,99	10	1,94	6,50

Table 4. Results of previous work

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map.VNs	C/Map. VN	R/Map. VN
0,1	10	682,60	397,62	1,71	67,00	6,70	102,09	59,60
0,2	10	1254,90	708,56	1,79	60,50	6,05	209,27	117,25
0,3	10	1295,41	713,81	1,83	38,00	3,80	348,31	189,82
0,4	10	1427,72	779,20	1,83	32,00	3,20	445,72	242,79
0,5	10	1347,53	726,04	1,88	24,00	2,40	577,55	307,47
0,6	10	1477,07	770,66	1,93	19,50	1,95	711,33	367,71
0,7	10	1181,30	614,52	1,95	13,50	1,35	826,91	421,30
0,8	10	1205,97	623,40	1,95	11,50	1,15	987,10	505,60
0,9	10	928,05	478,77	1,93	7,50	0,75	928,05	478,77
0,95	10	1105,54	568,63	1,95	7,00	0,70	1032,42	528,47
0,99	10	1213,45	632,44	1,94	8,50	0,85	952,58	486,57

Table 5. Validation results

For the graphics of Cost/Revenue and Acceptance Ratio, the dotted line corresponds to the previous work and the solid line, to the validations.

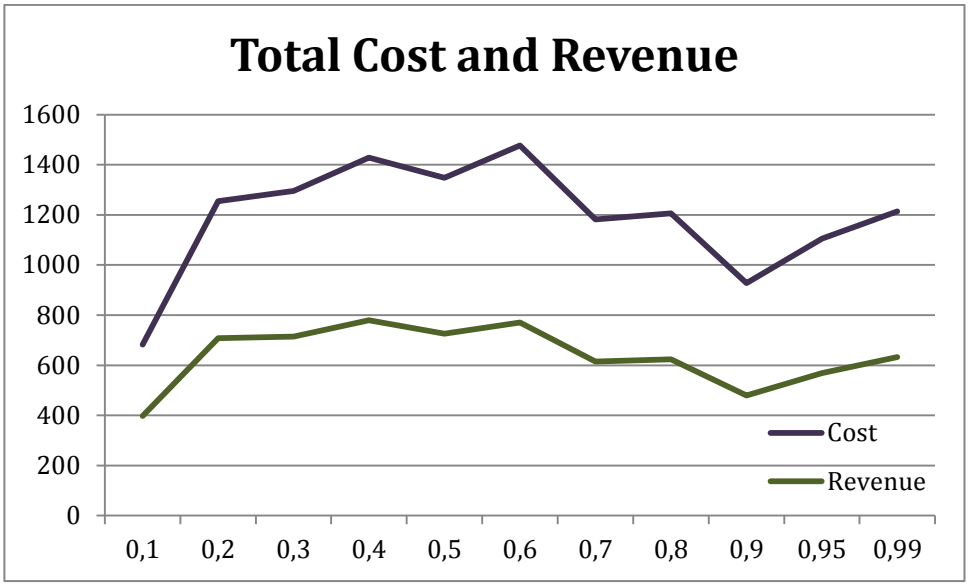

Figure 18. Validation scenario: Total Cost and Revenue

The graphic in Figure 18 has the total Cost and Revenue of the validation simulations. For low loads (0.2 to 0.6) the total Cost and Revenue remain approximately constant, while for higher loads, the values are lower. This behavior may be due to the algorithm is only able to assign few VNs: these have a high demand, but the fact that there are few mapped VNs implies a lower total Cost and Revenue.

The Cost/Revenue graphic (Figure 19) shows a growing tendency. This means that, as the load increases, the mapping becomes more difficult. For example, for higher loads the value is approximately 2, so the fact of mapping a VN with a certain demand implies that the resources used on the SN is twice the demand.

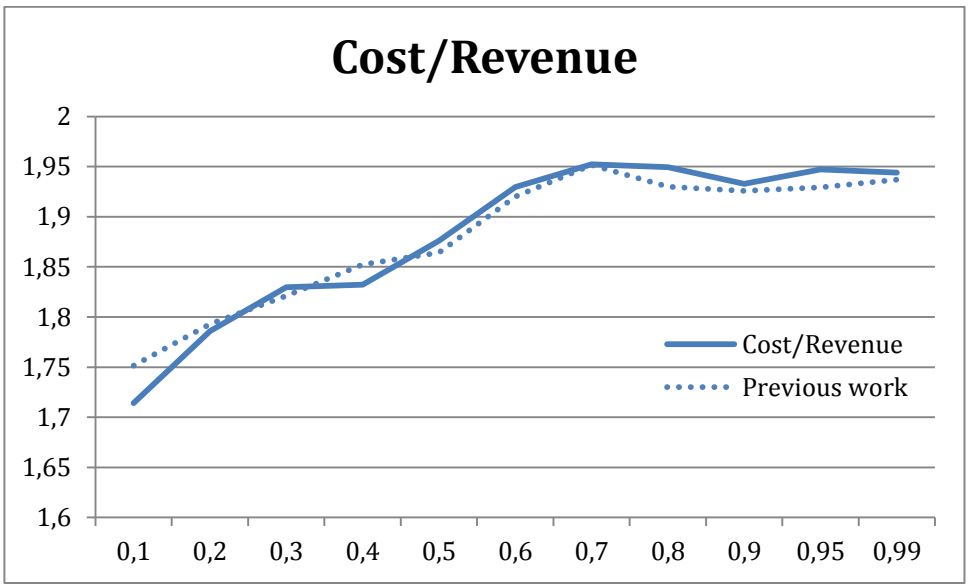

Figure 19. Validation scenario: Cost/Revenue

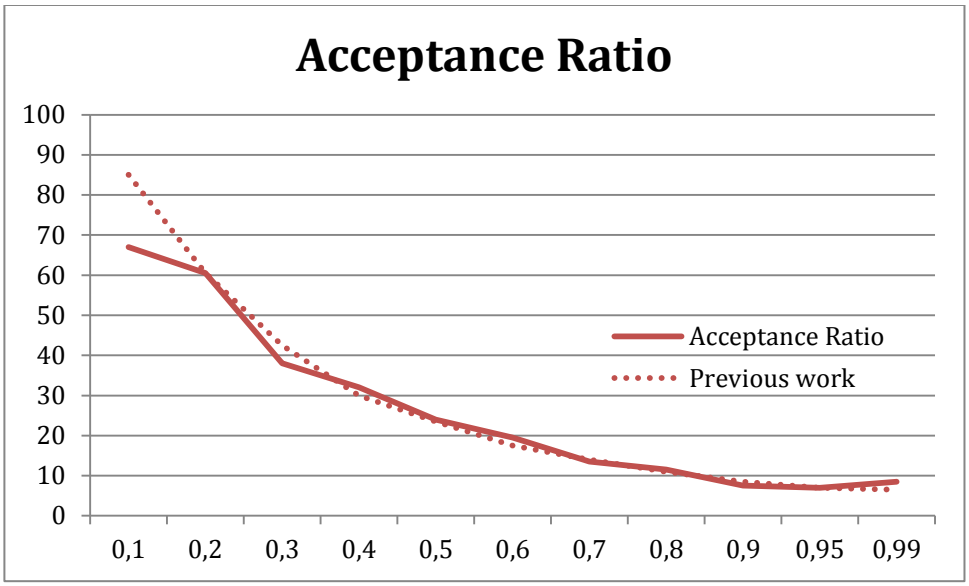

Figure 20. Validation scenario: Acceptance Ratio

The Acceptance Ratio graphic (Figure 20) shows a decreasing tendency, which has a logical relation with the Cost/Revenue graphic: this type of scenario, in which the number of VNRs is constant for all loads, implies a decrease of Acceptance Ratio when the load increases.

The graphic in the Figure 21 shows the number of VNs mapped for each load. It has the same tendency as the previous one, due to the constant number of VNRs. For a load higher than or equal to 0.9, the number of mapped VNs is between 0 and 1, so it is possible that the algorithm cannot assign any VN.

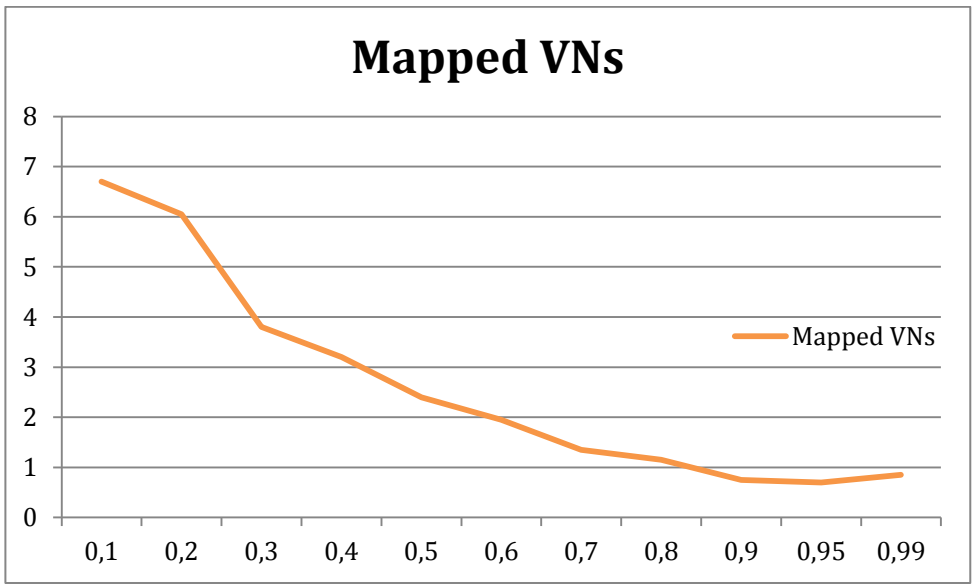

Figure 21. Validation scenario: Mapped VNs

Finally, the last graphic (Figure 22) combines the Total Cost and Revenue and the number of mapped VNs. By this one, the behavior shown in the first graphic can be viewed from another perspective that will help to understand why the Cost/Revenue has

a growing tendency. The Cost per mapped VN has a higher slope than the Revenue per mapped VN, so the division of them (Cost/Revenue) will have a growing tendency. Moreover, it also shows that a VN with higher demands carries a higher Cost, so it is harder to map.

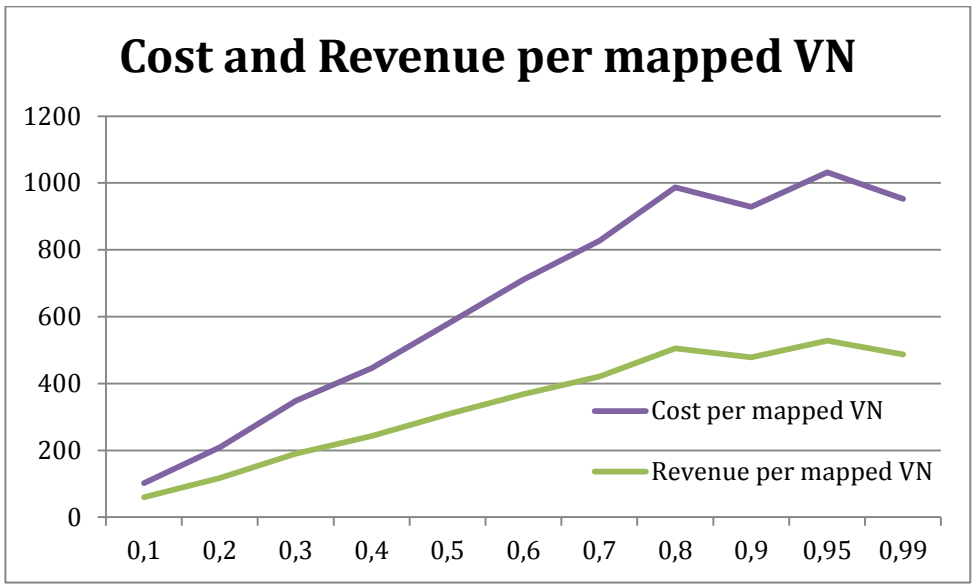

Figure 22. Validation scenario: Cost and Revenue per mapped VN

5.2. Results of proposed scenario

The new approach is based on raising the number of VNRs instead of the load per each VN. Table 6 shows new approach's results. Note that for increasing the total load of the SN without increasing the demands of each VN, the load and the number of VNRs must be increased.

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	10	682,60	397,62	1,71	67,00	6,70	102,09	59,60
0,2	20	1144,90	666,31	1,72	58,00	11,60	98,67	57,47
0,3	30	1485,49	860,35	1,72	47,17	14,15	105,54	61,20
0,4	40	1698,31	950,63	1,78	38,88	15,55	108,24	60,65
0,5	50	2002,76	1131,28	1,80	35,80	17,90	115,22	63,91
0,6	60	2139,77	1203,91	1,80	31,75	19,05	114,75	63,66
0,7	70	2136,69	1189,56	1,81	26,43	18,50	116,39	64,41
0,8	80	2144,31	1198,97	1,81	22,94	18,35	118,06	65,29
0,9	90	2298,03	1289,61	1,79	21,33	19,20	120,53	67,38
0,95	95	2305,39	1296,20	1,80	20,79	19,75	119,25	66,23
0,99	99	2171,27	1214,79	1,80	18,64	18,45	119,95	66,40

Table 6. Results of proposed scenario

From a mathematical point of view, the total load increases in the same way for both old and new cases, so some results are compared with the previous validation results. The solid line corresponds to the new approach and the dotted line, to the validations.

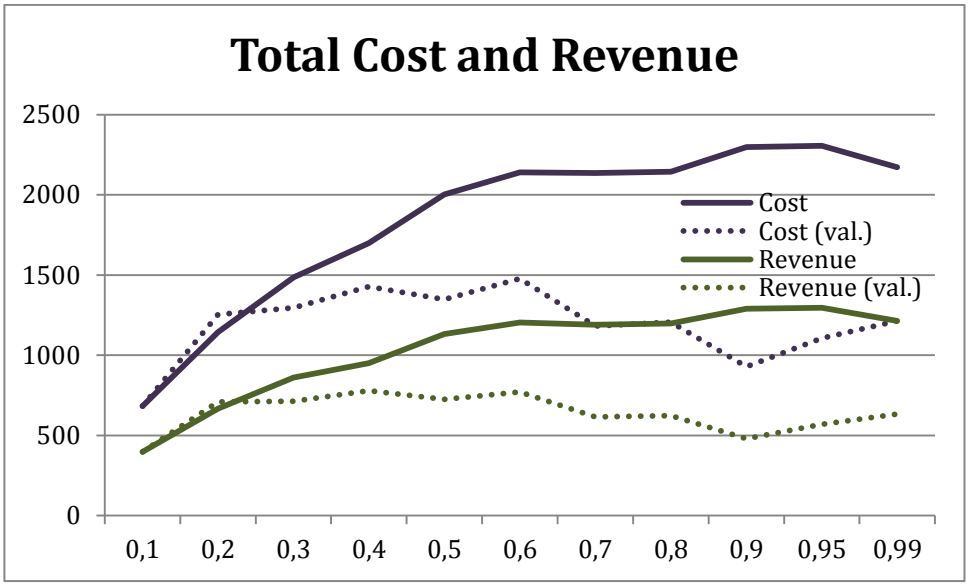

Figure 23. Proposed scenario: Total Cost and Revenue

Both the total Cost and the total Revenue (Figure 23) are higher than the previous approach. This behavior means a greater SN utilization when the VNs have less demands. The fact that the SN has less resources used when VNs are larger is explained by using the Figure 14 in the section 4.2.

The Cost/Revenue (Figure 24) is lower than the previous approach for each load, so with respect to this metric, the new approach has better performances. Retrieving the comparison with the Knapsack problem, the results demonstrate that the fact of introducing smaller items (VNs) into the knapsack (SN) is easier than introducing bigger ones, and also has better results. The Cost/Revenue only increases between the loads 0.3 and 0.5, whereas the Total Cost and Revenue does not have a strange behavior for these values.

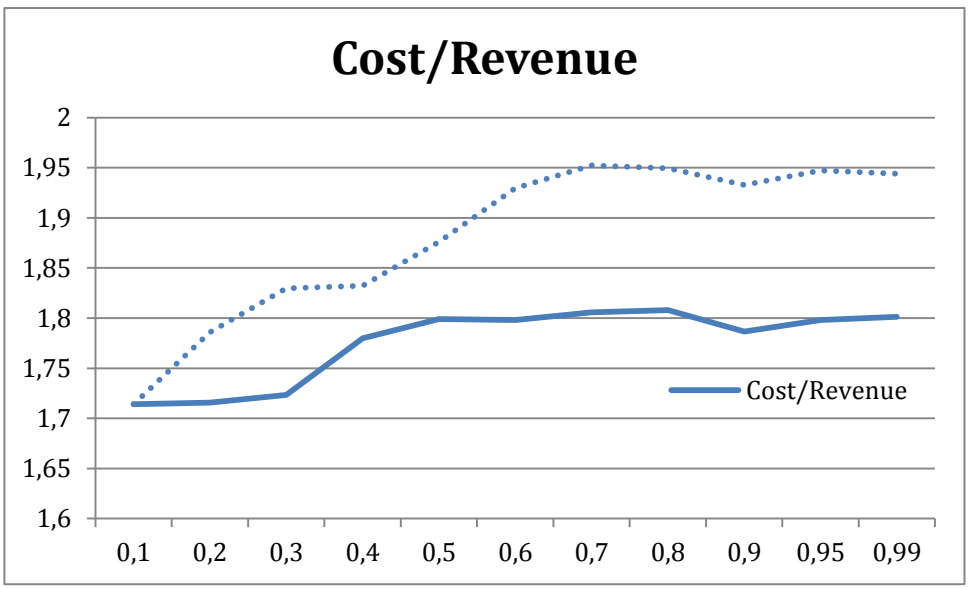

Figure 24. Proposed scenario: Cost/Revenue

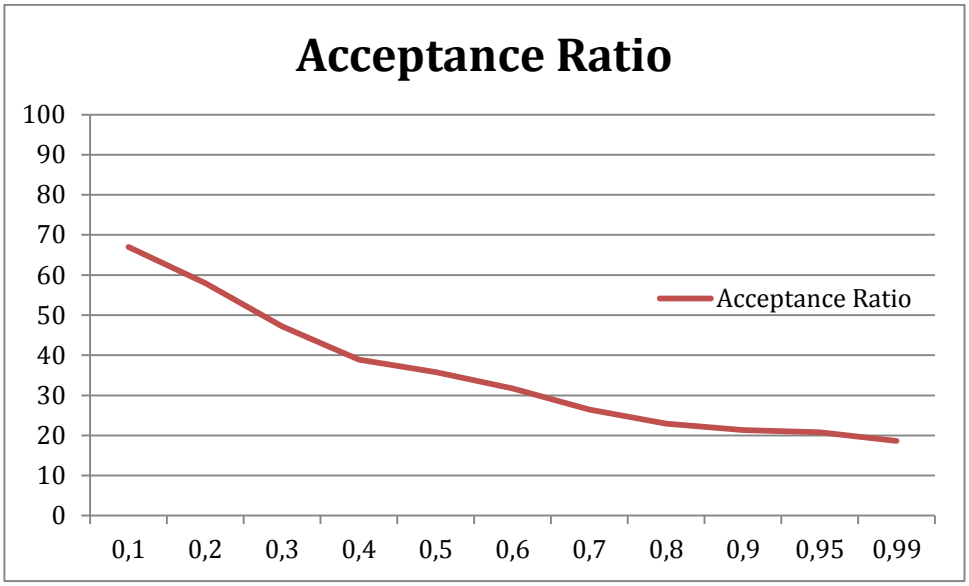

Figure 25. Proposed scenario: Acceptance Ratio

Like in the previous work, the Acceptance Ratio (Figure 25) has a decreasing tendency, but both old and new approaches cannot be compared because in the first case the number of VNRs is constant for all loads, whereas in this case the number of VNRs is increased.

Although the Acceptance Ratio decreases, the number of Mapped VNs (Figure 26) increases up to 0.6. From this load, the number of accepted VNs is stable between 18 and 20 VNs (approximately), so 20 is considered as the maximum number of assignments in this type of scenario. As seen previously, the Total Cost and Revenue graphic (Figure 23) follows the same tendency of the Mapped VNs one. This behavior occurs because all VNs have the same demands and the total Cost and Revenue are proportional to the number of allocated VNs.

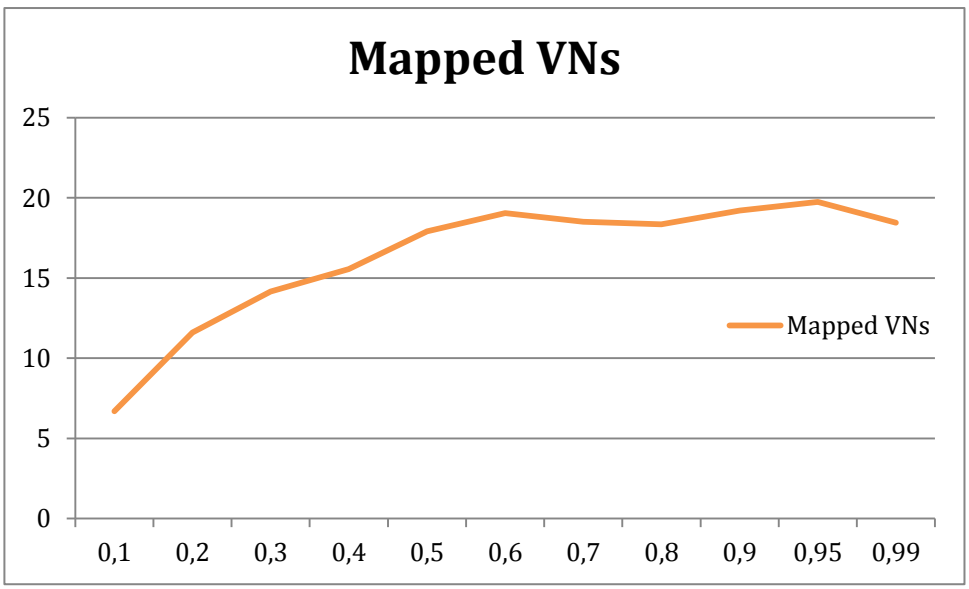

Figure 26. Proposed scenario: Mapped VNs

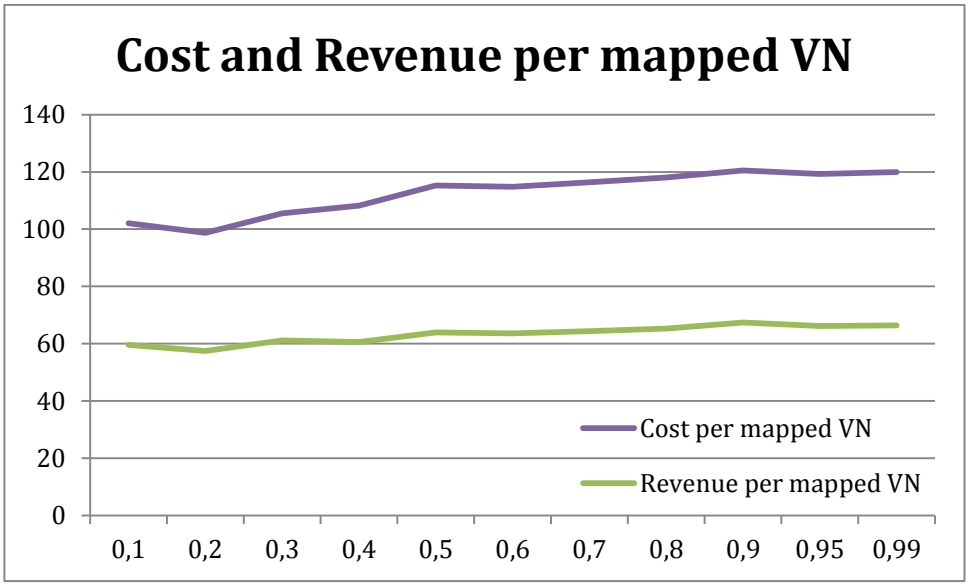

Figure 27. Proposed scenario: Cost and Revenue per mapped VN

Finally, the Cost and Revenue per mapped VN graphic (Figure 27) cannot be compared with the previous approach because the values differ greatly. Regarding the Revenue, it can be considered as constant because all networks have the same demands, from a statistical point of view. On the other hand, the Cost has a slightly increasing: when the number of mapped VNs increases, the fact of embedding new VNs has a higher Cost.

5.3. Results of low load scenario

The low load scenario is based on maintaining the same load and raise the number of VNRs. Table 7 shows the results obtained for this scenario.

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	10	682,60	397,62	1,71	67,00	6,70	102,09	59,60
0,1	20	741,14	429,26	1,73	71,25	14,25	49,41	28,61
0,1	30	703,89	408,98	1,71	70,00	21,00	33,46	19,53
0,1	40	701,23	406,93	1,73	69,00	27,60	25,61	14,79
0,1	50	658,36	385,37	1,70	65,60	32,80	19,99	11,77
0,1	60	645,77	380,78	1,69	65,00	39,00	16,54	9,79
0,1	70	692,41	401,23	1,72	69,14	48,40	14,33	8,33
0,1	80	681,50	399,73	1,70	68,44	54,75	12,48	7,33
0,1	90	645,43	377,31	1,70	64,11	57,70	11,18	6,56
0,1	100	717,67	417,46	1,73	71,30	71,30	10,11	5,86

Table 7. Results of low load scenario

This scenario cannot be compared with the previous ones because the total load remains equal to 0.1.

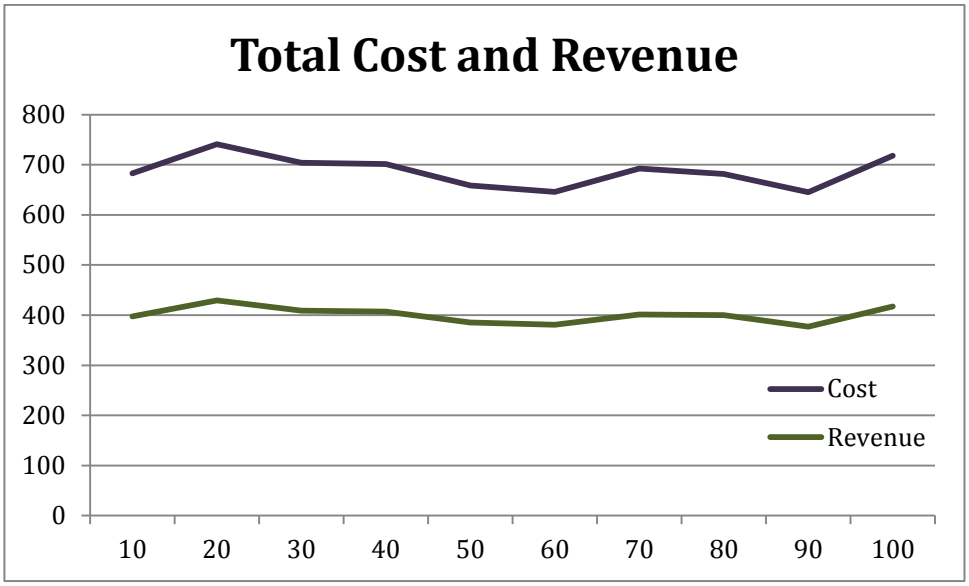

Figure 28. Low load scenario: Total Cost and Revenue

Figure shows the Total Cost and Revenue of this scenario. Firstly, as the load of the SN is constant, the demands are proportional to this load, so the total Revenue also remains constant. Regarding the total Cost, it is also constant, so the fact of assigning more VNs in this type of scenario does not mean an additional Cost. As the Cost and Revenue remain constant, Cost/Revenue (Figure 29) is also constant for all VNRs.

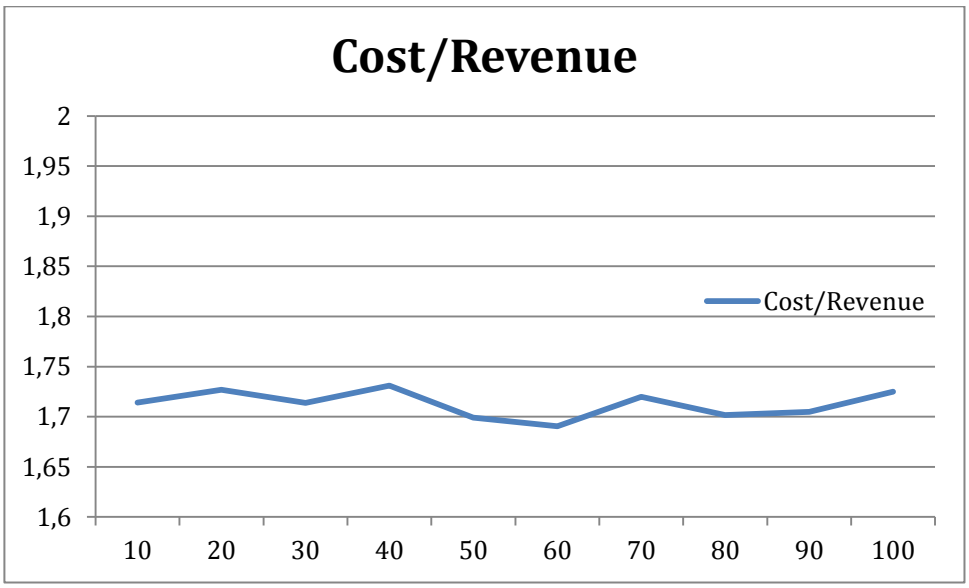

Figure 29. Low load scenario: Cost/Revenue

The Acceptance Ratio (Figure 25) also remains constant. This graphic is studied together with the number of Mapped VNs (Figure 26). As the first is constant, the second increase due to the increasing of the VNRs.

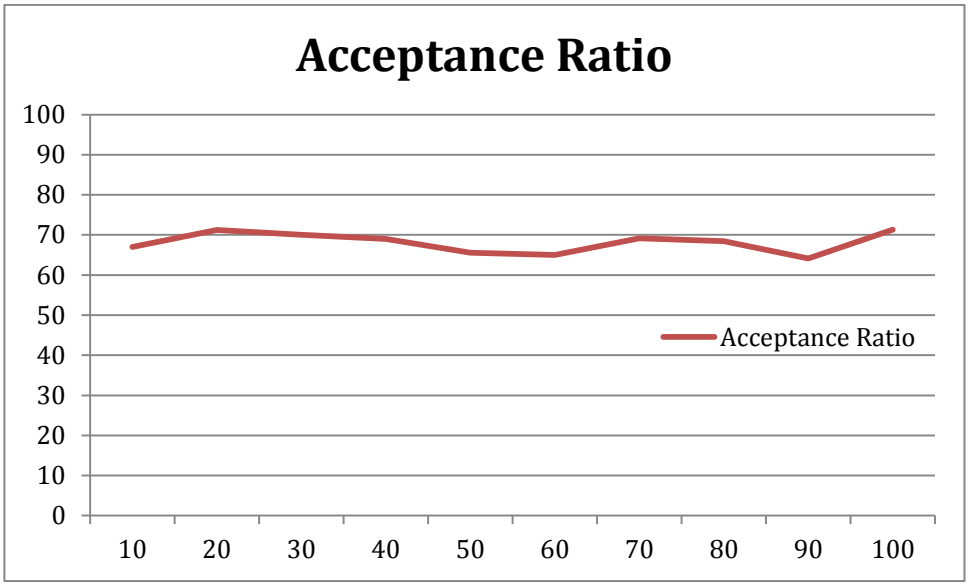

Figure 30. Low load scenario: Acceptance Ratio

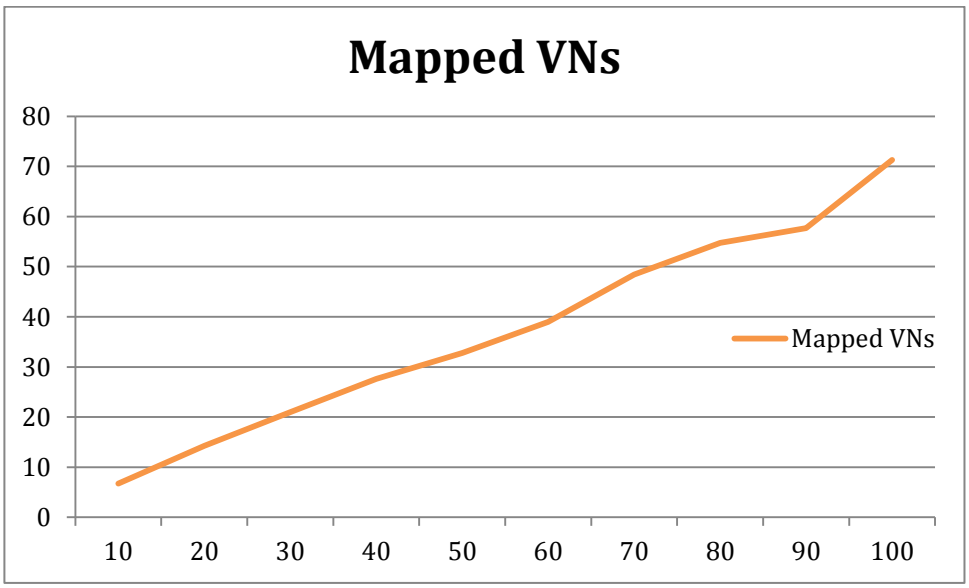

Figure 31. Low load scenario: Mapped VNs

Finally, the last graphic (Figure 27) is the combination of the Total Cost and Revenue and the number of mapped VNs. As seen in previous graphics, the total Cost and Revenue remains constant, but the number of mapped VNs increases. As a result, both values have a decreasing tendency. It also can be explained by taking into account the specifications of the VNRs: when raising the number of VNRs, the demand of each VN is smaller, so the Revenue associated to them and the Cost to map each one will be also smaller.

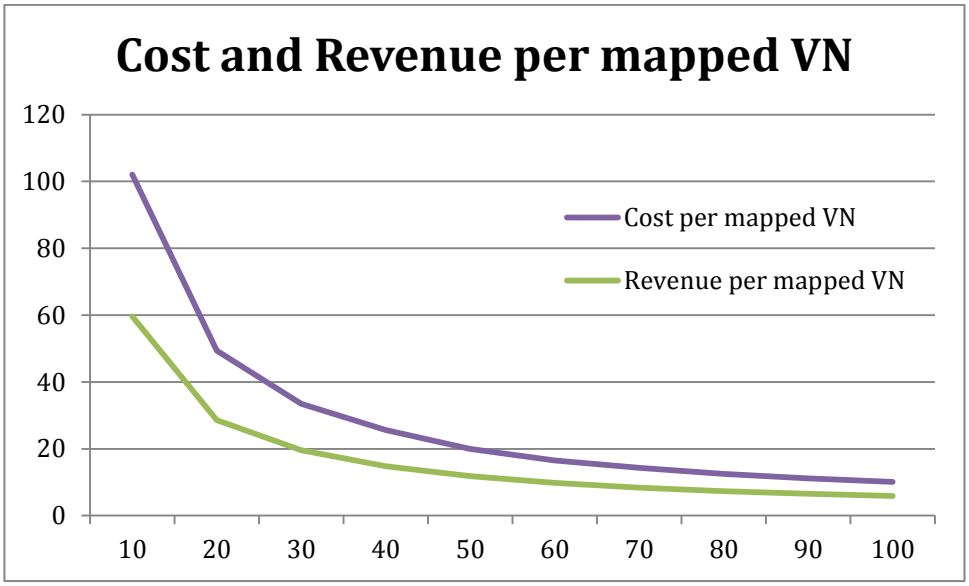

Figure 32. Low load scenario: Cost and Revenue per mapped VN

6. Conclusions and future development

After obtaining the results of the simulations, some conclusions have been extracted from the objectives proposed at the beginning of the thesis. For a better comprehension, those objectives were the following:

1. Study the cloud computing terminology and NV in order to understand the main problem in embedding networks
2. Analyze the framework used to resolve the VNE problem and make an user guide of the simulation environment
3. Study the previous work and methodologies
4. Determine metrics for comparing different scenarios
5. Validate the results of previous work
6. Propose a new scenario in order to improve the previous results
7. Run simulations with the new scenario to validate its better results

The objectives are analyzed one by one:

- Objective 1: A background study has been done, especially in the areas of cloud computing and NV. From that, the VNE problem and the algorithm used to solve it have been studied. The Chapter 2 summarizes the background knowledge, as long as the PA framework used to resolve the problem
- Objective 2: The simulation environment used in this thesis is presented as a user guide in the Chapter 3. The GUI has been studied only for the realization of the user guide, while the Java-coded environment has been analyzed more closely, as is the from used for subsequent simulations
- Objective 3: The approach presented in the previous work [2] is analyzed in the first section of the Chapter 4
- Objective 4: The metrics used to compare scenarios are in two last sections of Chapter 4. They are based on the efficiency when mapping and the percentage of allocated VNs. In addition, an example is presented to better understand how to calculate them
- Objective 5: The results of previous work's validations (Chapter 5) demonstrate that the parameters used in both theses are the same. Hence, new scenarios can be compared with the previous one
- Objective 6: The proposed scenario is explained in the second section of the Chapter 4, in which the parameters to run the simulations are defined and a theoretical reasoning of its better performance is presented
- Objective 7: The results of proposed scenario (Chapter 5) demonstrate that the new approach is better in terms of efficiency when assigning VNs

In summary, the main objective based on analyzing the behavior when embedding smaller VNs has been properly accomplished. The results of the proposed metrics are better than the previous work.

The analysis of the results has begun with an evaluation of the previous work by using the obtained results of the validation. From these validations, the values of the proposed metrics are obtained and can be analyzed more closely in order to better understand their behavior. From these values, a small increase in load results in a decrease of the Acceptance Ratio and a higher Cost/Revenue, so the fact of mapping a new VN means a

very high Cost. Hence, the maximum load recommendable on this type of scenario would be 0.2, since a load of 0.3 means a decrease of Acceptance Ratio from 60% to 40%.

Regarding the proposed scenario, better results than the previous work has been achieved in all metrics. First, this new approach allows taking advantage of SN resources when mapping VNs. The total Cost and Revenue follows the same tendency as the number of mapped VNs, so the value of a metric can be predicted by using the other. In addition, the fact of allocating a new VN does not imply a very high additional Cost. Then, the Cost/Revenue is in any case lower than in the previous approach, so VNs are mapped in the SN more efficiently: the fact of embedding VNs with less demands implies an assignment with better performances because the algorithm can fill the SN more efficiently with smaller VNs. A future work might include what is happening in the Cost/Revenue between the loads 0.3 and 0.5, in which there are an increasing, whereas the other loads have a constant value.

For this new scenario, the maximum number of mapped VNs is between 18 and 20, achieved from a load of 0.6. For higher loads the value is maintained, so if this scenario were real, it would be recommendable to have this load or higher in order to allocate the maximum number of VNs. It means that the minimum number of VNRs would be 60. Although the Cost/Revenue is higher for these loads, it is considered that the SN has better results because the Total Cost and Revenue remains constant and the number of accepted VNs is the maximum. For lower loads, the resources offered by the SN would not be fully exploited.

Finally, the new scenario based on low load was not mentioned in the objectives, but it has interesting results. From this scenario, it is demonstrated that the fact of raising the number of VNRs for the same load does not affect in the Cost and Revenue.

Obviously, all results are the most important part of the thesis, but the background knowledge is an essential part to carry out this work, especially the section of the simulation environment, which has involved a lot of time to understand its operation.

Further work would be a study of other scenarios in which the VNs have lower demands. In addition, it might include the use of new metrics. Other works could be by using other methodologies to improve the obtained results, e.g. by using other algorithms to allocate VNs. Moreover, another way to simulate the scenarios can be done by analyzing the behavior when there are VNs with several demands, since in this work all VNs studied have the same demand, from a statistical point of view.

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Appendix

The appendix contains all tables of results obtained in the project. There are the results of the validations (Tables 8 to 18), the results of the new proposed scenario (Tables 19 to 29), and the results of the low load scenario (Tables 30 to 39). Note that the mean values of all scenarios are in the corresponding tables in the Results chapter.

The following tables correspond to the validation results.

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	10	480,44	293,03	1,64	50,00	5	96,09	58,61
0,1	10	814,64	462,72	1,76	80,00	8	101,83	57,84
0,1	10	701,82	426,54	1,65	70,00	7	100,26	60,93
0,1	10	706,46	437,30	1,62	70,00	7	100,92	62,47
0,1	10	742,31	418,01	1,78	70,00	7	106,04	59,72
0,1	10	651,02	373,09	1,74	70,00	7	93,00	53,30
0,1	10	476,00	299,38	1,59	50,00	5	95,20	59,88
0,1	10	571,45	336,84	1,70	60,00	6	95,24	56,14
0,1	10	509,71	308,36	1,65	50,00	5	101,94	61,67
0,1	10	727,10	442,60	1,64	70,00	7	103,87	63,23
0,1	10	481,05	269,56	1,78	40,00	4	120,26	67,39
0,1	10	616,44	347,78	1,77	60,00	6	102,74	57,96
0,1	10	530,62	297,32	1,78	50,00	5	106,12	59,46
0,1	10	948,14	543,59	1,74	90,00	9	105,35	60,40
0,1	10	601,37	359,46	1,67	60,00	6	100,23	59,91
0,1	10	967,62	531,21	1,82	90,00	9	107,51	59,02
0,1	10	647,02	385,74	1,68	60,00	6	107,84	64,29
0,1	10	992,44	581,82	1,71	100,00	10	99,24	58,18
0,1	10	795,13	457,44	1,74	80,00	8	99,39	57,18
0,1	10	691,20	380,62	1,82	70,00	7	98,74	54,37

Table 8. Validation results: Load 0.1

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,2	10	1401,96	746,72	1,88	60,00	6	233,66	124,45
0,2	10	1487,41	780,21	1,91	70,00	7	212,49	111,46
0,2	10	1082,91	654,63	1,65	60,00	6	180,49	109,10
0,2	10	1333,25	734,19	1,82	60,00	6	222,21	122,36
0,2	10	1512,63	867,85	1,74	70,00	7	216,09	123,98
0,2	10	1174,85	617,38	1,90	50,00	5	234,97	123,48
0,2	10	1065,90	555,43	1,92	50,00	5	213,18	111,09
0,2	10	1591,85	926,47	1,72	80,00	8	198,98	115,81
0,2	10	590,39	336,08	1,76	30,00	3	196,80	112,03
0,2	10	701,31	392,29	1,79	30,00	3	233,77	130,76
0,2	10	1387,18	756,51	1,83	70,00	7	198,17	108,07
0,2	10	1228,75	737,85	1,67	60,00	6	204,79	122,97
0,2	10	1221,32	646,78	1,89	60,00	6	203,55	107,80
0,2	10	669,09	329,88	2,03	30,00	3	223,03	109,96
0,2	10	1180,94	727,76	1,62	60,00	6	196,82	121,29
0,2	10	1659,53	957,33	1,73	80,00	8	207,44	119,67
0,2	10	1432,63	738,82	1,94	60,00	6	238,77	123,14
0,2	10	1509,78	950,04	1,59	80,00	8	188,72	118,75
0,2	10	1574,04	909,17	1,73	80,00	8	196,75	113,65
0,2	10	1292,36	805,74	1,60	70,00	7	184,62	115,11

Table 9. Validation results: Load 0.2

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,3	10	1267,12	726,16	1,74	40,00	4	316,78	181,54
0,3	10	991,22	621,49	1,59	40,00	4	247,81	155,37
0,3	10	1123,81	603,88	1,86	30,00	3	374,60	201,29
0,3	10	998,10	573,89	1,74	30,00	3	332,70	191,30
0,3	10	1172,83	696,62	1,68	40,00	4	293,21	174,16
0,3	10	2076,05	1160,23	1,79	60,00	6	346,01	193,37
0,3	10	921,78	425,84	2,16	20,00	2	460,89	212,92
0,3	10	750,92	392,58	1,91	20,00	2	375,46	196,29
0,3	10	1630,07	877,05	1,86	50,00	5	326,01	175,41
0,3	10	1057,14	635,06	1,66	30,00	3	352,38	211,69
0,3	10	1355,81	748,85	1,81	40,00	4	338,95	187,21
0,3	10	1193,22	597,55	2,00	30,00	3	397,74	199,18
0,3	10	929,49	586,03	1,59	30,00	3	309,83	195,34
0,3	10	1483,40	796,92	1,86	40,00	4	370,85	199,23
0,3	10	1126,41	551,87	2,04	30,00	3	375,47	183,96
0,3	10	2370,02	1412,89	1,68	80,00	8	296,25	176,61
0,3	10	1782,48	882,89	2,02	40,00	4	445,62	220,72
0,3	10	1033,58	529,98	1,95	30,00	3	344,53	176,66
0,3	10	1280,88	691,77	1,85	40,00	4	320,22	172,94
0,3	10	1363,93	764,66	1,78	40,00	4	340,98	191,16

Table 10. Validation results: Load 0.3

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,4	10	2308,47	1273,39	1,81	50,00	5	461,69	254,68
0,4	10	1198,28	714,03	1,68	30,00	3	399,43	238,01
0,4	10	1693,60	794,13	2,13	30,00	3	564,53	264,71
0,4	10	1052,38	477,45	2,20	20,00	2	526,19	238,72
0,4	10	1308,45	735,67	1,78	30,00	3	436,15	245,22
0,4	10	735,87	421,08	1,75	20,00	2	367,94	210,54
0,4	10	1185,26	617,99	1,92	20,00	2	592,63	309,00
0,4	10	2799,51	1593,61	1,76	60,00	6	466,58	265,60
0,4	10	968,92	559,56	1,73	20,00	2	484,46	279,78
0,4	10	2073,86	1063,88	1,95	50,00	5	414,77	212,78
0,4	10	889,56	504,77	1,76	20,00	2	444,78	252,38
0,4	10	2014,00	1066,06	1,89	40,00	4	503,50	266,51
0,4	10	1429,66	795,76	1,80	40,00	4	357,41	198,94
0,4	10	1836,56	992,19	1,85	40,00	4	459,14	248,05
0,4	10	897,97	471,68	1,90	20,00	2	448,98	235,84
0,4	10	1060,53	640,29	1,66	30,00	3	353,51	213,43
0,4	10	1906,62	1035,08	1,84	40,00	4	476,66	258,77
0,4	10	710,04	425,34	1,67	20,00	2	355,02	212,67
0,4	10	719,12	398,45	1,80	20,00	2	359,56	199,23
0,4	10	1765,65	1003,58	1,76	40,00	4	441,41	250,90

Table 11. Validation results: Load 0.4

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,5	10	1792,04	946,44	1,89	30,00	3	597,35	315,48
0,5	10	1355,26	746,52	1,82	20,00	2	677,63	373,26
0,5	10	1095,04	540,85	2,02	20,00	2	547,52	270,43
0,5	10	2371,48	1216,99	1,95	40,00	4	592,87	304,25
0,5	10	1390,78	790,19	1,76	30,00	3	463,59	263,40
0,5	10	1583,13	697,07	2,27	20,00	2	791,57	348,54
0,5	10	1457,60	838,75	1,74	30,00	3	485,87	279,58
0,5	10	1193,93	654,75	1,82	20,00	2	596,96	327,37
0,5	10	1883,74	1116,61	1,69	40,00	4	470,94	279,15
0,5	10	666,58	386,20	1,73	10,00	1	666,58	386,20
0,5	10	1823,17	1172,59	1,55	40,00	4	455,79	293,15
0,5	10	522,80	276,24	1,89	10,00	1	522,80	276,24
0,5	10	1047,69	586,39	1,79	20,00	2	523,84	293,20
0,5	10	467,01	235,50	1,98	10,00	1	467,01	235,50
0,5	10	1996,81	933,72	2,14	30,00	3	665,60	311,24
0,5	10	624,59	328,51	1,90	10,00	1	624,59	328,51
0,5	10	2536,13	1458,58	1,74	50,00	5	507,23	291,72
0,5	10	1049,05	547,74	1,92	20,00	2	524,53	273,87
0,5	10	1450,46	697,74	2,08	20,00	2	725,23	348,87
0,5	10	643,40	349,51	1,84	10,00	1	643,40	349,51

Table 12. Validation results: Load 0.5

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,6	10	1684,07	989,17	1,70	30,00	3	561,36	329,72
0,6	10	857,44	455,01	1,88	10,00	1	857,44	455,01
0,6	10	1606,89	787,87	2,04	20,00	2	803,45	393,94
0,6	10	1174,81	638,68	1,84	20,00	2	587,40	319,34
0,6	10	837,05	433,48	1,93	10,00	1	837,05	433,48
0,6	10	1963,81	1004,14	1,96	30,00	3	654,60	334,71
0,6	10	x	x	x	0,00	0	x	x
0,6	10	1128,39	569,75	1,98	20,00	2	564,20	284,87
0,6	10	1966,58	990,26	1,99	30,00	3	655,53	330,09
0,6	10	1535,21	798,89	1,92	20,00	2	767,60	399,44
0,6	10	1956,13	1117,70	1,75	30,00	3	652,04	372,57
0,6	10	1198,09	667,06	1,80	20,00	2	599,04	333,53
0,6	10	1455,04	686,85	2,12	20,00	2	727,52	343,42
0,6	10	902,90	420,48	2,15	10,00	1	902,90	420,48
0,6	10	1679,90	955,39	1,76	30,00	3	559,97	318,46
0,6	10	1240,87	633,17	1,96	20,00	2	620,43	316,59
0,6	10	980,13	487,76	2,01	10,00	1	980,13	487,76
0,6	10	2251,43	1125,93	2,00	30,00	3	750,48	375,31
0,6	10	x	x	x	0,00	0	x	x
0,6	10	2168,47	1110,22	1,95	30,00	3	722,82	370,07

Table 13. Validation results: Load 0.6

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,7	10	2437,24	1426,71	1,71	40,00	4	609,31	356,68
0,7	10	937,88	434,51	2,16	10,00	1	937,88	434,51
0,7	10	x	x	x	0,00	0	x	x
0,7	10	2086,53	1020,41	2,04	20,00	2	1043,27	510,20
0,7	10	1091,94	472,65	2,31	10,00	1	1091,94	472,65
0,7	10	1507,77	790,29	1,91	20,00	2	753,88	395,15
0,7	10	1031,27	484,55	2,13	10,00	1	1031,27	484,55
0,7	10	1118,63	640,61	1,75	20,00	2	559,31	320,30
0,7	10	965,31	447,88	2,16	10,00	1	965,31	447,88
0,7	10	660,12	380,68	1,73	10,00	1	660,12	380,68
0,7	10	1022,81	443,22	2,31	10,00	1	1022,81	443,22
0,7	10	538,06	330,99	1,63	10,00	1	538,06	330,99
0,7	10	1392,54	778,99	1,79	20,00	2	696,27	389,49
0,7	10	824,84	538,71	1,53	10,00	1	824,84	538,71
0,7	10	1660,01	829,50	2,00	20,00	2	830,00	414,75
0,7	10	x	x	x	0,00	0	x	x
0,7	10	1336,50	756,05	1,77	20,00	2	668,25	378,03
0,7	10	730,89	438,01	1,67	10,00	1	730,89	438,01
0,7	10	993,74	464,17	2,14	10,00	1	993,74	464,17
0,7	10	927,31	383,51	2,42	10,00	1	927,31	383,51

Table 14. Validation results: Load 0.7

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,8	10	1162,01	536,43	2,17	10,00	1	1162,01	536,43
0,8	10	1581,24	929,46	1,70	20,00	2	790,62	464,73
0,8	10	1778,31	1018,54	1,75	20,00	2	889,16	509,27
0,8	10	862,12	517,72	1,67	10,00	1	862,12	517,72
0,8	10	1335,37	626,57	2,13	20,00	2	667,68	313,29
0,8	10	1626,89	873,06	1,86	20,00	2	813,45	436,53
0,8	10	x	x	x	0,00	0	x	x
0,8	10	1194,33	518,99	2,30	10,00	1	1194,33	518,99
0,8	10	x	x	x	0,00	0	x	x
0,8	10	1224,01	596,36	2,05	10,00	1	1224,01	596,36
0,8	10	947,63	519,90	1,82	10,00	1	947,63	519,90
0,8	10	1169,51	551,33	2,12	10,00	1	1169,51	551,33
0,8	10	1557,60	793,41	1,96	20,00	2	778,80	396,70
0,8	10	921,84	486,77	1,89	10,00	1	921,84	486,77
0,8	10	1360,47	663,80	2,05	10,00	1	1360,47	663,80
0,8	10	866,94	521,42	1,66	10,00	1	866,94	521,42
0,8	10	910,59	465,64	1,96	10,00	1	910,59	465,64
0,8	10	984,24	550,81	1,79	10,00	1	984,24	550,81
0,8	10	922,13	458,66	2,01	10,00	1	922,13	458,66
0,8	10	1302,32	592,42	2,20	10,00	1	1302,32	592,42

Table 15. Validation results: Load 0.8

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,9	10	x	x	x	0,00	0	x	x
0,9	10	1095,61	564,56	1,94	10,00	1	1095,61	564,56
0,9	10	923,53	537,89	1,72	10,00	1	923,53	537,89
0,9	10	1211,26	597,60	2,03	10,00	1	1211,26	597,60
0,9	10	x	x	x	0,00	0	x	x
0,9	10	868,70	422,43	2,06	10,00	1	868,70	422,43
0,9	10	1074,14	498,68	2,15	10,00	1	1074,14	498,68
0,9	10	761,51	418,11	1,82	10,00	1	761,51	418,11
0,9	10	979,78	509,37	1,92	10,00	1	979,78	509,37
0,9	10	979,37	515,58	1,90	10,00	1	979,37	515,58
0,9	10	x	x	x	0,00	0	x	x
0,9	10	1118,63	553,92	2,02	10,00	1	1118,63	553,92
0,9	10	942,78	488,78	1,93	10,00	1	942,78	488,78
0,9	10	946,25	495,65	1,91	10,00	1	946,25	495,65
0,9	10	x	x	x	0,00	0	x	x
0,9	10	x	x	x	0,00	0	x	x
0,9	10	560,63	321,70	1,74	10,00	1	560,63	321,70
0,9	10	858,25	439,62	1,95	10,00	1	858,25	439,62
0,9	10	918,83	419,21	2,19	10,00	1	918,83	419,21
0,9	10	681,46	398,46	1,71	10,00	1	681,46	398,46

Table 16. Validation results: Load 0.9

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,95	10	x	x	x	0,00	0	x	x
0,95	10	x	x	x	0,00	0	x	x
0,95	10	x	x	x	0,00	0	x	x
0,95	10	x	x	x	0,00	0	x	x
0,95	10	x	x	x	0,00	0	x	x
0,95	10	1060,90	516,78	2,05	10,00	1	1060,90	516,78
0,95	10	1341,22	721,20	1,86	10,00	1	1341,22	721,20
0,95	10	x	x	x	0,00	0	x	x
0,95	10	1126,80	600,82	1,88	10,00	1	1126,80	600,82
0,95	10	1010,31	502,25	2,01	10,00	1	1010,31	502,25
0,95	10	x	x	x	0,00	0	x	x
0,95	10	614,49	354,29	1,73	10,00	1	614,49	354,29
0,95	10	1072,46	582,80	1,84	10,00	1	1072,46	582,80
0,95	10	585,31	361,19	1,62	10,00	1	585,31	361,19
0,95	10	1186,47	596,69	1,99	10,00	1	1186,47	596,69
0,95	10	1168,99	517,01	2,26	10,00	1	1168,99	517,01
0,95	10	884,97	532,09	1,66	10,00	1	884,97	532,09
0,95	10	1901,05	1044,34	1,82	20,00	2	950,53	522,17
0,95	10	1014,40	427,34	2,37	10,00	1	1014,40	427,34
0,95	10	1404,61	635,45	2,21	10,00	1	1404,61	635,45

Table 17. Validation results: Load 0.95

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,99	10	710,73	447,65	1,59	10,00	1	710,73	447,65
0,99	10	x	x	x	0,00	0	x	x
0,99	10	883,87	414,85	2,13	10,00	1	883,87	414,85
0,99	10	943,80	552,83	1,71	10,00	1	943,80	552,83
0,99	10	2854,76	1530,24	1,87	30,00	3	951,59	510,08
0,99	10	x	x	x	0,00	0	x	x
0,99	10	1448,32	594,15	2,44	10,00	1	1448,32	594,15
0,99	10	1054,33	487,00	2,16	10,00	1	1054,33	487,00
0,99	10	x	x	x	0,00	0	x	x
0,99	10	x	x	x	0,00	0	x	x
0,99	10	1313,73	654,01	2,01	10,00	1	1313,73	654,01
0,99	10	1523,66	888,04	1,72	20,00	2	761,83	444,02
0,99	10	1452,72	864,25	1,68	20,00	2	726,36	432,12
0,99	10	1117,97	494,48	2,26	10,00	1	1117,97	494,48
0,99	10	x	x	x	0,00	0	x	x
0,99	10	647,61	336,00	1,93	10,00	1	647,61	336,00
0,99	10	x	x	x	0,00	0	x	x
0,99	10	728,10	398,48	1,83	10,00	1	728,10	398,48
0,99	10	1095,32	559,77	1,96	10,00	1	1095,32	559,77
0,99	10	x	x	x	0,00	0	x	x

Table 18. Validation results: Load 0.99

The following tables correspond to the proposed scenario results.

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	10	480,44	293,03	1,64	50,00	5	96,09	58,61
0,1	10	814,64	462,72	1,76	80,00	8	101,83	57,84
0,1	10	701,82	426,54	1,65	70,00	7	100,26	60,93
0,1	10	706,46	437,30	1,62	70,00	7	100,92	62,47
0,1	10	742,31	418,01	1,78	70,00	7	106,04	59,72
0,1	10	651,02	373,09	1,74	70,00	7	93,00	53,30
0,1	10	476,00	299,38	1,59	50,00	5	95,20	59,88
0,1	10	571,45	336,84	1,70	60,00	6	95,24	56,14
0,1	10	509,71	308,36	1,65	50,00	5	101,94	61,67
0,1	10	727,10	442,60	1,64	70,00	7	103,87	63,23
0,1	10	481,05	269,56	1,78	40,00	4	120,26	67,39
0,1	10	616,44	347,78	1,77	60,00	6	102,74	57,96
0,1	10	530,62	297,32	1,78	50,00	5	106,12	59,46
0,1	10	948,14	543,59	1,74	90,00	9	105,35	60,40
0,1	10	601,37	359,46	1,67	60,00	6	100,23	59,91
0,1	10	967,62	531,21	1,82	90,00	9	107,51	59,02
0,1	10	647,02	385,74	1,68	60,00	6	107,84	64,29
0,1	10	992,44	581,82	1,71	100,00	10	99,24	58,18
0,1	10	795,13	457,44	1,74	80,00	8	99,39	57,18
0,1	10	691,20	380,62	1,82	70,00	7	98,74	54,37

Table 19. Proposed scenario: Load 0.1

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,2	20	399,92	241,41	1,66	20,00	4	99,98	60,35
0,2	20	1357,23	778,10	1,74	60,00	12	113,10	64,84
0,2	20	1317,74	769,67	1,71	70,00	14	94,12	54,98
0,2	20	871,09	585,41	1,49	55,00	11	79,19	53,22
0,2	20	1065,48	591,88	1,80	50,00	10	106,55	59,19
0,2	20	948,38	585,38	1,62	50,00	10	94,84	58,54
0,2	20	1036,78	581,39	1,78	50,00	10	103,68	58,14
0,2	20	1085,59	638,69	1,70	55,00	11	98,69	58,06
0,2	20	1520,82	901,99	1,69	75,00	15	101,39	60,13
0,2	20	1159,24	651,47	1,78	55,00	11	105,39	59,22
0,2	20	1510,68	932,92	1,62	75,00	15	100,71	62,19
0,2	20	789,59	454,01	1,74	45,00	9	87,73	50,45
0,2	20	1538,20	894,96	1,72	85,00	17	90,48	52,64
0,2	20	963,69	590,05	1,63	55,00	11	87,61	53,64
0,2	20	1295,46	769,37	1,68	60,00	12	107,96	64,11
0,2	20	1503,50	772,45	1,95	65,00	13	115,65	59,42
0,2	20	1216,60	693,86	1,75	65,00	13	93,58	53,37
0,2	20	749,59	431,02	1,74	40,00	8	93,70	53,88
0,2	20	1308,22	725,03	1,80	60,00	12	109,02	60,42
0,2	20	1260,28	737,08	1,71	70,00	14	90,02	52,65

Table 20. Proposed scenario: Load 0.2

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,3	30	940,43	545,25	1,72	30,00	9	104,49	60,58
0,3	30	2022,96	1153,95	1,75	63,33	19	106,47	60,73
0,3	30	1961,20	1179,30	1,66	70,00	21	93,39	56,16
0,3	30	1244,76	726,98	1,71	36,67	11	113,16	66,09
0,3	30	1676,70	997,87	1,68	53,33	16	104,79	62,37
0,3	30	1673,32	953,74	1,75	50,00	15	111,55	63,58
0,3	30	1810,25	970,00	1,87	56,67	17	106,49	57,06
0,3	30	1015,75	660,00	1,54	36,67	11	92,34	60,00
0,3	30	700,85	399,36	1,75	23,33	7	100,12	57,05
0,3	30	1009,22	638,16	1,58	33,33	10	100,92	63,82
0,3	30	1542,91	787,15	1,96	36,67	11	140,26	71,56
0,3	30	2216,23	1308,81	1,69	73,33	22	100,74	59,49
0,3	30	1515,03	856,74	1,77	46,67	14	108,22	61,20
0,3	30	1387,82	833,18	1,67	43,33	13	106,76	64,09
0,3	30	1810,31	1018,76	1,78	56,67	17	106,49	59,93
0,3	30	1846,10	1047,93	1,76	60,00	18	102,56	58,22
0,3	30	877,53	516,60	1,70	26,67	8	109,69	64,58
0,3	30	1088,17	644,13	1,69	36,67	11	98,92	58,56
0,3	30	1387,27	812,30	1,71	46,67	14	99,09	58,02
0,3	30	1983,08	1156,89	1,71	63,33	19	104,37	60,89

Table 21. Proposed scenario: Load 0.3

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,4	40	1501,27	884,75	1,70	37,50	15	100,08	58,98
0,4	40	1003,40	549,25	1,83	22,50	9	111,49	61,03
0,4	40	1633,31	970,08	1,68	42,50	17	96,08	57,06
0,4	40	273,01	181,89	1,50	10,00	4	68,25	45,47
0,4	40	1317,55	753,10	1,75	30,00	12	109,80	62,76
0,4	40	1271,38	684,47	1,86	27,50	11	115,58	62,22
0,4	40	1723,21	927,64	1,86	35,00	14	123,09	66,26
0,4	40	1282,89	674,01	1,90	27,50	11	116,63	61,27
0,4	40	2416,23	1249,01	1,93	50,00	20	120,81	62,45
0,4	40	2405,71	1397,34	1,72	57,50	23	104,60	60,75
0,4	40	2039,89	1160,08	1,76	47,50	19	107,36	61,06
0,4	40	1897,46	1054,76	1,80	42,50	17	111,62	62,04
0,4	40	1638,18	950,35	1,72	37,50	15	109,21	63,36
0,4	40	1056,16	613,08	1,72	25,00	10	105,62	61,31
0,4	40	2894,65	1759,45	1,65	72,50	29	99,82	60,67
0,4	40	1407,41	785,92	1,79	35,00	14	100,53	56,14
0,4	40	1717,21	962,80	1,78	37,50	15	114,48	64,19
0,4	40	2271,37	1191,13	1,91	47,50	19	119,55	62,69
0,4	40	1986,02	1039,47	1,91	40,00	16	124,13	64,97
0,4	40	2229,98	1223,95	1,82	52,50	21	106,19	58,28

Table 22. Proposed scenario: Load 0.4

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,5	50	1806,60	940,88	1,92	30,00	15	120,44	62,73
0,5	50	2039,90	1129,61	1,81	36,00	18	113,33	62,76
0,5	50	1143,52	615,30	1,86	20,00	10	114,35	61,53
0,5	50	2250,34	1306,38	1,72	44,00	22	102,29	59,38
0,5	50	1493,18	868,23	1,72	28,00	14	106,66	62,02
0,5	50	1964,66	1040,56	1,89	34,00	17	115,57	61,21
0,5	50	2909,64	1834,02	1,59	62,00	31	93,86	59,16
0,5	50	1531,79	859,96	1,78	28,00	14	109,41	61,43
0,5	50	1296,17	721,41	1,80	22,00	11	117,83	65,58
0,5	50	2602,23	1464,23	1,78	48,00	24	108,43	61,01
0,5	50	2277,36	1345,22	1,69	42,00	21	108,45	64,06
0,5	50	3421,20	2080,29	1,64	68,00	34	100,62	61,19
0,5	50	2586,16	1507,05	1,72	48,00	24	107,76	62,79
0,5	50	1281,22	607,18	2,11	18,00	9	142,36	67,46
0,5	50	2043,91	1044,76	1,96	30,00	15	136,26	69,65
0,5	50	1705,62	975,95	1,75	30,00	15	113,71	65,06
0,5	50	1559,17	856,59	1,82	26,00	13	119,94	65,89
0,5	50	2004,64	1211,36	1,65	36,00	18	111,37	67,30
0,5	50	2514,71	1398,87	1,80	44,00	22	114,30	63,59
0,5	50	1623,09	817,77	1,98	22,00	11	147,55	74,34

Table 23. Proposed scenario: Load 0.5

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,6	60	2428,01	1300,85	1,87	33,33	20	121,40	65,04
0,6	60	1607,16	965,57	1,66	26,67	16	100,45	60,35
0,6	60	1728,87	954,14	1,81	26,67	16	108,05	59,63
0,6	60	2343,29	1268,62	1,85	31,67	19	123,33	66,77
0,6	60	2766,15	1686,90	1,64	45,00	27	102,45	62,48
0,6	60	2261,79	1324,05	1,71	38,33	23	98,34	57,57
0,6	60	1959,20	1168,24	1,68	31,67	19	103,12	61,49
0,6	60	2156,03	1231,78	1,75	31,67	19	113,48	64,83
0,6	60	2860,33	1555,36	1,84	40,00	24	119,18	64,81
0,6	60	1954,82	1052,64	1,86	26,67	16	122,18	65,79
0,6	60	1316,04	644,12	2,04	16,67	10	131,60	64,41
0,6	60	1798,34	1033,86	1,74	28,33	17	105,78	60,82
0,6	60	2473,24	1412,86	1,75	36,67	22	112,42	64,22
0,6	60	2467,68	1328,84	1,86	33,33	20	123,38	66,44
0,6	60	2958,42	1778,20	1,66	46,67	28	105,66	63,51
0,6	60	2391,67	1309,64	1,83	33,33	20	119,58	65,48
0,6	60	2562,02	1551,43	1,65	46,67	28	91,50	55,41
0,6	60	2017,91	1139,64	1,77	28,33	17	118,70	67,04
0,6	60	1287,11	653,02	1,97	16,67	10	128,71	65,30
0,6	60	1457,34	718,44	2,03	16,67	10	145,73	71,84

Table 24. Proposed scenario: Load 0.6

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,7	70	2346,90	1210,16	1,94	25,71	18	130,38	67,23
0,7	70	3025,29	1838,27	1,65	41,43	29	104,32	63,39
0,7	70	1556,09	793,07	1,96	17,14	12	129,67	66,09
0,7	70	1472,43	830,88	1,77	17,14	12	122,70	69,24
0,7	70	1464,54	809,88	1,81	18,57	13	112,66	62,30
0,7	70	1714,74	931,70	1,84	20,00	14	122,48	66,55
0,7	70	2673,78	1532,76	1,74	32,86	23	116,25	66,64
0,7	70	1900,44	1023,25	1,86	22,86	16	118,78	63,95
0,7	70	1549,30	886,81	1,75	21,43	15	103,29	59,12
0,7	70	2791,10	1532,96	1,82	32,86	23	121,35	66,65
0,7	70	2536,24	1445,57	1,75	34,29	24	105,68	60,23
0,7	70	2308,58	1325,43	1,74	30,00	21	109,93	63,12
0,7	70	1600,34	912,04	1,75	20,00	14	114,31	65,15
0,7	70	1970,28	1075,00	1,83	24,29	17	115,90	63,24
0,7	70	2510,84	1301,29	1,93	27,14	19	132,15	68,49
0,7	70	1702,70	894,02	1,90	21,43	15	113,51	59,60
0,7	70	2531,90	1396,68	1,81	31,43	22	115,09	63,49
0,7	70	2326,65	1277,79	1,82	27,14	19	122,46	67,25
0,7	70	2474,70	1437,87	1,72	30,00	21	117,84	68,47
0,7	70	2276,91	1335,71	1,70	32,86	23	99,00	58,07

Table 25. Proposed scenario: Load 0.7

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,8	80	2887,45	1680,33	1,72	31,25	25	115,50	67,21
0,8	80	2262,98	1155,33	1,96	22,50	18	125,72	64,19
0,8	80	1223,32	699,46	1,75	12,50	10	122,33	69,95
0,8	80	1312,18	711,34	1,84	15,00	12	109,35	59,28
0,8	80	3072,75	1790,78	1,72	33,75	27	113,81	66,33
0,8	80	2404,46	1453,27	1,65	27,50	22	109,29	66,06
0,8	80	3294,42	2008,22	1,64	37,50	30	109,81	66,94
0,8	80	1959,27	1181,12	1,66	21,25	17	115,25	69,48
0,8	80	1282,46	719,61	1,78	15,00	12	106,87	59,97
0,8	80	1534,76	784,92	1,96	15,00	12	127,90	65,41
0,8	80	1605,98	917,57	1,75	18,75	15	107,07	61,17
0,8	80	2837,81	1495,07	1,90	27,50	22	128,99	67,96
0,8	80	2310,55	1197,04	1,93	23,75	19	121,61	63,00
0,8	80	1582,81	883,69	1,79	17,50	14	113,06	63,12
0,8	80	1782,48	910,70	1,96	17,50	14	127,32	65,05
0,8	80	1275,93	640,11	1,99	11,25	9	141,77	71,12
0,8	80	2336,12	1243,20	1,88	22,50	18	129,78	69,07
0,8	80	2927,05	1659,88	1,76	32,50	26	112,58	63,84
0,8	80	2531,81	1349,82	1,88	26,25	21	120,56	64,28
0,8	80	2461,63	1497,87	1,64	30,00	24	102,57	62,41

Table 26. Proposed scenario: Load 0.8

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,9	90	1985,51	1158,89	1,71	18,89	17	116,79	68,17
0,9	90	2032,79	1080,07	1,88	16,67	15	135,52	72,00
0,9	90	2400,63	1367,17	1,76	23,33	21	114,32	65,10
0,9	90	2130,37	1145,70	1,86	18,89	17	125,32	67,39
0,9	90	2671,29	1437,05	1,86	25,56	23	116,14	62,48
0,9	90	2242,02	1299,11	1,73	22,22	20	112,10	64,96
0,9	90	1945,38	1095,63	1,78	18,89	17	114,43	64,45
0,9	90	1815,04	997,77	1,82	17,78	16	113,44	62,36
0,9	90	1722,89	1008,49	1,71	16,67	15	114,86	67,23
0,9	90	2559,79	1338,29	1,91	20,00	18	142,21	74,35
0,9	90	2277,67	1183,23	1,92	17,78	16	142,35	73,95
0,9	90	2195,27	1218,08	1,80	18,89	17	129,13	71,65
0,9	90	2057,80	1106,52	1,86	18,89	17	121,05	65,09
0,9	90	3083,11	1815,91	1,70	30,00	27	114,19	67,26
0,9	90	2943,80	1668,64	1,76	27,78	25	117,75	66,75
0,9	90	3059,69	1830,72	1,67	31,11	28	109,27	65,38
0,9	90	2210,92	1224,55	1,81	18,89	17	130,05	72,03
0,9	90	1852,48	1108,49	1,67	20,00	18	102,92	61,58
0,9	90	2440,00	1371,12	1,78	22,22	20	122,00	68,56
0,9	90	2334,13	1336,85	1,75	22,22	20	116,71	66,84

Table 27. Proposed scenario: Load 0.9

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,95	95	3207,88	1904,28	1,68	33,68	32	100,25	59,51
0,95	95	2054,44	1129,50	1,82	16,84	16	128,40	70,59
0,95	95	1126,11	683,24	1,65	11,58	11	102,37	62,11
0,95	95	2302,39	1386,32	1,66	22,11	21	109,64	66,02
0,95	95	1342,14	678,21	1,98	10,53	10	134,21	67,82
0,95	95	1624,93	792,37	2,05	12,63	12	135,41	66,03
0,95	95	2771,27	1469,75	1,89	23,16	22	125,97	66,81
0,95	95	3340,17	1913,83	1,75	32,63	31	107,75	61,74
0,95	95	3832,89	2324,19	1,65	36,84	35	109,51	66,41
0,95	95	1168,32	680,19	1,72	10,53	10	116,83	68,02
0,95	95	2006,45	1106,81	1,81	17,89	17	118,03	65,11
0,95	95	2255,49	1254,41	1,80	20,00	19	118,71	66,02
0,95	95	1581,56	842,48	1,88	13,68	13	121,66	64,81
0,95	95	1961,58	1060,32	1,85	16,84	16	122,60	66,27
0,95	95	2588,19	1442,90	1,79	22,11	21	123,25	68,71
0,95	95	2189,51	1142,80	1,92	15,79	15	145,97	76,19
0,95	95	2686,66	1486,99	1,81	23,16	22	122,12	67,59
0,95	95	2142,43	1240,03	1,73	18,95	18	119,02	68,89
0,95	95	3542,91	2099,75	1,69	35,79	34	104,20	61,76
0,95	95	2382,59	1285,67	1,85	21,05	20	119,13	64,28

Table 28. Proposed scenario: Load 0.95

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,99	99	1475,75	930,85	1,59	15,15	15	98,38	62,06
0,99	99	2635,61	1353,07	1,95	20,20	20	131,78	67,65
0,99	99	2746,49	1737,29	1,58	29,29	29	94,71	59,91
0,99	99	1709,62	965,38	1,77	15,15	15	113,97	64,36
0,99	99	2978,24	1739,87	1,71	27,27	27	110,31	64,44
0,99	99	2146,30	1189,45	1,80	19,19	19	112,96	62,60
0,99	99	2435,17	1450,26	1,68	22,22	22	110,69	65,92
0,99	99	1491,00	841,60	1,77	12,12	12	124,25	70,13
0,99	99	1830,28	902,20	2,03	12,12	12	152,52	75,18
0,99	99	2636,72	1403,59	1,88	19,19	19	138,77	73,87
0,99	99	2637,11	1436,23	1,84	21,21	21	125,58	68,39
0,99	99	1244,70	616,33	2,02	9,09	9	138,30	68,48
0,99	99	2819,91	1558,98	1,81	22,22	22	128,18	70,86
0,99	99	2349,16	1191,37	1,97	18,18	18	130,51	66,19
0,99	99	2677,67	1518,77	1,76	25,25	25	107,11	60,75
0,99	99	2029,22	1153,62	1,76	18,18	18	112,73	64,09
0,99	99	2662,78	1523,07	1,75	23,23	23	115,77	66,22
0,99	99	1846,84	1100,50	1,68	18,18	18	102,60	61,14
0,99	99	1190,11	626,94	1,90	9,09	9	132,23	69,66
0,99	99	1882,65	1056,43	1,78	16,16	16	117,67	66,03

Table 29. Proposed scenario: Load 0.99

The following tables correspond to the low load scenario results.

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	10	480,44	293,03	1,64	50,00	5	96,09	58,61
0,1	10	814,64	462,72	1,76	80,00	8	101,83	57,84
0,1	10	701,82	426,54	1,65	70,00	7	100,26	60,93
0,1	10	706,46	437,30	1,62	70,00	7	100,92	62,47
0,1	10	742,31	418,01	1,78	70,00	7	106,04	59,72
0,1	10	651,02	373,09	1,74	70,00	7	93,00	53,30
0,1	10	476,00	299,38	1,59	50,00	5	95,20	59,88
0,1	10	571,45	336,84	1,70	60,00	6	95,24	56,14
0,1	10	509,71	308,36	1,65	50,00	5	101,94	61,67
0,1	10	727,10	442,60	1,64	70,00	7	103,87	63,23
0,1	10	481,05	269,56	1,78	40,00	4	120,26	67,39
0,1	10	616,44	347,78	1,77	60,00	6	102,74	57,96
0,1	10	530,62	297,32	1,78	50,00	5	106,12	59,46
0,1	10	948,14	543,59	1,74	90,00	9	105,35	60,40
0,1	10	601,37	359,46	1,67	60,00	6	100,23	59,91
0,1	10	967,62	531,21	1,82	90,00	9	107,51	59,02
0,1	10	647,02	385,74	1,68	60,00	6	107,84	64,29
0,1	10	992,44	581,82	1,71	100,00	10	99,24	58,18
0,1	10	795,13	457,44	1,74	80,00	8	99,39	57,18
0,1	10	691,20	380,62	1,82	70,00	7	98,74	54,37

Table 30. Low load scenario: 10 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	20	701,52	441,46	1,59	80,00	16	43,85	27,59
0,1	20	859,85	466,47	1,84	85,00	17	50,58	27,44
0,1	20	881,40	520,08	1,69	90,00	18	48,97	28,89
0,1	20	644,96	357,12	1,81	60,00	12	53,75	29,76
0,1	20	814,61	498,63	1,63	85,00	17	47,92	29,33
0,1	20	849,17	520,28	1,63	95,00	19	44,69	27,38
0,1	20	825,64	493,42	1,67	85,00	17	48,57	29,02
0,1	20	668,31	409,98	1,63	75,00	15	44,55	27,33
0,1	20	853,42	476,10	1,79	85,00	17	50,20	28,01
0,1	20	732,23	411,17	1,78	70,00	14	52,30	29,37
0,1	20	630,13	324,66	1,94	60,00	12	52,51	27,05
0,1	20	406,45	236,84	1,72	40,00	8	50,81	29,60
0,1	20	x	x	x	0,00	0	x	x
0,1	20	884,59	484,81	1,82	85,00	17	52,03	28,52
0,1	20	585,34	348,68	1,68	65,00	13	45,03	26,82
0,1	20	856,22	504,84	1,70	90,00	18	47,57	28,05
0,1	20	272,80	167,69	1,63	30,00	6	45,47	27,95
0,1	20	808,30	472,03	1,71	75,00	15	53,89	31,47
0,1	20	822,20	459,78	1,79	80,00	16	51,39	28,74
0,1	20	984,49	561,84	1,75	90,00	18	54,69	31,21

Table 31. Low load scenario: 20 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	30	964,69	569,24	1,69	96,67	29	33,27	19,63
0,1	30	755,59	428,98	1,76	76,67	23	32,85	18,65
0,1	30	421,22	265,79	1,58	43,33	13	32,40	20,45
0,1	30	772,02	451,63	1,71	80,00	24	32,17	18,82
0,1	30	555,15	317,51	1,75	50,00	15	37,01	21,17
0,1	30	747,67	431,32	1,73	73,33	22	33,98	19,61
0,1	30	821,08	471,11	1,74	76,67	23	35,70	20,48
0,1	30	821,68	478,21	1,72	80,00	24	34,24	19,93
0,1	30	877,78	511,29	1,72	90,00	27	32,51	18,94
0,1	30	215,11	134,20	1,60	23,33	7	30,73	19,17
0,1	30	685,21	387,79	1,77	66,67	20	34,26	19,39
0,1	30	941,48	522,47	1,80	90,00	27	34,87	19,35
0,1	30	672,37	403,83	1,66	70,00	21	32,02	19,23
0,1	30	839,72	476,43	1,76	80,00	24	34,99	19,85
0,1	30	839,41	464,56	1,81	83,33	25	33,58	18,58
0,1	30	780,32	436,94	1,79	76,67	23	33,93	19,00
0,1	30	519,01	300,47	1,73	50,00	15	34,60	20,03
0,1	30	463,43	278,14	1,67	50,00	15	30,90	18,54
0,1	30	909,98	564,50	1,61	96,67	29	31,38	19,47
0,1	30	474,87	285,22	1,66	46,67	14	33,92	20,37

Table 32. Low load scenario: 30 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	40	776,00	444,01	1,75	77,50	31	25,03	14,32
0,1	40	475,70	267,94	1,78	50,00	20	23,78	13,40
0,1	40	773,03	448,36	1,72	75,00	30	25,77	14,95
0,1	40	732,22	441,83	1,66	72,50	29	25,25	15,24
0,1	40	846,28	508,28	1,66	85,00	34	24,89	14,95
0,1	40	445,38	240,13	1,85	40,00	16	27,84	15,01
0,1	40	502,72	316,07	1,59	55,00	22	22,85	14,37
0,1	40	671,54	387,36	1,73	62,50	25	26,86	15,49
0,1	40	628,94	375,50	1,67	62,50	25	25,16	15,02
0,1	40	732,33	410,80	1,78	70,00	28	26,15	14,67
0,1	40	752,71	452,43	1,66	80,00	32	23,52	14,14
0,1	40	723,29	411,93	1,76	70,00	28	25,83	14,71
0,1	40	827,82	505,18	1,64	85,00	34	24,35	14,86
0,1	40	682,95	416,32	1,64	72,50	29	23,55	14,36
0,1	40	760,29	410,66	1,85	67,50	27	28,16	15,21
0,1	40	912,25	542,48	1,68	97,50	39	23,39	13,91
0,1	40	724,21	414,43	1,75	67,50	27	26,82	15,35
0,1	40	493,87	261,08	1,89	40,00	16	30,87	16,32
0,1	40	834,92	433,73	1,92	77,50	31	26,93	13,99
0,1	40	728,22	450,12	1,62	72,50	29	25,11	15,52

Table 33. Low load scenario: 40 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	50	882,08	535,22	1,65	92,00	46	19,18	11,64
0,1	50	584,19	347,21	1,68	62,00	31	18,84	11,20
0,1	50	609,06	367,72	1,66	64,00	32	19,03	11,49
0,1	50	846,10	464,75	1,82	78,00	39	21,69	11,92
0,1	50	868,09	495,92	1,75	82,00	41	21,17	12,10
0,1	50	460,87	286,99	1,61	48,00	24	19,20	11,96
0,1	50	639,81	366,11	1,75	60,00	30	21,33	12,20
0,1	50	861,36	512,23	1,68	86,00	43	20,03	11,91
0,1	50	675,08	402,92	1,68	68,00	34	19,86	11,85
0,1	50	731,15	423,58	1,73	74,00	37	19,76	11,45
0,1	50	269,13	173,17	1,55	30,00	15	17,94	11,54
0,1	50	377,78	213,07	1,77	38,00	19	19,88	11,21
0,1	50	591,83	344,23	1,72	62,00	31	19,09	11,10
0,1	50	750,89	471,76	1,59	80,00	40	18,77	11,79
0,1	50	335,89	199,76	1,68	32,00	16	20,99	12,49
0,1	50	873,53	485,32	1,80	84,00	42	20,80	11,56
0,1	50	441,81	275,62	1,60	44,00	22	20,08	12,53
0,1	50	933,11	524,72	1,78	90,00	45	20,74	11,66
0,1	50	533,83	317,19	1,68	52,00	26	20,53	12,20
0,1	50	901,66	499,87	1,80	86,00	43	20,97	11,62

Table 34. Low load scenario: 50 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	60	603,16	361,23	1,67	65,00	39	15,47	9,26
0,1	60	875,72	507,46	1,73	86,67	52	16,84	9,76
0,1	60	351,79	208,05	1,69	35,00	21	16,75	9,91
0,1	60	806,74	512,38	1,57	86,67	52	15,51	9,85
0,1	60	853,86	516,02	1,65	86,67	52	16,42	9,92
0,1	60	578,98	346,83	1,67	56,67	34	17,03	10,20
0,1	60	251,63	158,32	1,59	26,67	16	15,73	9,89
0,1	60	476,58	280,17	1,70	45,00	27	17,65	10,38
0,1	60	601,43	347,07	1,73	58,33	35	17,18	9,92
0,1	60	620,89	365,27	1,70	60,00	36	17,25	10,15
0,1	60	506,44	320,49	1,58	55,00	33	15,35	9,71
0,1	60	886,14	489,79	1,81	86,67	52	17,04	9,42
0,1	60	670,36	395,33	1,70	70,00	42	15,96	9,41
0,1	60	720,86	439,52	1,64	73,33	44	16,38	9,99
0,1	60	560,47	328,51	1,71	56,67	34	16,48	9,66
0,1	60	858,18	478,86	1,79	83,33	50	17,16	9,58
0,1	60	713,44	422,92	1,69	73,33	44	16,21	9,61
0,1	60	549,42	353,75	1,55	61,67	37	14,85	9,56
0,1	60	631,47	357,52	1,77	61,67	37	17,07	9,66
0,1	60	797,84	426,08	1,87	71,67	43	18,55	9,91

Table 35. Low load scenario: 60 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	70	453,56	274,08	1,65	42,86	30	15,12	9,14
0,1	70	548,63	329,59	1,66	57,14	40	13,72	8,24
0,1	70	673,28	403,84	1,67	72,86	51	13,20	7,92
0,1	70	675,20	407,06	1,66	68,57	48	14,07	8,48
0,1	70	321,60	195,33	1,65	34,29	24	13,40	8,14
0,1	70	545,84	303,76	1,80	50,00	35	15,60	8,68
0,1	70	881,39	509,02	1,73	90,00	63	13,99	8,08
0,1	70	833,17	504,87	1,65	90,00	63	13,22	8,01
0,1	70	606,26	365,52	1,66	61,43	43	14,10	8,50
0,1	70	590,33	380,63	1,55	65,71	46	12,83	8,27
0,1	70	864,02	528,96	1,63	92,86	65	13,29	8,14
0,1	70	669,27	401,51	1,67	65,71	46	14,55	8,73
0,1	70	875,57	522,64	1,68	91,43	64	13,68	8,17
0,1	70	403,81	224,95	1,80	37,14	26	15,53	8,65
0,1	70	938,19	486,70	1,93	81,43	57	16,46	8,54
0,1	70	970,13	497,29	1,95	85,71	60	16,17	8,29
0,1	70	807,30	461,60	1,75	84,29	59	13,68	7,82
0,1	70	585,24	358,50	1,63	62,86	44	13,30	8,15
0,1	70	896,86	466,83	1,92	80,00	56	16,02	8,34
0,1	70	708,53	401,94	1,76	68,57	48	14,76	8,37

Table 36. Low load scenario: 70 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	80	839,72	520,75	1,61	90,00	72	11,66	7,23
0,1	80	683,37	397,99	1,72	65,00	52	13,14	7,65
0,1	80	592,59	342,48	1,73	60,00	48	12,35	7,13
0,1	80	951,73	525,36	1,81	90,00	72	13,22	7,30
0,1	80	552,74	366,93	1,51	60,00	48	11,52	7,64
0,1	80	741,26	438,66	1,69	75,00	60	12,35	7,31
0,1	80	95,11	58,73	1,62	10,00	8	11,89	7,34
0,1	80	843,32	478,65	1,76	80,00	64	13,18	7,48
0,1	80	926,63	553,00	1,68	92,50	74	12,52	7,47
0,1	80	747,51	414,37	1,80	71,25	57	13,11	7,27
0,1	80	873,48	499,69	1,75	91,25	73	11,97	6,85
0,1	80	865,10	512,28	1,69	87,50	70	12,36	7,32
0,1	80	830,97	514,70	1,61	91,25	73	11,38	7,05
0,1	80	466,95	254,05	1,84	40,00	32	14,59	7,94
0,1	80	265,77	157,91	1,68	26,25	21	12,66	7,52
0,1	80	872,85	498,73	1,75	85,00	68	12,84	7,33
0,1	80	829,01	495,83	1,67	85,00	68	12,19	7,29
0,1	80	687,64	405,02	1,70	73,75	59	11,65	6,86
0,1	80	643,65	364,66	1,77	61,25	49	13,14	7,44
0,1	80	320,55	194,81	1,65	33,75	27	11,87	7,22

Table 37. Low load scenario: 80 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	90	702,84	394,86	1,78	66,67	60	11,71	6,58
0,1	90	594,72	331,42	1,79	58,89	53	11,22	6,25
0,1	90	653,34	394,17	1,66	65,56	59	11,07	6,68
0,1	90	65,46	40,69	1,61	6,67	6	10,91	6,78
0,1	90	409,67	243,04	1,69	42,22	38	10,78	6,40
0,1	90	845,81	453,56	1,86	78,89	71	11,91	6,39
0,1	90	620,14	351,84	1,76	57,78	52	11,93	6,77
0,1	90	592,34	342,47	1,73	55,56	50	11,85	6,85
0,1	90	481,00	300,93	1,60	48,89	44	10,93	6,84
0,1	90	809,45	421,24	1,92	68,89	62	13,06	6,79
0,1	90	876,89	488,29	1,80	85,56	77	11,39	6,34
0,1	90	729,81	452,09	1,61	78,89	71	10,28	6,37
0,1	90	736,93	467,83	1,58	82,22	74	9,96	6,32
0,1	90	827,56	515,21	1,61	87,78	79	10,48	6,52
0,1	90	565,29	340,21	1,66	57,78	52	10,87	6,54
0,1	90	784,84	470,10	1,67	78,89	71	11,05	6,62
0,1	90	861,77	505,87	1,70	86,67	78	11,05	6,49
0,1	90	460,23	276,32	1,67	47,78	43	10,70	6,43
0,1	90	536,31	322,86	1,66	54,44	49	10,95	6,59
0,1	90	754,19	433,13	1,74	72,22	65	11,60	6,66

Table 38. Low load scenario: 90 VNRs

Load	VNRs	Cost	Revenue	C/R	Acc. Ratio	Map. VNs	C/Map. VN	R/Map. VN
0,1	100	622,69	349,11	1,78	58,00	58	10,74	6,02
0,1	100	816,81	499,66	1,63	86,00	86	9,50	5,81
0,1	100	750,07	452,17	1,66	79,00	79	9,49	5,72
0,1	100	858,89	493,65	1,74	87,00	87	9,87	5,67
0,1	100	419,18	234,75	1,79	41,00	41	10,22	5,73
0,1	100	703,04	427,79	1,64	76,00	76	9,25	5,63
0,1	100	531,13	328,16	1,62	55,00	55	9,66	5,97
0,1	100	811,08	453,77	1,79	78,00	78	10,40	5,82
0,1	100	720,19	454,53	1,58	78,00	78	9,23	5,83
0,1	100	685,25	401,33	1,71	67,00	67	10,23	5,99
0,1	100	732,38	453,43	1,62	77,00	77	9,51	5,89
0,1	100	881,12	529,40	1,66	88,00	88	10,01	6,02
0,1	100	788,52	446,55	1,77	73,00	73	10,80	6,12
0,1	100	689,02	388,77	1,77	63,00	63	10,94	6,17
0,1	100	558,42	322,84	1,73	56,00	56	9,97	5,77
0,1	100	870,77	467,77	1,86	79,00	79	11,02	5,92
0,1	100	676,68	396,69	1,71	69,00	69	9,81	5,75
0,1	100	721,35	349,96	2,06	60,00	60	12,02	5,83
0,1	100	836,66	503,88	1,66	87,00	87	9,62	5,79
0,1	100	680,20	395,05	1,72	69,00	69	9,86	5,73

Table 39. Low load scenario: 100 VNRs

Glossary

ALEVIN: *Algorithms for Embedding Virtual Networks*

BW: *Bandwidth*

CPU: *Central Processing Unit*

GUI: *Graphical User Interface*

IaaS: *Infrastructure as a Service*

IDE: *Integrated Development Environment*

InP: *Infrastructure Provider*

ISP: *Internet Service Provider*

LADN: *Loop Avoidance by the Destination*

NIST: *National Institute of Standards and Technology*

NV: *Network Virtualization*

PA: *Paths Algebra*

PaaS: *Platform as a Service*

SaaS: *Software as a Service*

SN: *Substrate Network*

SP: *Service Provider*

VN: *Virtual Network*

VNE: *Virtual Network Embedding*

VNR: *Virtual Network Request*

VNREAL: *Virtual Network Resource Embedding Algorithms*