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Abstract— Network virtualization is a promising technique for building the Internet of the future since it enables the low cost introduction of new features into network elements. An open issue in such virtualization is how to effect an efficient mapping of virtual network elements onto those of the existing physical network, also called the substrate network. Mapping is an NP-hard problem and existing solutions ignore various real network characteristics in order to solve the problem in a reasonable time frame. This paper introduces new algorithms to solve this problem based on 0–1 integer linear programming, algorithms based on a whole new set of network parameters not taken into account by previous proposals. Approximative algorithms proposed here allow the mapping of virtual networks on large network substrates. Simulation experiments give evidence of the efficiency of the proposed algorithms.

Index Terms— Virtual networks,Mapping,Motivation,Related Work,Proposed Algorithms,Performance Evaluation, Future internet.

1 Introduction

THe The minimalism approach of the architecture of the Internet specific network has enabled its global spread. One consequence of this simplicity, known as the ossification of the Internet, has been the impossibility to provide missing features in the original design. These limitations has prevented the development of many possible applications and services, although various attempts have been made to provide some of the features missing in its design .These attempts to overcome the original limitations include various new mechanisms proposed to promote the evolution of the Internet. Those based on network virtualization allow the definition of virtual networks composed of virtual routers and links; these are then hosted by routers and links of the real network called "substrate network". Network virtualization permits the coexistence of various protocol stacks and architectures on a single substrate, without the need to modify the actual physical network. Moreover, this approach imposes no restrictions on the protocols and architectures involved. One of the main issues in network virtualization is the efficient mapping of virtual networks onto the substrate network . However, the search for the optimal mapping of virtual neworks is an NP-hard problem.

This paper proposes a novel solution to the mapping problem to helps to overcome such limitations which imposes fewer restrictions than previous proposals. Our proposal does not consider previous knowledge of virtual network requests; but rather considers that the substrate has a finite capacity, although no specific network topology is assumed. It considers more realistic scenarios and, hence, can handle a large number of parameters that impact on the complexity of a solution.

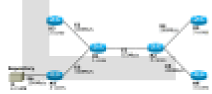

Figure 2. Example of a substrate network.

Figure 3. Example of a virtual network.

2 Motivation

2.1 Formulation

The formulation proposed here models various characteristics of existing operational networks. One of the most important is link delays, which impact on the time needed to instantiate a virtual network, that is, a requirement of service providers. Another important issue is the characteristics of the physical routers.

2.2 Router

The router **R1** has no resources available for the allocation of a virtual router since it has a single core and a virtual router requires two cores. Thus, if the transfer of images is ignored, the virtual network using routers (**R2**,**R5**) and link **E4** or routers (**R2**,**R6**) and link **E5** would be instantiated. As a result of such mapping the required image would be transferred to the physical routers via the link **E1**, which has an available bandwidth of only 0.5Mb/s. Thus requiring 404.5

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seconds for the transfer, four times as long as the time limit to instantiate the virtual network. Even the use of multicast routing would only reduce this to 202.5 seconds, i.e. twice the limit.

2.3 Algorithms

However, the use of the algorithms proposed in this paper would lead to the use of routers (**R3**, **R4**) and links (**E2**, **E3**), since the approach introduced here considers the transfer delay of images and the image transfer would take only four seconds, i.e. much less than the time permitted.

3 Related Work

This section summarizes major existing proposals for network virtualization.

The "Cabo" solution is composed of two layers managed by separate providers with infrastructure providers responsible for controlling the elements in the physical layer, and service providers for the provision of network services in the application layer. The approach presented here, however, considers the existence of an additional layer managed by the connectivity providers. This three-layer architecture is based on the Cabernet architecture , which was designed to eliminate some of the limitations in the deployment of virtual services in Wide Area Networks (WAN). This elimination results from by making the infrastructure transparent to the services provider.

The initial design of the Underlay Fused with Overlays (UFO) architecture is first presented in. This solution is also limited to two layers, with the underlay notifying the overlay about changes in network resources. The overlay receives notifications and, in order to increase efficiency and scalability of the virtual networks, can propose routing changes in the underlay. The mapping algorithms in the presented paper can be used in conjunction with the UFO architecture.

In most of the existing proposals, the resources considered are limited to bandwidth and routers processing capacity. Some papers do suggest the inclusion of other characteristics as a topic for future work; nonetheless, no solution has yet been published. Our proposal has been able to make several realistic assumptions about resource availability, memory available, the number of processing elements of routers, and the time required to instantiate a virtual router. Our work differ by that in by the modelling of repositories of images in the substrate.

4 Proposed Algorithms

The algorithms in this paper model requests dynamically arriving for virtual network establishment on network substrates. Each request specifies the topology of the virtual network, the resources demanded by the virtual network elements, and the QoS requirements, which include a time limit to instantiate it.

The proposed algorithms are based on 0-1 ILP formulations. One algorithm, called the Optimal algorithm, uses the exact solution of the formulations to define the mappings. The other algorithms, called approximated algorithms, employ relaxation techniques to reduce the time needed to find a solution for the formulations. Before presenting the algorithms, we will present the ILP formulations. This formulation differs from that in our previous work since a two step approach has been introduced which reduce memory demands.

4.1 ILP Formulations

All the algorithms proposed in this paper are based on two ILP formulations that must be sequentially executed. The first (ILP-Mapping) searches for the solution of the problem of mapping routers and link s of VNs onto routers and links of the substrate. The second (ILP-Image) searches for routes in the substrate for transferring images from the repositories to the nodes in the substrate which will host the virtual nodes.
The employment of two ILPs reduces the time needed to find solutions when compared to the execution time needed for our previous formulation, which try to find routes and allocate physical routers and links in a single ILP. The reduction in execution time is mainly due to the reduction of thesearch space.

4.2 Optimal Algorithm

The Optimal algorithm implements the two ILP formulations exactly as shown in Subsection "ILP formulations". To find the solution to the problem, it uses the Branch and Cut technique which builds a tree with the root corresponding to the solution of a relaxed formulation of the original ILP and each node to a solution of the relaxed ILP formulation.

4.3 Root Approximative Algorithm

Preliminary experiments with the Opt algorithm showed that it takes too long to find solutions involving substrates with more than 100 routers. This motivated us to implement an approximative algorithm, called the Root Approximative algorithm. This algorithm stops the traversal at the root of the tree. By doing that, a reduction on execution time is expected in comparison with the time required by the Opt algorithm. Such a criterion was derived from the observation that several solutions for the optimal problem are obtained at the root of the tree.

4.4 Algorithms based on relaxed versions of ILPs

In addition to the Root algorithm, four other approxi- mative algorithms are proposed. These algorithms relax integer constraints of the two ILP formulations in an attempt to reduce execution time.Each of the four algorithms consists of three steps: node mapping, link mapping and definition of paths for transfer of the required images. For each step two procedures defines: how to round the real values off to binary ones and

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when such rounding off should take place. In node mapping, the first procedure defines which variable will be rounded off to 1 since only one $X_{n,m,i}$ can be set to 1 for each virtual node *m*. The second procedure determines whether or not all the other variables values should be rounded off to 1. There are two options for each of these two procedures with their combinations defining the four different algorithms proposed.

4.4 .1 How to round off variables

The rounding off of real numbers can be either deterministic or random. In deterministic, the highest real value for a virtual node is rounded off to 1. In random algorithms, a random number is drawn and if this is lower than the value of the real variable, then the real value is rounded off to 1. Such procedure is also employed for the *Y* and *Z* variables.

4.4 .2 When to round off variables

After the execution of the relaxed ILP, another decision must be made. It is possible either to round all the *X* variables associated with all the virtual nodes at once or to round off only the *X* variables related to a specific virtual node, and then run the relaxed ILP as for each X variables. The same procedure applies to the *Y* and *Z* variables. The option that round off all the variables at once implies two executions of the relaxed version of the ILP-Mapping. For the first, the value of the *X* variables are set and later used as input for setting the values of the *Y* variables. After the values of *X* and *Y* variables are set, the relaxed version of the ILP-Image is executed once to find the values of the *Z* variables. This is the procedure adopted by the non-iterative algorithms, i. e., the Deterministic Approximative Algorithm (DDA) and the Random Approximative Algorithm (RAA). The other way is to set the value of a single variable after each execution of the relaxed ILP.

5 PERFORMANCE EVALUATION

This section assesses the efficiency of the proposed mapping algorithms. Numerical examples presented in this section compare the performance of the algorithms in both static and dynamic scenarios. The static scenario involves only the mapping of a single request. The dynamic scenarios involves requests arrive during a certain time interval, with the availability of resources in the substrate network varying over time.
The algorithms were evaluated in terms of run time, the amount of bandwidth allocated to the virtual networks requests, and the blocking probability. A description of the experimental setup is followed by a comparison of the Opt and Root algorithms and another of the performance of the approximative algorithms. Comparisons with existing algorithms were not performed, since these do not consider all of the parameters considered by the algorithms presented here.

5.1Experimental Setup

All the algorithms and the simulator were implemented in C++ with the linear program formulations implemented using the CPLEX optimization library version 12.0. All were executed on a computer running the operating system Debian GNU/Linux Squeeze. The computer was equipped with two Intel Xeon 2.27GHz processors each one with 6 cores capable of running 12 simultaneous threads and 40GB of RAM.

5.2 Optimal and root approximative algorithms

5.2.1 Static Scenarios

The static scenarios involved only a single request, since the aim was to evaluate the differences between the proposed algorithms. The mapping of each request deals with an unallocated substrate. In this way, restrictions due to previous allocation have no impact on the difference of performance of the algorithms.

5.2.2 DynamicScenarios

In the dynamic scenarios, several requests are included in each configuration of the network, so that the algorithms can be evaluated as the availability of the network changes as a function of time. The different sequence of resource allocations produced by different algorithms leads to different resource availability scenarios which implies different probabilities of success in the acceptance a request.

5.3 Approximative Algorithms

The results produced by the approximative algorithms introduced in “Algorithms based on relaxed versions of ILPs” were compared to those yielded by the Root algorithm. In order to evaluate the growth in computational demands and the quality of the solution with an increase on the number of nodes in the substrate, the number of nodes in the substrate was up to 400 and the results are shown as a function of the number of nodes in the substrate.

6 Conclusions and Future work

Mapping virtual networks onto networks substrates is a crucial step for processing of VN services. Therefore efficient mapping algorithms are of paramount for network virtualization. This paper introduced six novel algorithms based on 0-1 ILP: one optimal and five approximative algorithms. These algorithms can be easily integrated to admission control mechanisms. They differ from previous proposals by the consideration of a large number of characteristics existing in real networks. It was shown via numerical examples that the Root algorithm demands considerably less computational time than the Opt algorithm and the iterative approximative algorithms. Such demand allows the adoption of Root algorithm for admission control in real time. It gives similar blocking ratio as does the Opt algorithm, and lower ratios than those of by the other approximative algorithms.

For future work, we intend to modify the formulation to consider the migration of virtual elements (routers and links), so that the algorithms potential migrations of VNs can be suggested. Formulations for the mapping problem considering path splitting are under development. We intent to verify results derived in a testbed for further validation.

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