VCG Auction-based Approach for Efficient Virtual Network Embedding

Abdallah Jarray
SITE, University of Ottawa
Ottawa, Ontario,K1N 6N5 Canada
Email: ajarray@uottawa.ca

Ahmed Karmouch
SITE, University of Ottawa
Ottawa, Ontario, K1N 6N5 Canada
Email: Karmouch@site.uottawa.ca

***Abstract*—In this paper, our focus is on the embedding problem which consists on the mapping of Virtual Network (VN) resources onto physical network. In literature, number of approaches have been proposed for embedding problem where the following limitations can be noticed: *(i)* mapping of VN links and nodes is performed on two separate stages, which may ensue in a high blocking of VN requests, and *(ii)* pricing of resources are based on linear functions, accordingly there is no competition among VN users resulting in reduced profit for the Physical Infrastructure Provider (PIP). To address these concerns, we propose deploying a periodical one-shot node and link embedding approach that increases the PIP profit's and VN users satisfaction ratio by allocating resources based on auction mechanism. Experiments on large mix of VN requests show a clear advantage of auctioning based models over benchmarks in terms of PIP profit's, VN users acceptance ratio and resources utilization.**

I. Introduction

The concept of network virtualization has been proposed as a promising approach to overcome Internet ossification by allowing multiple customized Virtual Networks (VNs) with different Quality of Service (QoS) requirements to be setup on a shared physical infrastructure. In literature, number of proposals for network virtualization architecture have been proposed in several contexts [1] and [2]. For convenience, we will adopt in this work 4WARD architecture [2], where in a VN three main players are identified, namely Physical Infrastructure Providers (PIPs), Virtual Network Providers (VNPs), and Virtual Network Operators (VNOs).

Our main interest in this paper is in evaluating the impact of virtualization on the underlying physical infrastructure (substrate network). To do so, we propose to focus on the embedding problem which consists on a cost-efficient mapping of VN (called also VNP request) resources (nodes and links), onto substrate network (layer 1), i.e., find an assignment where virtual nodes are hosted into specific physical nodes and virtual links span over paths in the substrate network. In literature, most proposals in this regard [3]-[8] have been focused on designing heuristic-based algorithms or on restricting the embedding problem in some particular scenarios, which may ensue on one or more of the following drawbacks.

1) As the mapping of VN links and nodes is performed in two separate stages, it may ensue in a high blocking of VNPs requests and a reduced PIP profit's.
2) As pricing of embedding resources uses linear functions, accordingly it offers no competition mechanism among VNPs in order to maximize PIP profit's.

These limitations motivate us to propose a periodical approach that performs one-shot mapping of VN resources and uses auctioning mechanism to increase PIP profit's. We call this approach *Auction-based Periodical Embedding* (APE). We propose that embedding of VNs is done by small-batches in order to optimize the trade-off that exists between maximizing PIP profit's over time and minimizing the waiting time between VNP request and setup. To do so, we propose to divide the embedding planning time into a set of short-periods. At each new period of time, profitable VNPs requests are selected through an auction mechanism [9], [10], and [12] in order to maximize PIP profit's and VNPs satisfaction ratio. We note that time granularity depends on the type of offered service as well as on the trade-off between maximizing PIP profit's over time and minimizing VNP waiting time between VN request and setup.

However, in realistic auctioning scenario bidders are not cooperatives [9] and may exaggerate their real need. Exaggeration means that VNP users ask for more resource than their real need during the negotiation phase to guarantee their QoS, and to cope with any unpredicted network state variation. Such a behavior can lead to inefficient resource utilization, and can decrease significantly the PIP revenue. Indeed, reserved unused resources can be used to accept new VNPs requests which can offer better bids. To circumvent these issues, we propose using two dynamic pricing approaches based on Vickrey-Clarke-Groves (VCG) mechanism [10] and [11] to detect exaggerated bidders and to apply penalties consequently.

Accordingly, our VN embedding scenario can be defined as following: *(a)* our proposal is from the PIP point of view, *(b)* there is no need for VNP to bid in future auction to keep assigned resources for his accepted VNs, and *(c)* to motivate VNPs to use such a service, PIP defines the following auctioning policy: *(i)* before bidding all VNPs are aware of this policy, *(ii)* PIP offers low resource costs compare to concurrences, *(iii)* resource pricing is based on stepwise pricing curves [11], where costs are decreased in case of low traffic load and increased to some upper bound otherwise, and *(iv)* a penalty is applied only in case of PIP detects an exaggeration behavior, which guarantees a certain fairness among the VNPs. Accordingly, a cooperative behavior will be beneficial for the current and the future new VNs.

In summary the main contributions of this paper are as following.

978-3-901882-50-0

- Proposes a periodical auctioning mechanism to create competition among VNPs which will result in an increase of PIP profit's.
- Proposed APE approach performs join node and link embedding with Quality of Service guarantees.
- Proposes two VCG techniques to be applied in case of non-cooperative bidders scenario.

The remainder of the paper is organized as follows. Section II presents related works. Section III defines the mathematical modeling of the embedding problem. Sections IV and V introduce the Auction-based Periodical Embedding approach (APE). Section VI lists performance evaluation metrics, followed by the numerical results. Finally, Section VII concludes the paper.

II. Related work

A number of approaches have been proposed in the literature to handle complexity issue of VN embedding problem. Most of proposals in this regard have been focused on a two-phase embedding approach, which consists on preselecting in a first stage the mapping of virtual nodes. The assignment of virtual links to substrate paths is done in a second stage.

Lu et *al.* [3] assumed that substrate links have sufficient capacity not to constraint the mapping of VNPs requests. They also ignored the cost related to the mapping of backbone nodes to different locations. Doing so, might help on reducing the complexity issue of the embedding problem however it may lead in poor solution in terms of PIP profit's and VNPs satisfaction ratio.

He et *al.* [5] proposed an approach that deals with one-shot node and link embedding, however as they considered a distributed approach, performance and optimality-gap of the embedding solution are still not comparable with centralized approach. Moreover, time-reservation constraint is relaxed. Indeed, allocated resources for previously accepted VNPs requests and still alive for the coming time might be subject for future contention with new ones.

Yu et *al.* [6] have considered all the aforementioned issues except location constraints on virtual nodes. Indeed, virtual nodes can be mapped to any substrate nodes using path splitting, path migration, and customized embedding algorithms for specific VN topologies.

Chowdhury et *al.* [7] proposed a mathematical programming based scheme to coordinate node and link mapping. Similar to [6], they use geo-locations of VN nodes as heuristic information to reduce search space, which may causes node hot-spot problem. Moreover, embedding approach is based on a simple economic model where pricing/cost is linear function which offers no competition mechanism among VNPs in order to maximize PIP profit's.

III. VN Embedding problem description

A. Substrate network

The physical network S is represented by an undirected graph $G_s = (W_s, L_s)$. Without loss of generality, we assume in this paper that CPU (Processing Unit) and bandwidth are the main substrate resources. We show in Figure 1a an example, where each physical link $l \in L_s$ offers a bandwidth capacity b_l (number over link) and each substrate node $u \in W_s$ has a CPU capacity p_u (number over the node). We introduce a distinguish bandwidth unit cost c_l per each substrate link $l \in L_s$, for load balancing purpose. Similarly, we associate a CPU unit cost c_u for each substrate node $u \in W_s$.

B. VNP request

Similarly, a Virtual Network $n \in N$ called also VNP request, is represented by a directed graph $G_n(A_n, E_n)$. The QoS requirements of each virtual link $e \in E_n$ belonging to class $j \in Q_1$ are defined by the couple (b^j, d^j), where b^j is the required bandwidth and d^j is the maximum number of switching nodes as an indirect way to upper-bound the end-to-end delay, we assume that number of used links has a neglect effect on the end-to-end delay. Similarly, QoS requirements of each virtual node $a \in A_n$ belonging to class $j \in Q_2$ are defined by the couple (p_j, t_j), where p_j is the required CPU and t_j is the potential nodal mapping locations. We denote by $c(a)$ (resp. $c(u)$) the QoS class of virtual link a (resp. node u). We show in Figure 1a an example of two VNPs requests V_1 and V_2. We assume that each VNP offers the bid P_n for VN request n generated based on relevant information provided bay PIP including: bandwidth and CPU unit cost, geographic reach of the substrate network and offered QoS.

C. VN mapping

The mapping of each VN can be decomposed into node and link mapping as following.

1) Node mapping: Each virtual node $a \in A_n$ from the same VN n is embedded to different substrate node $u \in W_s$ by mapping: $M_{\text{N}} : A_n \mapsto W_s$

2) Link mapping: Similarly, each virtual link $e \in E_n$ from the same VN n is embedded to different substrate path $\pi^e_{uv} \in \Pi^s$ by mapping: $M_{\text{L}} : E_n \mapsto \Pi^s$, where (u, v) are substrate nodes assigned to virtual nodes (s, d) source and destination nodes of virtual link e respectively.

D. PIP objective function

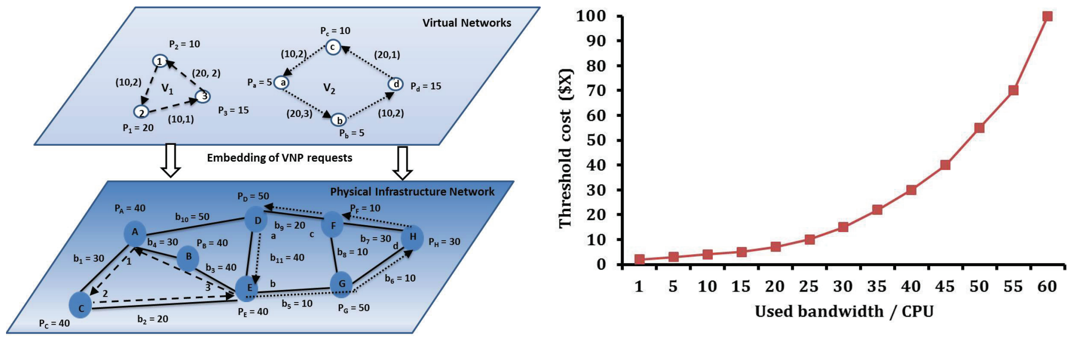
The main guideline of PIP decision to accept or to reject a VN request is based on availability of substrate resources and on economic benefit. Thus, we propose to calculate the PIP profit's of each VNP request n as following.

$$\text{REV}(G_n) = P_n - \text{COST}\left[M_{\text{N}}(A_n), M_{\text{L}}(E_n)\right] \quad (1)$$

Where the first term of Equation (1) calculates the revenue collected from embedding VN n and the second term calculates the cost of assigned substrate resources in order to handle the bandwidth and CPU requirements.

IV. Periodical small-bacth embedding approach

In a realistic virtualization scenario VNPs requests may not usually arrive one after another [7] in regular intervals of time. Thus, a realistic VN embedding scenario could be based on a periodical approach [12], where VNPs requests are queued and then process them in small-batches in order to optimize PIP profit's over time. To do so, we model the VN demand



(a) Embedding VNs on substrate network (b) Bandwidth/CPU pricing curve

Figure 1: VN Embedding and substrate resources cost

as following. Let P be the set of embedding planning periods of time and $R(0)$ the initial set of VNPs requests. The set of VNPs requests $R(p)$ indexed by $p \geq 1$ is defined as:

$$R(p) = R(p-1) + R_{\text{NEW}}(p) - R_{\text{DROP}}(p) \tag{2}$$

Where $R(p-1)$ is the set of accepted VNPs requests at the ending of period $p-1$. $R_{\text{NEW}}(p)$ is the set of new incoming and $R_{\text{DROP}}(p)$ is the set of ending VNPs requests at the outset of period p. Where NEW and DROP are randomly selected between 10% and 40%, giving us a range of cases from slowly fluctuating (10%) to fast changing (40%) of VN demand.

V. Auction-based Periodical Embedding (APE)

In this context of periodical embedding approach, we propose that accepted VNPs requests will be selected using a single-round and sealed-bid auctioning mechanism [9], [10] and [12]. We call this approach APE for Auction-based Periodical Embedding. Allocation (VN embedding) and pricing rules (revenue/profit's of PIP and payments of VNPs) are defined in the following Sections. Our proposal of using auctioning mechanism instead of only a cost function is motivated by the fact that PIP wants to create competition among VNPs in order to increase his revenue as well as offering a competitive resource pricing.

A. Allocation rule

The APE allocation rule determines the node and link embedding of each VN that maximizes the PIP profit's. To do so, we proceed as following. First, we define the bandwidth and CPU threshold unit cost to be used in the embedding of VNs. Next, we formulate the VN embedding auction as an Integer Linear Program called EA-ILP.

1) Threshold unit cost: In order to motivate VNPs to propose competitive bids under the threat of not accepting their VN requests, we define a threshold unit cost (minimum selling unit price) for bandwidth and CPU resources based on non-linear pricing curve of Figure 1b. This curve reflects the applied pricing policy, which consists on decreasing cost in case of low-traffic load and increasing it up to a defined upper bound otherwise. Similar to our previous work [11], at each new auctioning period, PIP updates the unitary costs of bandwidth and CPU resources based-on their history usage and according to the pricing curve of Figure 1b. This curve: *(1)* emulates the fact of having upper bound limits on the available amounts of bandwidth and CPU resources, and *(2)* motivates the VNPs to follow a desired behavior and not to collude among each other.

2) EA-ILP embedding auction: We define in following the EA-ILP model that aims to calculate the optimal one-shot node and link embedding solution using auctioning technique.

a) Decision Variables: To decide on the acceptance of a VNP request n, we need to define the following decision variables.

- $z_n = 1$, if VN request n is accepted and 0 otherwise.
- $x_a^u = 1$, if VN node a is assigned to node $u \in W_s$ and 0 otherwise.
- $x_\pi^e = 1$, if path π uses link e and 0 otherwise.

To alleviate the notation, we omit the index of period p except for the parameters $b_l(p)$, $p_u(p)$, c_u^p and c_v^p.

b) Objective function:

$$Z_{\text{ILP}} = \max \sum_{n \in N} \Big[P_n z_n - \sum_{(u,v) \in W_s^2} \sum_{e \in E_n} \sum_{\pi \in \Pi_{uv}^e} \Big(c_u^p \, p_u + c_v^p \, p_v + \sum_{l \in \pi} c_l b^{c(e)} \Big) \; x_\pi^e \Big] \tag{3}$$

c) Constraints:

$$z_n \leq \sum_{(u,v) \in W_s^2} x_s^u \, x_d^v \;\; ; (sd) = e \in E_n, n \in N \tag{4}$$

$$\sum_{u \in W_s} x_a^u \leq z_n \;\; ; \;\; a \in A_n, n \in N. \tag{5}$$

$$x_a^u = 0 \; ; \; \forall u \in W_s, \; u \notin t_{c(a)}, \forall \, a \in A_n, n \in N. \tag{6}$$

$$x_s^u x_d^v \leq \sum_{\pi \in \Pi_{uv}^e} x_\pi^e \, ; (u,v) \in W_s^2, (sd) = e \in E_n, n \in N. \tag{7}$$

$$\sum_{(u,v)\in W_s^2} \sum_{\pi\in\Pi_{uv}^e} x_\pi^e \le z_n \ ; \ e\in E_n, n\in N. \quad (8)$$

$$L(\pi_{uv}^e) - 1 \le d^{c(e)}; \ (u,v)\in W_s^2, e\in E_n, n\in N. \quad (9)$$

$$\sum_{n\in N}\sum_{e\in E_n} b^{c(e)} \sum_{(u,v)\in W_s^2}\sum_{\pi\in\Pi_{uv}^e} \delta_l^\pi x_\pi^e \le b_l(p) \ \ l\in L_s. \quad (10)$$

$$\sum_{n\in N}\sum_{a\in A_n} x_a^u \, p_{c(u)} \le \ p_u(p) \ \ ; u\in W_s. \quad (11)$$

Equation (3) expresses the PIP profit's defined as the sum of accepted VNP bids minus the cost of VNs embedding. Equations (4), (5), and (6) express QoS requirements for the embedding of virtual network nodes. Equations (7) and (8) ensue that only one embedding path is assigned for each virtual link. Equation (9) expresses QoS requirements for the embedding of virtual network links in terms of maximum number of used switching nodes ($L(\pi_{uv}^e)$: number of used embedding links). Equations (10) and (11) express the updated available bandwidth and CPU capacities of substrate links and nodes respectively.

B. Pricing rule

The pricing rule defines the revenue of seller (PIP) and payments of buyers (VNPs). To calculate these values, we distinguish the two following scenarios depending on the behavior of bidders.

1) Cooperative scenario: In cooperative auctioning scenario, it is assumed that bidders reveal their real needs and do not exaggerate by reserving unused resources. Accordingly, APE defines the pricing rule using the following Equation (12) derived from (1) by summing the offered bids and the costs of used resources of all VNP requests.

$$\text{REV}(\text{PIP}) = \sum_{n\in N} \left(P_n - \text{COST}\left[M_{\text{N}}(A_n), M_{\text{L}}(E_n)\right]\right) \quad (12)$$

We note that equation (12) is the same as the objective function (3) used in the allocation rule, accordingly solving EA-ILP model will define also the pricing rule. Indeed, the value of parameter $\text{REV}(\text{PIP})$ defines the profit of the seller (PIP), the first term defines the payments of buyers (bids) and the second term represents the offered sellers prices (threshold cost) regards each used substrate resource.

2) Non-cooperative scenario: In realistic auctioning scenario bidders are not cooperatives and may exaggerate their real need and reserve unused resources, which can be used to accept new VNPs requests that offer better bids. In such a scenario, Equation (12) is unable to take into account the misuse of VNP exaggeration. Accordingly, we propose to use a threat model based on Vickrey-Clarke-Groves (VCG) mechanism [10] that is able to penalize exaggerated bidders according to the inconveniences they cause to the whole system, i.e., PIP and other VNPs. Consequently, we modify Equation (12) as following:

$$\text{REV}(\text{PIP}) = \sum_{n\in N} \left(P_n^{'}(p) - \text{COST}\left[M_{\text{N}}(A_n), M_{\text{L}}(E_n)\right]\right) \quad (13)$$

where $P_n^{'}(p)$ is the new pricing of each reserving request $n \in V_{\text{RES}}(p)$ at period p and it is calculated, as the sum of the initial offered bid P_n and the inconvenience $I_n(p)$ that it causes to other VNPs and PIP.

$$P_n^{'}(p) = P_n + I_n(p) \quad (14)$$

To measure the inconvenience $I_n(p)$, we propose to use one of the two following pricing techniques.

a) Pricing based on threshold cost variation: This pricing technique is based on the variation of the threshold unit cost of bandwidth and CPU resources used by new VNPs requests ($V_{\text{ADD}}(p)$) at period p. Indeed, we compare the cost of the amount of resources used by reserving VNPs requests $V_{\text{RES}}(p)$ and the overall VNPs requests $V(p)$ at period p, then we deduce the variation of the threshold unit cost. To do so, we proceed as following. At each new period p, after applying the APE allocation rule using EA-ILP model, we perform the following steps. For each substrate network link $l \in L_s$ (resp. each substrate network node $u \in W_s$) do:

- Find the bandwidth $B_{\text{ADD}}^l(p)$ (resp. the CPU $C_{\text{ADD}}^u(p)$) used by new VNPs requests $V_{\text{ADD}}(p)$ at period p on link l (resp. on node u) as following:

  $$B_{\text{ADD}}^l(p) = b_l(p) - b_l(p-1); \ \ U_{\text{ADD}}^u(p) = p_u(p) - p_u(p-1)$$

- Using the pricing curve of Figure 1b, find the dynamic cost $C_{\text{ADD}}^l(p)$ of bandwidth $B_{\text{ADD}}^l(p)$ (resp. $C_{\text{ADD}}^u(p)$ of CPU $U_{\text{ADD}}^u(p)$) and then calculate the bandwidth threshold unit-cost (resp. the CPU threshold unit-cost) without reservation on link l (resp. on node u) as following:

  $$c_l^{'}(p) = \frac{C_{\text{ADD}}^l(p)}{B_{\text{ADD}}^l(p)}; \ c_u^{'}(p) = \frac{C_{\text{ADD}}^u(p)}{U_{\text{ADD}}^u(p)}$$

- Calculate the variation of the threshold unit cost of bandwidth $B_{\text{ADD}}^l(p)$ (resp. of CPU $U_{\text{ADD}}^u(p)$), due to the reservation as following:

  $$\Delta_{\text{ADD}}(c_l(p)) = B_{\text{ADD}}^l(p)(c_l(p) - c_l^{'}(p))$$
  $$\Delta_{\text{ADD}}(c_u(p)) = B_{\text{ADD}}^l(p)(c_u(p) - c_u^{'}(p))$$

- Calculate the unitary inconvenience per unit of bandwidth $I^l(p)$ (resp. per unit of CPU $I^u(p)$) on link l (resp. on node u) caused by the reserved bandwidth (resp. CPU) for VNPs requests accepted at previous periods and still active at the current period as following.

  $$I^l(p) = \frac{\Delta_{\text{ADD}}(c_l(p))}{b_l(p-1)}; \ I^u(p) = \frac{\Delta_{\text{ADD}}(c_u(p))}{p_u(p-1)}$$

- We calculate the inconvenience $I_n(p)$ of each active VNP request $n \in V_{\text{RES}}(p)$ as following.

  $$I_n(p) = \sum_{e\in E_n} b^{c(e)} \sum_{l\in\pi} \left[I^l(p) + p_u I^u(p) + p_v I^v(p)\right]$$

  Where u and v are the selected embedding nodes by EA-ILP model for virtual nodes s and d, source and destination of virtual link $e \in E_n$ respectively. π is the embedding path between nodes u and v. Using Equation (14), we calculate the new pricing of each VNP request $n \in N$ as following.

$$P_n^{'}(p) = P_n + \sum_{e \in E_n} b^{c(e)} \sum_{l \in \pi} \left[I^l(p) + p_u I^u(p) + p_v I^v(p) \right]$$

b) Pricing based on utility drop: In this technique, the created inconvenience is defined in terms of utility drop that was caused to the PIP and VNPs owning requests ($V_{\text{ADD}}(p)$). We define the VNP revenue ρ_n^p that can be collected at period p from embedding of VN request n as follows:

$$\rho_n^p = \eta_n^p - \zeta_n^p \tag{15}$$

where η_n^p is the expected *gain/utility* or *payoff* from the embedding of VN n and ζ_n^p is the charge or *cost* of the used resources. Assuming that VNPs are *rational* users aiming to maximize their own utility function. Accordingly, they will avoid reservation unless the payoff gained is greater than the *cost*. Such a mechanism will define an optimal decision θ_{N} that provides fair allocation of substrate network resources among N VNPs requests, and calculates the transfer value τ_n^p that represents the inconvenience each VNP request n will cause to the other competing VNPs requests and consequently to PIP. Such a transfer value τ_n^p to be added to the offered bid, so Equation (15) could be reformulated as follows:

$$\rho_n^p = \eta_n^p - (P^n + \tau_n^p)$$

We compute the transfer function τ_n^p for VNP request n as:

$$\tau_n^p = \sum_{i \neq n} \eta_i^p(\theta_{\text{N}}) - \sum_{i \neq n} \eta_i^p(\theta_{\text{N}-\{n\}}) \tag{16}$$

where, the first term of Equation (16) represents the sum of the optimal aggregated utilities of all VNPs requests except VNP request n and this in case of VNP request n participates in the auctioning process. While the second term represents the optimal sum of aggregated utilities that all VNPs requests can obtain if VNP request n does not participate in the auctioning at period p. Relying on the APE approach, the transfer function τ_n^p of each VNP request $n \in V_{\text{RES}}(p)$ can be calculated as the difference in the PIP profit's resulting from applying EA-ILP model at period p in the two following scenarios:

- PIP profit's collected from VNPs requests except request n, assuming VNP request n participates in the embedding auction EA-ILP .
- PIP profit's collected from all VNPs requests except request n, assuming VNP request n does not participate in the embedding auction EA-ILP .

Similarly to pricing approach based on threshold unit cost variation, we use equation (14) to calculate the new pricing of VNP request $n \in N$ as following.

$$P_n^{'}(p) = P_n + \tau_n^p$$

C. Benchmark

To assess the efficiency of the proposed auction-based APE approaches, we define the following scenarios:

- Cooperative VNP bidders: APE approach.
- Non-cooperative VNP bidders:
  - APE-TCP: APE combined with pricing rule based on threshold unit cost variation.
  - APE-UDP: APE combined with pricing rule based on utility drop.

To evaluated the performances of these approaches we propose using the two following benchmarks.

1) Two-phases embedding approach (2P-NLE): It is an adaptation of the two-phase VN embedding approach proposed in [3] and [6].

2) One-shot embedding using k-shortest paths and stress function: We propose as a second benchmark an adaptation of the heuristic embedding approach based on node and link stress functions, proposed in [4] and [7].

VI. Numerical results

A. Simulation setup

We carried out experiments of APE approaches on US backbone substrate network [3]. VNs requests are generated using our generator inspired from GT-ITM tool proposed in [13]. QoS requirements of VNs are randomly determined by a uniform distribution among $|Q_1| = 5$ QoS classes for VN nodes and among $|Q_2| = 5$ QoS classes for VN links. We note that VNPs bids are generated randomly based on an estimation of the required VN embedding resources and on the unit costs of substrate resources provided by the PIP at each auctioning period. Bids, bandwidth and CPU threshold unit costs are expressed in terms of $\$X$. Without loss of generality, we assume that the price of 1 Mb of bandwidth and 1 CPU unit is similar and equal to $\$X$. Our simulation are done using Visual Studio C++ 8.0 and IBM CPLEX 12.1.

B. Performance evaluation metrics

To evaluate the performance of our proposed VN embedding approaches, we are measuring the following metrics.

a) PIP Profit's: measured as sum of bids of VNPs requests, reduced by the cost of used substrate resources.

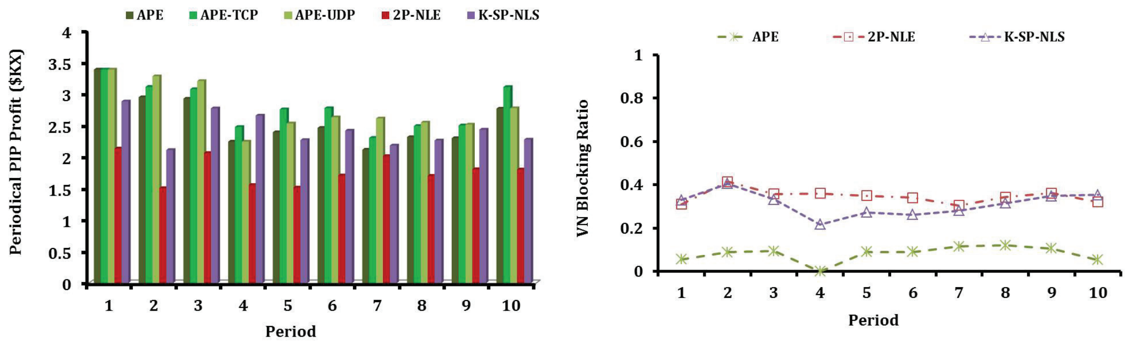
b) VNPs requests blocking ratio: measured as the ratio between the number of rejected and the overall VNPs requests.

c) Bandwidth/CPU utilization: measured as the ratio between the used and the total bandwidth/CPU amounts.

C. Evaluation results

Our focus in this Section, is on quantifying the advantage of VCG auction-based approaches that perform one-shot node and link mapping in terms of PIP profit, VNP request acceptance ratio and substrate resources usage. We note that, since auction-based embedding approaches APE, APE-TCP and APE-UDP differer only regarding the calculated PIP profit's, accordingly in Figures 2b, 3a and 3b, we compare only APE approach vs. benchmarks.

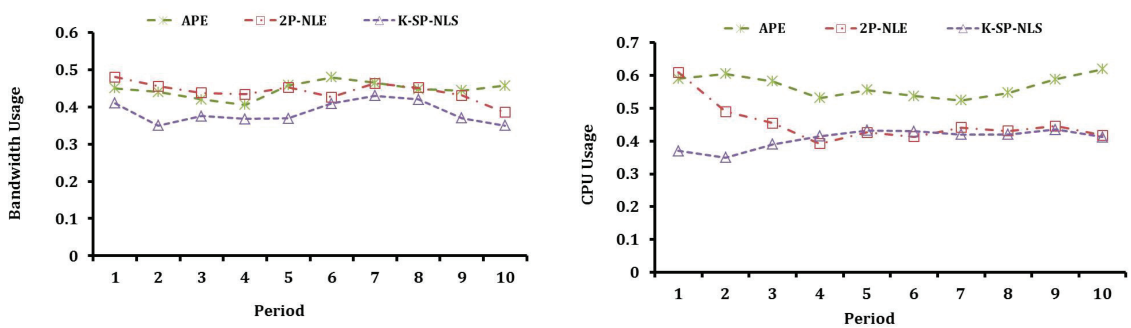
1) VCG auctioning leads into less blocking and higher PIP profit's: In Figures 2a and 2b, we observe that as expected on average auction-based approaches outperform benchmarks in terms of periodical PIP profit as well as blocking ratio over a large mix of QoS requirements of VNPs requests. The only exception is for period 4, where K-SP-NLS provides the highest profit; the explanation of this gap is straightforward.



(a) Periodical PIP profit's

(b) Blocking ratio of VNP requests

Figure 2: PIP profit's and VN blocking ratio



(a) Bandwidth utilization

(b) CPU utilization

Figure 3: Substrate resources usage

Indeed, in period 3, K-SP-NLS blocks roughly 30% more VNPs requests than auction-based approaches, consequently in period 4 there will be more available resources to accept more VNPs requests resulting in more PIP profit's. We believe that the superiority of proposed approaches APE is related to the adopted auctioning mechanism. Indeed, VCG auctioning creates competition among VNPs customer resulting in high PIP profit's and an efficient resources utilization, which increases VNs acceptance ratio.

Periodical profit parameter is also used to compare the two VCG-based pricing approaches. We noticed that APE-TCP offers on average more profit for PIP than APE-UDP. This gap is mainly related to the fact that these two pricing mechanisms are based on different models. Indeed, the pricing mechanism of the former embedding approach is based on the fluctuation of bandwidth/CPU unit cost depending on their history usage level. Such a mechanism reflects more the market fluctuation of substrate resources costs according to pricing curve of Figure 1b, where user pays several times more for an incremental increases of used resources. On the other side, the pricing mechanism of the latter one is more related to VNPs behavior. Indeed, the utility of new VNPs requests is mainly affected by the exaggeration-level of reserving VNPs.

2) One-shot node and link mapping increases resource usage: Figures 3a and 3b plot the percentage of bandwidth and CPU utilization vs. the allocation time periods. In these Figures, we are showing that APE models provide the highest bandwidth and CPU utilization over a large mix of QoS requirements of VNPs requests. We believe that the reason behind this is that auction-based model combined with one-shot node and link embedding approach provides the highest acceptance ratio of VNPs requests. Accordingly, the results showed in these curves confirm our expectation that the two-phases embedding approaches may result in a lack of PIP profit's to gain. Indeed, a myopic node embedding that consider only CPU capacities will ensue in scares of bandwidth in substrate links resulting in high blocking rate of VNPs requests.

VII. CONCLUSION

We proposed a periodical embedding approach that allows us to: *(i)* perform one-shot mapping of VN resources that increases the VNPs satisfaction ratio since resources are utilized efficiently, and (ii) increase PIP profit's by allocating embedding resources using auction mechanism combined with VCG technique to penalize exaggerated VNP bidders. Experiments showed that auction-based embedding approaches outperform benchmarks. On average, the PIP profit is increased up to 20%. Blocking of VNPs requests due to substrate resources scarce is reduced.

REFERENCES

[1] J. Carapinha, and J. Jimenez, *Network Virtualization - a View from the Bottom*, ACM SigComm (VISA'09), Barcelona, Spain, August 17, 2009.

[2] S. Baucke *et al.*, Virtualization Approach: Concept, 4WARD project, Deliverable 3.1.0, 2009.

[3] J. Lu, and J. Turner, *Efficient mapping of virtual networks onto a shared substrate*, DCSE department, Washington University in St Louis, Technical Report, Vol.35, pp.1-11, 2006.

[4] Y. Zhu and M. Ammar, *Algorithms for assigning substrate network resources to virtual network components*, IEEE INFOCOM, Barcelona, Spain, April 23-29, 2006.

[5] J. He *et al.*, *Davinci: dynamically adaptive virtual networks for a customized internet*, CoNEXT, Mardi, Spain, December 9-12, 2008.

[6] M. Yu, *et al.*, *Rethinking Virtual Network Embedding: Substrate Support for path Splitting and Migration*, ACM SIGCOMM Comp. Communication, Vol. 38, Issue 2, pp. 17-29, 2008.

[7] N. Chowdhury, M. Rahman, and R. Boutaba, *ViNEYard:Virtual Network Embedding Algorithms With Coordinated Node and Link Mapping*, ACM/IEEE Transaction on Networking, Vol. 20, pp. 206-2019, 2012.

[8] C. Marquezan *et al.*, *Distributed Autonomic Resource Management for Network Virtualization*, Network Operations and Management Symposium, IEEE/IFIP, Osaka, Japan, 19-23 April, 2010.

[9] M. Dramitinos *et al.*, *An auction mechanism for allocating the bandwidth of networks to their users*, Comp. Networks, Vol. 51 , pp. 4979-4996, 2007.

[10] A. Quttoum *et al.*, *ARMM: An Autonomic Resource Management Mechanism for Virtual Private Networks*, 7th IEEE CCNC, Las Vegas, USA, January 9-10, 2010.

[11] A. Jarray *et al.*, DDP: A Dynamic Dimensioning and Partitioning model of Virtual Private Networks resources, Com. Com., Vol. 35, pp. 906-915, 2012.

[12] A. Jarray, and A. Karmouch, *Periodical Auctioning for QoS Aware Virtual Network Embedding*, IEEE/ACM IWQoS, Coimbra, Portugal, June 4-5, 2012.

[13] E. Zegura, K. Calvert, and B. Bhattacharjee, *How to model an internetwork* in Proc. IEEE INFOCOM, pp. 594-602, 1996.