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Optimization Model for Bandwidth Allocation in a Network Virtualization Environment

Juan Felipe Botero · Xavier Hesselbach

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Abstract Bandwidth allocation is one of the main problems in network virtualization. Mechanisms to allocate bandwidth may avoid bottlenecked virtual links. This paper proposes a model based on optimization theory, to distribute the bandwidth among virtual links looking for the minimization of the spare bandwidth in the substrate network.

Keywords Network Virtualization · Bandwidth Allocation · Optimization Theory

1 Introduction

Network virtualization architectures [1,2], that allows multiple virtual networks (vn) to run on top of a shared physical substrate[1], has been proposed as an alternative to face up Internet ossification [3,4].

Some virtual links could become bottlenecked due to an aggressive bandwidth consume (e.g. UDP applications) in other virtual links belonging to the same physical one. This paper proposes an optimization model to distribute the bandwidth among virtual links accomplishing flow demands and trying, at the same time, to minimize the total spare bandwidth of the physical network.

The paper is organized as follows: Next section describes network virtualization's main challenges. Section 3 shows the notation used to create the bandwidth allocation model. Section 4 presents the proposed model to allocate bandwidth to virtual links. Finally, conclusions and future work are presented in section 5.

Juan Felipe Botero
Jordi Girona Street, 1 and 3, Barcelona, Spain
Tel.: +34-663-501824
E-mail: jfbotero@entel.upc.edu

Xavier Hesselbach
Jordi Girona Street, 1 and 3, Barcelona, Spain

[1] This paper will use indifferently the terms *substrate network* and *physical network*.

2 Research Challenges in Network Virtualization

In a network virtualization environment, multiple vns run on top of a substrate network by means of the interconnection of virtual routers (virtual instances of substrate's routers) using virtual links (virtual instances of substrate's links).

The main challenges to deploy a robust network virtualization are, among others, the *admission control* performed by the substrate, which will have to decide if a new vn is able to be created without harming the QoS of the active vns, standardize the functionality that *virtual routers* must obey and *bandwidth allocation* in vns that is the main focus of this paper.

Virtual links, instances of substrate's links, share the bandwidth of a common physical link. Static allocation of bandwidth among virtual links is the easier way to create an illusion of an isolated and dedicated network for each virtual one. However, static allocation entails the waste of bandwidth that is unused, by a virtual link, in certain time instant and could be used by other(s) virtual link(s). On the other hand, if a best-effort distribution is allowed, one virtual link can be bottlenecked and some vns might be left inoperative.

3 Modeling of Bandwidth Allocation

A network (substrate in our model) is a directed graph $G(V, E)$, where V is a set of elements called vertices and E is a set of elements called arcs or edges, with one or more numbers associated with each arc. Considering a ordered set of vertices $V_1, V_2, ..., V_n, V_{n+1}$; a *directed path* is any sequence of arcs $\in E$ of the following type: $\{(V_1, V_2), (V_2, V_3), ..., (V_n, V_{n+1}))\}$.

Given a network $G(V, E)$, where edge $(i, j) \in E$, $C(K)$ is a set of commodities, where $C_l(k)$ is the commodity l of the vn k. A commodity [5] is defined by $C_l(k) = (s_l(k), t_l(k), h_l(k))$, where $s_l(k)$ and $t_l(k)$ are the source and sink of commodity l, and $h_l(k)$ is the demand between the source and the sink in the vn k. The notation of the model variables is defined in Table 1.

Table 1 Definition of Variables

Terms	Definition
V	Set of physical nodes (routers) belonging to the substrate network
E	Set of links belonging to the substrate network
VN	Set of vns, virtualized from the substrate network
VN_k	$VN_k \in VN$ represents the vn number k
$C_l(k)$	Commodity number l of the vn k
$P_l(k)$	Allowed subset of directed paths for the commodity l in the vn k
$P_l^p(k)$	$P_l^p(k) \in P_l(k)$ is the directed path p for the commodity l in the vn k
$F_l^p(k)$	Bandwidth allocated to the flow that uses path p of commodity l in the vn k
$h_l(k)$	Minimum bandwidth required to the commodity l of the vn k.
$\rho_l^p(i, j, k)$	Binary variable it is 1 if the link (i, j), in the vn k, is part of the path p for the commodity l. It is 0 elsewhere.

4 Bandwidth Allocation Optimization Model

Minimize:

$$F = \sum_{(i,j)\in E}^{|E|} \left(B(i,j) - \sum_{k=1}^{|VN|} \sum_{l=1}^{|C(k)|} \sum_{p=1}^{|P_l(k)|} \rho_l^p(i,j,k) F_l^p(k) \right) \tag{1}$$

Subject to:

$$B(i,j) - \sum_{k=1}^{|VN|} \sum_{l=1}^{|C(k)|} \sum_{p=1}^{|P_l(k)|} \rho_l^p(i,j,k) F_l^p(k) \geq 0 \quad for (i,j) \in E \tag{2}$$

$$\sum_{p=1}^{|P_l(k)|} F_l^p(k) \geq h_l(k) \quad for \quad 1 \leq k \leq |VN| \quad and \quad 1 \leq l \leq |C(k)| \tag{3}$$

$$\exists! F_l^p(k) \neq 0 \quad \forall p | P_l^p(k) \in P_l(k) \tag{4}$$

$$\begin{aligned} &|VN| \geq 0 \quad |E| \geq 0 \\ &|F_l^p(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN|, \quad 1 \leq l \leq |C(k)| \quad and \quad 1 \leq p \leq |P_l(k)| \\ &|C(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN| \\ &|p_l(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN| \quad 1 \leq l \leq |C(k)| \\ &\rho_l^p(i,j,k) \geq 0 \quad for \quad (i,j) \in E, \quad 1 \leq k \leq |VN|, \quad 1 \leq l \leq |C(k)| \quad and \quad 1 \leq p \leq |P_l(k)| \end{aligned} \tag{5}$$

The objective is to find the $F_l^p(k)$ minimizing the objective function (OF) F (Equation (1)), representing the spare bandwidth in the substrate network, subjected to a set of constraints. First group of constraints (2) are of capacity, they assure the sum of the bandwidths assigned to each virtual link does not exceed physical link capacity. Second group of constraints are related with demand (3); they assure that each commodity obeys its assigned demand. Third set of constraints (4) assures the uniqueness of the chosen path for a commodity. Last set of constraints (5) force variables to be positive.

5 Modeling of a Simple Network Topology

Figure 1 is formed by tree vns on top of a substrate. There are three commodities crossing the network with node 1 as source and 11 as the sink, this network environment carries out each commodity in a different VN. Example variables are presented in Table 2.

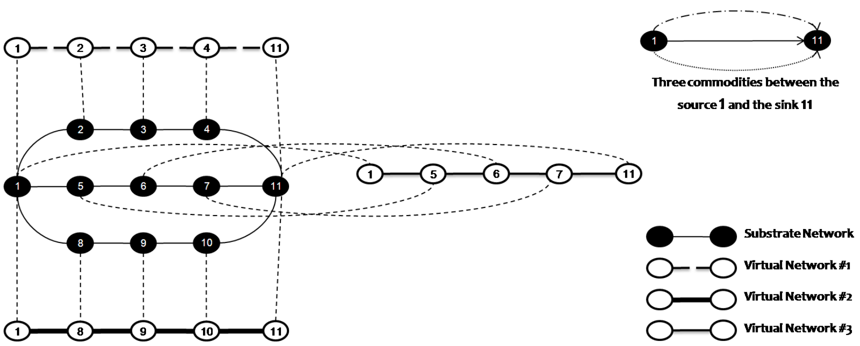

Fig. 1 Example of three VNs running on top of a substrate with three commodities, each carried out by each VN

Table 2 Definition of Example Variables

Variable	Value
V	$\{1,2,3,4,5,6,7,8,9,10,11\}$
E	$\{(1,2),(2,3),(3,4),(4,11),(1,5),(5,6),(6,7),(7,11),(1,8),(8,9),(9,10),$ $(10,11)\}$
VN	$\{VN_1, VN_2, VN_3\}$
$B(i,j)$	$1Mbps \quad \forall(i,j) \in E$
$C(k), k \in VN$	$\{C_1(k)\}, C_1(k) = (s_1(k), t_1(k), h_1(k)) = (1,11,1) \quad k \in \{1,2,3\}$
$P_1(1)$	$\{P_1^1(1)\}, P_1^1(1) = \{(1,2),(2,3),(3,4),(4,11)\}$
$P_1(2)$	$\{P_1^1(2)\}, P_1^1(2) = \{(1,5),(5,6),(6,7),(7,11)\}$
$P_1(3)$	$\{P_1^1(3)\}, P_1^1(3) = \{(1,8),(8,9),(9,10),(10,11)\}$
$F_k^1(1), k \in VN$	$?, \quad k \in VN \to k \in \{1,2,3\}$
$h_1^1(k), k \in VN$	Commodity demands, 1 Mbps, $\quad k \in VN \to k \in \{1,2,3\}$
$\rho_l^p(i,j,k)$	$\rho_1^1(i,j,k) = 0 \quad \forall(i,j,k) - \{\rho_1^1(1,2,1), \rho_1^1(2,3,1), \rho_1^1(3,4,1), \rho_1^1(4,11,1),$ $\rho_1^1(1,5,2), \rho_1^1(5,6,2), \rho_1^1(6,7,2), \rho_1^1(7,11,2), \rho_1^1(1,8,3), \rho_1^1(8,9,3),$ $\rho_1^1(9,10,3), \rho_1^1(10,11,3)\}$

The model for this example is the following one: Minimize: $F = 12 - 4F_1^1(1) - 4F_1^1(2) - 4F_1^1(3)$, subject to: $F_1^1(1) \geq 1$, $F_1^1(2) \geq 1$ and $F_1^1(3) \geq 1$

The OF (Equation (1)) is reduced to an easier expression. Capacity and demand restrictions are the same, that's why only one set of restrictions are shown. It is simple to find the optimal values; $F_1^1(k)$ is 1 for $k = 1, 2, 3$.

6 Conclusions and Future Work

This paper has proposed an optimization model to overcome the consequences of bandwidth sharing in virtual networks. The model tries to minimize the spare bandwidth in the substrate while allocates bandwidth to each commodity by using a unique-path flow accomplishing certain constraints, among them, the assurance of a minimal bandwidth allocation to each commodity. This model avoids the bottlenecking because each virtual link will receive scarcely the bandwidth it has demanded. Future work will be concentrated in the search of efficient algorithms that allocate that bandwidth.

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