Bandwidth Allocation in a Network Virtualization Environment

Juan Felipe Botero jfbotero@entel.upc.edu
Xavier Hesselbach xavierh@entel.upc.edu

Department of Telematics
Technical University of Catalonia

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Outline

1. Introduction
   - Network Virtualization Architecture
   - Bandwidth Allocation in Virtual Networks

2. Proposal
   - Optimization Model
   - Simple Network Topology Modeling Example

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Network Virtualization

- Network Virtualization implies an architectural change
  - Many networks on top of a shared substrate
  - Each virtual network is independent of the others
  - Virtual networks are composed of virtual nodes (routers) and virtual links
  - Network virtualization allow the testing and the deployment of new protocols
  - Allows multiple end-to-end packet delivery systems
- Network Virtualization architecture [Feamster, 2007]
  - Infrastructure Provider
  - Service Provider
  - End User

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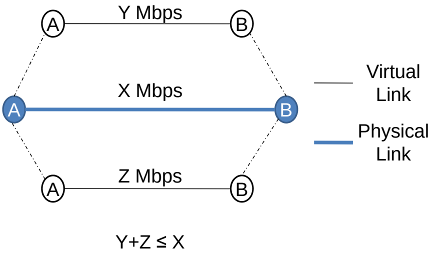
Bandwidth Allocation in Virtual Links

- Resource scheduling is one of the main challenges in the deployment of a new Internet architecture based on Network Virtualization
  - The resources to be scheduled are the CPU processing rate and the Bandwidth
  - Bandwidth is shared among virtual links

Physical and Virtual Links



- Physical links are split in virtual links
- Each virtual link is logically independent of each other
- Virtual link must share the bandwidth of a physical link
- Correct bandwidth allocation must be done among virtual links

Bandwidth Allocation Approaches

Static Allocation Approach

Provides static bandwidth to each virtual link by allocating the demanded bandwidth when VN is created

Best-Effort Approach

Sharing, following a best-effort paradigm, the bandwidth of the physical links among the virtual ones

QoS Based Approach [Jiayue He, 2008]

Taking into account QoS requirements of the flows that are crossing each virtual network.

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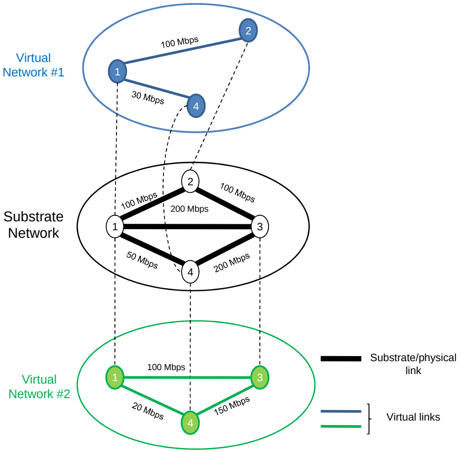
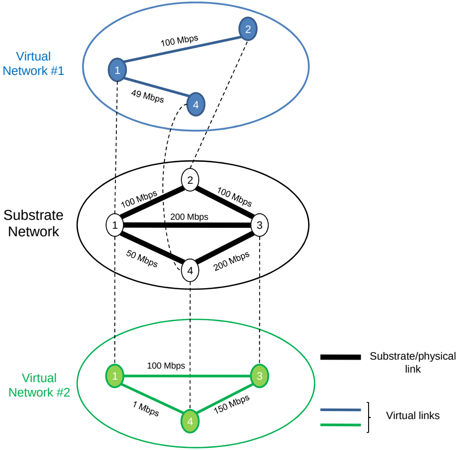
Static Allocation



- Advantages
  - Bandwidth resources isolation
  - Each user is provided with the demanded bandwidth

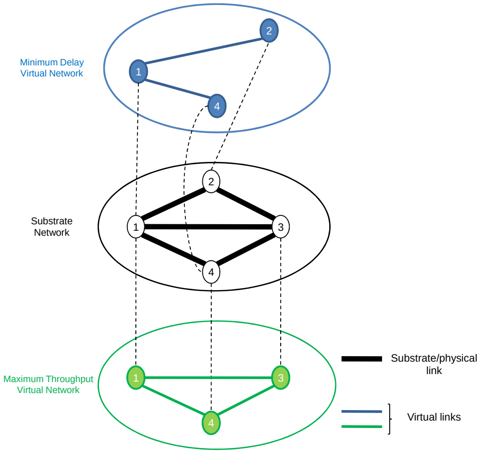
Limitations
  - Bandwidth resources are not fully used
  - Bandwidth of one virtual link could be wasted when unused
  - It is not enough, resources are wasted

Best Effort



- Advantages
  - Maximum use of the bandwidth resources
- Limitations
  - No fairness among virtual links
  - Greedy bandwidth applications using a virtual link lead to loss of service in others

QoS Based Approach



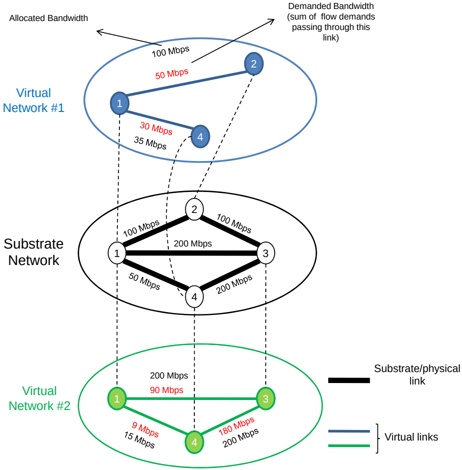
- Advantages
  - This mechanism provides an optimum allocation
  - It distributes the bandwidth periodically
  - It adjusts the virtual network parameters taking into account the current network behavior

Limitations

  - It creates virtual networks based on the class of service.
  - Virtual networks are not created by clients (Virtual Service Providers)

Outline

Spare Bandwidth Optimization Approach



- Advantages
  - Bandwidth is allocated to obtain the minimum spare bandwidth in substrate network
  - Each demand requests, in advance, a specific bandwidth that is assured
  - The remaining bandwidth in each virtual link, is distributed other virtual links

Limitations

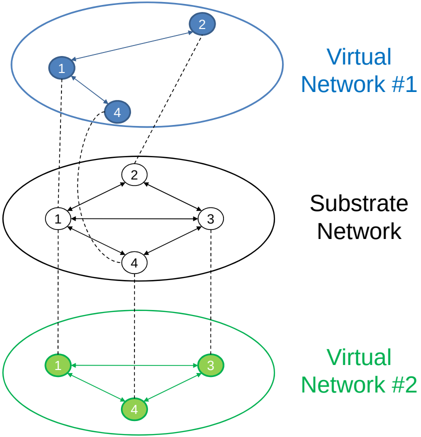
  - Bandwidth is not totally used

Some Definitions

Definition

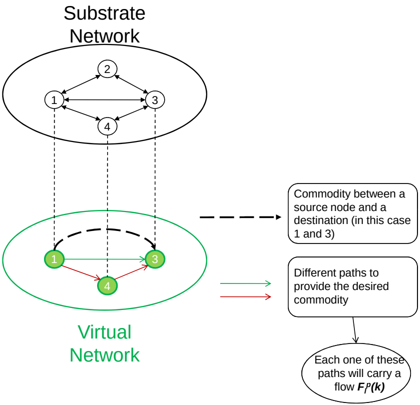
- Substrate Network is represented by a directed graph $G(V, E)$
- Considering an ordered set of vertices $V_1, V_2, ..., V_n, V_{n+1}$; a directed path is any sequence of arcs $\in E$ of the following type: $\{(V_1, V_2), (V_2, V_3), ..., (V_n, V_{n+1}))\}$
- Given a network $G(V, E)$, $C(K)$ is a set of commodities (Multi-Commodity), where $C_l(k)$ is the commodity l of the vn k. A commodity 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

Substrate Network Variables



Terms	Definition
$G(V, E)$	Directed graph representing the substrate network
V	Set of physical nodes (routers) belonging to the substrate network
E	Set of links belonging to the substrate network
(i, j)	$(i, j) \in E$ is the link from node i to node j
VN	Set of virtual networks, virtualized from the substrate network
VN_k	$VN_k \in VN$ represents the virtual network number k
$B(i, j)$	Bandwidth capacity of the substrate network's link (i, j)

Virtual Network Variables



Terms	Definition
$C_l(k)$	Commodity number l of the virtual network k
$P_l(k)$	Allowed subset of directed paths for the commodity l in the virtual network k
$P_l^p(k)$	$P_l^p(k) \in P_l(k)$ is the directed path number p for the commodity l in the virtual network k
$F_l^p(k)$	Bandwidth allocated to the flow that uses the p possible path of the l commodity in the virtual network k
$h_l(k)$	Minimum bandwidth that must be assigned to the commodity l of the virtual network k. (Commodity demand)
$\rho_l^p(i,j,k)$	Binary variable k It is 0 $\longrightarrow$ if the link (i,j) in the virtual network k. is not part of the path p for the commodity l It is 1 $\longrightarrow$ if the link (i,j) in the virtual network k. is part of the path p for the commodity l

Optimization Model(I)

Minimize:

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

Subject to:

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

$\sum_{p=1}^{|P_l(k)|} F_l^p(k) \geq h_l(k) \quad for \quad 1 \leq k \leq |VN|, \quad 1 \leq l \leq |C(k)|$ → **Demand constraints**

$\exists! F_l^p(k) \neq 0 \quad \forall p | P_l^p(k) \in P_l(k)$ → **Unsplittable path constraints**

$|VN| \geq 0 \quad |E| \geq 0$ →**Non-negativity constraints**

$|F_l^p(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN|, \quad 1 \leq l \leq |C(k)|, \quad 1 \leq p \leq |P_l(k)|$

$|C(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN|$

$|p_l(k)| \geq 0 \quad for \quad 1 \leq k \leq |VN| \quad 1 \leq l \leq |C(k)|$

$\rho_l^p(i,j,k) \geq 0 \quad for \quad (i,j) \in E, \quad 1 \leq k \leq |VN|, \quad 1 \leq l \leq |C(k)|, \quad 1 \leq p \leq |P_l(k)|$

Optimization Model(II)

Objective Function

Minimize Spare bandwidth in the substrate Network

Capacity constraints

The sum of the bandwidths assigned to each virtual link cannot exceed the bandwidth of the physical link

Demand constraints

The demand (minimum bandwidth) of each commodity must be assured.

Unsplittable path constraints

This constraint assures that each commodity only uses one path from the source to the destination node

Non-negativity constraints

All the variables must be positive

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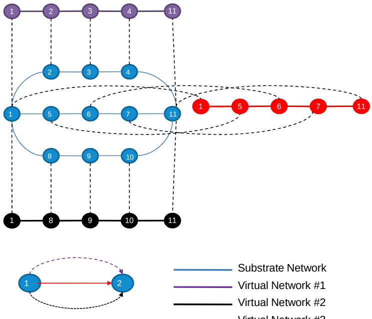
Simple Network Topology Variables



Three commodities between the source 1 and the sink 11

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

Model of Simple Network Topology

Minimize:

$F = 12 - 4F_1^1(1) - 4F_1^1(2) - 4F_1^1(3) \rightarrow$ **Objective function**

Subject to:

$F_1^1(1) \geq 1$, $F_1^1(2) \geq 1$ and $F_1^1(3) \geq 1 \rightarrow$ **Capacity constraints = Demand constraints**

$\exists! F_l^p(k) \neq 0 \quad \forall p | P_l^p(k) \in P_l(k) \rightarrow$ **Unsplittable path constraints**

All the variables must be positive$\rightarrow$ **Non-negativity constraints**

It is easy to find the optimal values in this case: $F_1^1(k)$ is 1 for $k = 1, 2, 3$

Summary

- Bandwidth Allocation is a critical challenge in an network virtualization environment
- A model based on the minimization of the spare bandwidth is proposed to allocate the bandwidth in virtual links

Future Work

- Show, by means of NP-Completeness theory, the complexity of the problem
- Look for efficient algorithms to approach the objective
- Take into account applications with different kind of services
- Consider not only the bandwidth, but other QoS parameters (Delay, Jitter) in the objective function

References

[Feamster, 2007]
N.Feamster, L. Gao, J. Rexford.
How to lease the Internet in your spare time, ACM SIGCOMM Computer Communication Review, pp. 61-64. (2007)

[Jiayue He, 2008]
J. He, R. Zhang-Shen, Y. Li, C.Y. Lee, J. Rexford, and M. Chiang.
Davinci: Dynamically adaptive virtual networks for a customized internet, ACM CoNEXT, 2008