Bandwidth Allocation in a Network Virtualization Environment

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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 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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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.

\[ Y + Z \leq X \]
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)
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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 to 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 $C_i(k)$ is the commodity $l$ of the $vn_k$. A commodity is defined by $C_i(k) = (s_l(k), t_l(k), h_l(k))$, 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**

<table>
<thead>
<tr>
<th>Terms</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G(V, E)$</td>
<td>Directed graph representing the substrate network</td>
</tr>
<tr>
<td>$V$</td>
<td>Set of physical nodes (routers) belonging to the substrate network</td>
</tr>
<tr>
<td>$E$</td>
<td>Set of links belonging to the substrate network</td>
</tr>
<tr>
<td>$(i, j)$</td>
<td>$(i, j) \in E$ is the link from node $i$ to node $j$</td>
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<tr>
<td>$VN$</td>
<td>Set of virtual networks, virtualized from the substrate network</td>
</tr>
<tr>
<td>$VN_k$</td>
<td>$VN_k \in VN$ represents the virtual network number $k$</td>
</tr>
<tr>
<td>$B(i, j)$</td>
<td>Bandwidth capacity of the substrate network’s link $(i, j)$</td>
</tr>
</tbody>
</table>
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 $k$
$P^D_l(k)$ | $P^D_l(k) \in P_l(k)$ is the directed path number $p$ for the commodity $l$ in the virtual network $k$
$F^D_p(k)$ | 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)
$\rho^D_l(i, j, k)$ | Binary variable $k$
  - It is $0 \rightarrow$ if the link $(i, j)$ in the virtual network $k$ is not part of the path $p$ for the commodity $l$
  - It is $1 \rightarrow$ if the link $(i, j)$ in the virtual network $k$ is part of the path $p$ for the commodity $l$
Minimize:

\[ F = \sum_{(i,j) \in E} \left( B(i,j) - \sum_{k=1}^{\|V\|} \sum_{l=1}^{\|C(k)\|} \sum_{p=1}^{\|P_l(k)\|} \rho^P(i,j,k) F^P_l(k) \right) \rightarrow \text{Objective function} \]

Subject to:

\[ B(i,j) - \sum_{k=1}^{\|V\|} \sum_{l=1}^{\|C(k)\|} \sum_{p=1}^{\|P_l(k)\|} \rho^P(i,j,k) F^P_l(k) \geq 0 \quad \text{for} \ (i,j) \in E \rightarrow \text{Capacity constraints} \]

\[ \sum_{p=1}^{\|P_l(k)\|} F^P_l(k) \geq h_l(k) \quad \text{for} \ 1 \leq k \leq |V|, \ 1 \leq l \leq |C(k)| \rightarrow \text{Demand constraints} \]

\[ \exists F^P_l(k) \neq 0 \quad \forall p | P^P_l(k) \in P_l(k) \rightarrow \text{Unsplittable path constraints} \]

\[ |V| \geq 0 \quad |E| \geq 0 \rightarrow \text{Non-negativity constraints} \]

\[ |F^P_l(k)| \geq 0 \quad \text{for} \ 1 \leq k \leq |V|, \ 1 \leq l \leq |C(k)|, \ 1 \leq p \leq |P_l(k)| \]

\[ |C(k)| \geq 0 \quad \text{for} \ 1 \leq k \leq |V| \]

\[ |p_l(k)| \geq 0 \quad \text{for} \ 1 \leq k \leq |V|, \ 1 \leq l \leq |C(k)| \]

\[ \rho^P(i,j,k) \geq 0 \quad \text{for} \ (i,j) \in E, \ 1 \leq k \leq |V|, \ 1 \leq l \leq |C(k)|, \ 1 \leq p \leq |P_l(k)| \]
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
### Optimization Model (II)

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<tr>
<td>$V$</td>
<td>{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}</td>
</tr>
<tr>
<td>$E$</td>
<td>{(1, 2), (2, 3), (3, 4), (4, 11), (1, 5), (5, 6), (6, 7), (7, 11), (1, 8), (8, 9), (9, 10), (10, 11)}</td>
</tr>
<tr>
<td>$VN$</td>
<td>{VN_1, VN_2, VN_3}</td>
</tr>
<tr>
<td>$B(i, j)$</td>
<td>1 Mbps $\forall (i, j) \in E$</td>
</tr>
<tr>
<td>$C(k)$, $k \in VN$</td>
<td>$C_1(k) = (s_1(k), t_1(k), h_1(k)) = (1, 11, 1)$ $k \in {1, 2, 3}$</td>
</tr>
<tr>
<td>$P_1(1)$</td>
<td>{{P_1^1(1)}, P_1^1(1) = {(1, 2), (2, 3), (3, 4), (4, 11)}}</td>
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<tr>
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<td>{{P_1^1(2)}, P_1^1(2) = {(1, 5), (5, 6), (6, 7), (7, 11)}}</td>
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<tr>
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<td>{{P_1^1(3)}, P_1^1(3) = {(1, 8), (8, 9), (9, 10), (10, 11)}}</td>
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<tr>
<td>$F_k^1(1)$, $k \in VN$</td>
<td>? $k \in VN \rightarrow k \in {1, 2, 3}$</td>
</tr>
<tr>
<td>$h_1^1(k)$, $k \in VN$</td>
<td>1 Mbps $k \in VN \rightarrow k \in {1, 2, 3}$</td>
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<tr>
<td>$\rho^P_i(i, j, k)$</td>
<td>$\rho_1^1(i, j, k) = 0$ $\forall (i, j, k) \in {\rho_1^1(1, 2, 1), \rho_1^1(2, 3, 1), \rho_1^1(3, 4, 1), \rho_1^1(4, 11, 1), \rho_1^1(1, 5, 2), \rho_1^1(5, 6, 2), \rho_1^1(6, 7, 2), \rho_1^1(7, 11, 2), \rho_1^1(1, 8, 3), \rho_1^1(8, 9, 3), \rho_1^1(9, 10, 3), \rho_1^1(10, 11, 3)}}$</td>
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</table>
Model of Simple Network Topology

Minimize:

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

Subject to:

$$F_1^1(1) \geq 1, \quad F_1^1(2) \geq 1 \quad \text{and} \quad F_1^1(3) \geq 1 \rightarrow \text{Capacity constraints = Demand constraints}$$

$$\exists ! F_i^p(k) \neq 0 \quad \forall p | P_i^p(k) \in P_i(k) \rightarrow \text{Unsplittable path constraints}$$

*All the variables must be positive* → *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]