Automated Bandwidth Allocation Problems in Data Centers

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Motivation

• Managing network resources is the key computational problem in Data Centers.
• Applying verification/synthesis tool to network resource management?
  – Benefits: exact solutions, correctness guarantees
  – Challenges: efficiency
• This work: bandwidth allocation by SAT/SMT solvers
Bandwidth Allocation Problem
Bandwidth Allocation Problem

Data Center’s Network

- **X₁**: 10G bps
  - **X₂**: 10G bps
    - **S₁**: 1G bps
    - **S₂**: 600M bps
  - **X₃**: 10G bps
    - **S₃**: 500M bps
    - **S₄**: 450M bps
Bandwidth Allocation Problem

Data Center’s Network

Virtual Network

10G bps

X₁

1G bps

10G bps

X₂

600M bps

X₃

500M bps

450M bps

S₁

S₂

S₃

S₄

400M bps

V₁

400M bps

V₂

V₃
Bandwidth Allocation Problem

Data Center’s Network

Virtual Network

1G bps
600M bps
500M bps
450M bps

10G bps
10G bps

400M bps
400M bps

S₁
S₂
S₃
S₄

V₁
V₂
V₃
Bandwidth Allocation Problem

Data Center’s Network

- $X_1$
  - 10G bps
  - $X_2$
    - 1G bps
    - 600M bps
  - $X_3$
    - 450M bps
    - 500M bps

Virtual Network

- $V_1$
  - 400M bps
  - $V_2$
  - 400M bps
  - $V_3$
Bandwidth Allocation Problem

Data Center’s Network

Virtual Network

X₁

X₂

X₃

V₁

V₂

V₃

V₄

10G bps

10G bps

1G bps

600M bps

500M bps

450M bps

400M bps

400M bps
BAP: Facts

• Complexity:
  – NP-complete: tree for physical network & virtual network

• Existing heuristics:
  – Pros: efficient
  – Cons: no guarantee

• Alternative approach: SAT/SMT solving
SAT Encoding: A Glimpse

- $X(v,s)$: VM $v$ is mapped to server $s$
- $Y(l,e)$: physical link $l$ is reserved bandwidth virtual link $e$
- $R(l,e,k)$: physical link $l$ is the $k$-th edge on the routing path for virtual link $e$
- Server capacity:
  - $\sum_v X(v,s) < c(s)$, for every server $s$
- Link capacity:
  - $\sum_e Y(l,e) < b(l)$, for every physical link $l$
Abstraction and Refinement

• Observation: Hierarchical physical network topology in data centers
  – Tree
  – Fat-tree
• Idea:
  – Abstract physical network: small size
  – Refine subgraphs
Abstraction
Abstraction
Abstraction
Abstraction
Abstraction
Refinement

1
2
4
2
Evaluation: Set up

• Physical network topology: tree with 200 servers:
Evaluation: Set up

- Virtual network topology: connected cliques
Evaluation: Set up

• Experiment:
  – Run allocation algorithm
  – Keep mapping the VN to the PN
  – Stop when no more VN can be mapped
Evaluation: Server Utilization

![Bar Chart]

- **Axes:**
  - **Y-axis:** Avg. server utilization
  - **X-axis:** # of VMs

- **Legend:**
  - secondnet
  - sat
  - sat_abs

- **Data Points:**
  - 9 vms: secondnet (0.2), sat (0.8), sat_abs (1.0)
  - 15 vms: secondnet (0.2), sat (1.0), sat_abs (1.2)
Evaluation: Link Utilization

![Graph showing average link utilization for different numbers of VMs. The x-axis represents the number of VMs (9 vms, 15 vms), and the y-axis represents the average link utilization. Three categories are plotted: secondnet, sat, sat_abs.](image)
Evaluation: Running Time per VN

- **Running Time per VN (seconds)**

  - # of VMs in the virtual network

  - secondnet
  - sat
  - sat_abs

  - 9 vms
  - 15 vms
Summary

• Alternative approach solving network resource allocation problem: using SAT/SMT solvers
• Abstract&refinement for scalability
• Strength: optimal solution
• Weakness: efficiency
  – Possible scenario: Optimal reallocation