CloudMirror: Application-Driven Bandwidth Guarantees in Datacenters

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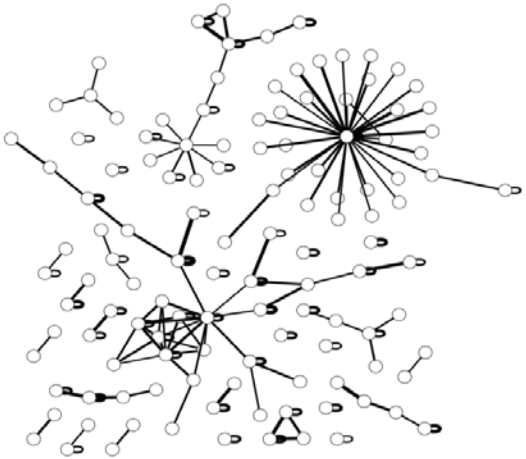
CloudMirror Motivation

Emerging Cloud applications are diverse

Complex combinations of interacting service components

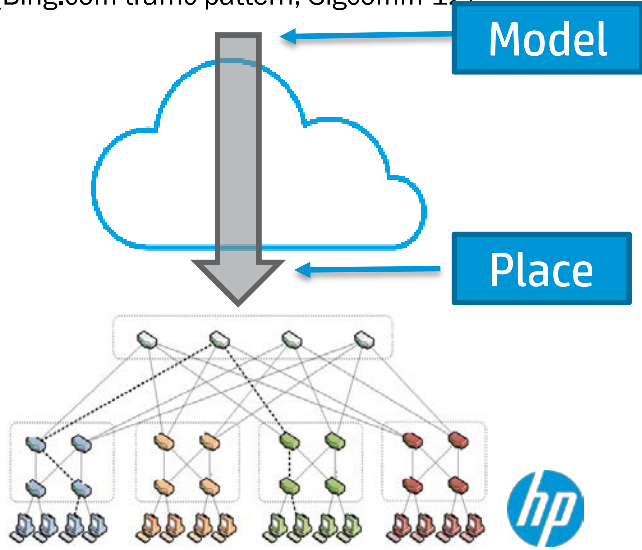
Require predictable performance:

via guaranteed bandwidth and high availability



[Bing.com traffic pattern, Sigcomm'12]

Need to accurately represent and efficiently map application requirements onto shared physical network



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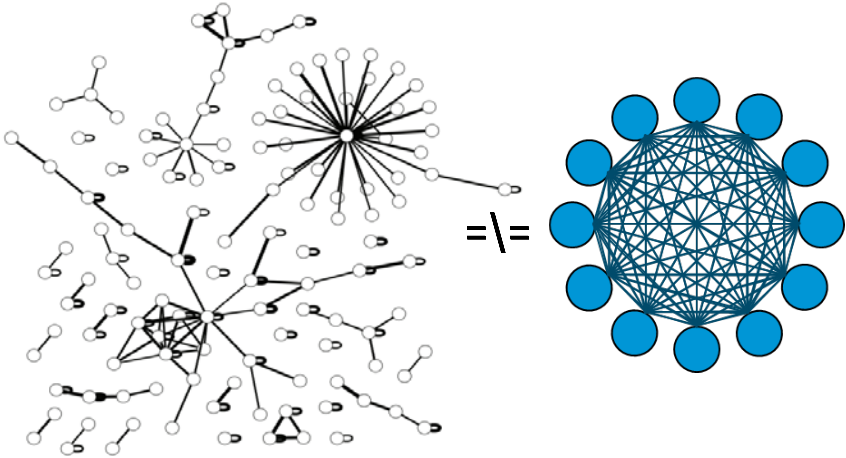

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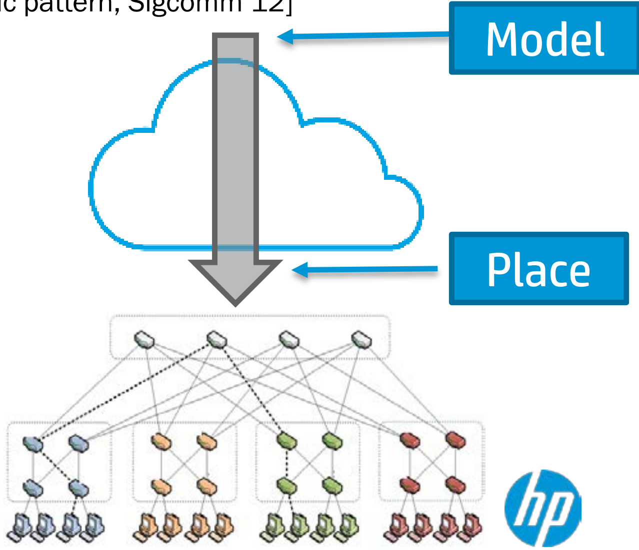


Existing models and systems fall short!

Have focused on batch applications like MapReduce, Hadoop w/

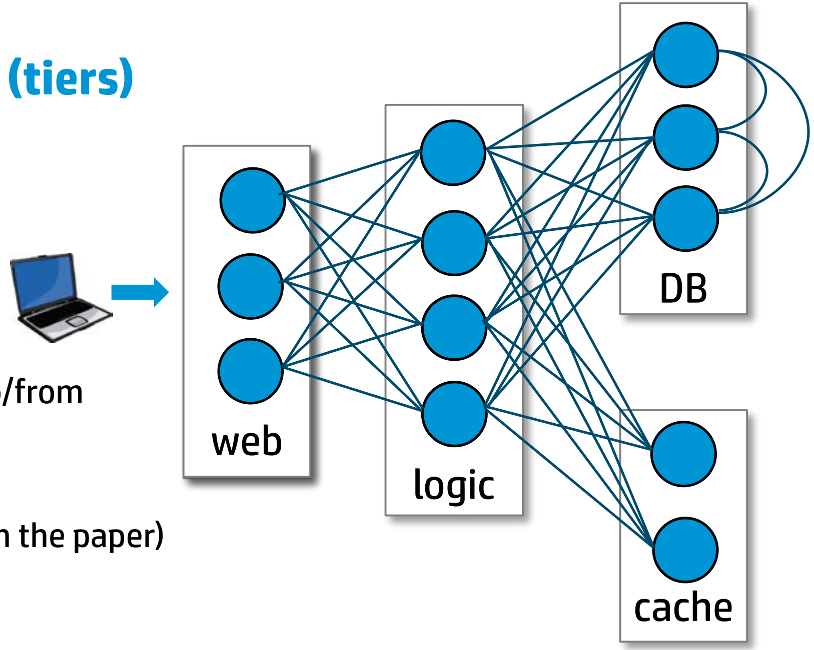
- All-to-all traffic patterns

Interactive online applications

E.g., 3-tier web, enterprise ERP, realtime analytics

Composed of communicating service components (tiers)

Diverse, complex structure



High BW requirement

- Facebook [Farrington, OI'13]

  One HTTP request triggered >500 internal calls

  "*Experiences 1000x more traffic inside its datacenters*" than traffic to/from outside users
- Widely used data-intensive framework

  Redis, VoltDB require up to 10x BW than Hadoop, Hive (benchmarks in the paper)

Delay-sensitive

- Amazon – "*Every 100ms latency costs 1% in (e-commerce) sales*"
- Insufficient bandwidth hurts response time

CloudMirror Goals and System Components

Bandwidth Model

- Accurate to complex applications
- Flexible to elastic scaling
- Intuitive

Tenant Application Graph (TAG)

↓

VM Placement

- Guarantee bandwidth and High-Availability
- Efficient to network and other resources

***CloudMirror* Algorithm**

↓

Runtime Enforcement

- Work-conserving, practical
- Easily guarantee the model

Leverage *ElasticSwitch* [Sigcomm'13]

CloudMirror Goals and System Components

Focus of this talk

Bandwidth Model

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- Flexible to elastic scaling
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CloudMirror Algorithm

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Leverage *ElasticSwitch* [Sigcomm'13]

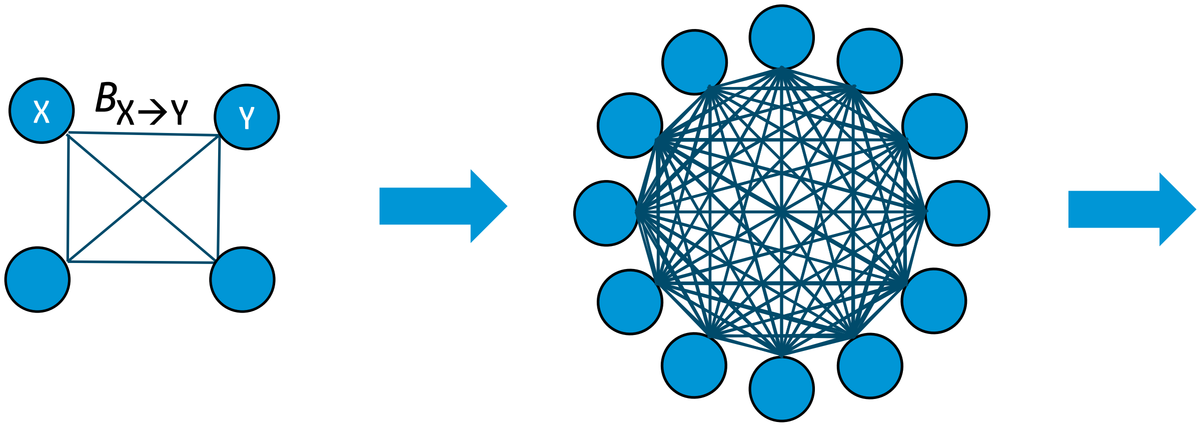
Prior work: Pipe model

Specifies every VM-to-VM pair bandwidth

O(n^2) pipes for n VMs

Not scalable, too slow to compute valid VM placements

- O(n^3) or higher time complexity, for resource-efficient placements

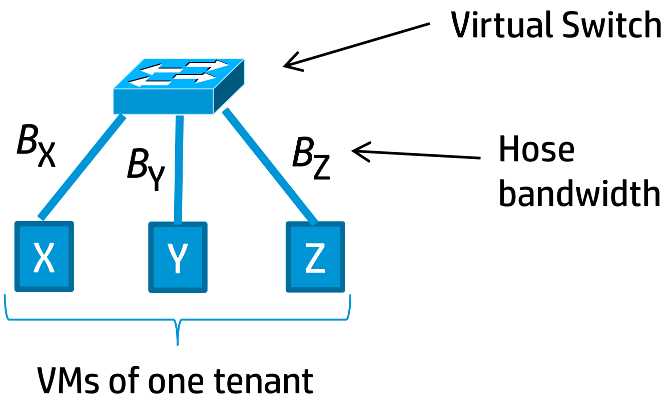


100 VMs
: up to 9,900 pipes

Prior work: Hose model [N. Duffield, Sigcomm'99]

Specifies per-VM aggregate bandwidth

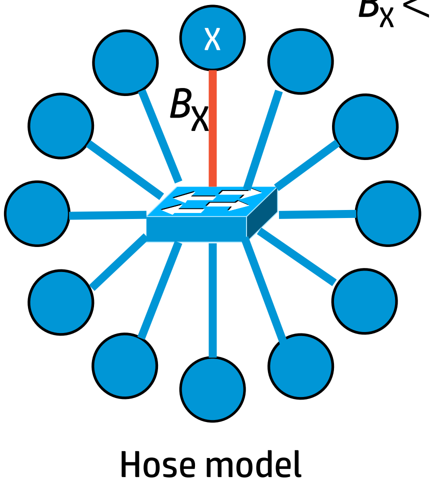
Simple, scalable

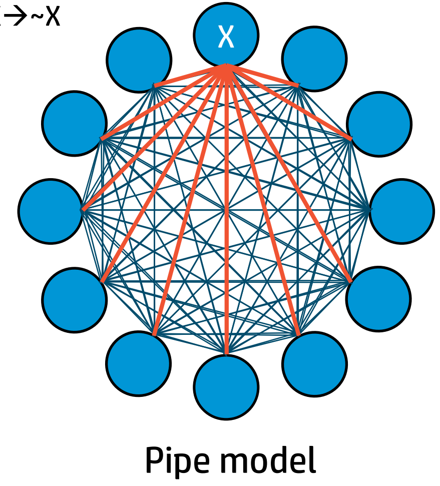


Aggregates BW demands towards all other VMs

Statistical multiplexing gain:

$B_X < \sum B_{X \to \sim X}$





Flat all-to-all communication structure fits well for batch applications like Hadoop

Hose model is unfit

Applications have diverse & complex structures

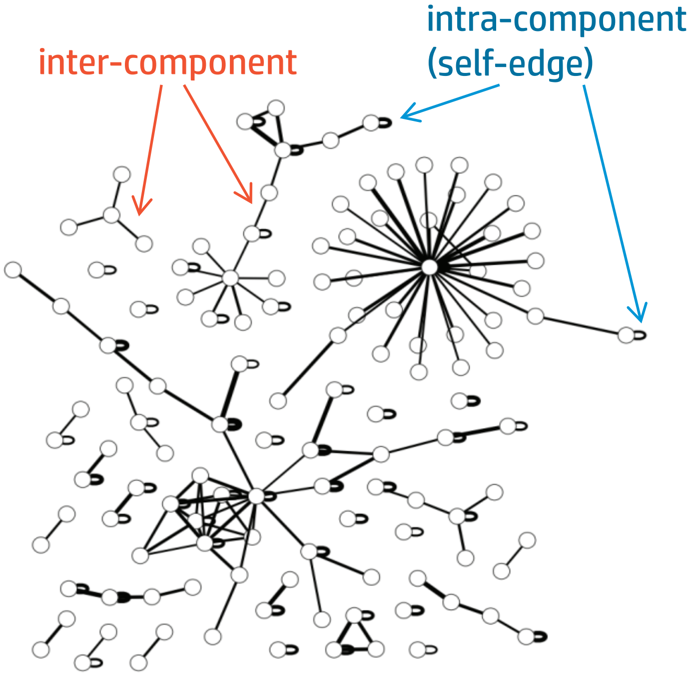
Star, linear, mesh, … from bing.com datacenter [Bodik, Sigcomm'12]

Inter-component traffic dominates

Hose aggregates BW towards different components

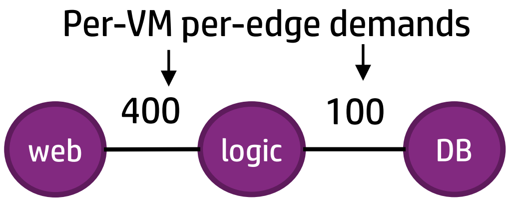
Too coarse-grained

Prevents accurate and efficient guarantees on infrastructure

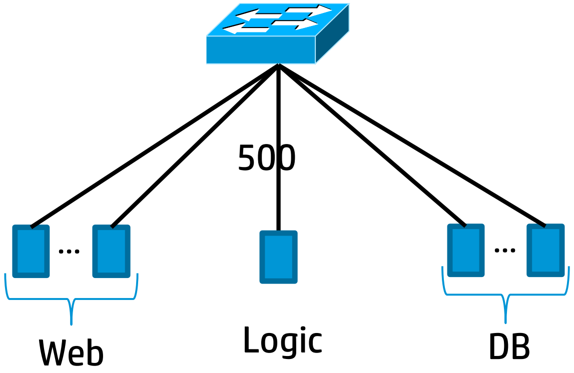


Hose is too coarse-grained

3-tier web example



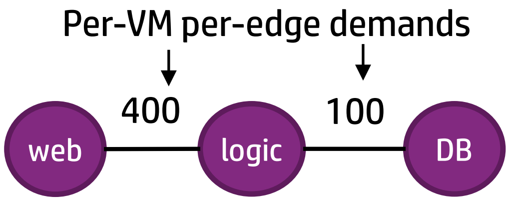
Hose model



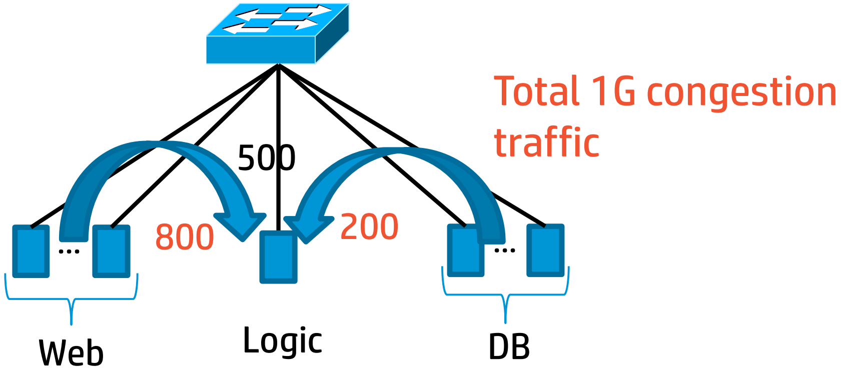
400+100 = 500 Mbps Hose guarantee for a Logic VM

Hose is too coarse-grained

3-tier web example



Hose model

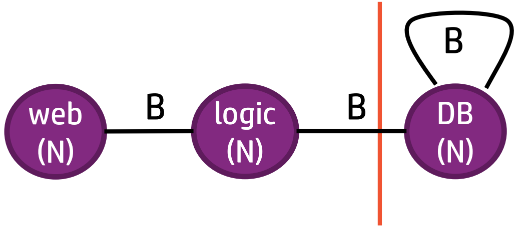


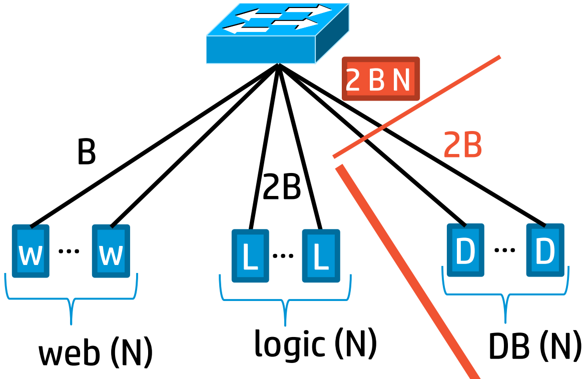
400+100 = 500 Mbps Hose guarantee for a Logic VM

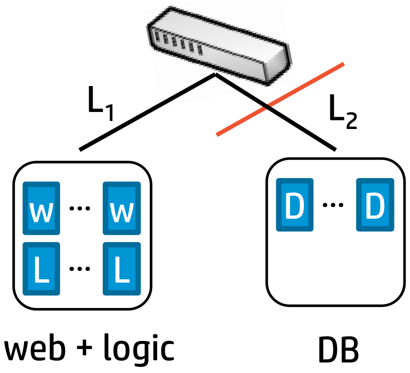
At congestion, TCP-like fair allocation would split 500 into 300:200

Failing to provide 400:100 that application requires

Hose over-provisions physical link bandwidth







Physical deployment example

N: # VMs in each tier

B: per-VM per-edge bandwidth

Hose model reservation at L_2 : $2B \cdot N$

logic - DB demand = $B \cdot N$

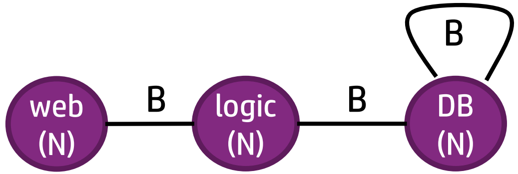
2X overprovision by Hose Model

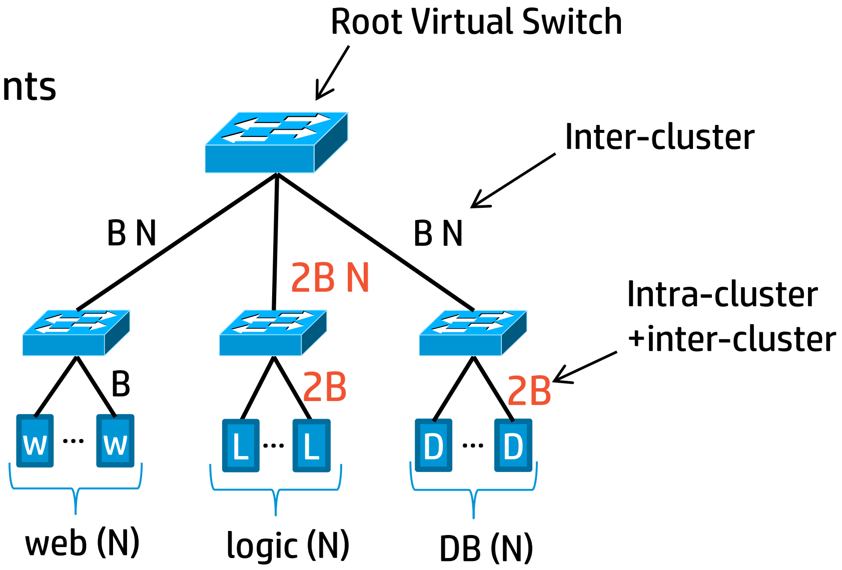
Virtual Oversubscribed Cluster (VOC) [Ballani, Sigcomm'11]

a.k.a Virtual Tree [NSDI'13]

2-level hierarchical hose model

To better model applications having multiple components





VOC model

Aggregates demands towards different clusters

→ too coarse-grained

Lessons

1. Aggregate pipes (like Hose)

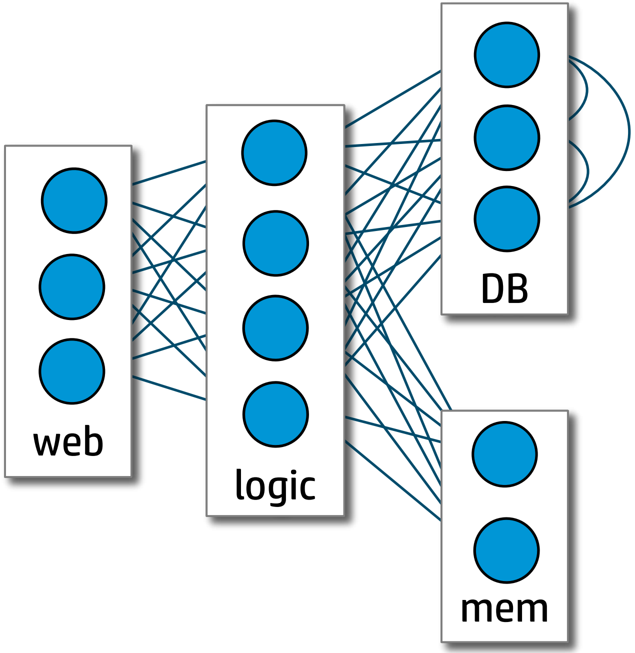
Model simplicity

Multiplexing gain

2. Preserve inter-component structure (like Pipe)

Accurately capture application demands

Efficiently utilize network resources



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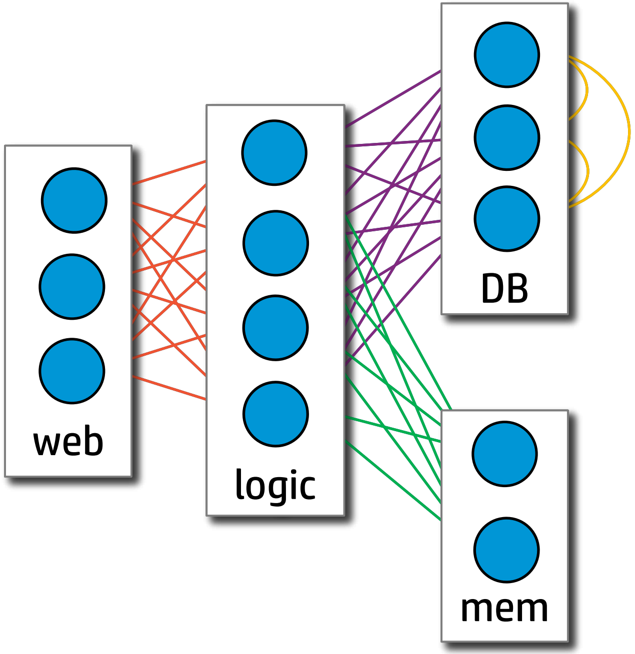
Solution:
aggregating pipes only between a pair of communicating tiers (same-color pipes)



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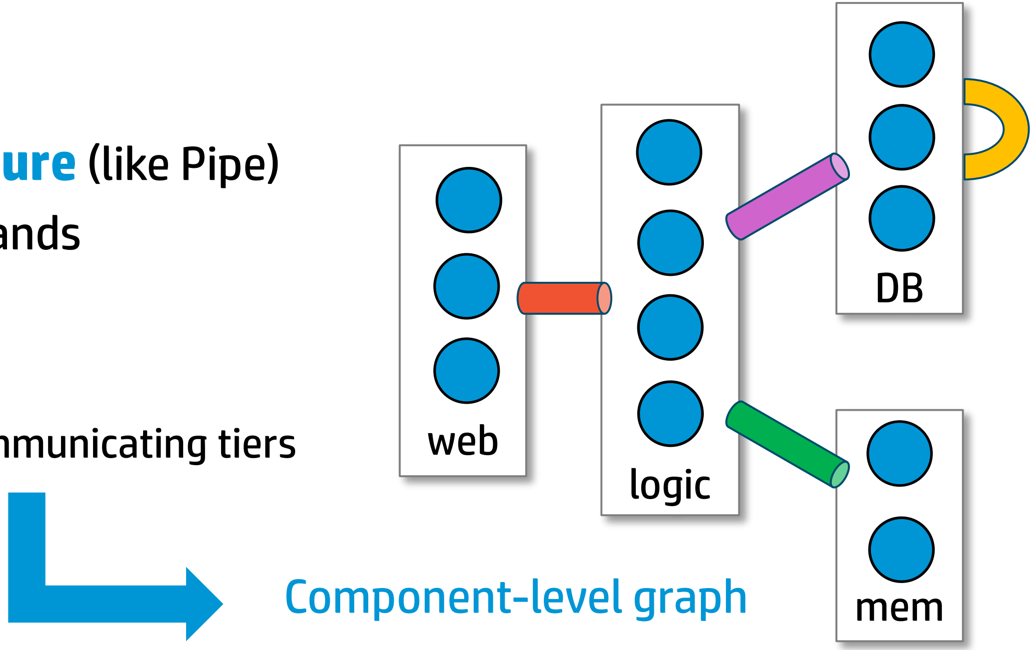


Tenant Application Graph (TAG)

Vertex = application component (or tier)

A group of VMs performing the same function

Vertex size N = # of VMs

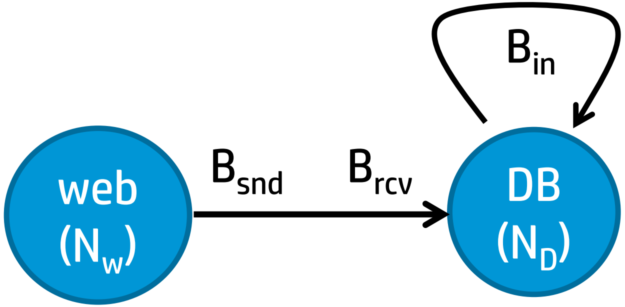
Two types of edges

Directional edge between two vertices: inter-component

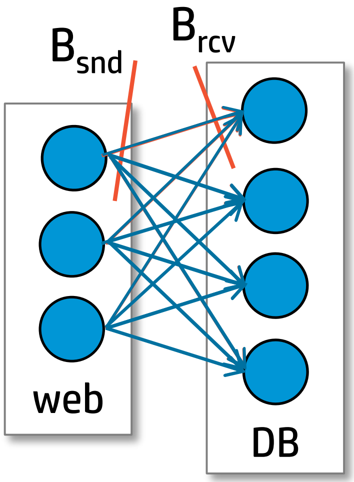
- B_{snd} = per-VM sending bandwidth (VM-to-component aggregation)
- B_{rcv} = per-VM receiving bandwidth (component-to-VM aggregation)

Self-edge: intra-component

- B_{in} = per-VM sending/receiving for traffic between the same tier VMs



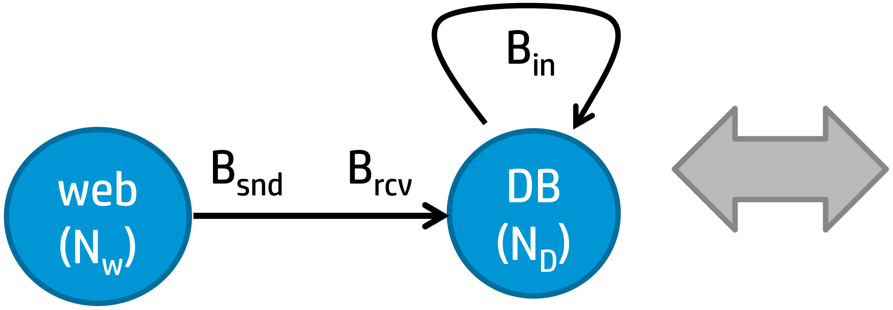
TAG model



Abstract models in TAG

Self-edge ↔ Hose

Directional edge ↔ directional Hose, Virtual Trunk



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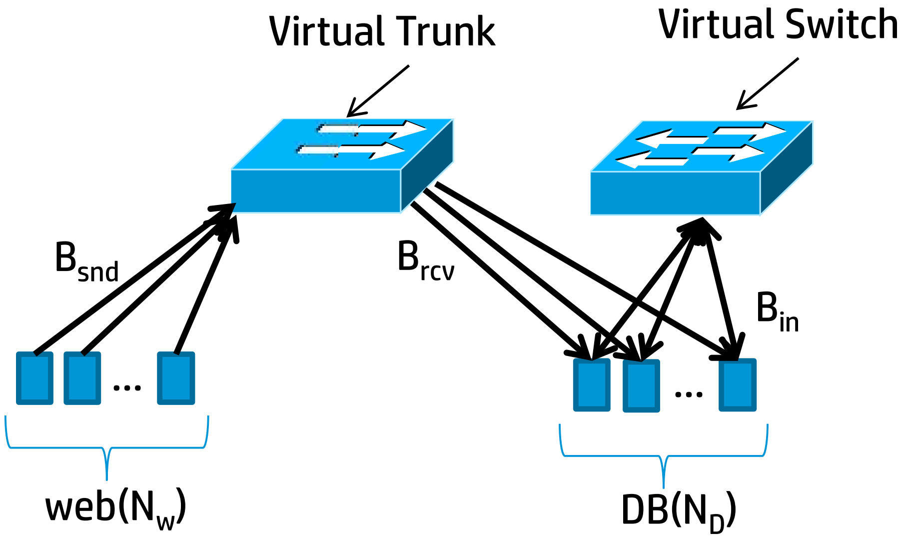


Total guarantee of virtual trunk

$= \min(B_{snd} \cdot N_w, B_{rcv} \cdot N_D)$

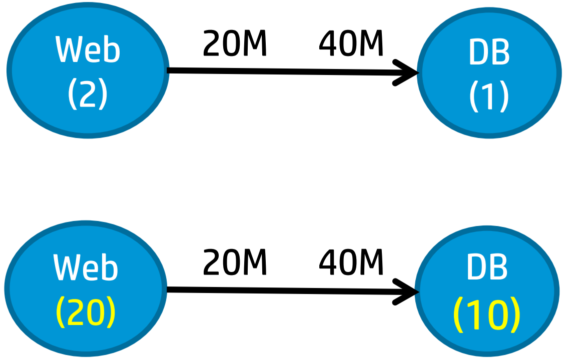
TAG is Flexible

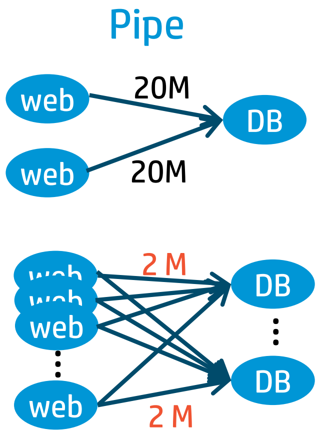
Per-VM aggregation from/to each other component

Flexible to dynamic load distribution between communicating tiers

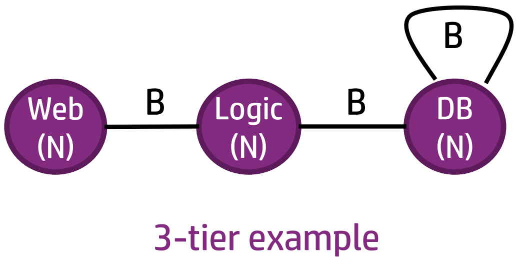
Flexible to elastic tenant scaling

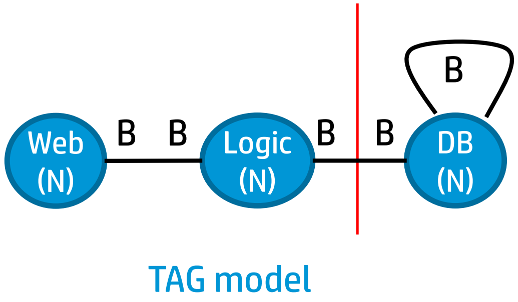
- TAG *per-VM* bandwidth guarantees invariant to scaling
- Pipe reservations need to be updated while scaling

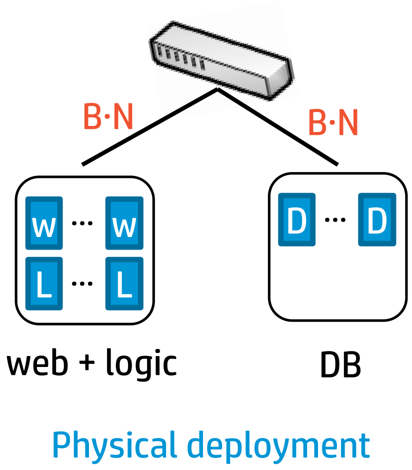




TAG is accurate and resource-efficient





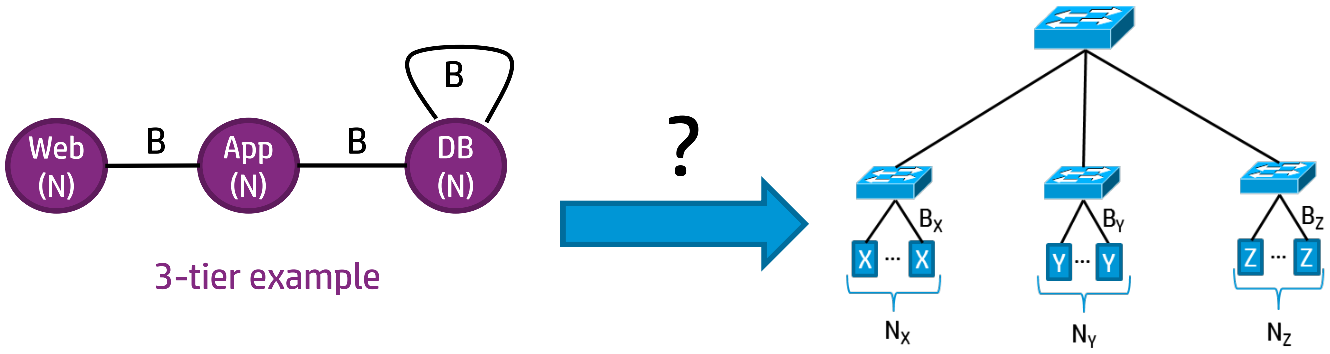


TAG requires less or equal BW than VOC

- Equal when there is no inter-component demand
- Mathematically proven

TAG is Intuitive

TAG is easy to use because it directly mirrors application structure



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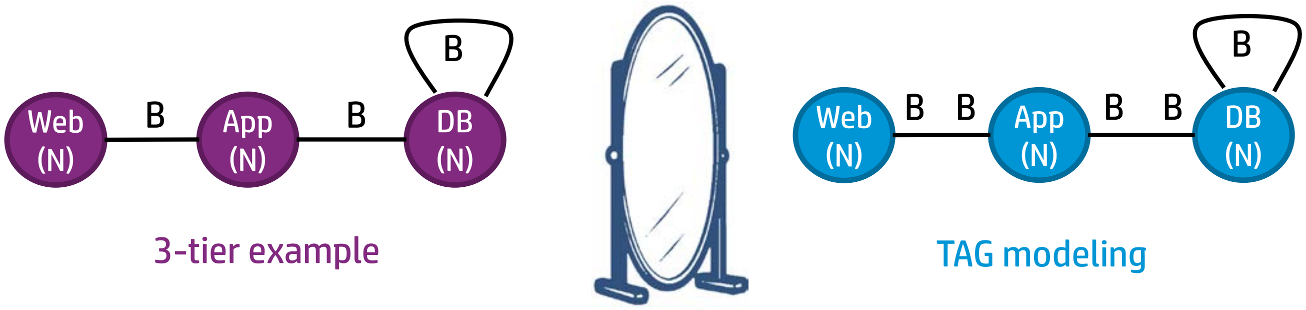
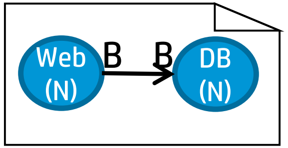


CloudMirror operation

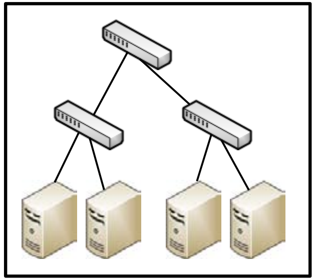
TAG spec



Available VM slots

host1	10
host2	50
host3	25

Network topology &
BW reservation state



VM placement
BW reservation
Admission control

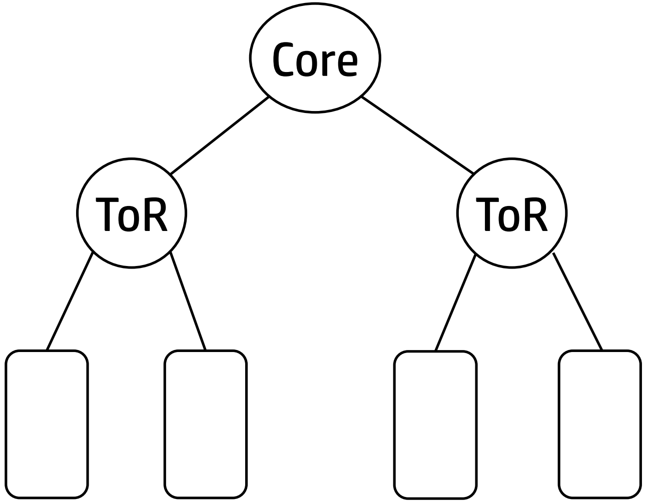
VM placement

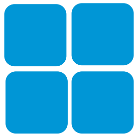
Goal

Deploy as many tenants as possible onto a tree-shaped topology while guaranteeing SLAs

➔ NP-hard problem

Prior heuristics = colocation, localize traffic and save core bandwidth





Client requests 4 VMs

VM placement

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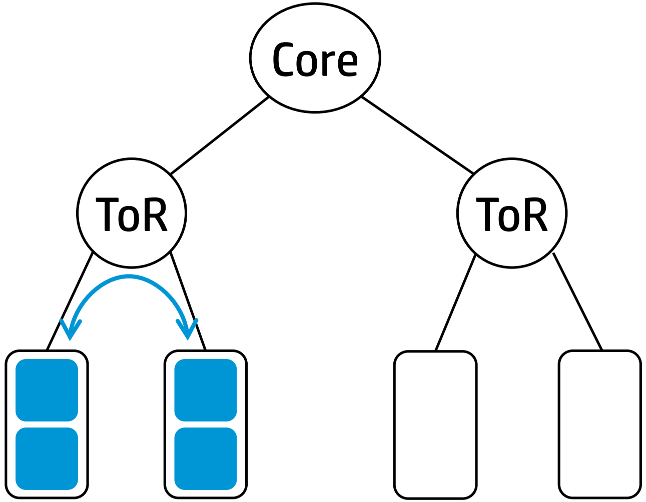
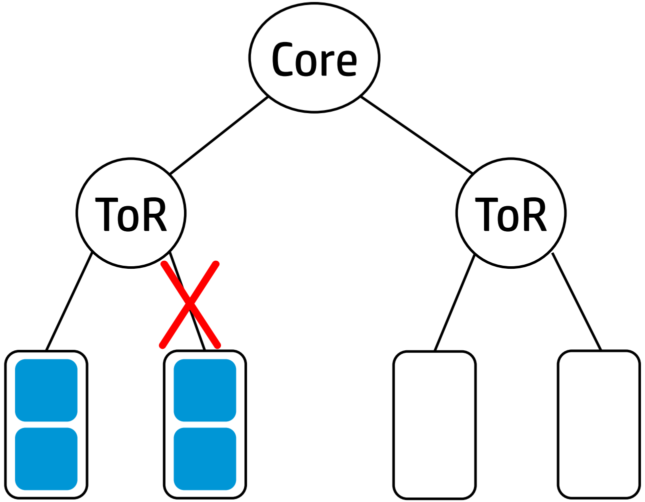


CloudMirror also takes colocation approach:

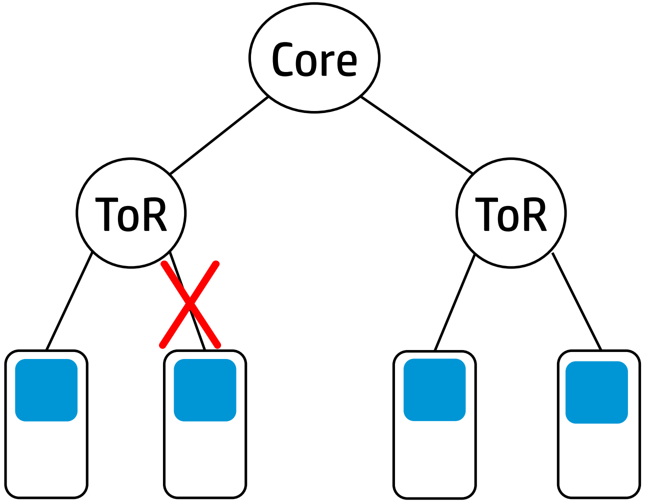
BW saving benefit using TAG $\geq$ VOC, Hose

Disadvantages of colocation

Colocation hurts high-availability [Bodik, Sigcomm'12]



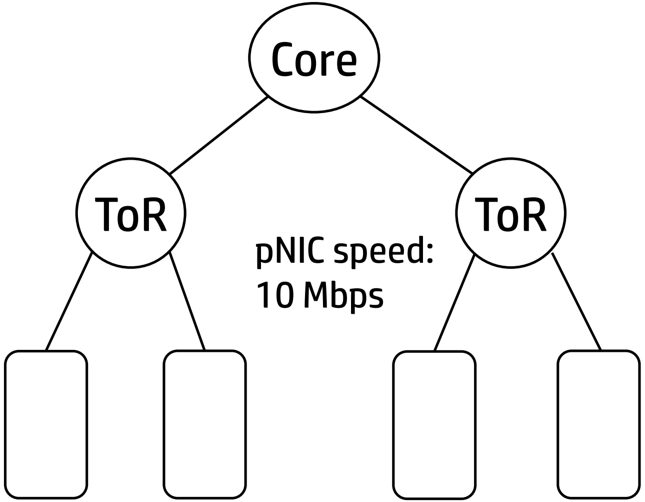
A server failure → 50% survive

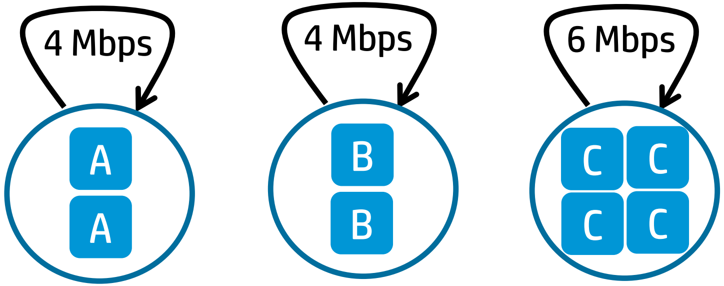


A server failure → **75%** survive

Disadvantages of colocation

Colocation can hurt efficient resource utilization

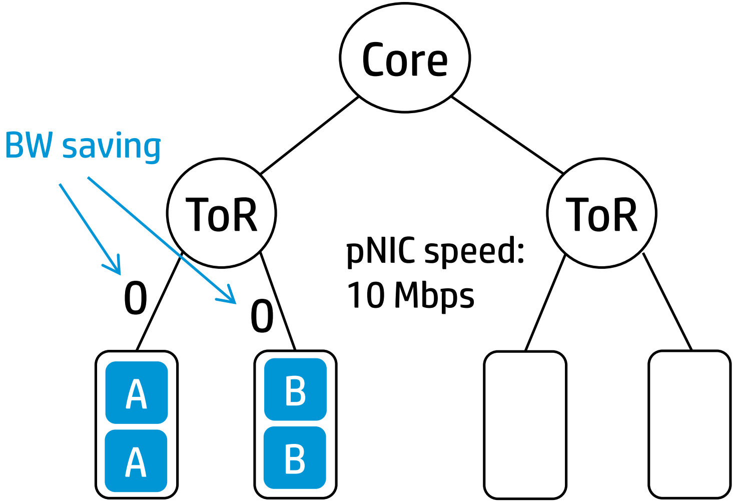




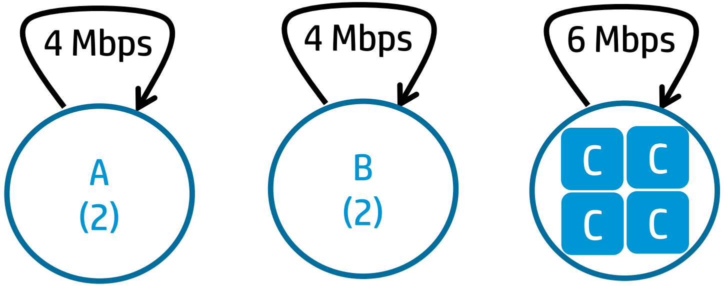
Client requests 3 hose components

Disadvantages of colocation

Colocation can hurt efficient resource utilization



Colocation for saving bandwidth of A and B



Client request

Disadvantages of colocation

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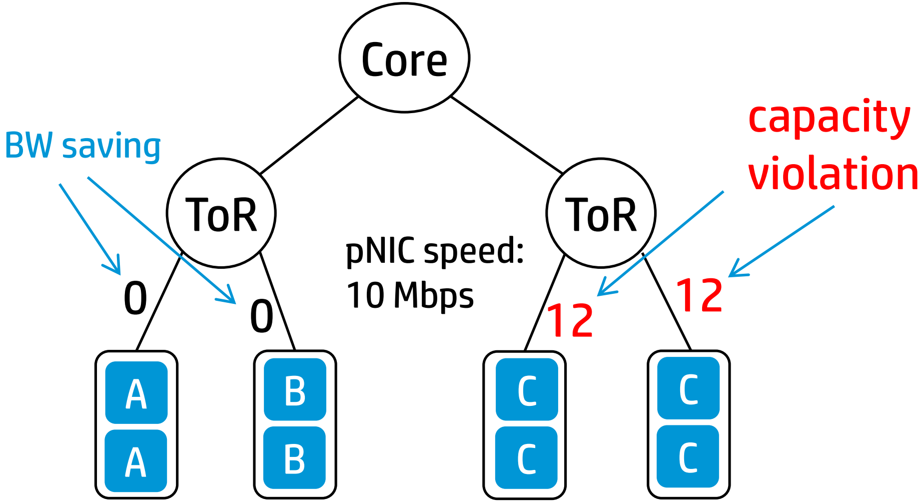

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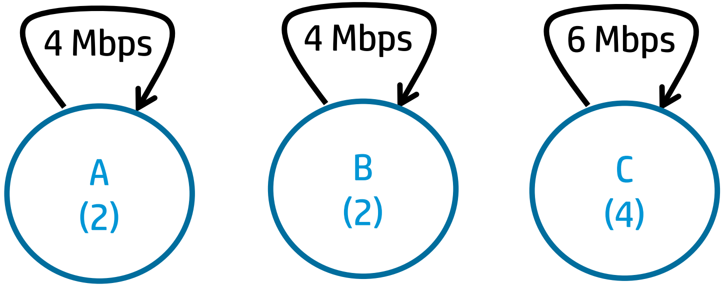

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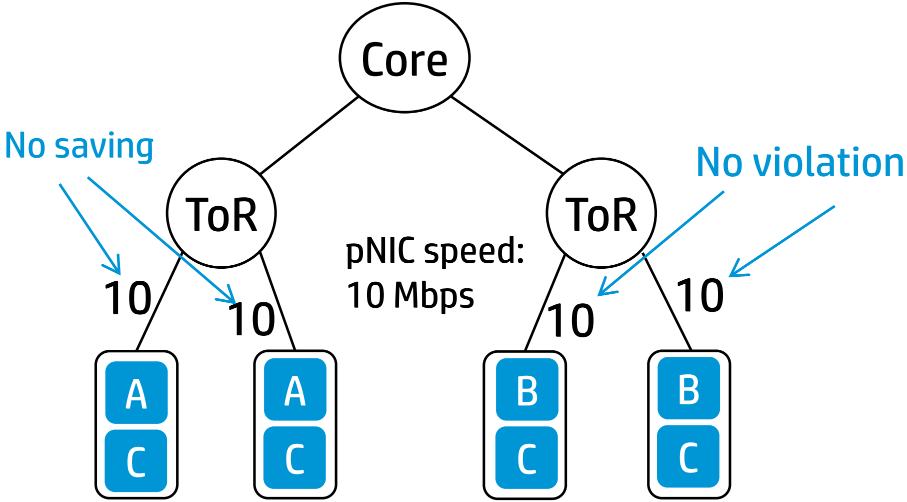
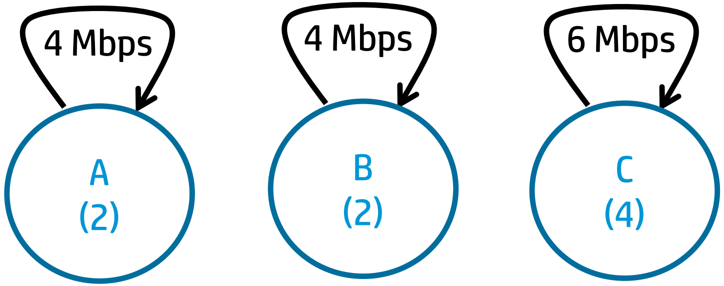




Client request

Valid placement: Colocate high-BW VMs (C) and low-BW VMs (A,B) though they don't talk to each other

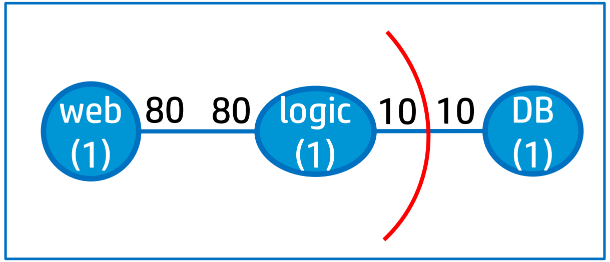
➔ **balanced, efficient utilization of network and VM slots**

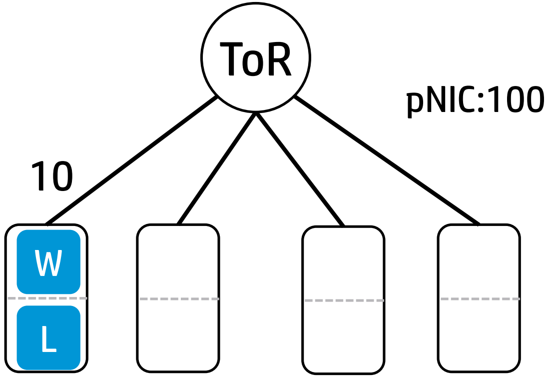
CloudMirror approach

Identify tiers that would benefit from ***colocation***

More than ½ VMs of communicating tiers should be colocated

Iterate over tier pairs: $O(T^2)$, T = # tiers





CloudMirror approach

Identify tiers that would benefit from *colocation*

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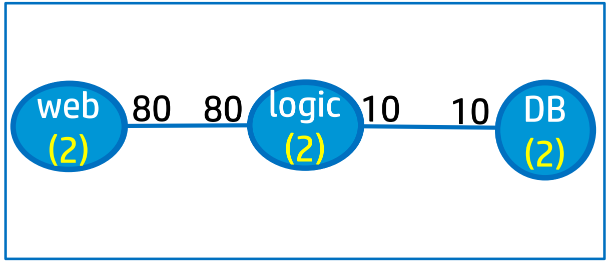
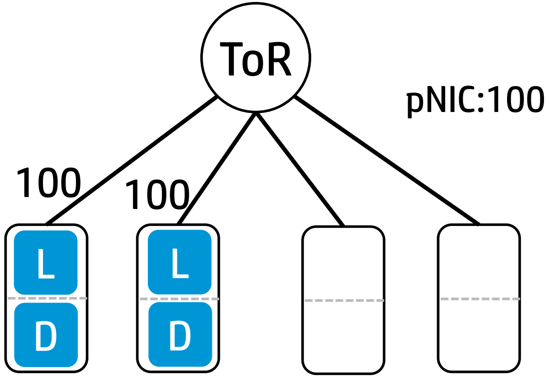


For tiers w/o BW saving benefit (too large to colocate)

Balance resource utilizations over subtrees and resource types

Multi-dimensional knapsack, Multi-resource 'VM' packing

- Our greedy heuristic: $O(N)$, N = #VMs
- VM scheduling/packing makes more sense than task/flow level scheduling for online-applications that handle continuous streams of user requests or realtime data

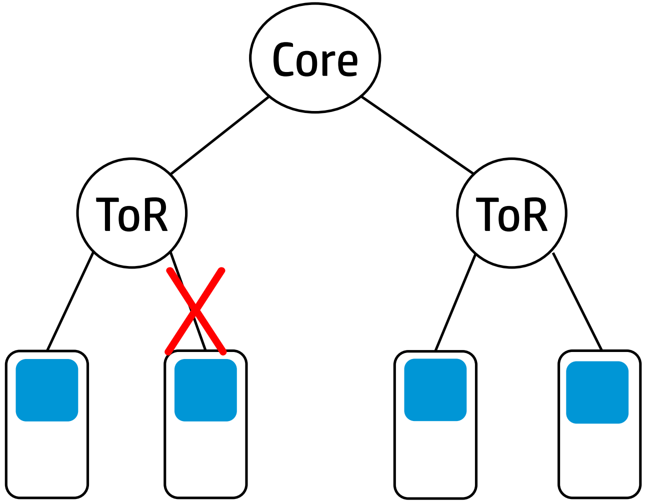


Achieving High-Availability

1) Guarantee survivability for requesting tiers

Limit #VMs colocated in the same subtree

- E.g., 75% survivability, 4-VM tier: at most 1 VM per subtree



A server failure → 75% survival guaranteed

Achieving High-Availability

1) Guarantee survivability for requesting tiers

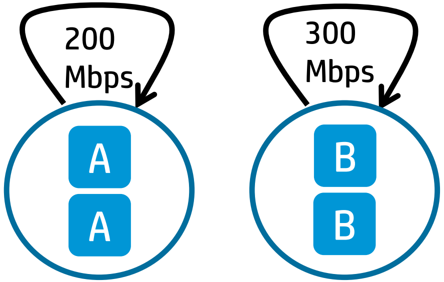
Limit #VMs colocated in the same subtree

- E.g., 75% survivability, 4-VM cluster: at most 1 VM per subtree

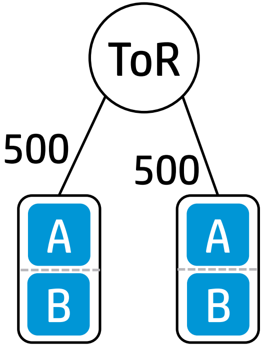
2) Opportunistically improve HA for others

Even for tiers with BW saving benefit,

distribute VMs when BW is not a bottleneck



Client request



Link capacity: 1Gbps

Evaluation

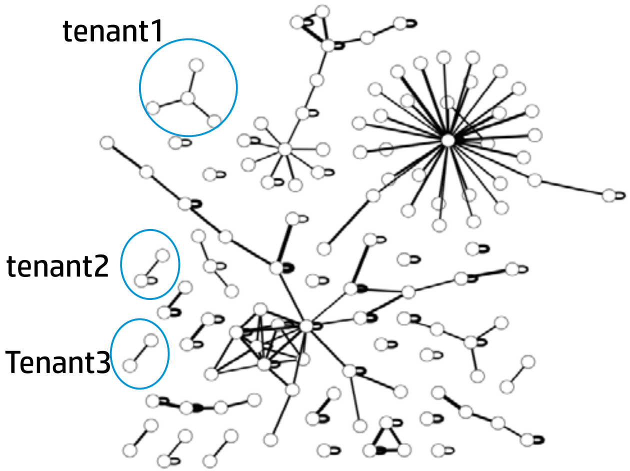
Methodology

Simulate a stream of (Poisson) tenant arrivals and departures

Workload: bing.com data

Various cluster sizes, communication patterns

Tenant: a set of connected components



Source: [Bodik, Sigcomm'12]

3-level tree topology

2048 hosts, 25 VM slots per host

Baseline

Model: VOC (2-level hose)

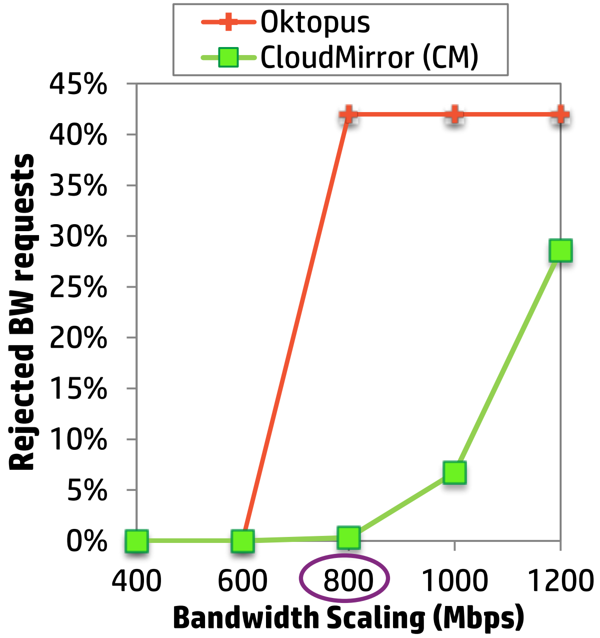
Algorithm: Oktopus [Sigcomm'11]

Resource efficiency

Metric: Rejected BW requests

Oktopus rejects 42% more BW requests

(Synthetic workload: up to 100% difference)



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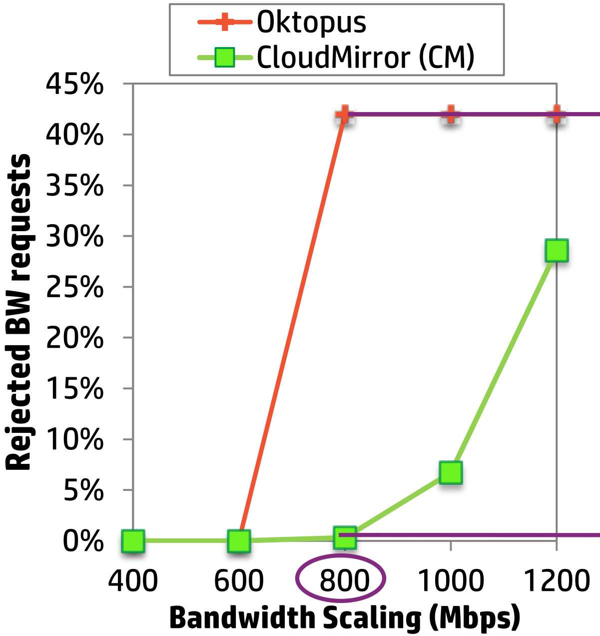
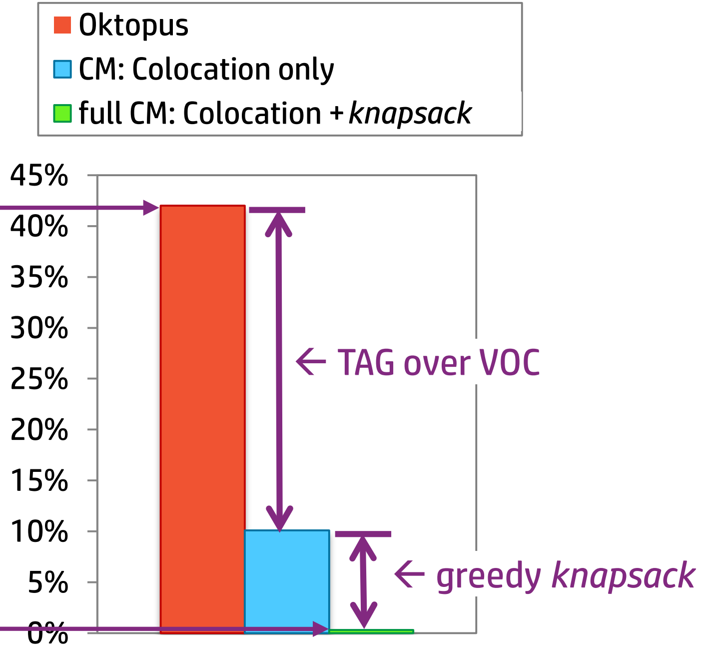


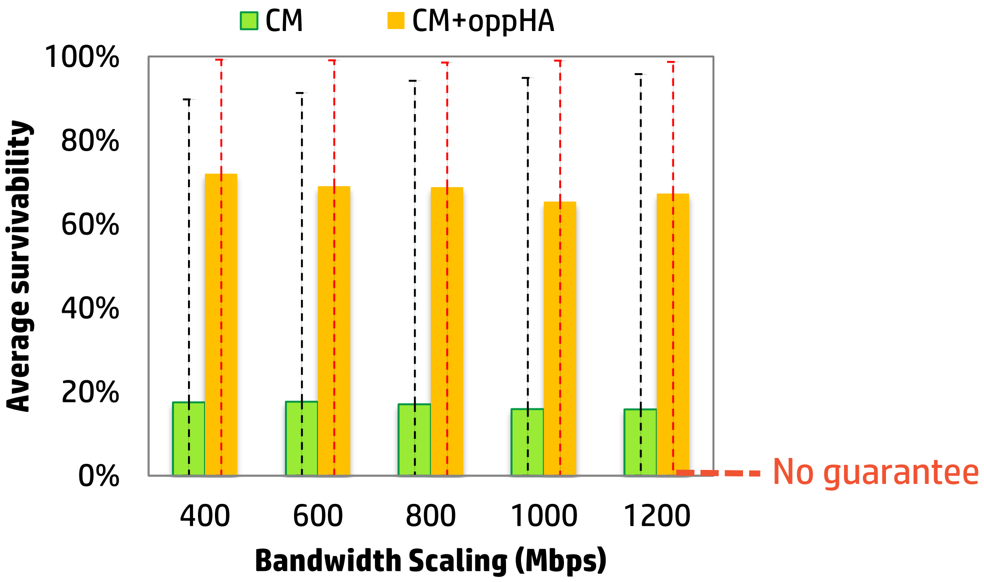
Dissect benefit of CloudMirror



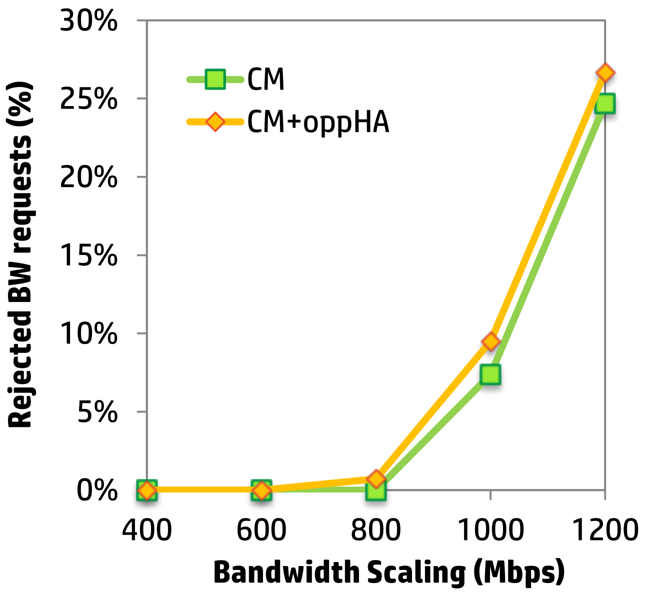
Opportunistic High-Availability

Achieved survivability

Over deployed application components



Rejected BW requests



CM+oppHA achieves high average survivability w/ marginal increase of rejected BW requests

CloudMirror recap

TAG models application structure

Intuitive, flexible and efficient

Algorithm efficiently places TAGs on tree-shaped topology

with High-Availability supports

Feasibility test with *ElasticSwitch* [Sigcomm'13] for TAG enforcement

30 lines of patch to support TAG

Ongoing work

Full implementation in *OpenStack*

Automatic generation of TAG models

Discussed in the paper

Generic graph model

Specify other SDN requirements and policies besides bandwidth