On-Demand Bandwidth Pricing for Congestion Control in Core Switches in Cloud Networks

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Introduction

- Cloud Computing
  - multiplexes computation, storage and network resources among different tenants

- Network resource
  - shared in a best-effort manner, especially at the core switches
  - Avoiding congestion is very important at the core switches

Goal

- Control the congestion over the core switches
- Propose nonlinear bandwidth pricing model
- Achieve load balancing over the core switches

System Model

- Each core switch ***s*** has a limited capacity:

$$B_s = D_s + \sum_{k=1}^{K} b_{k,s} \leq \eta B^{max}$$

Total bandwidth (B_s)

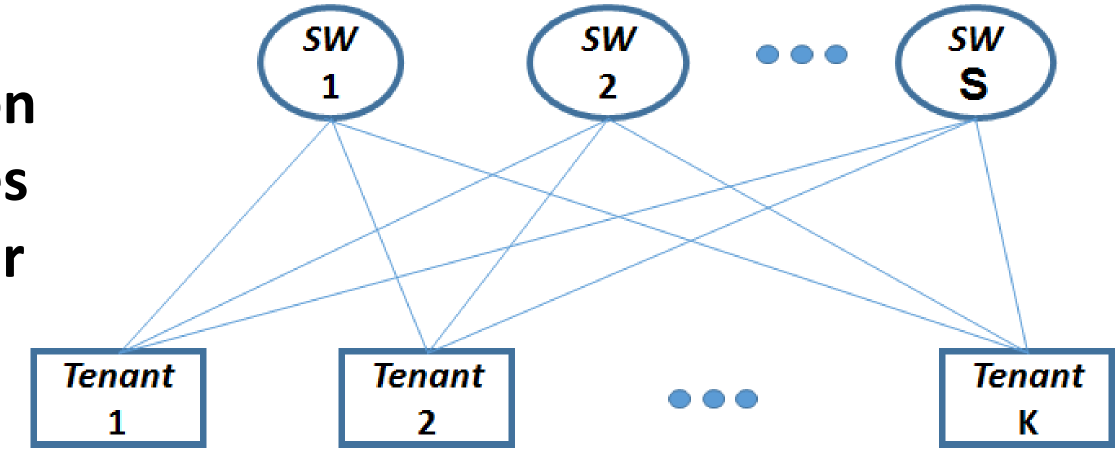
Reserved bandwidth (D_s)

Bandwidth of tenant k on core switch s ($b_{k,s}$)

Maximum capacity of each core switch (B^{max})

Safety factor (η)

Goal: **avoid congestion over the core switches while maximizing user satisfaction.**



Problem Formulation

- ***Social welfare*** of tenants = Total satisfaction – Total congestion cost.

$$S_w(\mathbf{b}) = \sum_{k=1}^{K} \mathcal{U}_k\left(\sum_{s=1}^{S} b_{k,s}\right) - \sum_{s=1}^{S}\left(\mathcal{V}(B_s) - \mathcal{V}(D_s)\right)$$

Social welfare

Bandwidth schedule of tenants

Satisfaction of tenant k

Bandwidth of tenant k on switch s

Congestion cost function

s.t. $$B_s - \eta B^{max} \leq 0.$$

Goal: Find a bandwidth schedule that maximizes social welfare.

Problem Formulation (Cont'd)

- Transformation of social welfare with adding constraints as penalty functions:

$$\mathcal{W}(\mathbf{b}) = \sum_{k=1}^{K} \mathcal{U}_k\left(\sum_{s=1}^{S} b_{k,s}\right) - \sum_{s=1}^{S}\left(\mathcal{V}(B_s) - \mathcal{V}(D_s)\right) - \sum_{s=1}^{S} \mathcal{C}(B_s - \eta B^{max})$$

- Social welfare
- Bandwidth schedule of tenants
- Utility of tenant k
- Bandwidth of tenant k on switch s
- Congestion cost function
- Overload penalty function

- Def: A bandwidth schedule is ***socially optimal*** if it maximizes the social welfare of the tenants.

Proposed Pricing Policy

- The cloud provider can minimize the congestion cost and avoid overloading by transferring cost to the tenants.

- Total cost of tenants on a core switch= congestion cost + overloading cost

$$\mathcal{Z}(B_s) = \big(\mathcal{V}(B_s) - \mathcal{V}(D_s)\big) + \mathcal{C}(B_s - \eta B^{max})$$

Total cost of tenants on core switch ***s***

Total bandwidth on core switch ***s***

Total congestion cost of tenants on core switch s

Overload cost on core switch s

Proposed Pricing Policy (Cont'd)

- Total cost a tenant ***k*** imposing on one core switch = total cost of all tenants – (total cost of all tenants excluding tenant ***k***)

$$\mathcal{Y}_{k,s}(\mathbf{b}_{-k}, \mathbf{b}_k) - \mathcal{Y}_{k,s}(\mathbf{b}_{-k}, \mathbf{0}) = \mathcal{Z}\left(D_s + \sum_{j \in \mathcal{K}-\{k\}} b_{j,s} + b_{k,s}\right) - \mathcal{Z}\left(D_s + \sum_{j \in \mathcal{K}-\{k\}} b_{j,s}\right)$$

Bandwidth schedule of other tenants excluding tenant ***k***

Total cost of tenants on switch s

Total cost of tenants excluding tenant ***k*** on switch ***s***

- **Proposed bandwidth payment function** of a tenant = total cost it imposes on the core switches

$$\xi_k(\mathbf{b}_{-k}, \mathbf{b}_k) = \sum_{s \in \mathcal{S}} \left[\mathcal{Y}_{k,s}(\mathbf{b}_{-k}, \mathbf{b}_k) - \mathcal{Y}_{k,s}(\mathbf{b}_{-k}, \mathbf{0})\right]$$

Optimal bandwidth scheduling of a tenant

- The utility of tenant ***k***

$$\mathcal{F}_k(\mathbf{b}_{-k}, \mathbf{b}_k) = \mathcal{U}_k\left(\sum_s b_{k,s}\right) - \xi_k(\mathbf{b}_{-k}, \mathbf{b}_k)$$

Utility of tenant ***k***

Satisfaction function of tenant ***k***

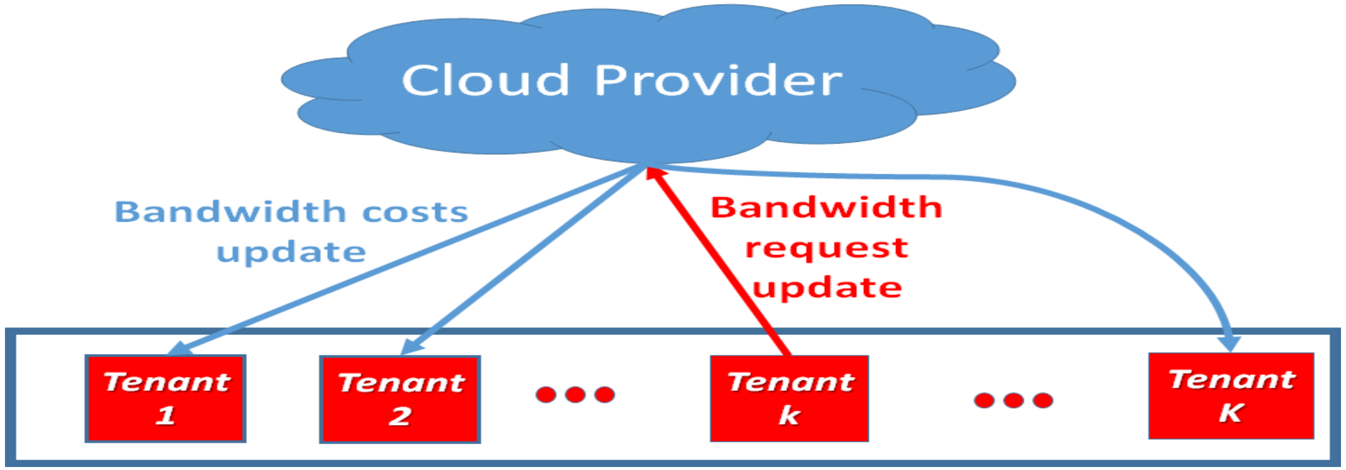
Payment function of tenant ***k***

- Each tenant attempts to maximize its own utility. We can prove that each tenant balances the total load over the core switches.

Best Response Update Process

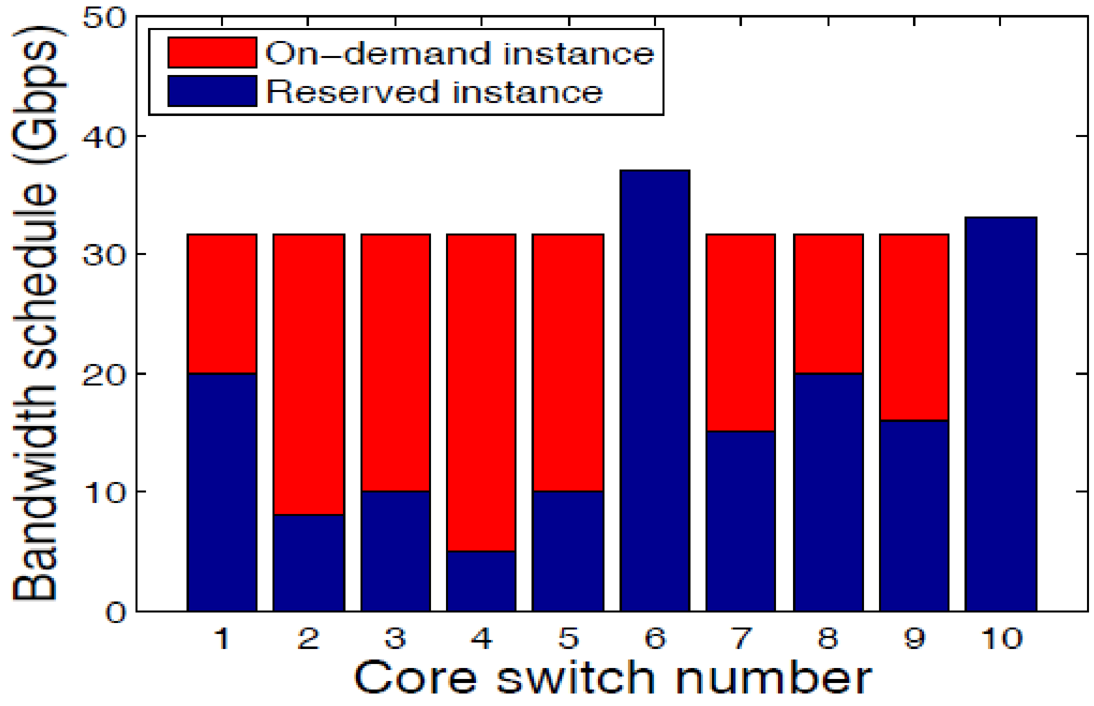
- The tenants do not reveal their private information such as utility function to the cloud provider.
- It results in decentralized bandwidth schedule optimization.
- At each step only one tenant (randomly chosen) updates its bandwidth schedule:

$$\mathbf{b}_k^{m+1} = arg \max_{\mathbf{b}_k \in \mathcal{B}_k} \mathcal{F}_k(b_{-k}^m, b_k)$$



- ***Theorem:*** The best response update process converges to a socially optimal bandwidth schedule.

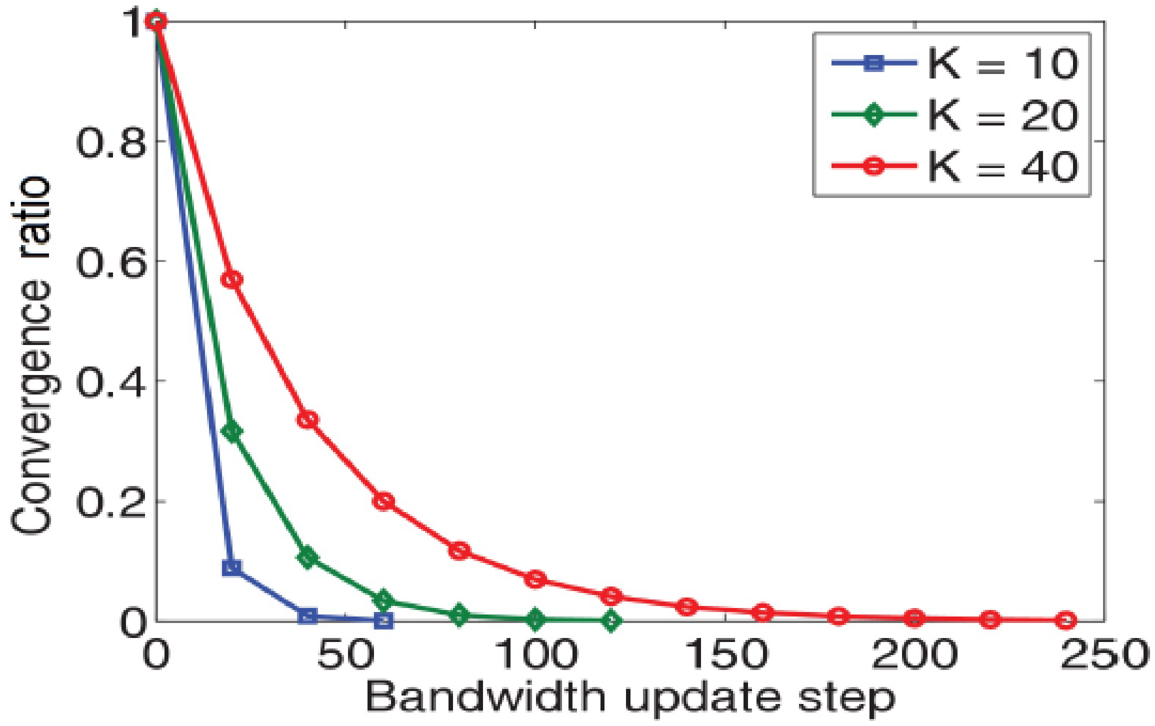
Evaluation



- S= 10 cores, $K = 40$ tenants, $B^{max} = 40Gbps$,

$$\mathcal{U}_k(b_k) = log(1 + b_k), \mathcal{V}(x) = \beta\left(1 + \frac{x}{B^{max}}\right)^2$$

Evaluation (Cont'd)



K = number of tenants,

S= 10 cores, $\mathcal{U}_k(b_k) = log(1 + b_k), \mathcal{V}(x) = \beta\left(1 + \frac{x}{B^{max}}\right)^2$

Concluding remarks

- Proposed load-dependent bandwidth pricing for congestion control over the core switches in the cloud networks.
- Maximized the utility of tenants while avoiding congestion.
- Nonlinear pricing mechanism results in load-balancing over the core switches.
- Best response strategy converges to the socially optimal bandwidth schedule.

Thank you!

Questions & Comments?

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