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A Model for Evaluating the Economics of Cloud Federation

George Darzanos, Iordanis Koutsopoulos, George D. Stamoulis

Athens University of Economics and Business (AUEB)

Network Economic and Services Laboratory (http://nes.aueb.gr)

Centre for Research and Technology Hellas (CERTH)

Why Cloud Service Providers Federate?

Motivation for Cloud Services Providers’ (CSPs) Federation

- To **achieve**:
  - Geographic footprint expansion, Dynamic scaling, Operational cost savings, QoS enhancement, load balancing, …
- To **avoid**:
  - Datacenter over-dimensioning, …

Forms of Federation

- Outsourcing of jobs
- Marketplace of CSPs

Examples of Existing Federations

Commercial Products

- **OnApp Federation:** is a network of IaaS that connects multiple CSPs, selling capacity through the OnApp market.
- **Arjuna's Agility framework:** SLAs and policies for federations.
- **RadiantOne Federation Service:** is a component of the RadiantOne suite and enables a secure federated infrastructure.

Academic Federated Environments

- **CERN Openlab project:** aims to build a seamless federation among multiple clouds on *OpenStack*. (*CERN* & *Rackspace*)
- **The European Grid Infrastructure Federated Cloud:** seamless grid of academic private clouds.
- **FP7 BonFIRE project:** offers a federated cloud testbed.

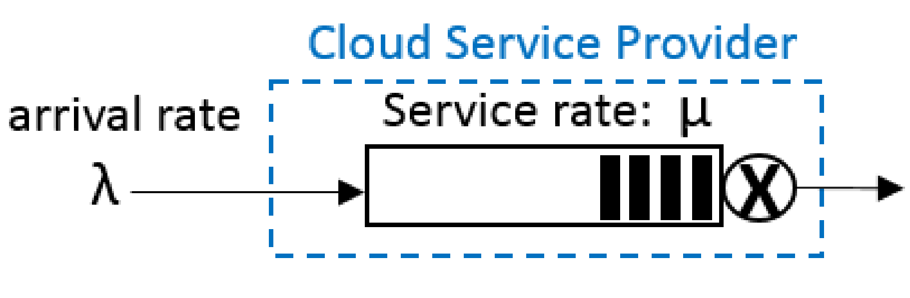
CSP as Queueing System

Assumptions

- Each CSP maintains $\boldsymbol{n}$ identical servers of capacity $\frac{\boldsymbol{C}}{\boldsymbol{n}}$
- An optimal intra-CSP dispatching and scheduling policy achieves the same average utilization level $\boldsymbol{\rho}$ in all CSP servers.

M/M/1 abstraction of CSP

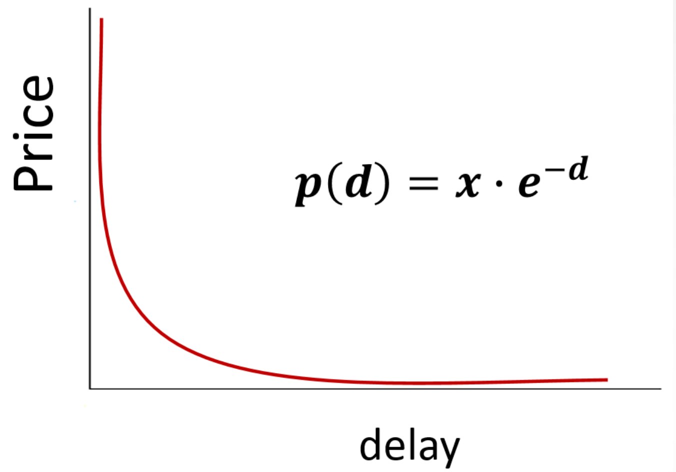
- **Poison arrivals**, with rate $\boldsymbol{\lambda}$
- Exponential distribution of **service time**, $\frac{1}{\mu} = \frac{L}{C}$
- Average delay, employed as **QoS metric**, $d = \frac{1}{\mu - \lambda}$



Economic Modelling of CSP

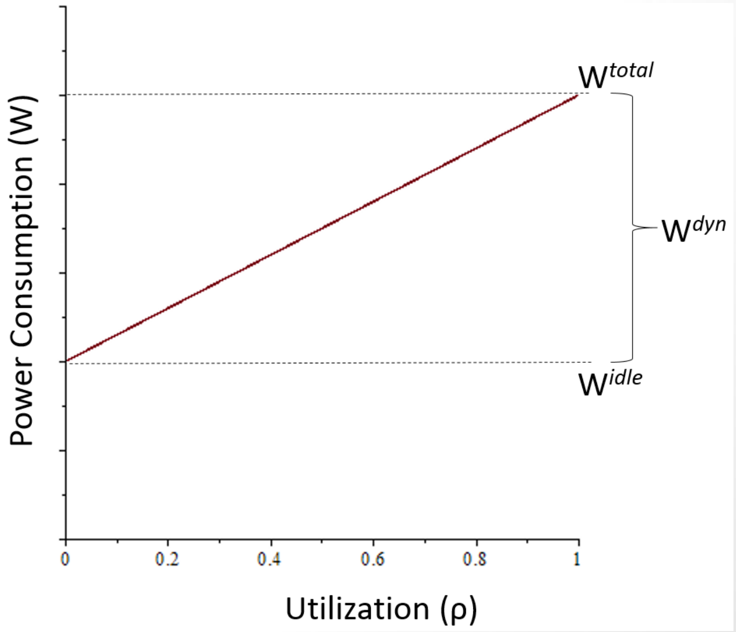
Revenues ($/sec)

- QoS-based pricing policy, $\boldsymbol{p(d)}$
- $R = \lambda \cdot p(d)$



Energy Consumption Cost ($/sec)

- Power consumption $\boldsymbol{W}$ is linearly increasing in the server utilization factor $\boldsymbol{\rho}$.
- $C = q \cdot W(\rho)$



Profit ($/sec)

- $P = R - C$

CSPs Federation Policy

Static approach for optimal resource allocation

- Both CSP can **outsource** incoming stream of requests.
- Additional average delay **D** for outsourced requests, due to intervening Internet links.

Total Input rate in each CSP queue

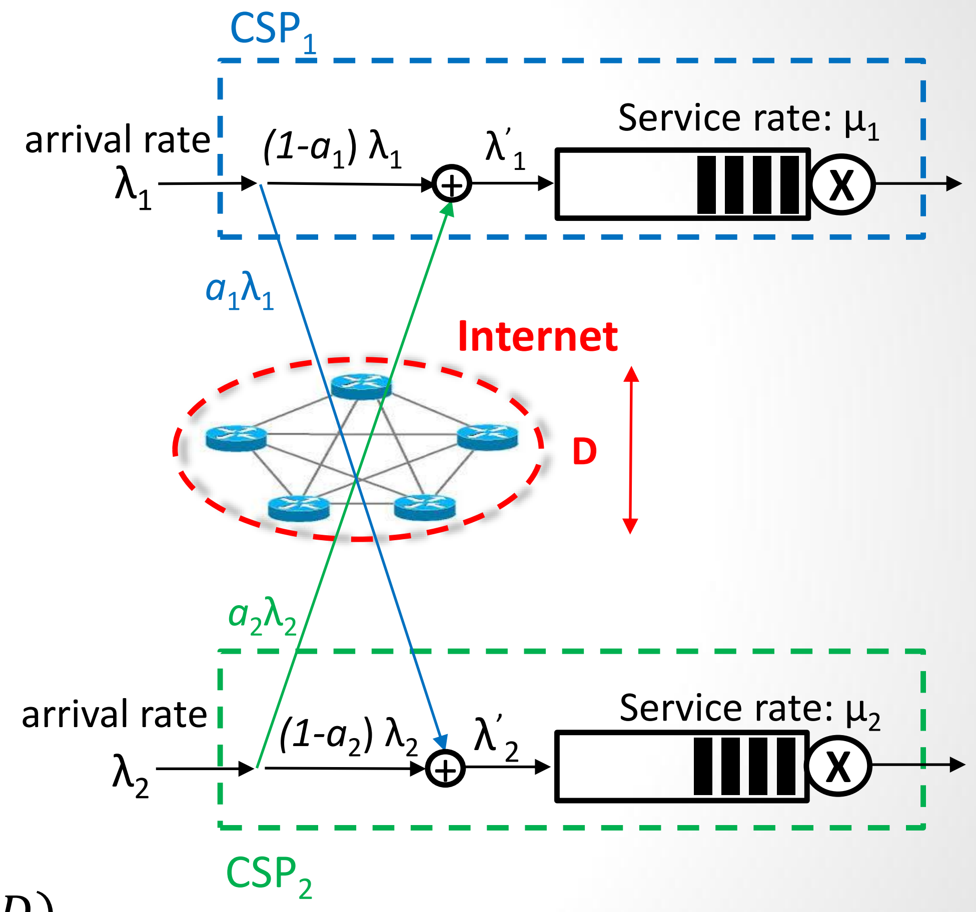
- $\lambda'_1(\alpha_1, \alpha_2) = (1 - \alpha_1) \cdot \lambda_1 + \alpha_2 \cdot \lambda_2$
- $\lambda'_2(\alpha_1, \alpha_2) = (1 - \alpha_2) \cdot \lambda_2 + \alpha_1 \cdot \lambda_1$

Average delay in each queue

- $d_i(a_1, a_2) = \frac{1}{\mu_i - \lambda'_i(a_1,a_2)}, i = 1,2$

Average delay for each CSP customers

- $T_1(a_1, a_2) = (1 - a_1) \cdot d_1\,(a_1, a_2) + a_1 \cdot (d_2(a_1, a_2) + D)$
- $T_2(a_1, a_2) = (1 - a_2) \cdot d_2\,(a_1, a_2) + a_2 \cdot (d_1(a_1, a_2) + D)$



New Pricing function of Federated CSP: $p_i(a_1, a_2) = x_i \cdot e^{-T_i(a_1,a_2)}$

Cooperative Federation

- The federation policy is defined by the optimal pair $(\boldsymbol{a_1^*}, \boldsymbol{a_2^*})$ that maximizes the total profit of the two CSPs.

$$\max_{a_1, a_2} \ [P_1(a_1, a_2) + P_2(a_1, a_2)]$$
$$s.t. \quad 0 \le a_i \le 1, \qquad i = 1, 2$$
$$\lambda_i'(\alpha_1, \alpha_2) < \mu_i, \qquad i = 1, 2$$

- If $(\boldsymbol{a_1^*}, \boldsymbol{a_2^*}) \neq (\mathbf{0}, \mathbf{0})$ then at least one of the CSPs makes higher profits than in stand-alone operation.
  - The other CSP should also have the incentive to participate in the federation.

Profit Sharing Policy

- Our profit sharing policy provides **participation incentive**:
  - leads to at least the **same or higher profit** for each CSP, compared to the standalone operation.

Profit share of CSP *i*: $\frac{\lambda_i'(\alpha_1^*,\alpha_2^*)}{\lambda_1+\lambda_2}\left(\mathrm{P}_{tot}(a_1^*,a_2^*)-\mathrm{P}_{tot}(0,0)\right)+P_i(0,0)$

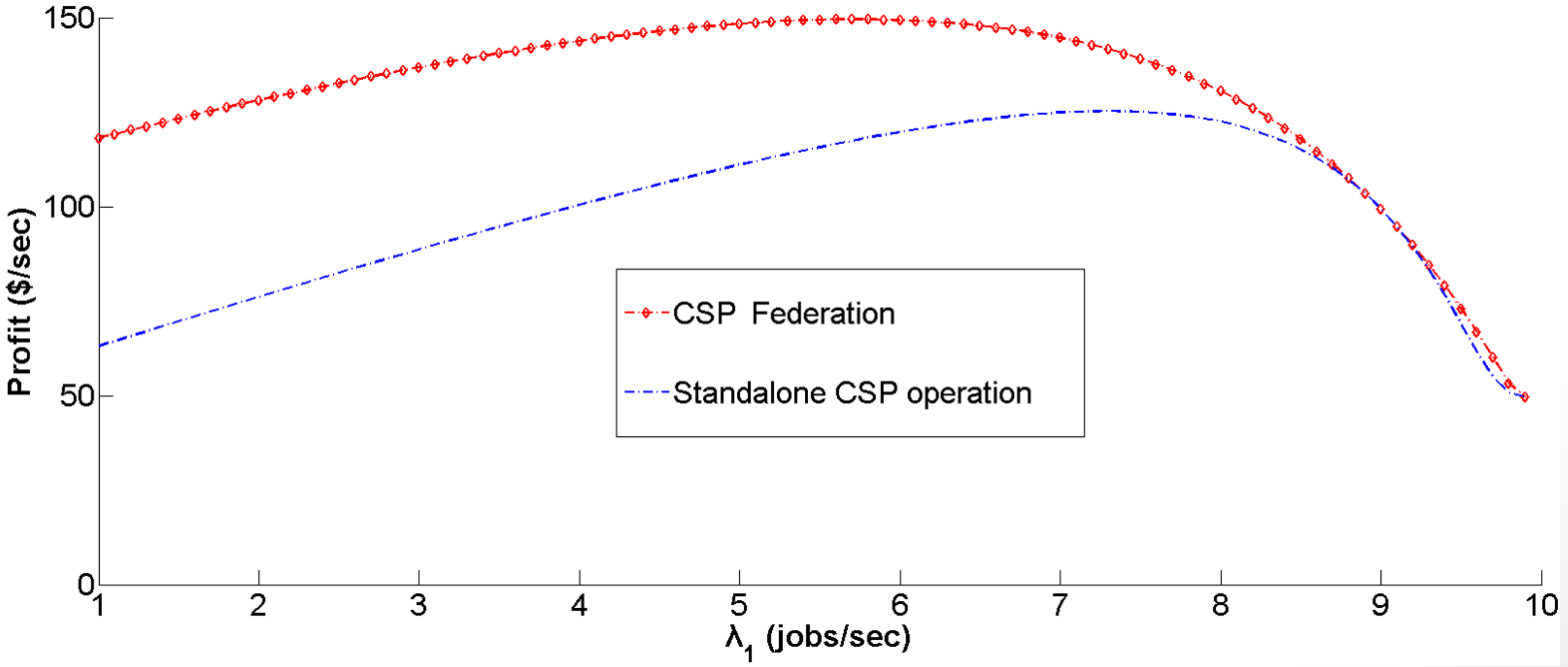
- $\mathrm{P}_i(0,0)$ → **individual** profit in **standalone** operation.
- $\mathrm{P}_{tot}(a_1^*,a_2^*)=\mathrm{P}_1(a_1^*,a_2^*)+\mathrm{P}_2(a_1^*,a_2^*)$ → **total profit** in optimal **federation**.
- $\mathrm{P}_{tot}(0,0)=\mathrm{P}_1(0,0)+\mathrm{P}_2(0,0)$ → **total profit** in **standalone** operation.

- Our profit sharing policy looks like a weighted instance of ***Shapley Value***.

Numerical Results (I)

Symmetric CSPs w.r.t. infrastructure $(C_1 = C_2)$

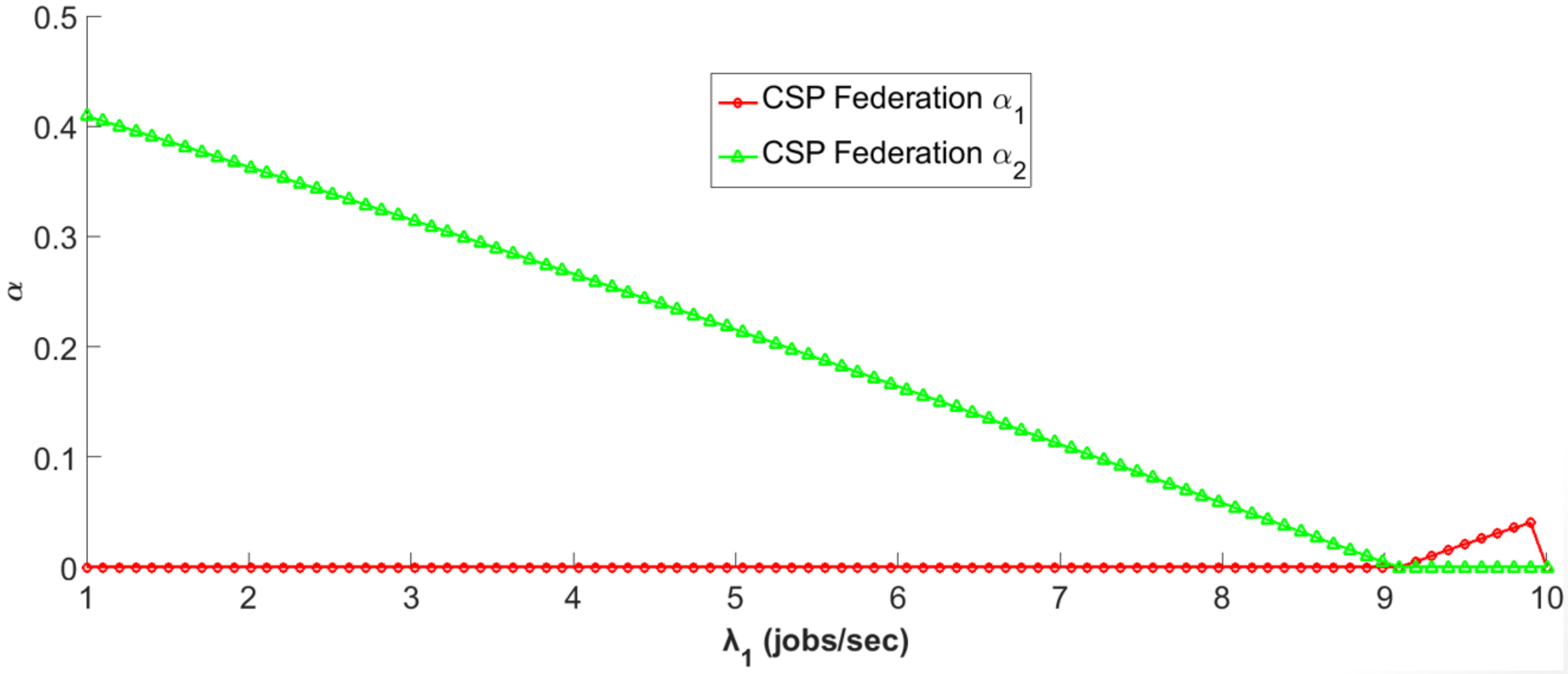
- Fixed $\lambda_2 = 9$ and $\lambda_1 \in [1,9.9]$
- Total profit: federation vs standalone
- Federation can lead to significantly higher total profit than standalone.



Numerical Results (II)

Symmetric CSPs (again, $C_1 = C_2$ fixed $\lambda_2 = 9$ and $\lambda_1 \in [1,9.9]$)

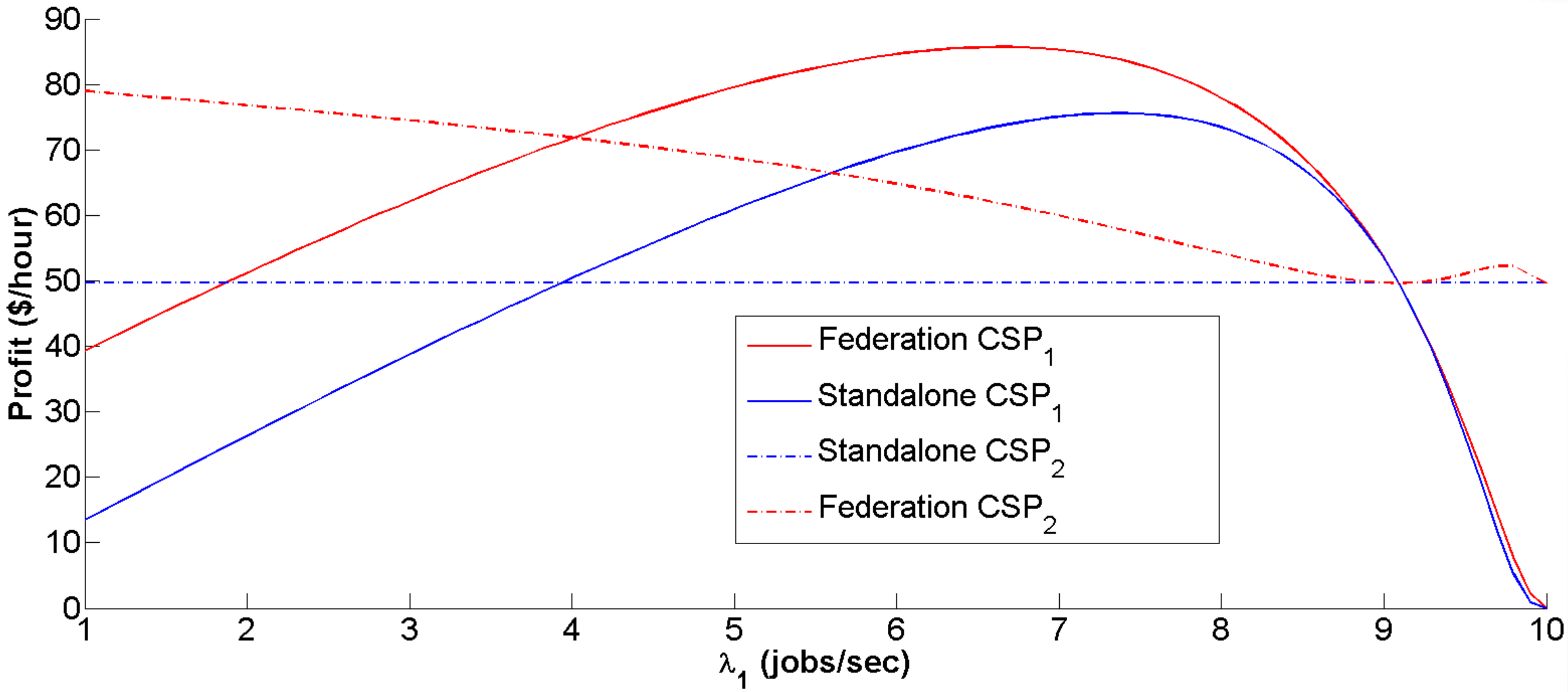
- Optimal pairs $(\boldsymbol{a}_1^*, \boldsymbol{a}_2^*)$
- Unilateral service property: in optimal federation, $\boldsymbol{a}_1^* = \mathbf{0}$ **or** $\boldsymbol{a}_2^* = \mathbf{0}$, given that $\boldsymbol{D} > \mathbf{0}$.
- The non-zero value always refers to the most utilized CSP.



Numerical Results (III)

Symmetric CSPs (again, $C_1 = C_2$ fixed $\lambda_2 = 9$ and $\lambda_1 \in [1,9.9]$)

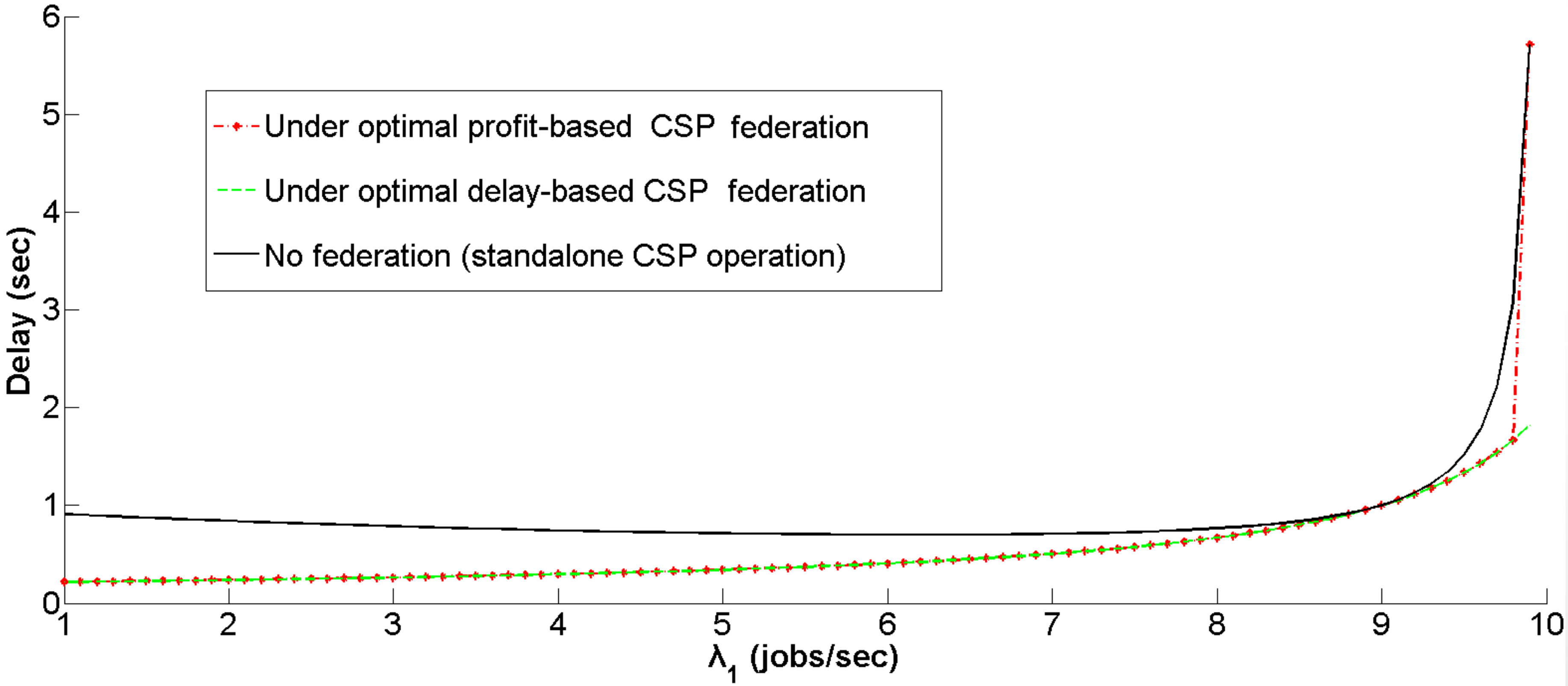
- **Individual profit**: federation vs standalone
  - **Profit sharing** policy is applied.



Numerical Results (IV)

Symmetric CSPs (again, $C_1 = C_2$ fixed $\lambda_2 = 9$ and $\lambda_1 \in [1,9.9]$)

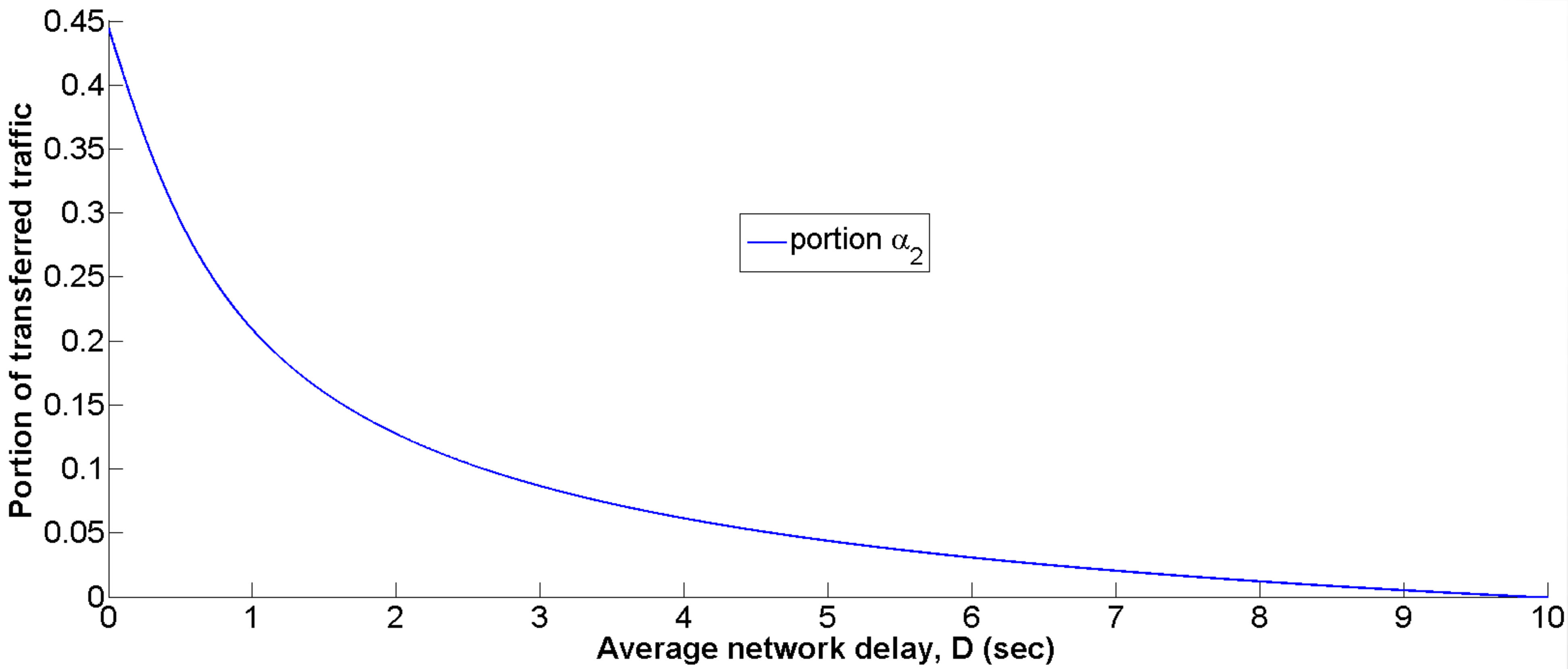
- Performance under different optimization criteria for federation.
  - Profit-optimal federation, Delay-optimal federation, Standalone
  - The performance of our Profit-optimal federation is very close to that of the delay-optimal.



Numerical Results (V)

Symmetric CSPs (again, $C_1 = C_2$, fixed λ_1 and λ_2 with $\lambda_2 > \lambda_1$)

- $\boldsymbol{a_1^* = 0}$
- As the transfer delay **D increases**, the CSPs **outsource less** jobs, and $\boldsymbol{a_2^*}$ gradually **drops to 0**.



Numerical Results (VI)

Asymmetric CSPs $(C_1 \neq C_2)$

- **Symmetric pricing** $x_1 = x_2$
  - Forming a federation is more beneficial than for symmetric CSPs.
  - When the largest CSP also has a higher utilization factor, then the federation achieves higher benefit than in the opposite case of asymmetry.

- **Asymmetric pricing** $x_1 \neq x_2$
  - When the **highly utilized** CSP is the one with the **highest value** of price $\boldsymbol{x_i}$**,** the benefit of federation is higher compared to the symmetric case.
  - The effect of price asymmetry is **less pronounced** when the CSPs have **similar utilization** levels.

Concluding Remarks

- The formation of a **cooperative federations** among CSPs can be beneficial:
  - for the CSPs as a whole → total profit
  - for each individual CSP → individual profit
  - for the users → QoS

- Our model can achieve further benefits by taking advantage of asymmetries either in infrastructure or in pricing.

- **Issue**: the optimal policy requires exchange of information between the CSPs.

- **Work in progress**: **Non-cooperative** federation policy
  - Game-theoretic formulation for the choice of (a_1, a_2)
    - ✓ Nash equilibrium rather than optimal federation policy.
    - ✓ Introduction of the "right" **compensation** function as a mechanism for providing incentives to the CSP receiving outsourced jobs.
      - Study the use of ***Shapley value***

Thank you for your attention!

Questions?

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ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS