Workflow Scheduling for SaaS / PaaS Cloud Providers Considering Two SLA Levels

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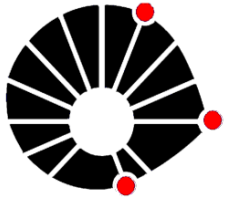
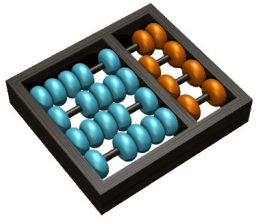




Outline

Introduction I

Cloud Computing overview:

- Provides resources as general utilities
- Resources can be leased and released on-demand
  - Virtualization layer
- *Pay-per-use* basis
- Split into three general models
  - IaaS – infrastructure as a service
  - PaaS – platform as a service
  - SaaS – software as a service

Introduction II

SaaS (or PaaS) Provider: our focus

- Provides a workflow execution service to its customers through service level agreements (SLA)
  - Must deal with seasonality of customer requests
  - Must be able to provide a good quality-of-service (QoS)
  - Must be prepared to attend a peak of demand
  - Must meet the execution deadline stipulated for each workflow
- Leases resource (VMs) from IaaS provider also through SLA contracts
  - Uses Multiple IaaS providers
  - Can lower its maintenance costs
  - Do not have to deal with peculiarities of hardware
  - Brings *elasticity* to its computational power

Introduction III

Main problems:

- **Workflow scheduling**: How to distribute the dependent services on the virtual machines leased by the SaaS provider?
  - NP-Complete problem
- **Financial issue**: How to minimize the monetary costs involved with leasing virtual machines?
- **SLA levels:** How to manage two SLA levels around the SaaS provider?
  - *First level:* SLAs between the SaaS provider and each customer
  - *Second level:* SLAs between the SaaS provider and each IaaS provider.

Introduction IV

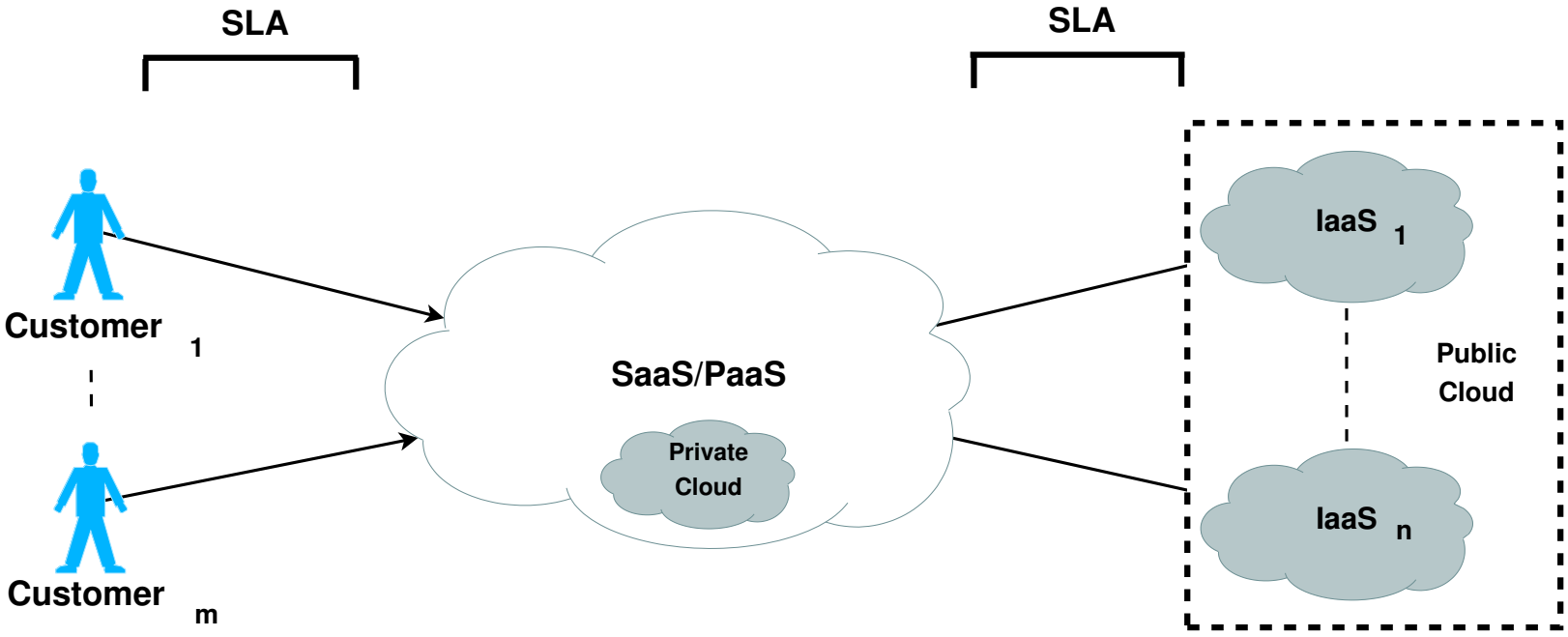
Purpose of this work: The SaaS provider goals are

- Execute the customers workflow within the deadline using VMs leased from multiple IaaS providers
- Minimize the monetary cost involved
- Indirectly, enable maximization of its profit

The Cloud Scenario I

Two SLA levels

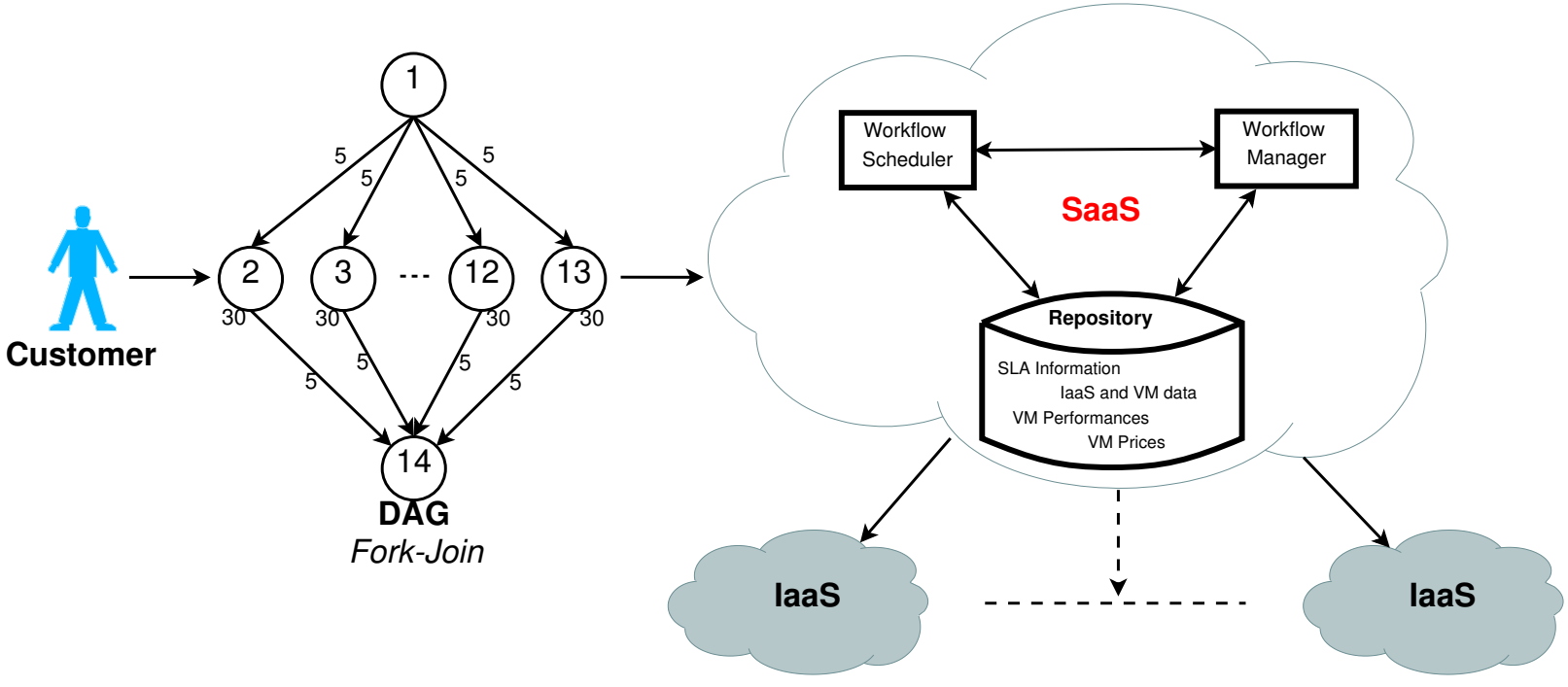
- The scenario considered for serving SaaS cloud customers:



The Cloud Scenario II

Two SLA levels

- Workflow: represented by a DAG $\mathcal{G} = \{\mathcal{U}, \mathcal{E}\}$, where:
  - each node $u_i \in \mathcal{U}$ represents a service
  - each edge $e_{i,j} \in \mathcal{E}$ is a data dependency between services i and j



Problem Modeling

The scheduling cost-optimization problem can be stated as:

"*Find a feasible mapping M between the nodes of the DAG* $\mathcal{G}$ *and the VMs from multiple IaaS providers, such that* **the sum of the monetary computation cost** *for all nodes* $u \in \mathcal{U}$ *on a VM* $v \in \mathcal{V}$ **is minimal**, *the* **dependencies** *among nodes* **are not violated**, *and* **the total execution time** *of the mapping M (makespan)* $\mathcal{M}_{\mathcal{G}}$ *is* **at most equal to the deadline** *required by user, i.e.,* $\mathcal{M}_{\mathcal{G}} \leq \mathcal{D}_{\mathcal{G}}$".

Methods used:

- Integer linear program (ILP)
- Heuristics to obtain integer solutions from the relaxed version of the proposed ILP

Formulation of the Integer Linear Program (ILP) I

Variables and constant used in the integer linear program:

- $x_{u,t,v}$: binary variable that assumes the value 1 if the node u finishes at time t in the VM v; otherwise this variable assumes the value 0;
- $y_{t,v}$: binary variable that assumes the value 1 if the VM v is being used at time t; otherwise this variable assumes the value 0;
- $\mathcal{C}_v$: constant that assumes the cost per time unit for using the VM v.

Linear objective function:

Minimize $\sum_{t \in \mathcal{T}} \sum_{v \in \mathcal{V}} y_{t,v} \times \mathcal{C}_v$

Formulation of the Integer Linear Program (ILP) II

Constraints:

(C1) $$\sum_{t \in \mathcal{T}} \sum_{v \in \mathcal{V}} x_{u,t,v} = 1; \quad \forall\ u \in \mathcal{U};$$

Specifies that a DAG node must be executed only once and in a single VM

(C2) $$\sum_{u \in \mathcal{U}} \sum_{v \in \mathcal{V}} \sum_{t=1}^{\lceil w_u \times \mathcal{J}_v \rceil} x_{u,t,v} = 0;$$

Establishes that a DAG node u can't be set as finished until it has been executed in a VM v

(C3) $$\sum_{s=1}^{t-\lceil w_z \times \mathcal{J}_r + f_{u,z} \times \mathcal{L}_{i,j} \rceil} x_{u,s,v} \geq \sum_{s=1}^{t} x_{z,s,r}$$
$$\forall\ z \in \mathcal{U},\ \forall\ u \in \mathcal{H}(z),\ \forall\ r, v \in \mathcal{V},$$
$$\forall\ t \in \mathcal{T},\ \forall\ i, j \in \mathcal{I} \mid \mathcal{B}_{i,v} = 1,\ \mathcal{B}_{j,r} = 1$$

Determines that a DAG node z cannot begin its execution until all preceding nodes have finished their processing and the resulting data has arrived at the VM that will run z

Formulation of the Integer Linear Program (ILP) III

Constraints:

$$\text{(C4)} \quad \sum_{u \in \mathcal{U}} \sum_{s=t:t \leq \mathcal{D}_\mathcal{G} - \lceil w_u \times \mathcal{J}_v \rceil}^{t+\lceil w_u \times \mathcal{J}_v \rceil - 1} x_{u,s,v} \leq \mathcal{P}_v$$
$$\forall\ v \in \mathcal{V},\ \forall\ t \in \mathcal{T}$$

Specifies that the number of DAG nodes executing on a VM v at a given time t cannot exceed the number of processing cores of v

$$\text{(C5)} \quad \sum_{s=t-\lceil w_u \times \mathcal{J}_v \rceil + 1}^{t} y_{s,v} \geq x_{u,t,v} \times \left(\lceil w_u \times \mathcal{J}_v \rceil \right)$$
$$\forall\ u \in \mathcal{U},\ \forall\ v \in \mathcal{V},\ \forall\ t \in \{\lceil w_u \times \mathcal{J}_v \rceil, \ldots, \mathcal{D}_\mathcal{G}\}$$

Determines that a VM must stay active while it is executing the node which requires it

Formulation of the Integer Linear Program (ILP) IV

Constraints:

(C6) $$\sum_{v \in \mathcal{V}} y_{t,v} \leq \delta_i \quad \forall\ i \in \mathcal{I},\ \forall\ t \in \mathcal{T} \mid \mathcal{B}_{i,v} = 1$$

Specifies that the number of reserved VMs plus the number of on-demand VMs cannot exceed the maximum number allowed by each IaaS provider

(C7) $$\sum_{v \in \mathcal{V}} y_{t,v} \leq \alpha_s \quad \forall\ s \in \zeta,\ \forall\ t \in \mathcal{T} \mid \mathcal{K}_{s,v} = 1$$

Establishes that the amount of VMs being used cannot exceed the limit stipulated in the SLA

(C8) $$x_{u,t,v} \in \{0,1\} \quad \forall\ u \in \mathcal{U},\ \forall\ t \in \mathcal{T},\ \forall\ v \in \mathcal{V}$$

(C9) $$y_{t,v} \in \{0,1\} \quad \forall\ t \in \mathcal{T},\ \forall\ v \in \mathcal{V}$$

Specifies that the variables of this ILP will only assume the binary values 0 or 1

Approaches to solve the ILP I

NP-Completeness

- The workflow scheduling problem is NP-Complete
- Time to solve the ILP increases exponentially with the input size
- We considered three different manners to cope with this:
  - Optimal approach
  - First solution approach
  - Relaxed approach

ILP Relaxation

- $\{0, 1\} \Rightarrow [0, 1]$ in constraints (C8) and (C9)
- Returns real numbers in the variable $x_{u,t,v}$
- Splits a node among virtual machines, however, each node in the DAG is indivisible

Approaches to solve the ILP II

Heuristics

- Iterative method to obtain an integer solution from a relaxed ILP
  - Tries to solve the problem $k \leq |\mathcal{U}| = n$ times
- Heuristics choose a variable $x_{u,t,v}$ to be set to 1, defining its scheduling
- Two heuristics have been developed:
  - *begin-minimum end-maximum times* (BMEMT)
    - Interchangeably gets one node from the beginning and one from the end of the DAG
    - sets the variabale $x_{u,t,v}$ such that t is minimum (or maximum if node is from the end).
  - *begin-minimum time* (BMT)
    - only ready tasks from the beginning of the DAG
    - sets the variable $x_{u,t,v}$ such that t is minimum

Approaches to solve the ILP III

General iterative algorithm

Require: DAG $\mathcal{G} = \{\mathcal{U}, \mathcal{E}\}$, deadline $\mathcal{D}_{\mathcal{G}}$, set of IaaSs $\mathcal{V}$
Ensure: Schedule of $\mathcal{G}$ in $\mathcal{V}$

1: Call relaxed ILP solver
2: **while** $\exists\ u \in \mathcal{U}$ such that $\sum_{t \in \mathcal{T}} \sum_{v \in \mathcal{V}} x_{u,t,v} \neq 1$ **do**
3: Choose a node $u_i \in \mathcal{U}$ according to the heuristic
4: Choose a resulting variable x_{u_i,t_a,v_x} according to the heuristic
5: Add new constraint $x_{u_i,t_a,v_x} = 1$ to the ILP
6: Call relaxed solver for the new ILP
7: **end while**
8: Return the solution from the last solver call

Evaluation I

Details of the simulation:

- Java and IBM ILOG CPLEX Optimizer
- First round:
  - BMEMT and BMT
  - Both with time limit of 1800 seconds on each solver iteration
  - Store the running times RT_{BMT} and RT_{BMEMT}
- Second round:
  - *Optimal solution* and *First solution*
  - Both with time limit equal to RT_{BMT} and RT_{BMEMT}
- The evaluated metrics are:
  - Monetary cost of the schedule
  - The workflow makespan
  - The solve time of the algorithm
  - The number of unfeasible solutions

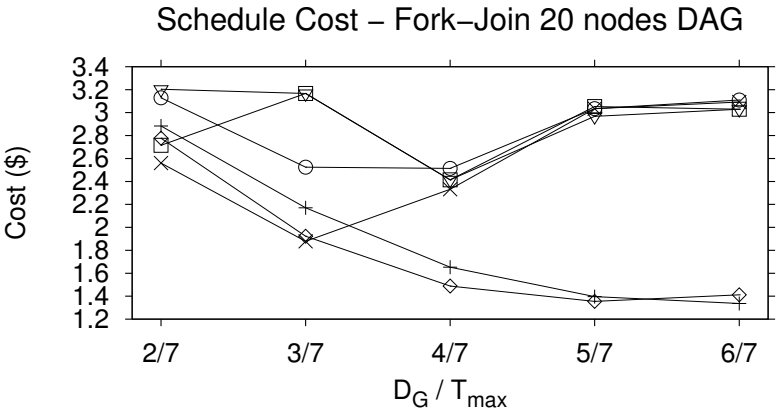
Evaluation II

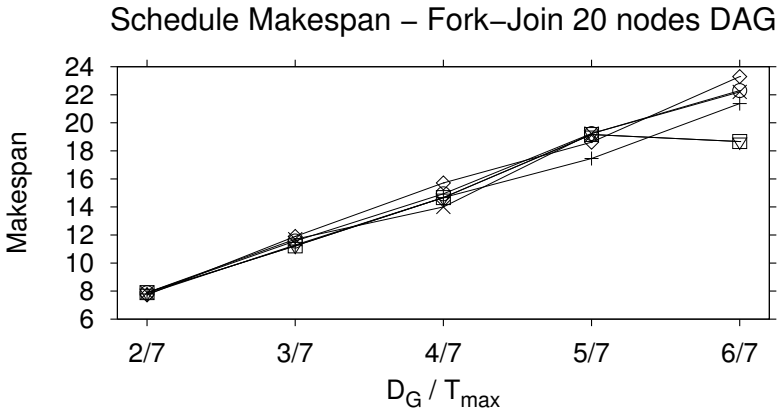
Simulation Configurations

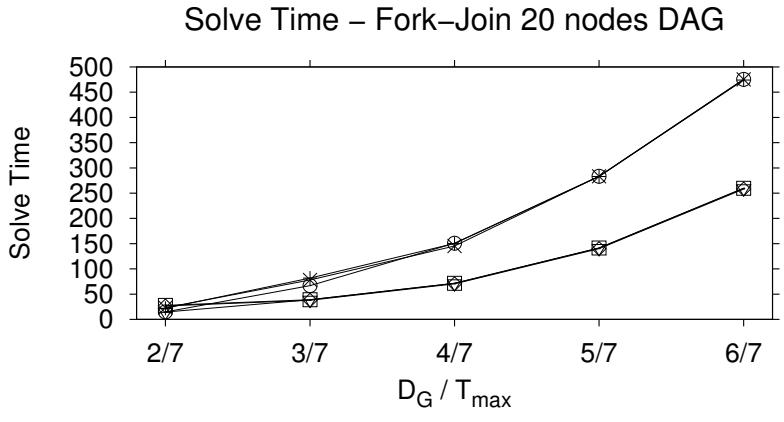
- We used 3 IaaS providers in our simulations
- Each SaaS had its own configurations and prices for reserved and on-demand VMs
- 1 to 8 cores
- Heterogeneous resources performance (processors and links)

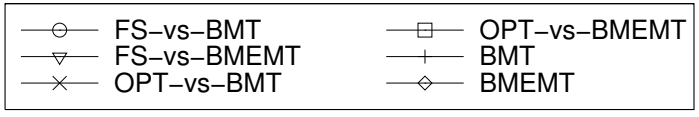
Evaluation III

- Results for the Fork-Join DAG with 20 nodes



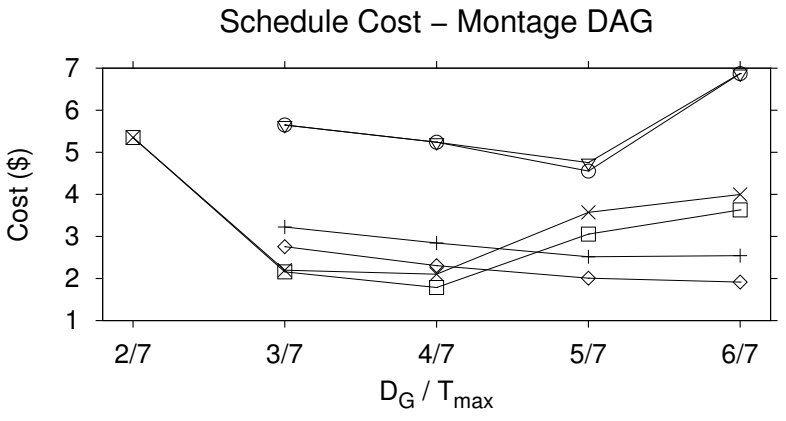


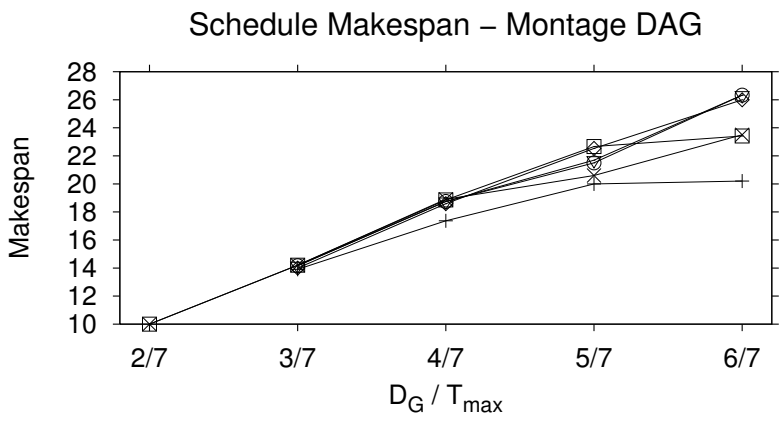


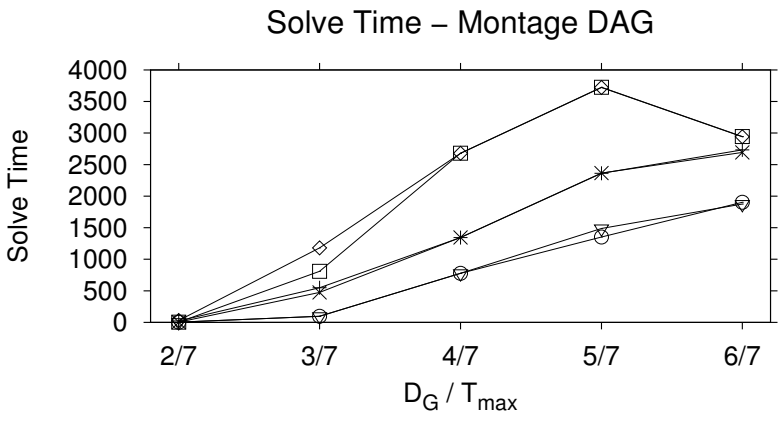


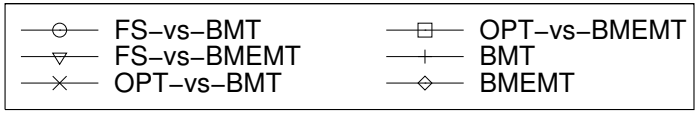
Evaluation IV

- Results for the Montage DAG.









Evaluation V

- Number of unfeasible solutions.

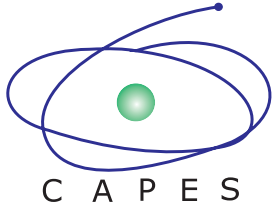
DAG	$\frac{\mathcal{D}_\mathcal{G}}{T_{max}}$	FS vs BMT	FS vs BMEMT	OPT vs BMT	OPT vs BMEMT	BMT	BMEMT
FJ-20	2/7	5	5	0	0	44	38
	3/7	0	57	4	57	0	9
	4/7	28	85	23	85	0	0
	5/7	19	71	19	71	4	0
	6/7	44	83	44	83	11	5
Mon.	2/7	100	100	94	94	100	100
	3/7	42	42	4	4	47	38
	4/7	4	4	0	0	9	19
	5/7	23	23	4	14	14	28
	6/7	50	50	33	33	44	50

Conclusion and Future works

- Customers want their jobs to be executed within an expected execution time
- The SaaS or PaaS clouds want to maximize its profit.
- We presented an ILP to solve the workflow scheduling problem in SaaS or PaaS clouds with two levels of SLA
- Two heuristics were presented (BMT and BMEMT) to find feasible integer solutions over the relaxed runs
- Simulation results shown that:
  - The optimal can generate low-cost solutions with shorter deadlines
  - The heuristics are effective to find low-cost solutions for larger deadlines
- Future works include:
  - Non-iterative methods (constraint programming, non-linear programming, ...)
  - Multiple workflow scheduling in the same set of resources

Thank You!
Questions?

Acknowledgment:



Simulation Configurations

- We used 3 IaaS providers in our simulations
- Each one with its own prices for reserved and on-demand VMs
- Maximum number of VMs that can be leased from each IaaS was:
  - $\delta_A = 4$, $\delta_B = 7$, $\delta_C = 2$.
- External links (links between IaaS providers):
  - Is taken randomly in the $[2, 3]$ interval
- Internal links (links between VMs inside the same IaaS provider):
  - Is taken randomly from the $[0.1, 0.2]$ interval
- Simulations with DAGs of real world applications:
  - Montage and Fork-join DAG with 20 nodes
- $\mathcal{D}_{\mathcal{G}}$ varying from $T_{max} \times 2/7$ to $T_{max} \times 6/7$ in $1/7$ steps
- Intel® Core™ 2 Quad CPU Q6700 2.66GHz and $8GB$ of RAM

Table : IaaS Provider A

Type	Core	Performance Per Core	On-demand Prices	Reserved Prices
Small	1	1.5	$0.13	$0.045
Medium	2	1.5	$0.20	$0.070

Table : IaaS Provider B

Type	Core	Performance Per Core	On-demand Prices	Reserved Prices
Small	1	2	$0.17	$0.045
Medium	2	2	$0.30	$0.059
Large	3	2	$0.40	$0.140
Extra-Large	4	2	$0.52	$0.183
Double Extra-Large	8	2	$0.90	$0.316

Table : IaaS Provider C

Type	**Core**	**Performance Per Core**	**On-demand Prices**	**Reserved Prices**
Small	1	2	$0.15	$0.052
Medium	2	2	$0.25	$0.088
Large	4	2.5	$0.50	$0.176
Extra-large	8	2.5	$0.80	$0.281

Table : SaaS SLAs for reserved VMs

Type	IaaS	VM	Number
Reserved	A	Small	1
Reserved	A	Medium	1
Reserved	B	Small	1
Reserved	B	Medium	1