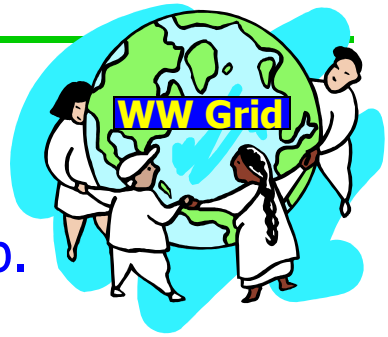
the gridbus project

Pricing for Utility-driven Resource Management and Allocation in Clusters



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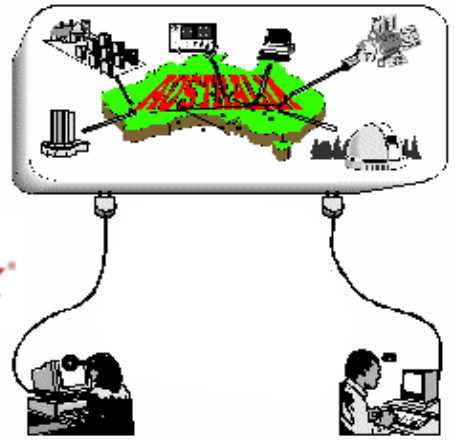


Presentation Outline

- Motivation
- Computation Economy
- Economy-based Admission Control, Resource Allocation & Job Control
- Pricing Function
- Performance Evaluation
- Conclusion and Future Work

Motivation

- Cluster-based systems have gained popularity and widely adopted
  - 75% of Top500 supercomputers world-wide based on Cluster architecture.
  - Clusters are used in not only used in scientific computing, but also in driving many commercial applications.
  - Many Corporate Data Centers are cluster-based systems.

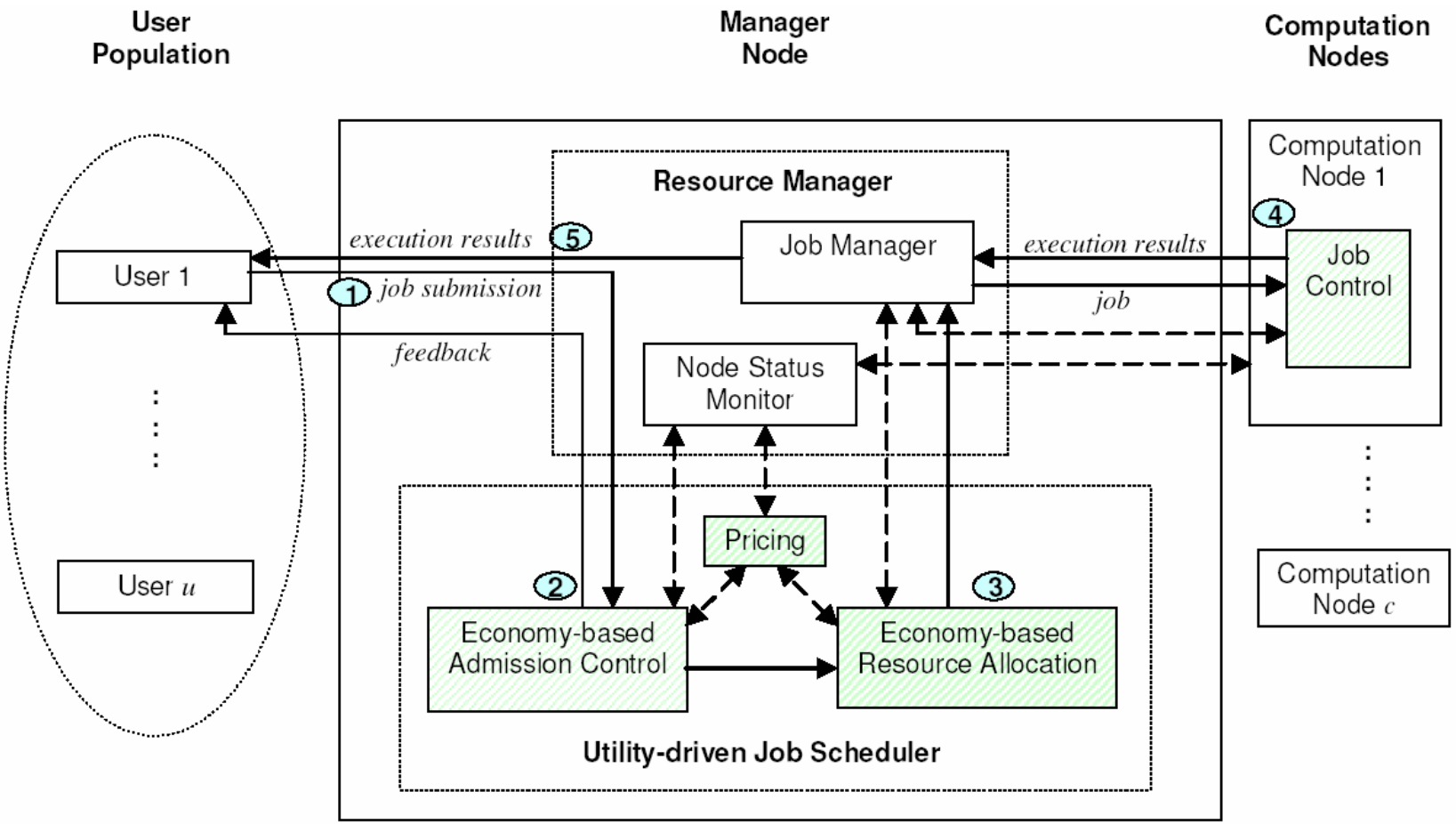
Problem and our Proposal

- However, RMS responsible for managing clusters and allocating resources to users
  - Still adopts system-centric approaches such as FCFS with some static pariorities.
    - Maximize CPU throughput & CPU utilization
    - Minimize average waiting time & average response time
  - They provide no or minimal means for users to define Quality-Of-Service (QoS) requirements.
- We propose the use of user-centric approaches such as computational economy in management of cluster resources.

Computational Economy

- Management of shared resources with economic accountability is effective:
  - Regulates supply and demand of cluster resources at market equilibrium
  - User-centric management of clusters
    - Users express Quality Of Service (QoS) requirements
    - Users express their valuation for the required service
  - Economic incentives for both users and cluster owner as a means of feedback

Utility-driven Cluster RMS Architecture



Economy-based Admission Control & Resource Allocation

- Uses the pricing function to compute cost for satisfying the QoS of a job as a means for admission control
  - Regulate submission of workload into the cluster to prevent overloading
  - Provide incentives
    - ⇧ Deadline -- ⇩ $
    - ⇩ Execution Time -- ⇩ $
    - ⇩ Cluster Workload -- ⇩ $
- Cost acts as a mean of feedback for user to respond to

Economy-based Admission Control & Resource Allocation

- Accept or reject based on 3 criteria (consider required QoS)
  - resource requirements that are needed by the job to be executed
  - deadline that the job has to be finished
  - budget to be paid by the user for the job to be finished within the deadline
- Requires estimated execution time
- Allocates job to node with least remaining free processor time

Job Control: Economy-based Proportional Resource Sharing

- Monitor and enforce required deadline.
  - Time-shared
  - Allocate resources proportional to the needs of jobs based on the estimated execution time and required deadline
  - Update processor time partition periodically

Essential Requirements for Pricing

- Flexible
  - Easy configuration
- Fair
  - Based on actual usage
- Dynamic
  - Not static
- Adaptive
  - Changing supply and demand of resources

Pricing Function

$$P_{ij} = (\alpha * PBase_j) + (\beta * PUtil_{ij}) \quad (3)$$

α - factor for static component based on the base pricing rate $PBase_j$ for utilizing the resource on computation node j

β - factor for dynamic component based on the utilization pricing rate $PUtil_{ij}$ of that resource that takes into account job i.

$PBase_j$ - fixed base pricing rate per unit of cluster resource specified by cluster owner.

$$PUtil_{ij} = \frac{RESMax_j}{RESFree_{ij}} * PBase_j \quad (4)$$

$RESMax_j$ is the maximum units of the resource on computation node j from time AT_i to DT_i.

Pricing Function

$$RESFree_{ij} = RESMax_j - \left(\sum_{k=1}^{n_{accept_j}} RES_k \right) - RES_i \quad (5)$$

n_{accept_j} - n_{accept} jobs (accepted by admission control) that are executing on computation node j from time AT_i to DT_i.

$$RESFree_{ij} = RESMax_j - \left(\sum_{k=1}^{n_{accept_j}} EE_k \right) - EE_i \quad (6)$$

Processing Cost Functions for Different Scheduling Algorithms

- First-Come-First-Served (FCFS)

$$C_i = EE_i * PBase_j$$

- Economy based Proportional Resource Sharing (Libra)

$$C_i = \gamma * EE_i + \delta * EE_i / D_i$$

- Libra with dynamic pricing (Libra+$)

$$P_{ij} = (\alpha * PBase_j) + (\beta * PUtil_{ij})$$

$$C_i = EE_i * P_{ij}$$

Performance Evaluation: Simulation

- Simulation Model
  - Simulated scheduling for a cluster computing environment using the GridSim toolkit (http://www.gridbus.org/gridsim)
- Simulated Cluster
  - manjra.cs.mu.oz.au (13 single-processor nodes with Pentium4 2-GHz CPU)

Experimental Methodology

Models a high demand for cluster resources where the majority of jobs have short deadlines:

- 200 jobs with exponentially distributed job inter-arrival time of mean 0.5 hours and exponentially distributed job execution time E_i of mean 10 hours
- 80% of the 200 jobs belongs to a *high urgency* job class with a low $D_i/E_i = 1.5$ and a high $B_i/f(E_i) = 6$, where $f(E_i)$ is a function to compute the minimum budget required for job execution time E_i
- 20% of the 200 jobs belongs to a *low urgency* job class with a high $D_i/E_i = 6$ and a low $B_i/f(E_i) = 1.5$
- D_i and B_i are normally distributed within each high/low D_i/E_i and $B_i/f(E_i)$
- The high urgency and low urgency job classes are randomly distributed in arrival sequence
- For Libra+$, static pricing factor $\alpha = 1$ and dynamic pricing factor $\beta = 0.01$

Evaluation Metrics

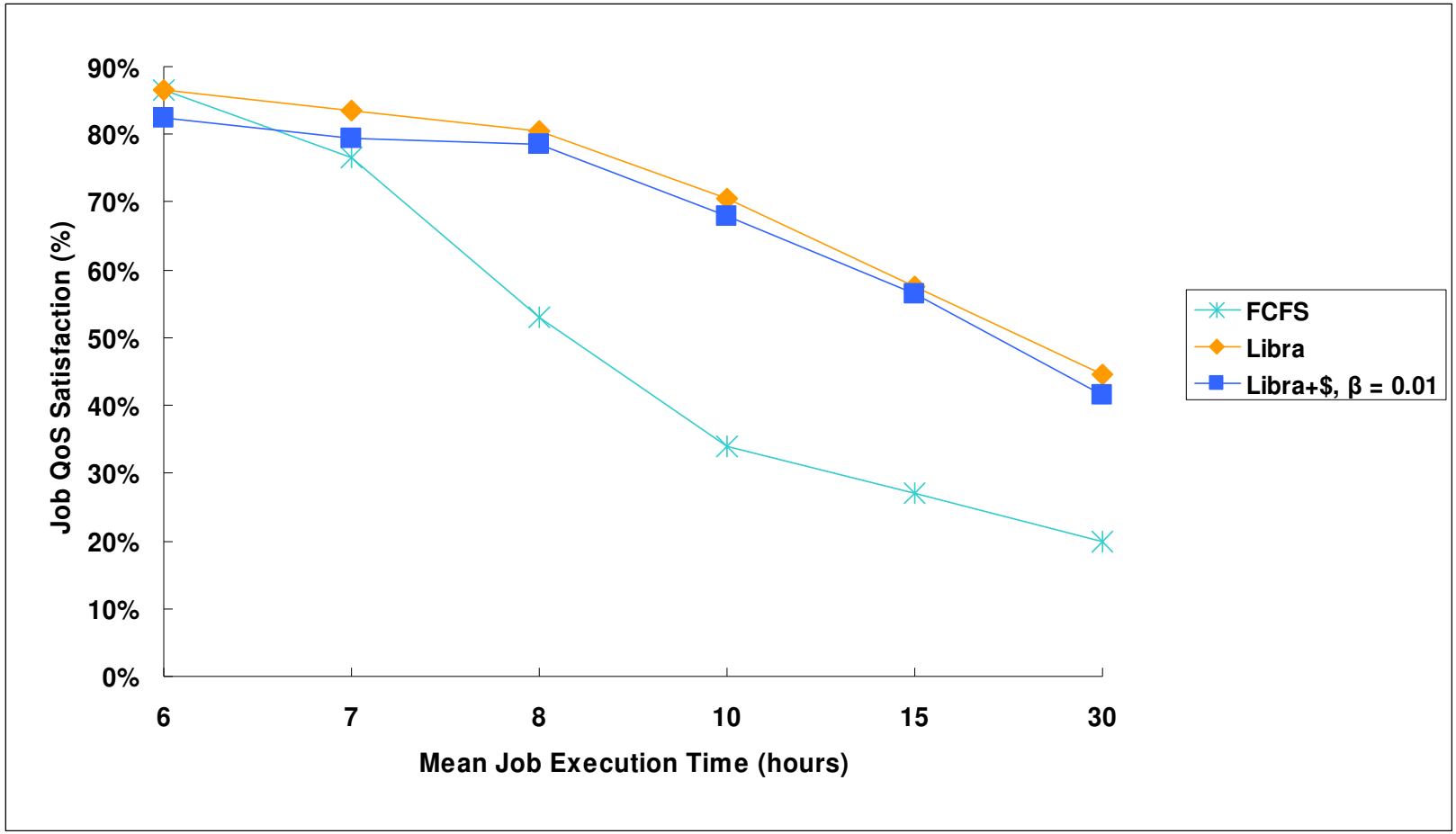
- Job QoS Satisfaction
- Cluster Profitability
- Average Waiting Time
- Average Response Time

Normalised Comparison of FCFS, Libra & Libra+$

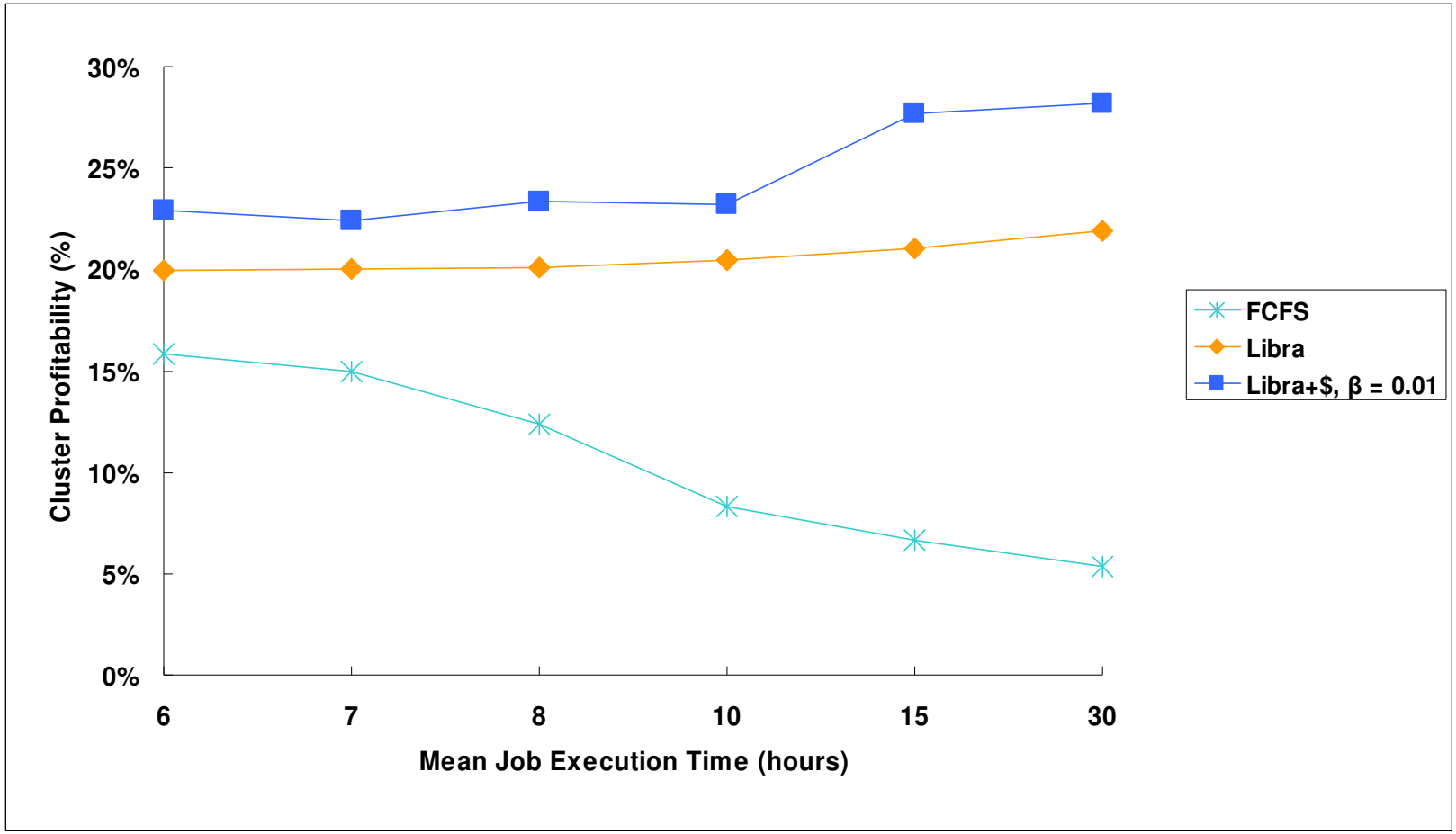
Varying Cluster Workload

- Scheduling policies
  - First-Come-First-Served (FCFS)
  - Economy based Proportional Resource Sharing (Libra)
  - Libra with dynamic pricing (Libra+$)
- An increasing mean job execution time
  - 6, 7, 8, 10, 15 and 30 hours

Impact of Increasing Job Execution Time on Job QoS Satisfaction



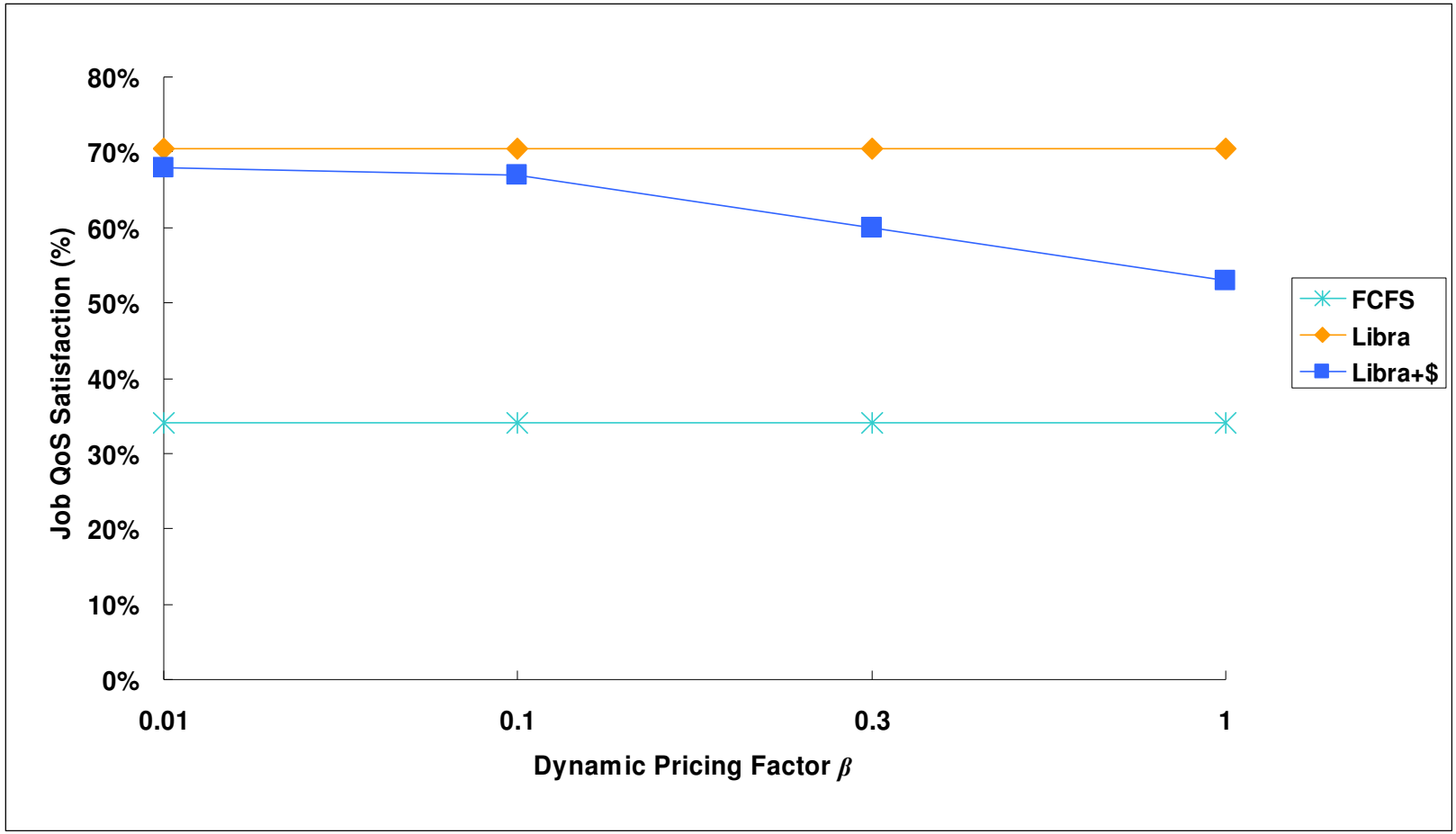
Impact of Increasing Job Execution Time on Cluster Profitability



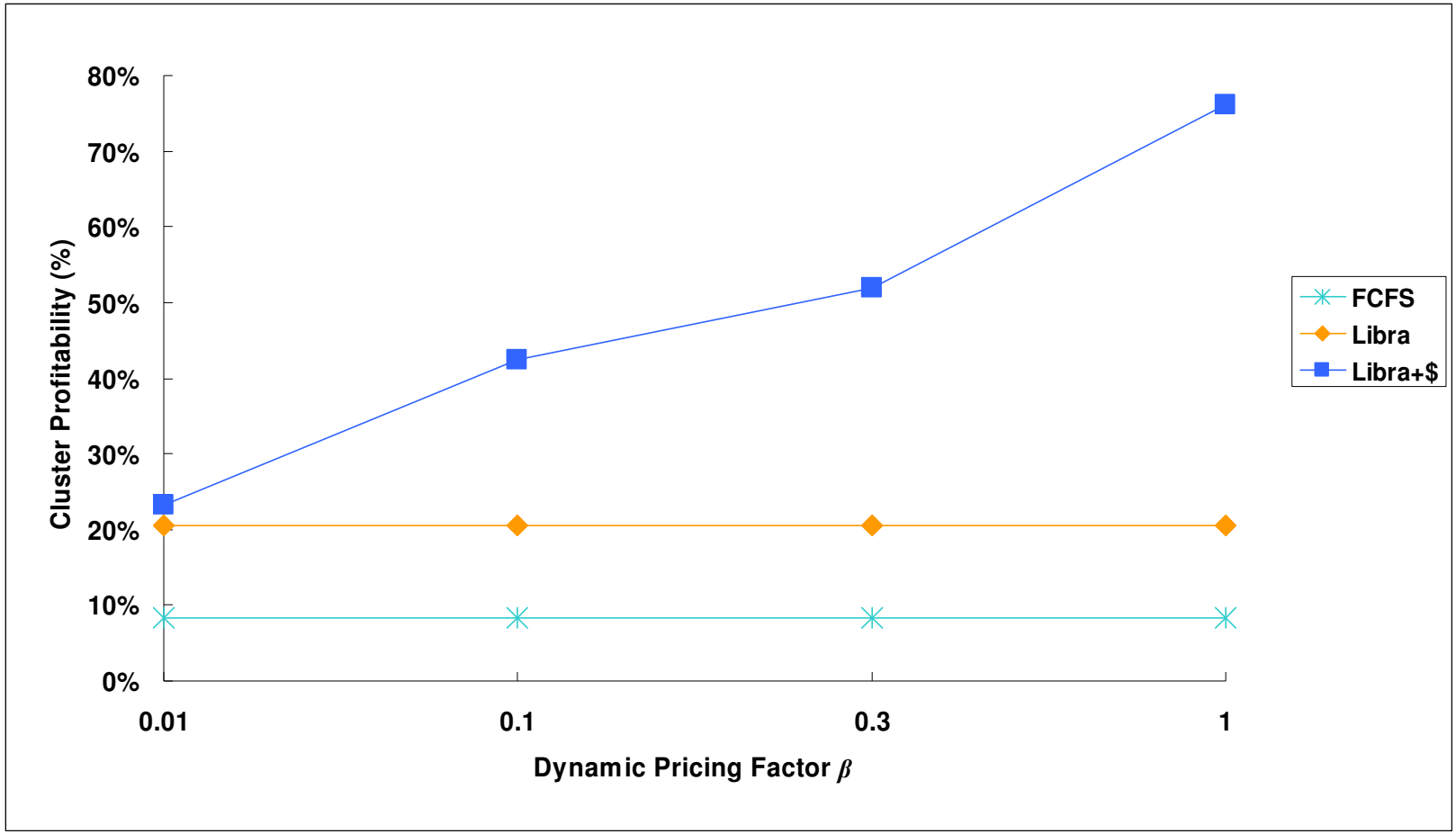
Varying Pricing Factor for Different Level of Sharing

- Scheduling policies
  - Libra with dynamic pricing (Libra+$)
- An increasing dynamic pricing factor β
  - 0.01, 0.1, 0.3, and 1

Impact of Increasing Dynamic Pricing Factor on Job QoS Satisfaction



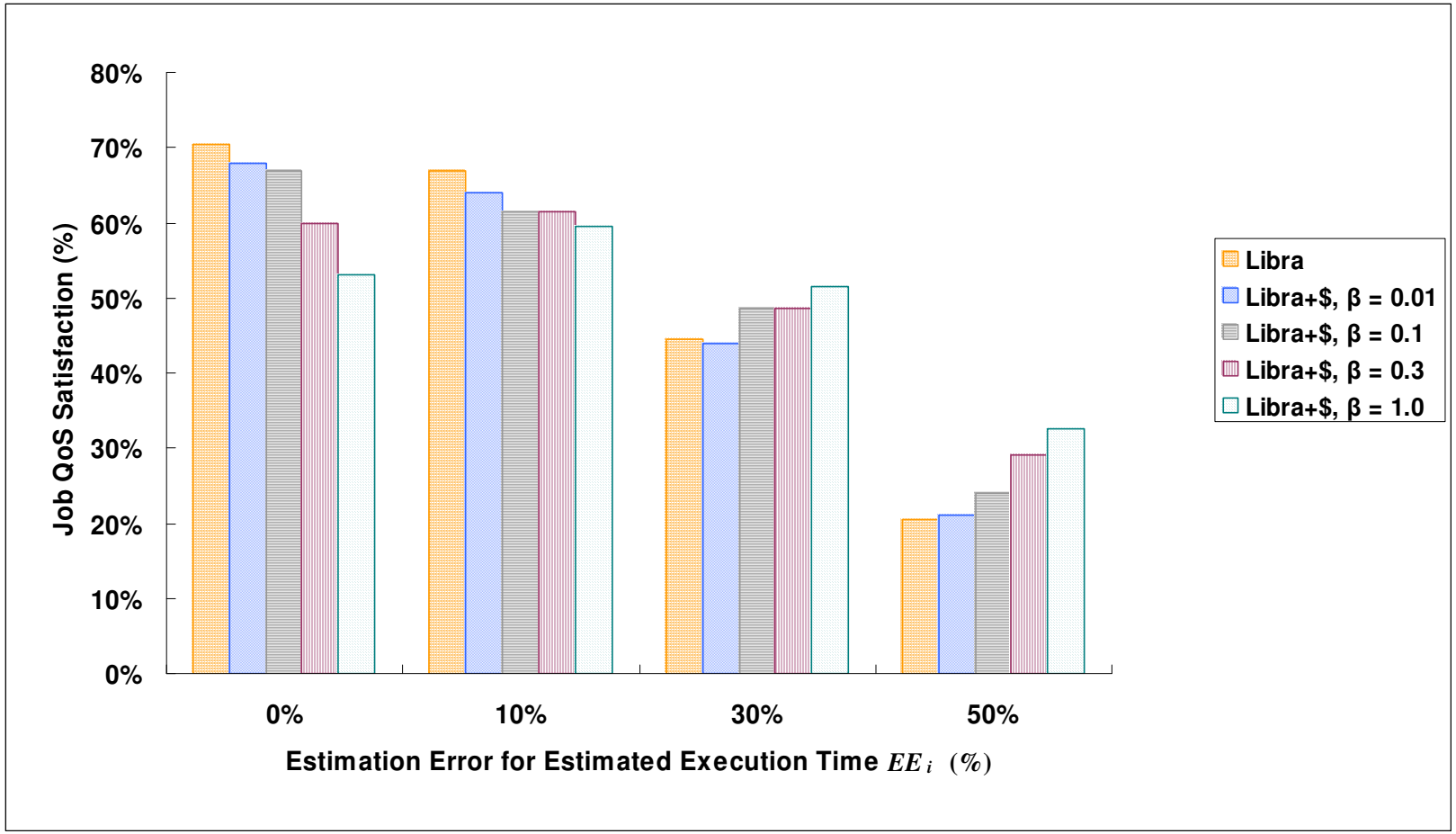
Impact of Increasing Dynamic Pricing Factor on Cluster Profitability



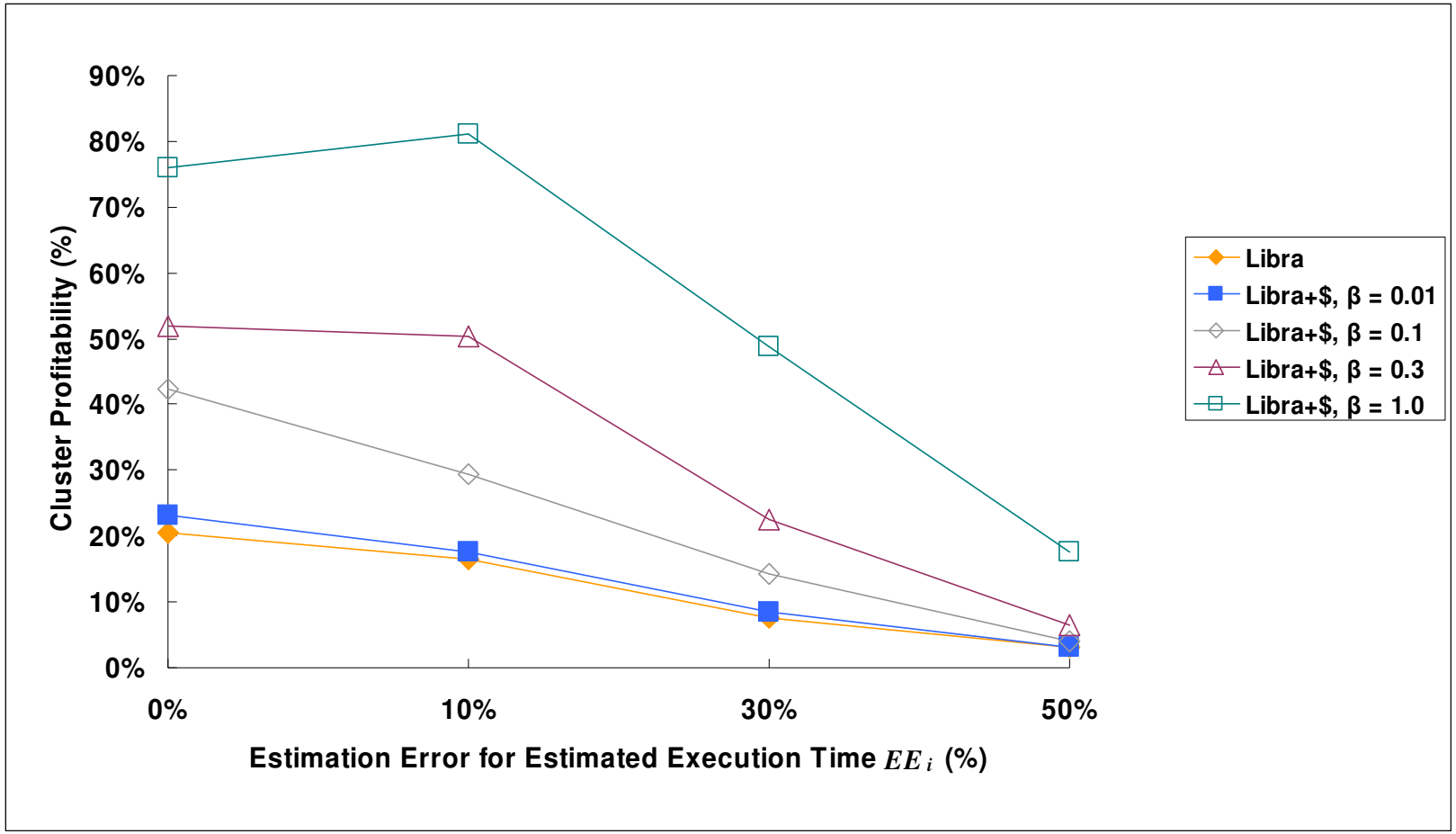
Tolerance against Estimation Error

- Under-estimated execution time EE_i
  - e.g. job whose execution time E_i = 60 hours has EE_i = 30 hours for estimation error = 50%
- Scheduling policies
  - Libra – Economy based Proportional Resource Sharing (Libra)
  - Libra with dynamic pricing (Libra+$)
- An increasing estimation error for estimated execution time EE_i
  - 0%, 10%, 30% and 50%

Impact of Increasing Estimation Error on Job QoS Satisfaction



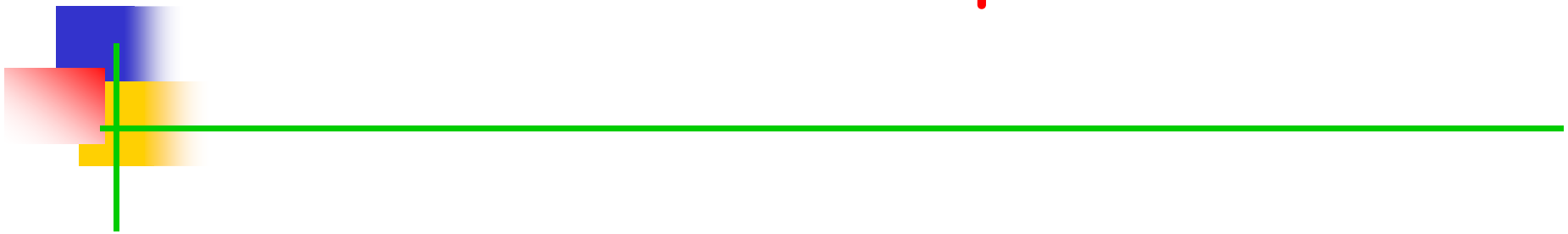
Impact of Increasing Estimation Error on Cluster Profitability



Conclusion & Future Work

- Importance of effective pricing function (demand exceeds supply of resources)
- Satisfy four essential requirements for pricing
- Serves as means of admission control
- Tolerance against estimation errors
- Higher benefits for cluster owner
- Future work
  - Explore different pricing strategies
  - Examine different application models

Backup



Related Work

- Traditional cluster RMS
  - Load Sharing Facility (LSF) – Platform
  - Load Leveler – IBM
  - Condor – University of Wisconsin
  - Portable Batch System (PBS) – Altair Grid Technologies
  - Sun Grid Engine (SGE) – Sun Microsystems
- Market-based cluster RMS
  - REXEC
  - Libra

User-level Job Submission Specification

$$job_i([Segment_1][Segment_2]...[Segment_s]) \quad (1)$$

$$job_i([JobDetails][ResourceRequirements][QoSConstraints][QoSOptimization]) \quad (2)$$

- Job details
  - eg. Estimated execution time
- Resource requirements
  - eg. Memory size, Disk storage size
- QoS constraints
  - eg. Deadline, Budget
- QoS optimization
  - eg. Time, Cost

Performance Evaluation Metrics

- Job QoS Satisfaction

Job QoS Satisfaction measures the level of utility for satisfying job requests. A higher Job QoS Satisfaction represents better performance. Computed as the proportion of n_{QoS} jobs whose required QoS (deadline and budget) are fulfilled out of n jobs submitted:

$$\textit{Job QoS Satisfaction} = n_{QoS}/n \tag{7}$$

n_{QoS} is n_{accept} jobs (accepted by the admission control) where $FT_i \leq DT_i$ and $C_i \leq B_i$.

Performance Evaluation Metrics

- Cluster Profitability

Cluster Profitability measures the level of utility for generating economic benefits for the cluster owner. A higher Cluster Profitability denotes better performance. Computed as the proportion of profit earned by the cluster out of the total budget of jobs that are accepted for execution:

$$\textit{Cluster Profitability} = \sum_{i=1}^{n_{accept}} C_i / \sum_{i=1}^{n_{accept}} B_i \qquad (8)$$

Performance Evaluation Metrics

- Average Waiting Time

Average Waiting Time is the average time a job waits in the cluster before it starts execution. A lower Average Waiting Time indicates better performance.

$$\textit{Average Waiting Time} = \frac{1}{n_{accept}} \sum_{i=1}^{n_{accept}} ST_i - AT_i \qquad (9)$$

Performance Evaluation Metrics

- Average Response Time

Average Response Time is the average time a job is completed and results returned to the user. A lower Average Response Time signifies better performance.

$$\textit{Average Response Time} = \frac{1}{n_{accept}} \sum_{i=1}^{n_{accept}} FT_i - AT_i \qquad (10)$$