Automated Control for Elastic Storage

Harold Lim, Shivnath Babu, Jeff Chase

Duke University

Motivation

- We address challenges for controlling elastic applications, specifically storage.

- Context: Cloud providers that offer a unified hosting substrate.

Motivation

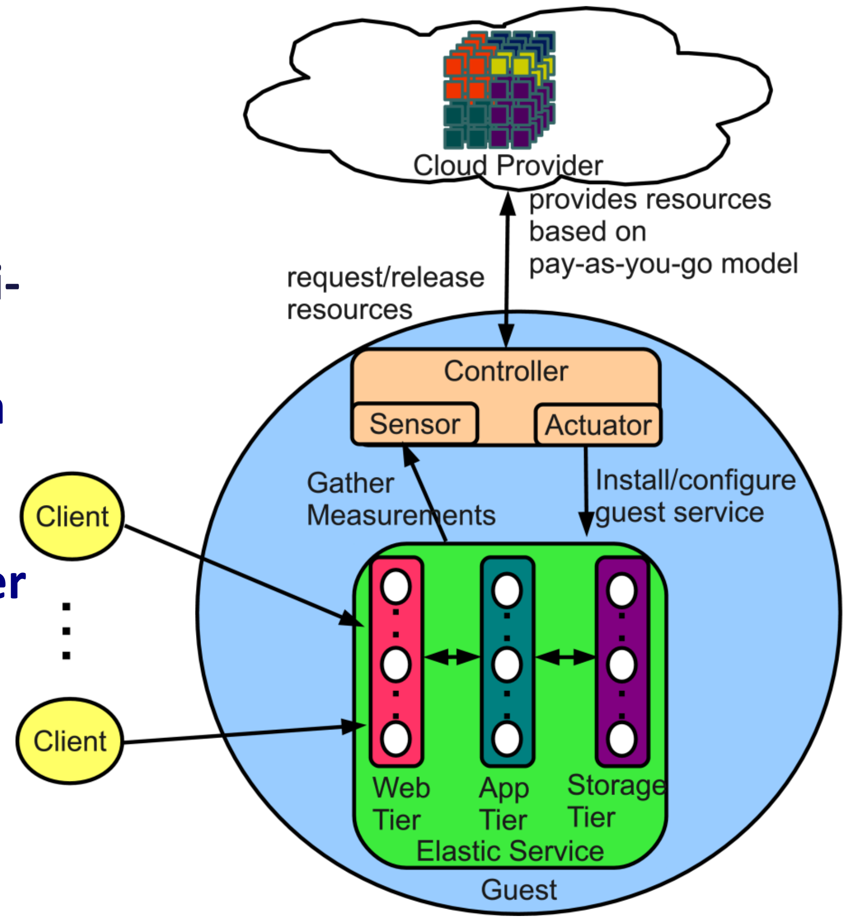
- Let us consider an *infrastructure as a service* cloud provider (e.g., Amazon EC2).
  - Cloud API allows customers to request, control, release virtual server instances on demand.
  - Customers are charged on a per instance-hour usage.
- Cloud computing allows customers to request only the number of instances they need.
- Opportunity for elasticity - where the customer acquires and releases resources in response to dynamic workloads.

Motivation

- Mechanisms for elastic scaling are already pres in a wide range of applications.
- We need to have a good automated control policy for elastic scaling.
- We build on the foundations of previous works (e.g., Parekh2002, Wang2005, Padala2007).

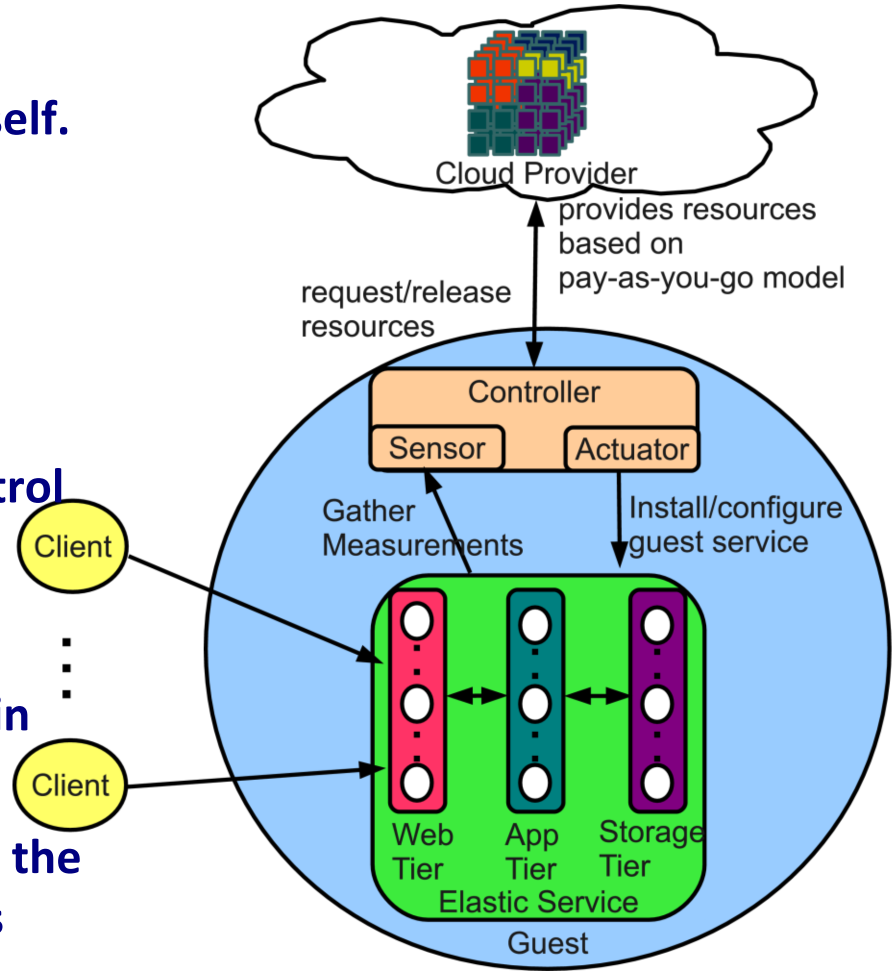
System Overview

- Figure shows our target environment.
  - Controlled Elasticity.
  - Dynamic workload.
  - Meet response time SLO.
- We designed a control policy for multi-tier web services.
  - We use Cloudstone application, a Web 2.0 events calendar, with HDFS as the storage tier.
  - Our approach views the controller as combining multiple elements with coordination.
  - Controlling the storage tier is a missing element of an integrated cluster-based control solution.



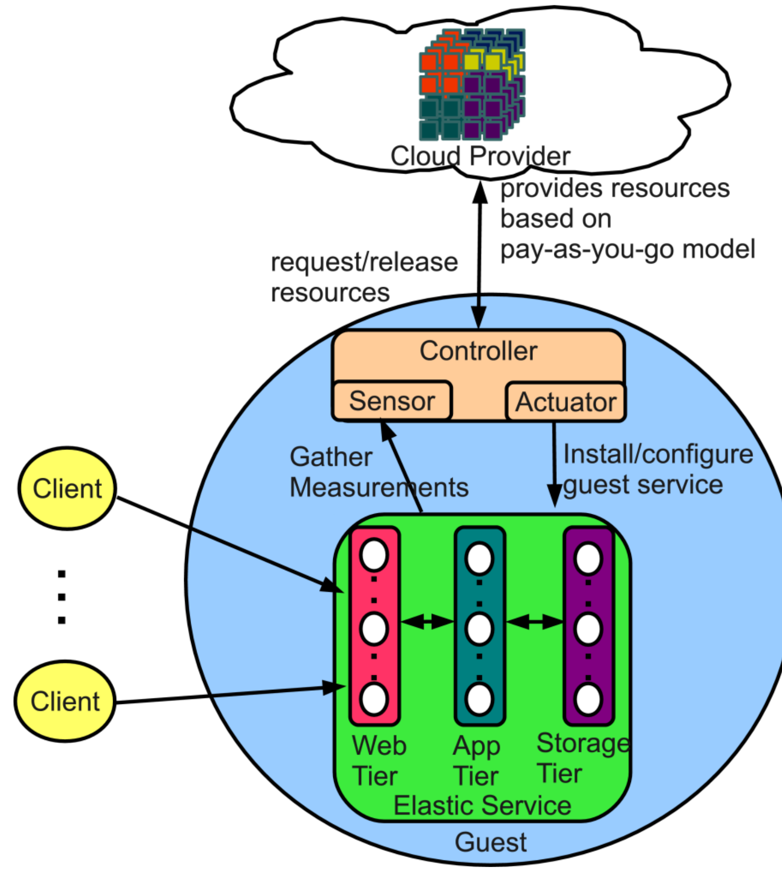
System Overview

- Controller
  - Runs outside of the cloud and distinct from the application itself.
  - Application control left to the guest.
  - Can combine multiple control elements.
  - Allows application-specific control policies.
- Control Goals
  - Handle unanticipated changes in the workload.
  - Resource efficiency (guest pays the minimum necessary to meet its SLO).



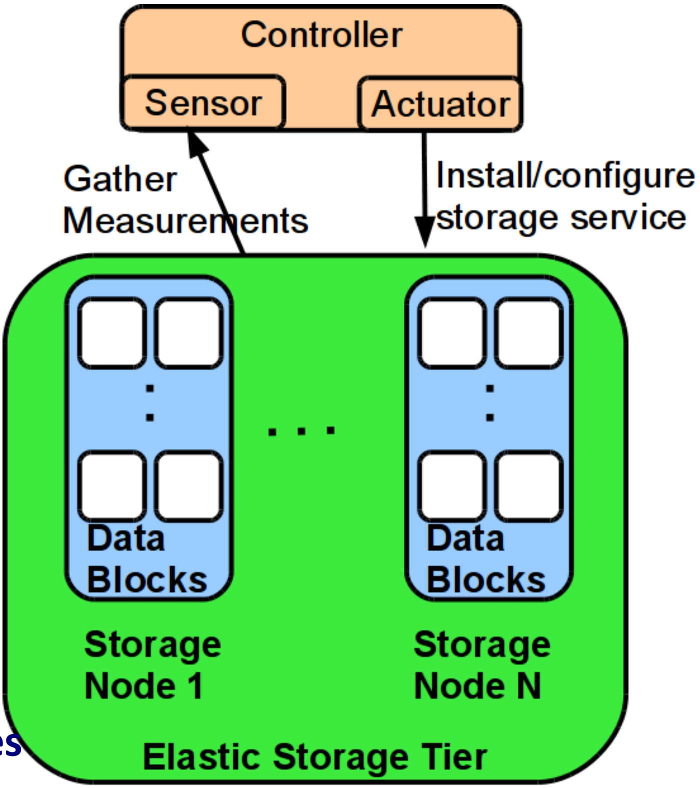
System Overview

- Cloudstone Application
  - Application has mechanism for elastic scaling.
  - There is a mechanism to balances Cloudstone requests across servers.
- HDFS Storage System
  - Data is distributed evenly across servers.
  - Storage and I/O capacity scales roughly linearly with cluster size.



System Overview

- Controller Issue – Discrete Actuator
  - Cloud providers allocate resources in discrete units.
  - No access to hypervisor-level continuous actuators.
- New Issues with Controlling Storage
  - Data Rebalancing
    - Need to move/copy data before getting performance benefits.
  - Interference to Guest Services
    - Data rebalancing uses the same resources to serve clients.
    - The amount of resources to use affects completion time and the degree of interference to client performance.
  - Actuator Delays
    - There is delay before improvements.

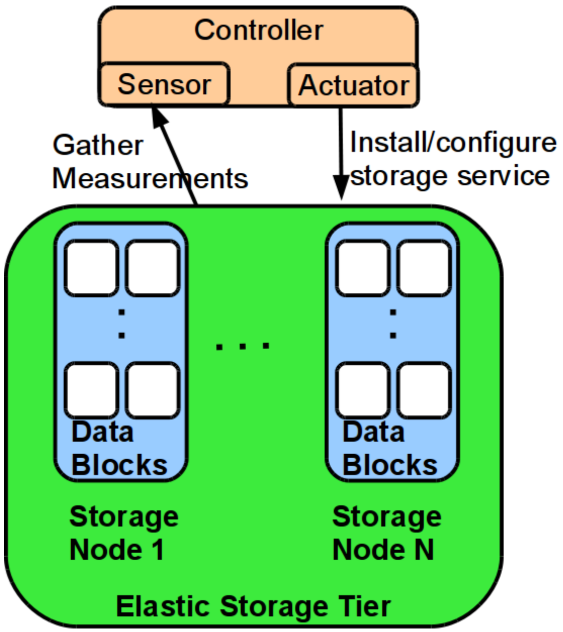


Outline

- **Motivation**
- **System Overview**
- ***Controller Design***
- **Implementation**
- **Evaluation**
- **Related Work**

Controller Design

- The elastic storage system has three components.
  - Horizontal Scale Controller (HSC)
    - Responsible for growing and shrinking the number of nodes.
  - Data Rebalance Controller (DRC)
    - Responsible for controlling data transfers to rebalance the cluster.
  - State machine
    - Responsible for coordinating the actions of HSC and DRC.

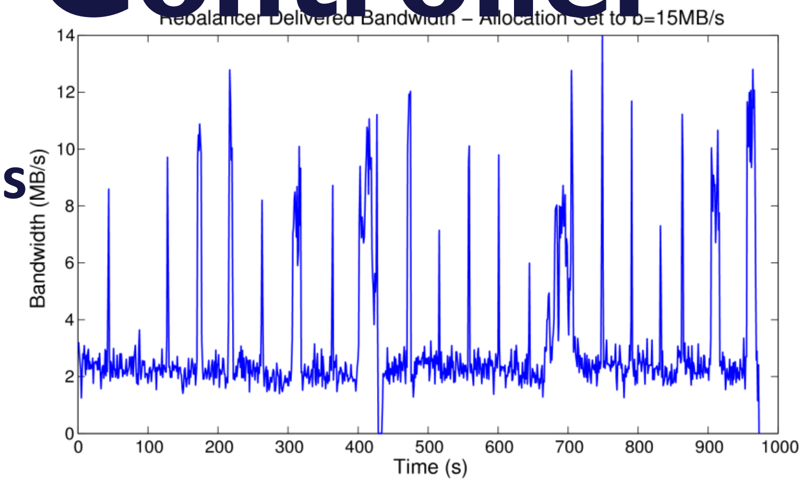


Horizontal Scale Controller

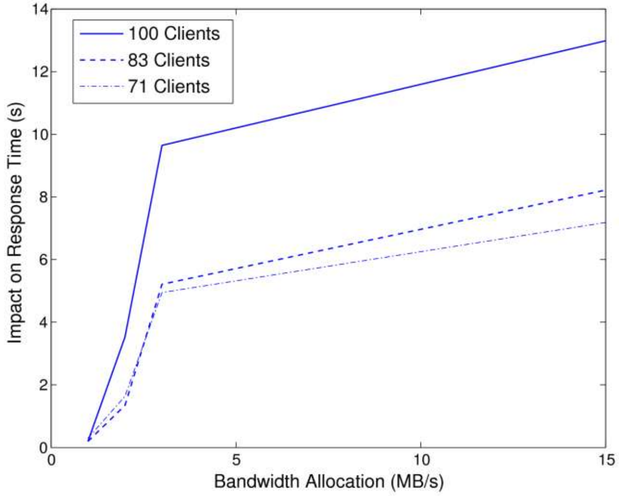
- Control Policy
  - Applied proportional thresholding (Lim2009) to control storage cluster size, with average CPU utilization as sensor.
    - Modifies classical integral control to have a dynamic target range (dependent on the size of the cluster).
    - Prevents oscillations due to discrete/coarse actuators.
    - Ensures efficient use of resources.

$$u_{k+1} = \begin{cases} u_k + K_i \times (y_h - y_k) & \text{if } y_h < y_k \\ u_k + K_i \times (y_l - y_k) & \text{if } y_l > y_k \\ u_k & \text{otherwise} \end{cases}$$

Data Rebalance Controller



- Uses the rebalance utility that comes with HDFS.
- Actuator – The bandwidth *b* allocated to the rebalancer.
  - The maximum amount of outgoing and incoming bandwidth each node can devote to rebalancing.
  - The choice of b affects the tradeoff between lag (time to completion of rebalancing) and interference (performance impact on foreground application).
  - We also discovered that HDFS rebalancer utility has a narrow actuator range.

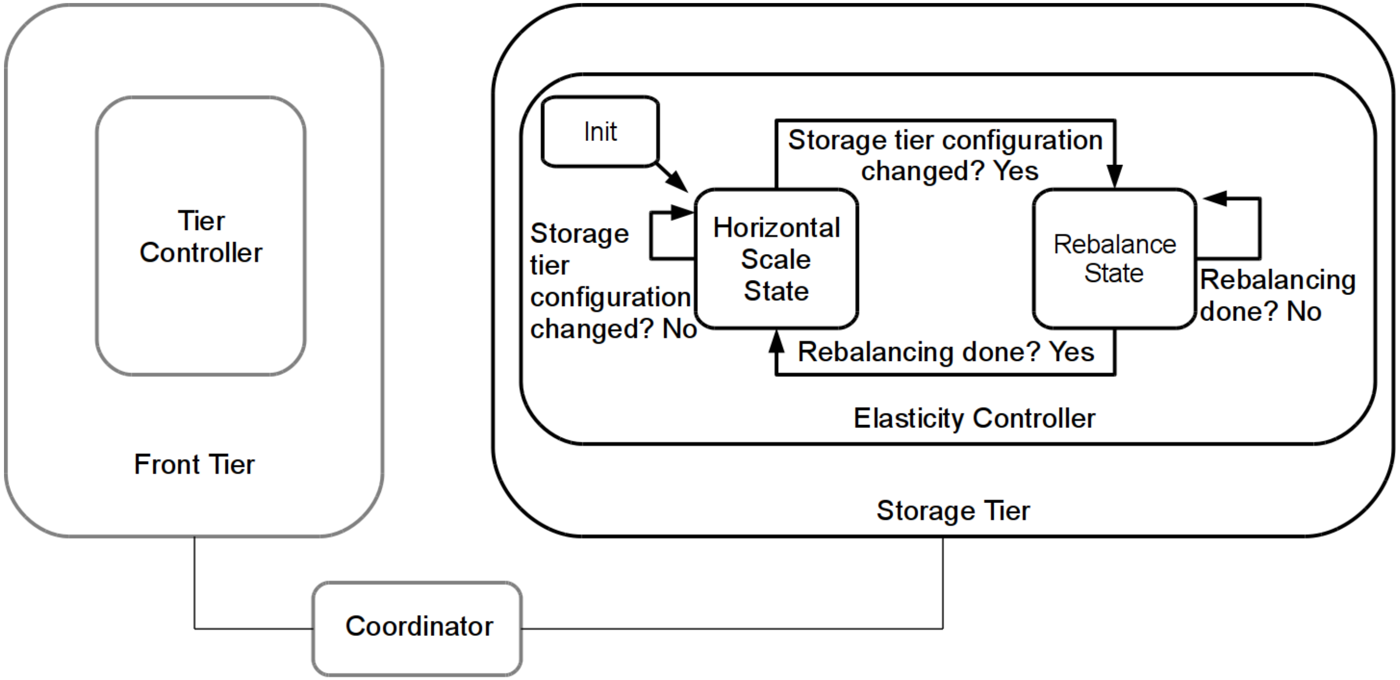


Data Rebalance Controller

- **Sensor and Control Policy**
  - **From the data gathered through a planned set of experiments, we modeled the following:**
    - **Time to completion of rebalancing as a function of bandwidth and size of data (Time = $f_t(b,s)$).**
    - **Impact of rebalancing as a function of bandwidth and per-node workload (Impact = $f_i(b,l)$).**
  - **The choice of b is posed as a cost-based optimization problem. Cost = *A x* time + *B x* Impact.**
    - **The ratio of A/B can be specified by the guest based on the relative preference towards Time over Impact.**

State Machine

- Manages the mutual dependencies between HSC and DRC.
  - Ensures the controller handles DRC's actuator lag.
  - Ensures interference and sensor noise introduced by rebalancing does not affect the HSC.



Implementation

- **Cloud Provider**
  - **We use a local ORCA cluster as our cloud infrastructure.**
    - **A resource control framework developed at Duke University.**
    - **Provides resource leasing service.**
  - **The test cluster exports an interface to instantiate Xen virtual machine instances.**

Implementation

- **Target Guest Service**
  - **Cloudstone - Mimics a Web 2.0 events calendar application that allows users to browse, create, join events.**
    - **Modified to run with HDFS for unstructured data.**
    - **HDFS does not ensure requests are balanced but the Cloudstone workload generator accesses data in a uniform distribution.**
    - **Modified HDFS to allow dynamically setting *b***

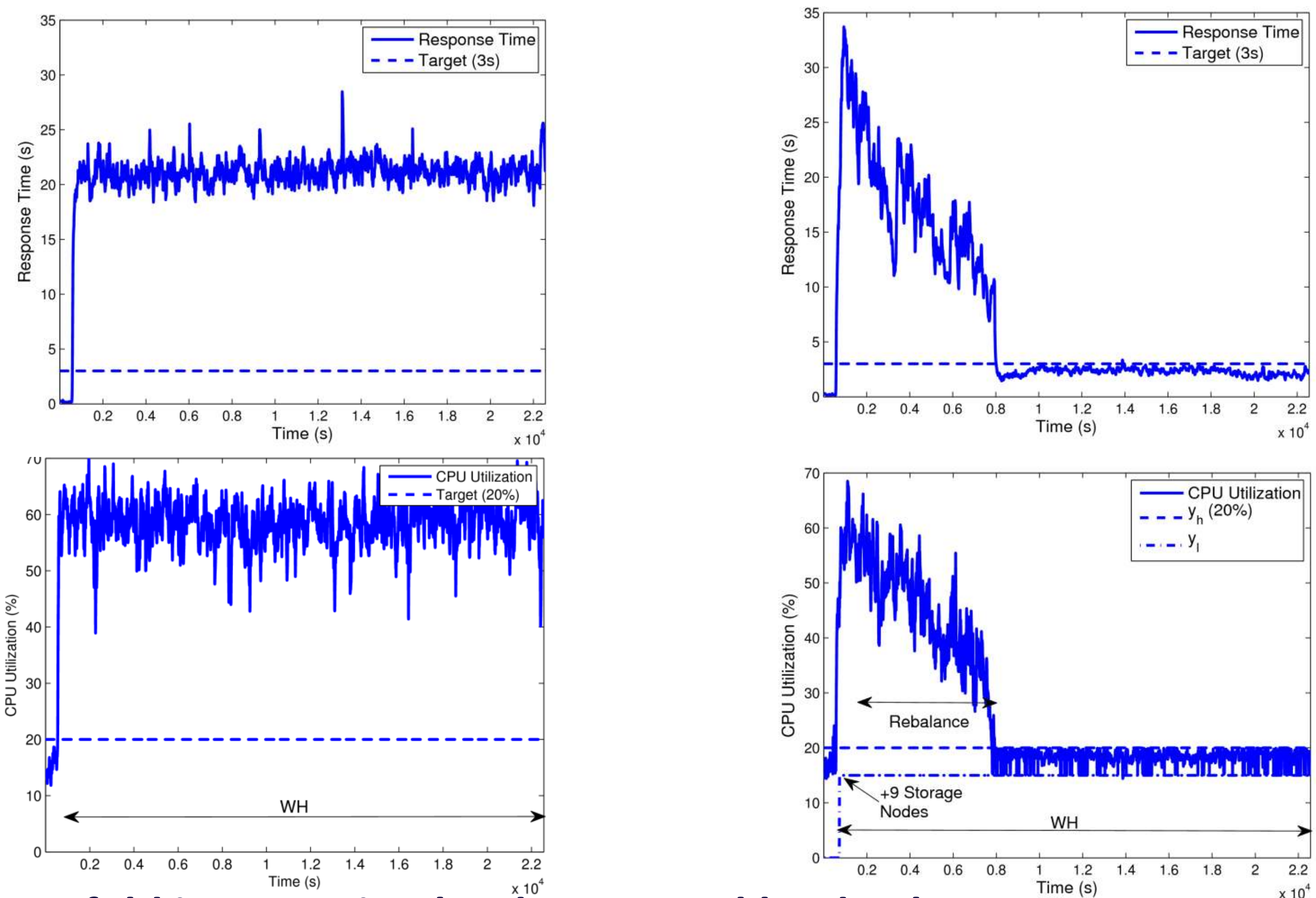
Implementation

- Controller
  - Written in Java.
  - Uses ORCA's API to request/release resources.
  - Storage node comes with Hyperic SIGAR library that allows the controller to periodically query for sensor measurements.
  - HSC and DRC runs on separate threads and are coordinated through the controller's state machine.

Evaluation

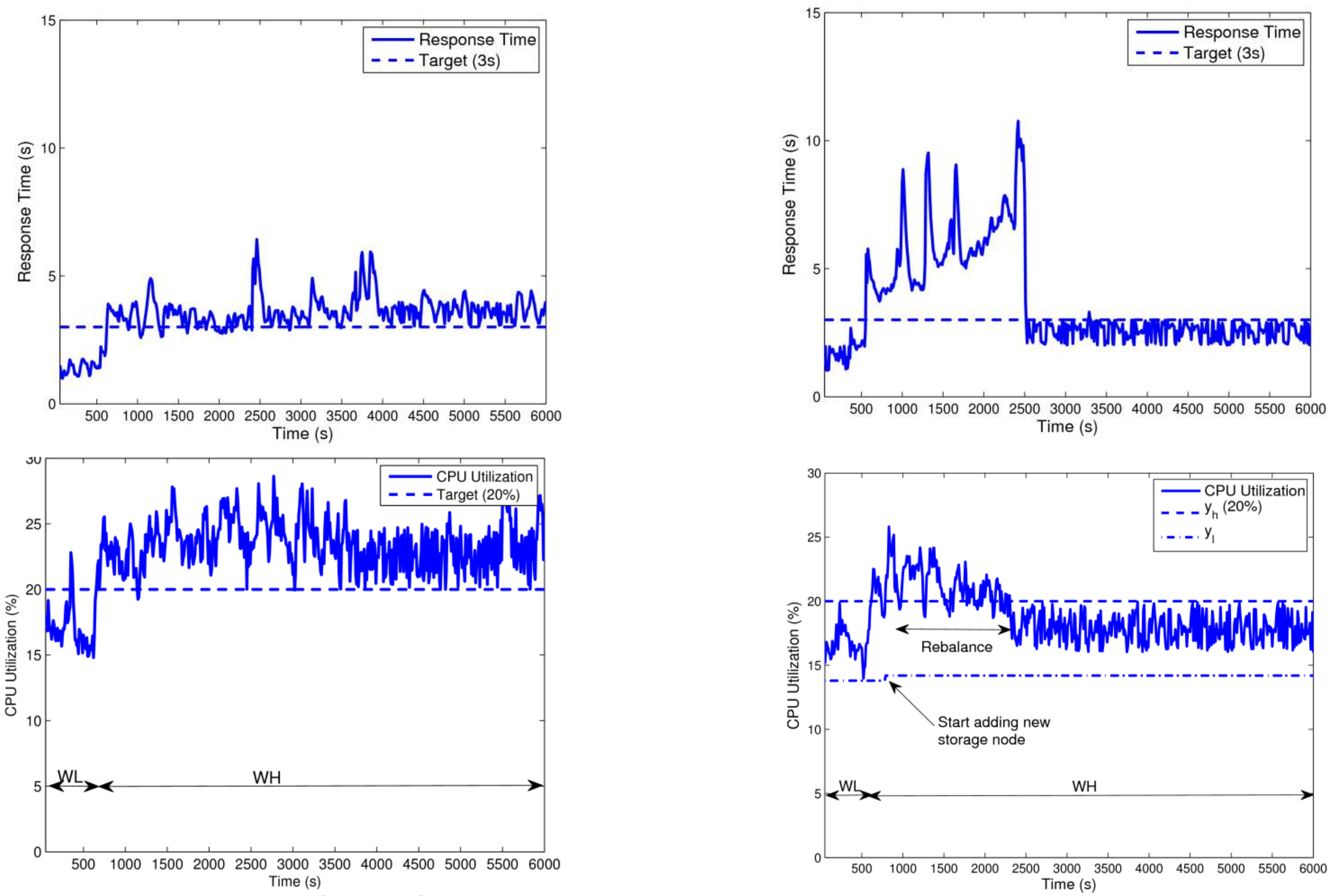
- Experimental Testbed
  - Database server (PostgreSQL) runs on a powerful server (8GB RAM, 3.16 GHz dual core CPU).
  - Forward Tier (GlassFish Web Server) runs in a fixed six-node cluster (1GB RAM, 2.8GHz CPU).
  - Storage nodes are dynamically allocated virtual machine instances, with 30GB disk space, 512MB RAM, 2.8GHZ CPU.
  - HDFS is preloaded with at least 36GB of data.

Evaluation



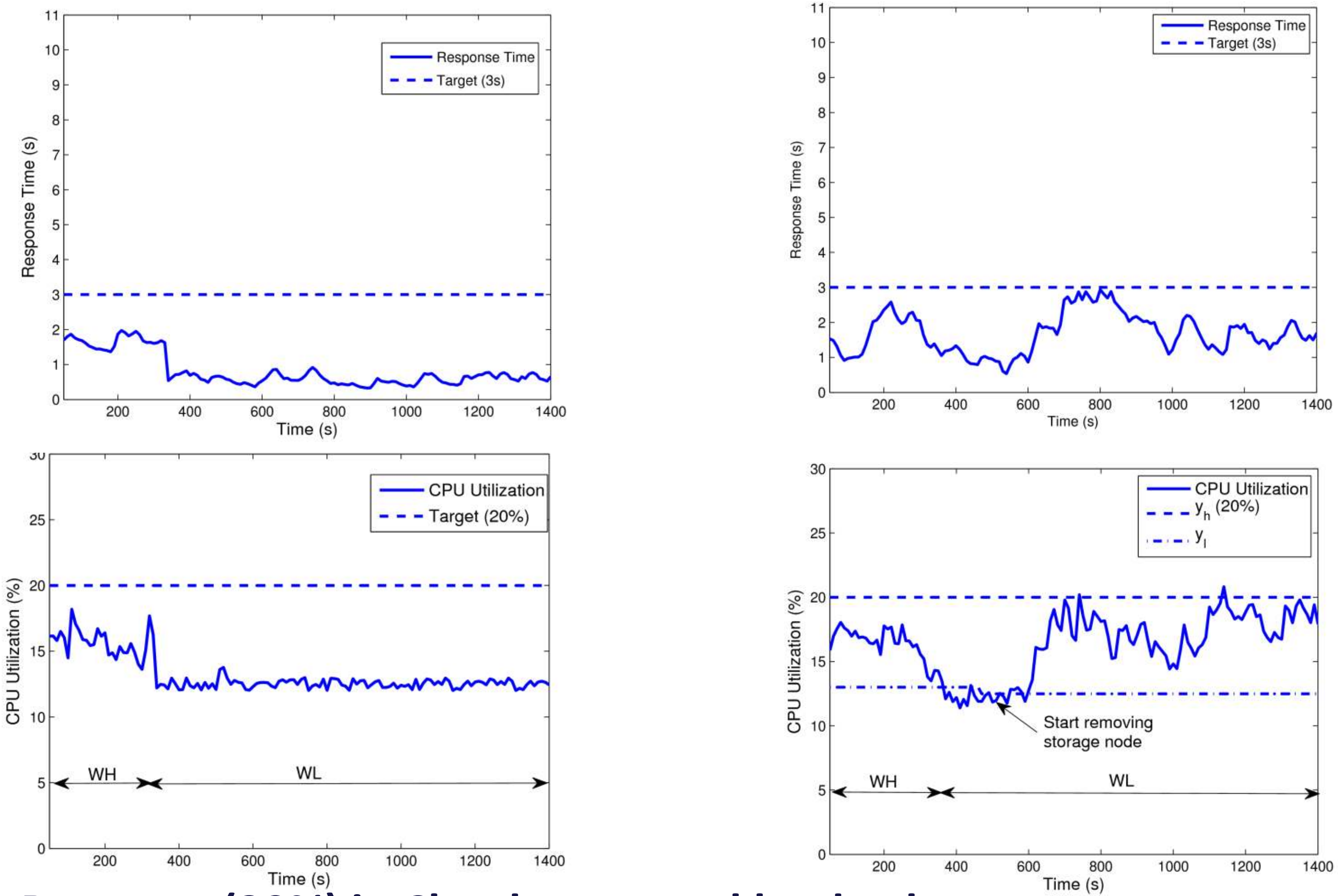
- **10-fold increase in Cloudstone workload volume**
- **Static vs Dynamic provisioning**

Evaluation



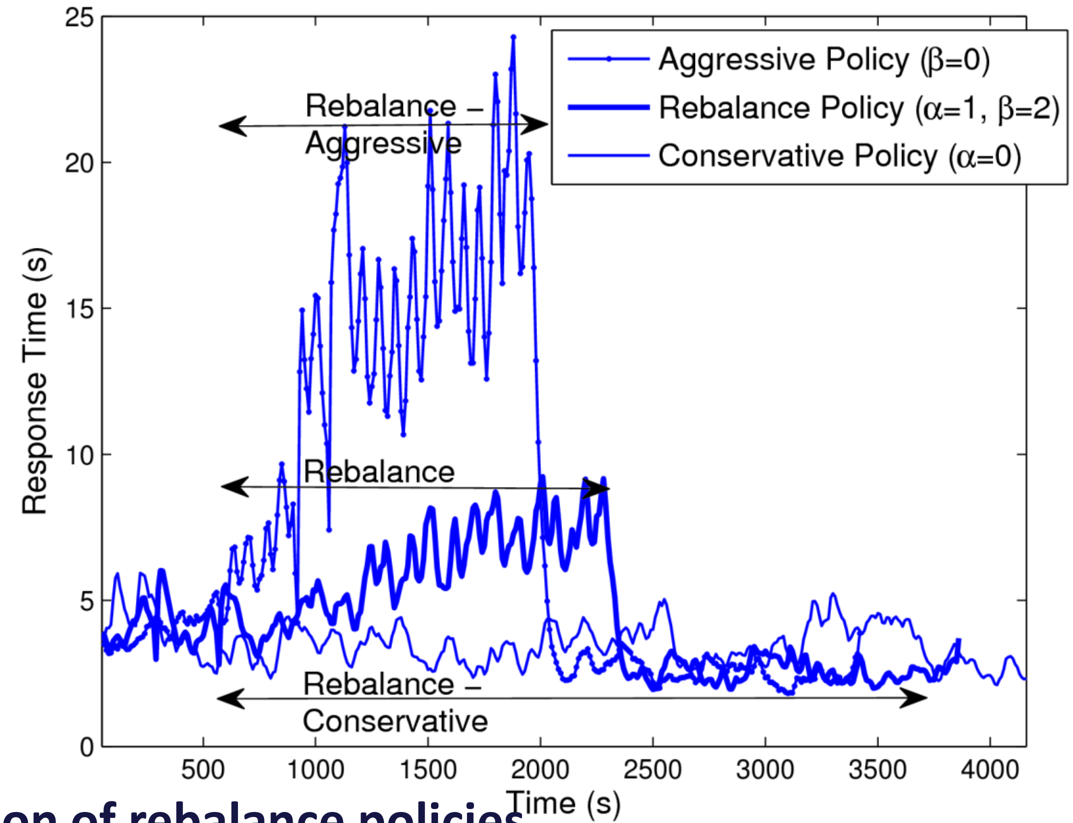
- Small increase(35%) in Cloudstone workload volume
- Static vs Dynamic provisioning

Evaluation



- Decrease (30%) in Cloudstone workload volume
- Static vs Dynamic provisioning

Evaluation



- **Comparison of rebalance policies**
- **An aggressive policy fixes SLO problems faster but incurs greater interference.**
- **A conservative policy has minimal interference but prolongs the SLO problems.**

Related Work

- Control of Computing Systems
  - Parekh2002, Wang2005, Padala2007, Padala2009
- Data Rebalancing
  - Anderson2001, Lu2002, Seo2005
- Actuator Delays
  - Soundararajan2006
- Performance Differentiation
  - Jin2004, Uttamchandani2005, Wang2007, Gulati2009

Thank You

- Controller runs outside of the cloud.
- Controller fixes SLO violations.
- Proportional thresholding to determine cluster size.
- For elastic storage, data rebalancing should be part of the control loop.
- State machine to coordinate between control elements.

System Overview

- Controller
  - Reflects the separation of concerns in the functionalities among provider and guests.
    - Guests are insulated from details of underlying physical resources.
    - Provider is insulated from details of application.
  - Application control is factored out of the cloud platform and left to the guest.

Horizontal Scale Controller

- Actuator - Uses cloud APIs to change the number of active server instances.
- Sensor – A good choice must satisfy the following properties.
    - Easy to measure without intrusive code instrumentation.
    - Should measure tier-level performance.
    - Should not have high variations and correlates to the measure of level of service as specified in the client's SLO.
- We use average CPU utilization of the nodes as our sensor.
    - Note that for other target applications, one has to find a suitable sensor and may differ from our choice of using CPU utilization.