Shaping NVMe SSD IO Performance in Virtual Environments

SSDS-102-1: Controllers for the Data Center

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Agenda

- WHY SSDS NEED PERFORMANCE SHAPING
- HOW DOES SSD PERFORMANCE SHAPING WORK
- MODELING -> DEMONSTRATION OF PERFORMASHAPE™

Problem Statement

The Challenge of QoS for multi-tenancy is inconsistent tenancy behavior in SSD. Noisy tendency may impact QoS of other tenancies who behaves consistently. Isolation is needed, HOWEVER:

- Restrict isolation (share nothing) has problems:
  - Difficult to implement, challenge to physically divide/isolate resources in the device into small independent pieces
  - Could leads to fragmentation and waste

- NVMe provides submission queue arbitration mechanism based WWR with urgent priority class. But this is limiting:
  - 4 level of priorities/weights
  - Focuses on submission queue level, not in IO command level with performance parameters (IOPS, or throughput as weights
  - No mechanism for arbitration between NVMe controllers on an NVMe subsystem which supports multiple PCIe ports and function

WHY SSDS NEED PERFORMANCE SHAPING

HOW DOES SSD PERFORMANCE SHAPING WORK

MODELING -> DEMONSTRATION OF PERFORMASHAPE™

SiliconMotion

Performance Shaping Mechanism

Flash Memory Summit

PerformaShape™ mechanism to shape IO requests per user defined **QoS set**.

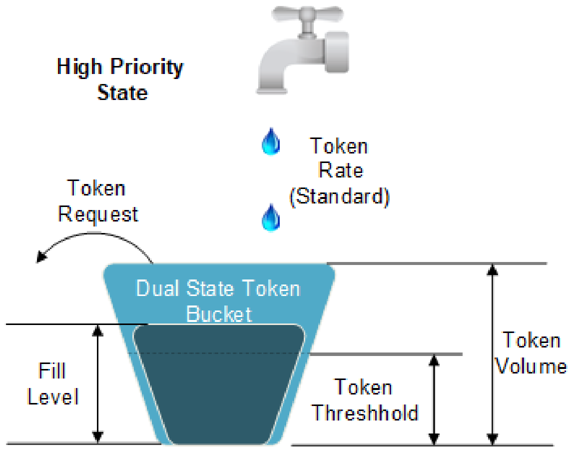
A QoS set is a group of one or multiple host tenants, and/or internal tasks (reclamation, etc.), which initiates IO type operations.

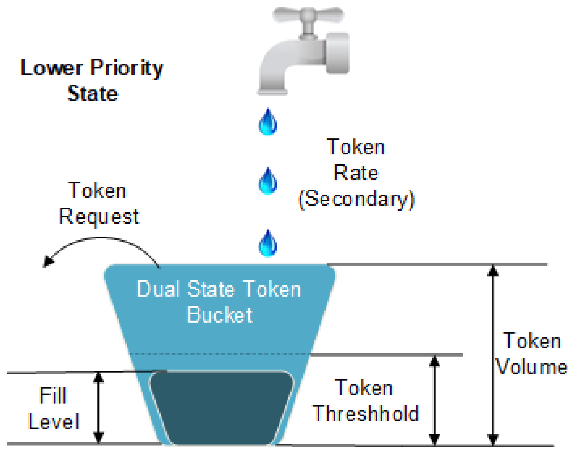
The shaping algorithm is based on **Dual State Token Bucket algorithm**.

- Each QoS set is assigned with a token bucket:
  - One token is a permission for an IO cmd, or some amount of KiB's.
  - Token rate: at which speed tokens fill the token bucket, configurable and variable.
  - Token volume / bucket size: max token number the token bucket can hold.
  - When a QoS set / client requests n tokens:
    - If the bucket has ≥ n tokens, grant permission to go.
    - Otherwise, the request waits until the bucket accumulates enough tokens.

Performance Shaping Mechanism

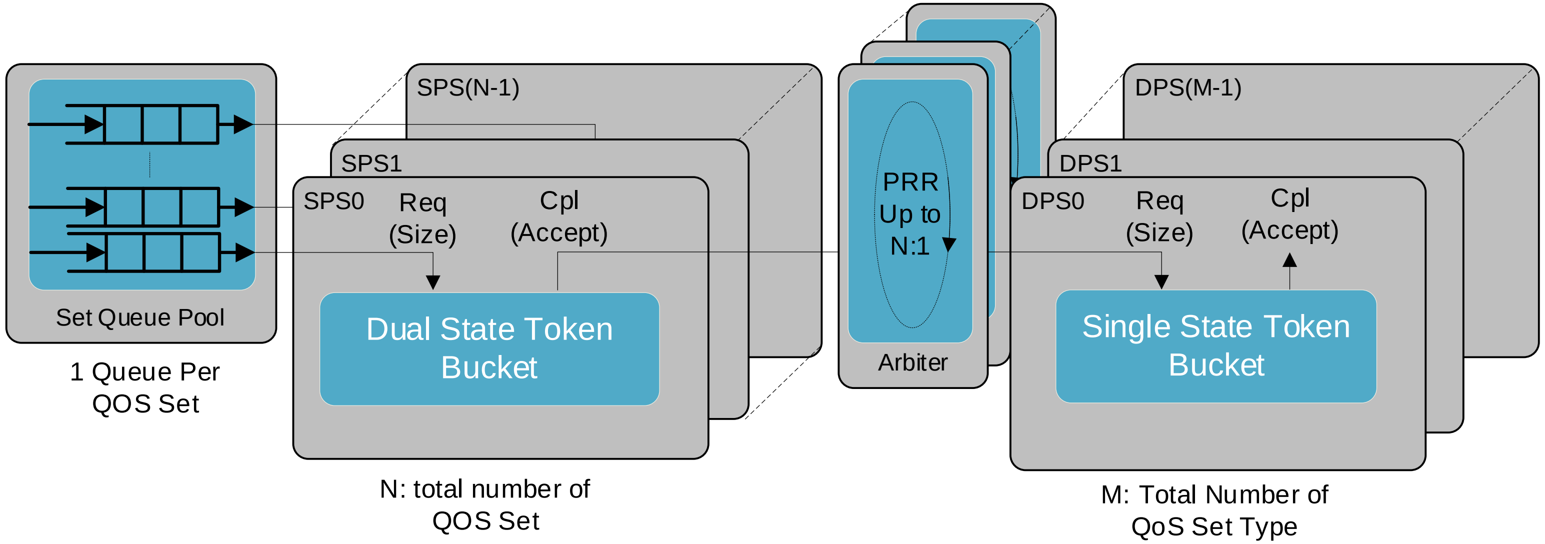
- **Dual-State Token Bucket Algorithm:**
  - Purpose: dual rates to allow the client to request more but given lower priority, processed opportunistically.
  - Token fill level ≥ token threshold: the token rate will be a standard token rate, and any token request will be accepted with high priority.
  - Otherwise, the token rate will be set to a secondary token rate (> standard token rate), and any token request will be accepted with low priority.





Performance Shaping Mechanism

- Two-Stage Shaping
  - Token bucket shaping smooths IO requests and limits the it's outliers to certain extent. The dual state token bucket algorism allow more IO burstiness, in order to optimize the utilization of the device bandwidth.
  - However, the device bandwidth is limited. When we have multiple noisy/demanding tenants, we need to make sure the device is not over-booked. Thus, we propose a second stage token bucket, namely Device Level Token bucket:
    - Simply one-state token bucket with a token rate = device bandwidth
    - Can have multiple of it used for different type of IO performance controls, e.g. IOPS, throughput (GB/S), read and write, etc.



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Performance Shaping Modeling

Performance Shaping Modeling Goals

- ❑ Smooth out fluctuations
- ❑ Isolate noisy neighbors
- ❑ Fully utilize the SSD bandwidth

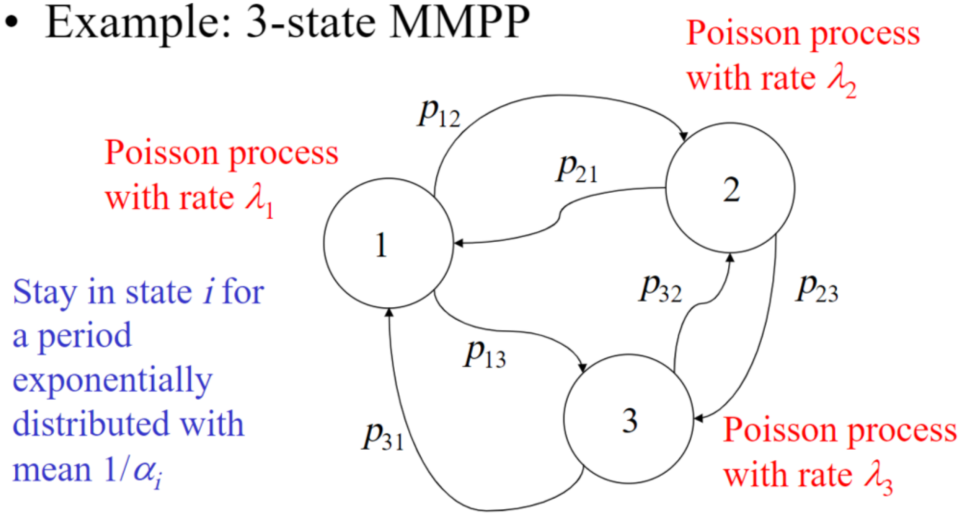
Key Modeling Components

- ❑ Host Workload Generator
- ❑ Simulator
- ❑ Output Analysis

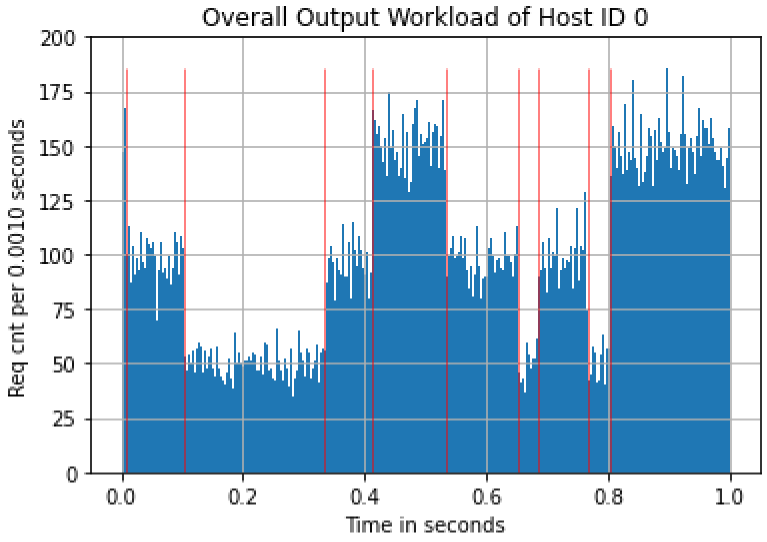
Workload Generator

- Target:
  - To emulate a host application that:
    - Multiple internal states and transition among these
    - Each internal state has its own IO rate that follows Poisson process
  - → MMPP (Markov-modulated Poisson process)
    - Poisson processes by N, each with its own rate.
    - Continuous Time Markov chain (CTMC): N * N matrix
- Tool:
  - Python Random
    - Exponential Random Var:
      - Generate Poisson processes
      - Determines the time to stay in one state
    - Random Choice Var: choose the next state
- Output:
  - Trace: List of (NLBA, time)
    - NLBA = 1 for the purpose of evaluating IOPS

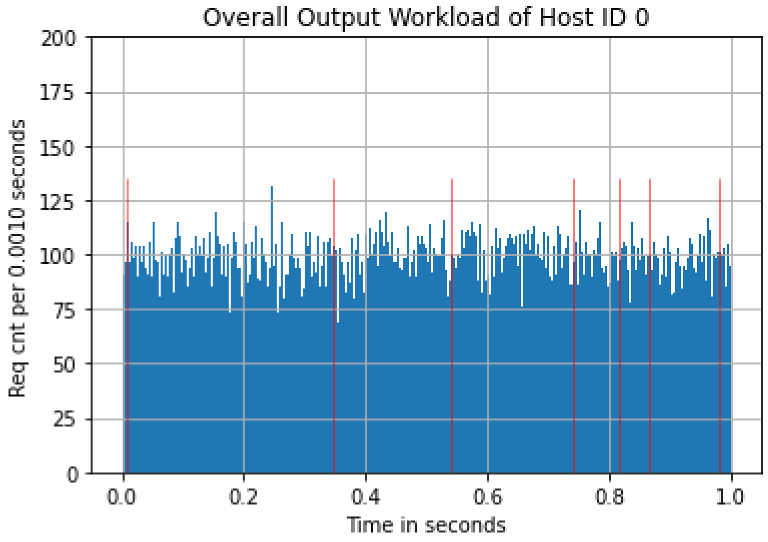
- Example: 3-state MMPP



Workload Examples



- Poisson's: 100K/150K/50K
- Noisy neighbor



- Poisson's: 100K/100K/100K
- Good neighbor

Simulation Details

Shaping Engine: Token Buckets + Arbiter

Bucket size:

- How much token to save for peaks

Token count threshold:

- If tokens are used up quickly (peaks), switch to high rate but mark as low_priority

Two token rates:

- Normal rate: ≈ the average workload rate
- High rate: allows peaks to pass through

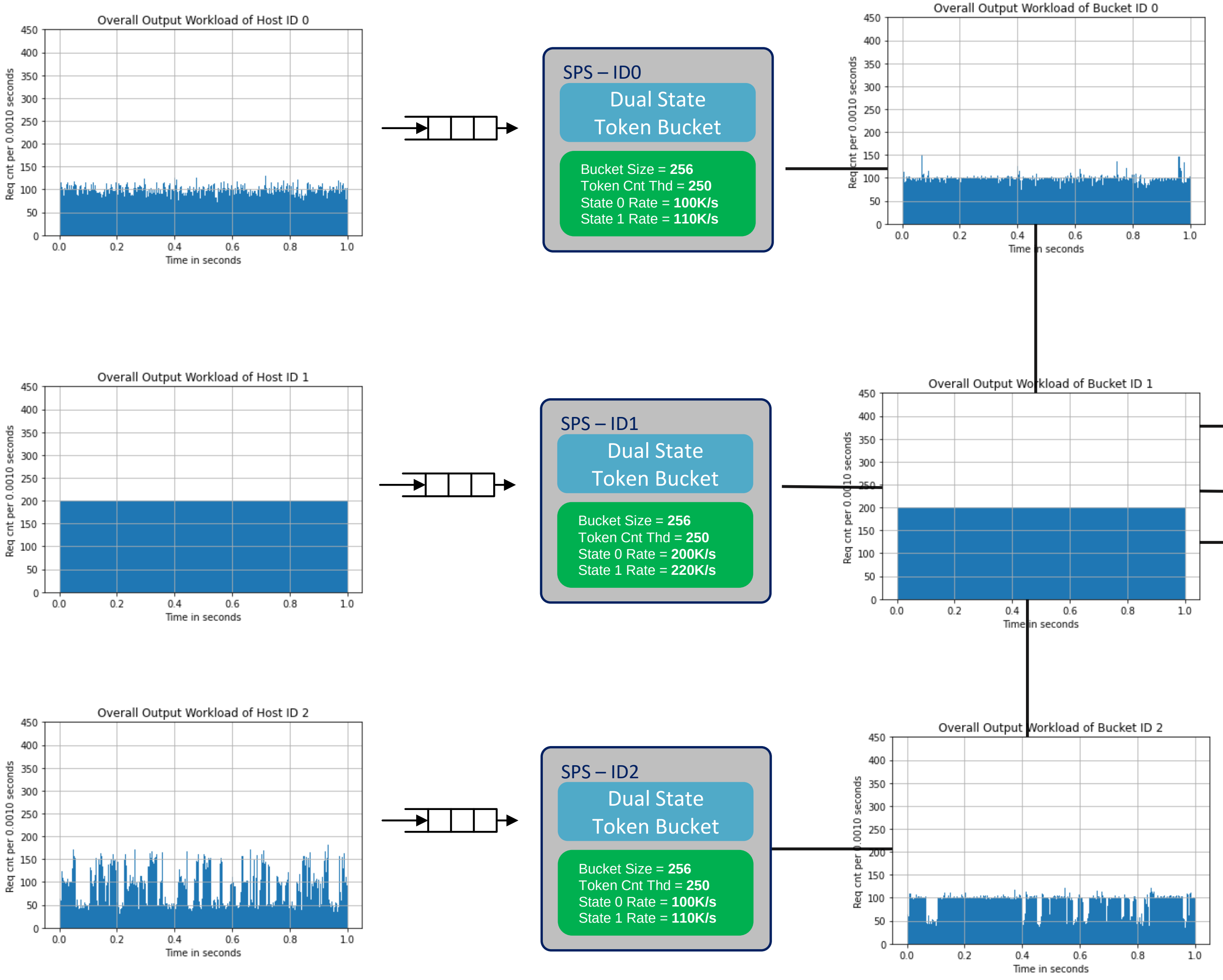
Tool:

Simpy (a Discrete Event Simulator in Python)

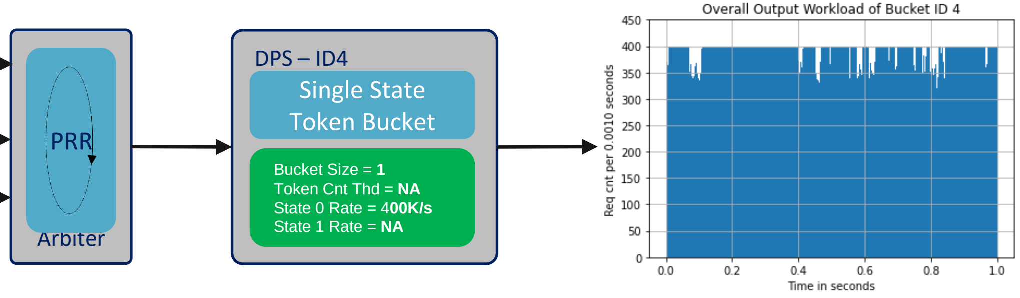
Output:

List of (NLBA, time, priority)

Simulation Example



Output Analysis
Two-stage Bucket



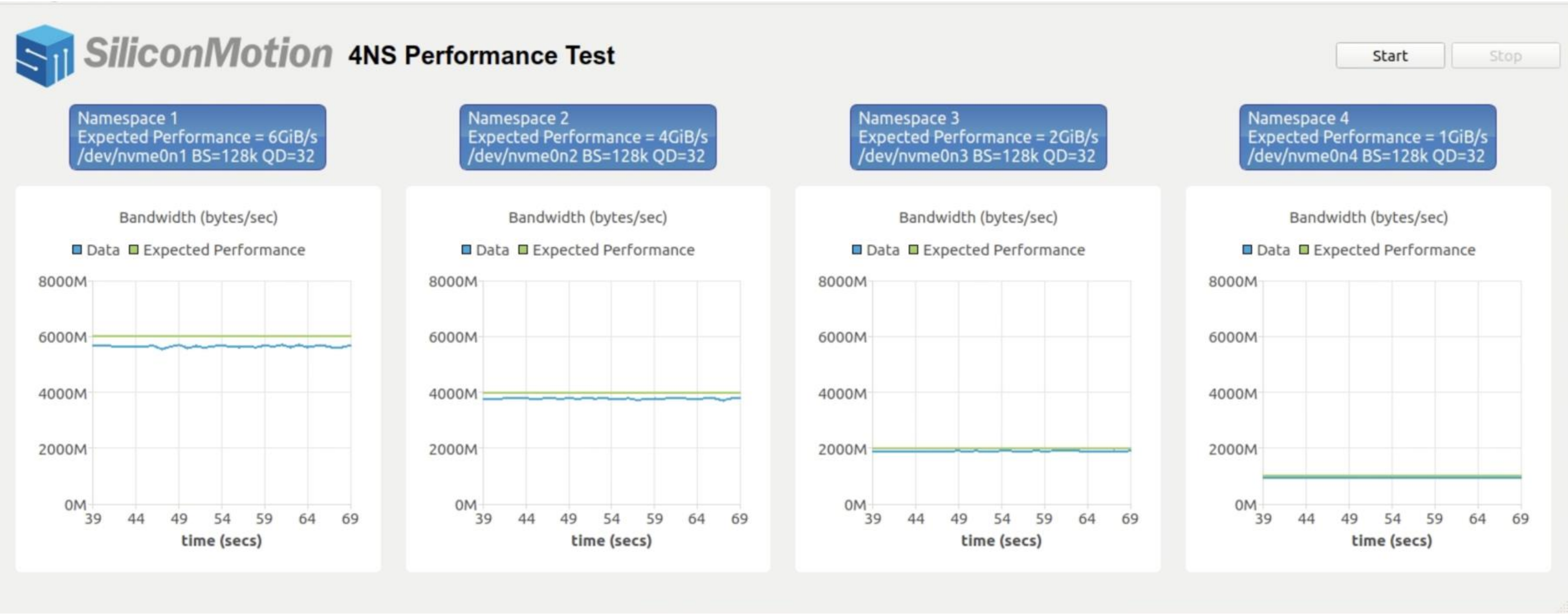
Conclusion PerformaShape™ Modeling

- ✓ Smooth out fluctuations
- ✓ Fully utilize the system bandwidth
- ✓ Isolate noisy neighbors

PerformaShape™ Demonstration

NS	Measurement	Performance Shapping Engine		Host Setting
		SPS Setting	DPS – ID4	
NS0 – ID0	5.97GB	6GB/S (8083)	12.9 - 13GB/s	6GB/S (5723MiB)
NS1 – ID1 – Noisy	3.98GB	4GB/S (12125)		6GB/S (5723MiB)
NS2 – ID2	1.99GB	2GB/S (24250)		2GB/S (1908MiB)
NS3 – ID3 - Noisy	0.96GB	1GB/S (48500)		2GB/S (1908MiB)

- ✓ 16GB/S Read Requests from Host in 13GB/S system
- ✓ Isolates and Guarantees Performance per Tenant
- ✓ Removes Noisy Neighbors



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