FarReach: Write-back Caching in Programmable Switches

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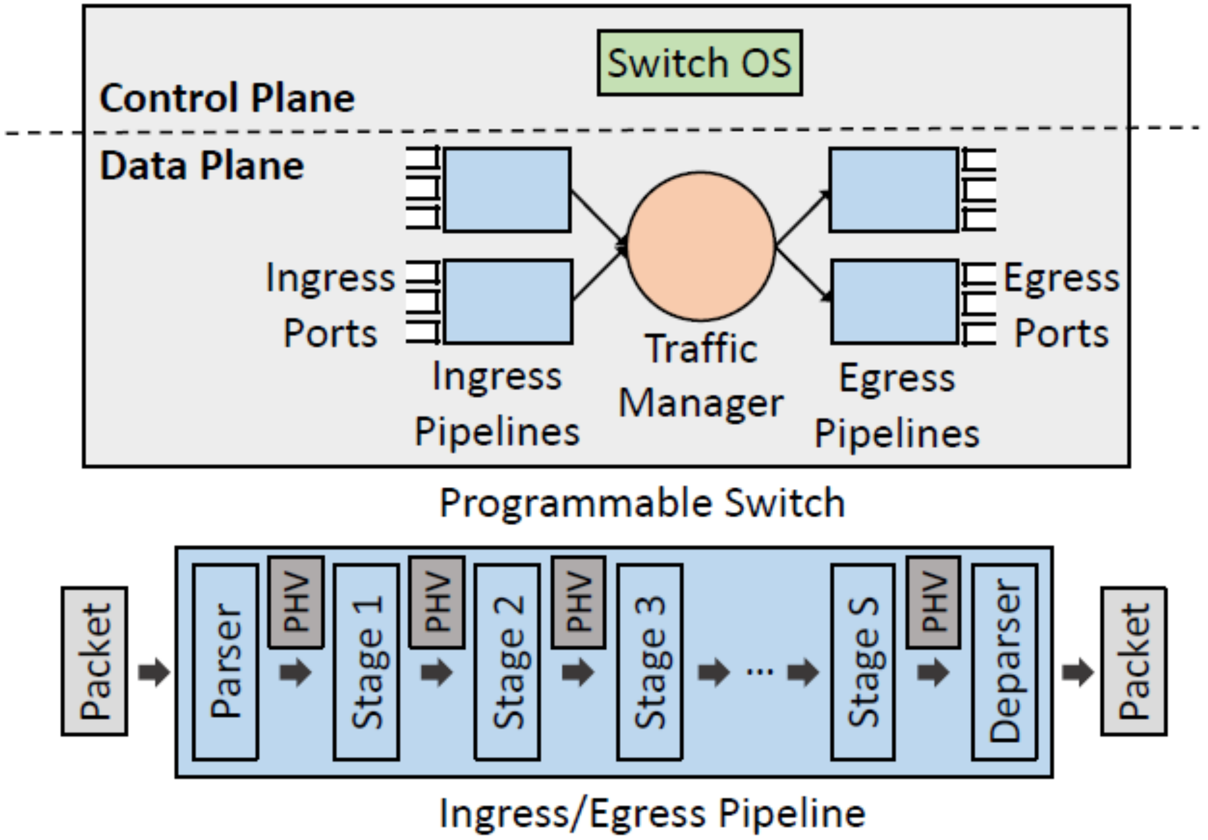
Writes in Key-value Stores

- Writes dominate in production key-value storage workloads
  - 20% of Twitter's Twemcache clusters are write-intensive
  - Facebook's RocksDB for AI services has 92.5% of read-modify-writes
- Challenges for high write performance
  - High round-trip latencies in transmission, queuing, and processing
  - Skewness introduces imbalanced server loads

In-switch Write-back Cache

- **Programmable switches** can help improve write performance
  - Switch OS controls multi-pipeline data plane
  - Each pipeline has multiple stages with stateful memory
- **Write-back policy:** caches popular write records in switch without immediately updating servers



Programmable switch architecture

Challenges

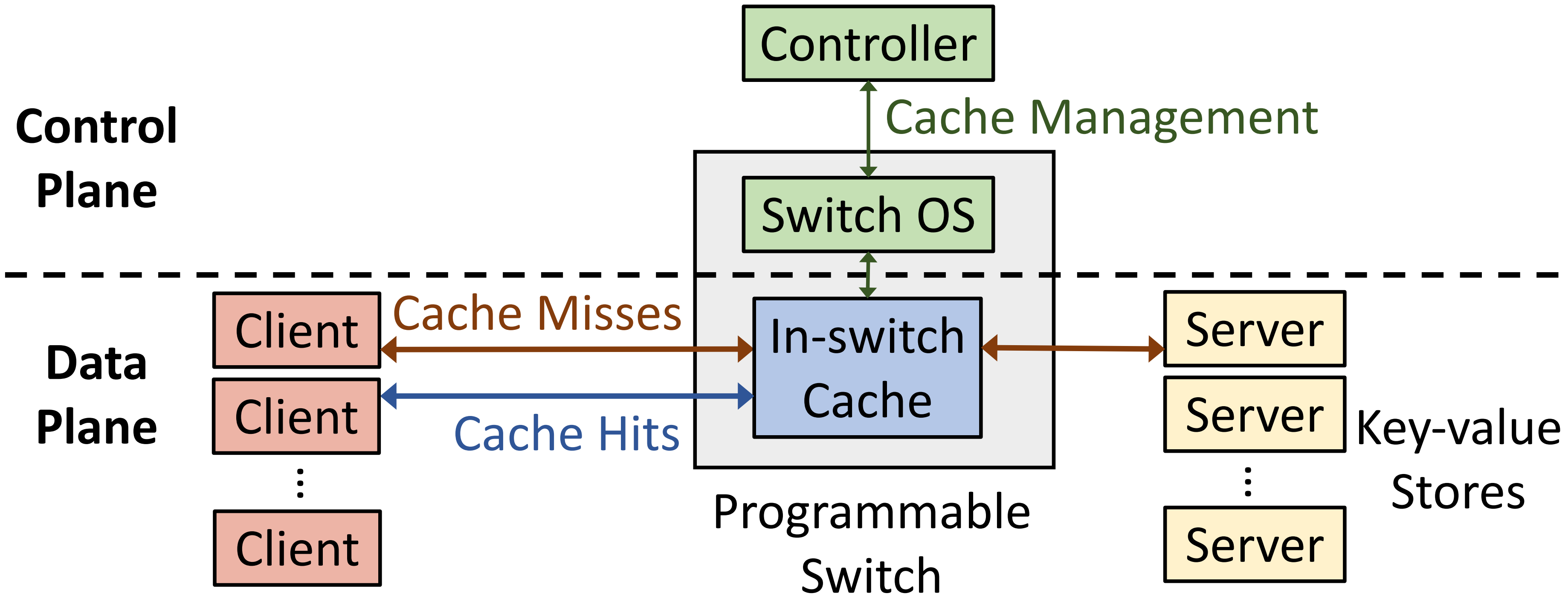
- Performance challenge
  - Scarce switch resources require offloading cache management to controller → high controller-to-switch latency
- Availability challenge
  - Synchronization between switch and servers is required to keep latest records available
- Reliability challenge
  - Latest records may be lost in switch failures under write-back caching

Our Contributions

- **FarReach**, a fast, available, and reliable in-switch write-back cache
  - Non-blocking cache admission for fast access
  - Available cache eviction
  - Crash-consistent snapshot generation and zero-loss recovery
- Prototype implementation
  - P4-based in-switch cache and RocksDB-based servers
- Tofino switch evaluation
  - Up to 6.6× throughput gain under 128 simulated servers
- Open-source FarReach prototype

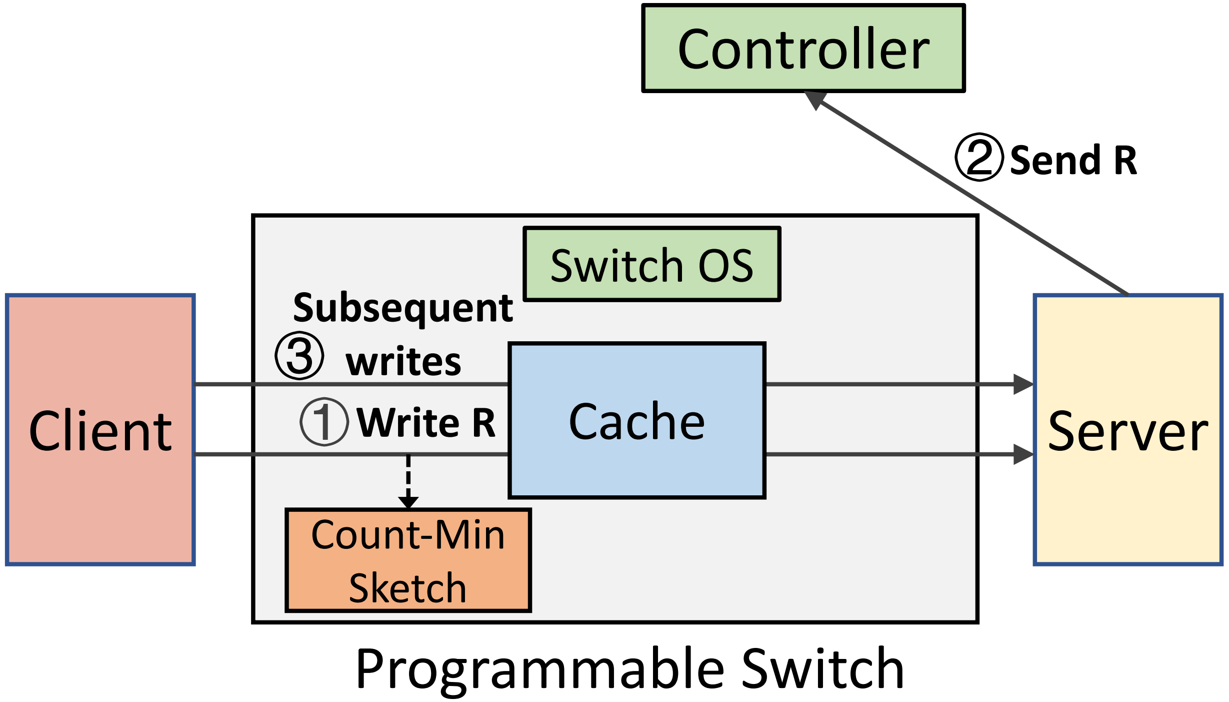
Design overview

- FarReach architecture
  - In-switch cache absorbs writes with cache hits
  - Controller performs cache management through switch OS
  - Carefully co-design control and data planes



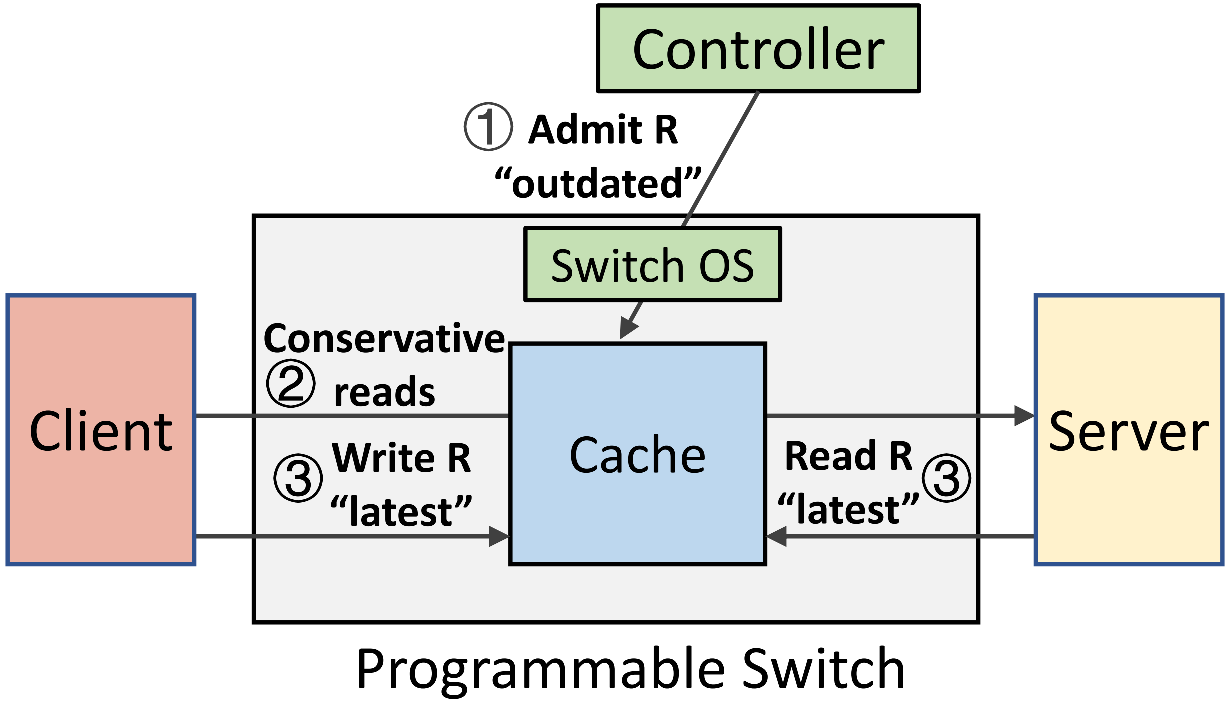
Problem of Cache Admission

- Suppose that a request triggers cache admission
  - Subsequent writes arrive at switch before admission
  - Blocking subsequent writes undermines I/O performance
  - Absorbing subsequent writes in switch undermines availability



Non-blocking Cache Admission

- Process subsequent writes in server without blocking
  - Mark admitted record as "outdated" as server is latest
  - Conservatively forward subsequent reads to server for availability
  - Mark admitted record as "latest" as early as possible



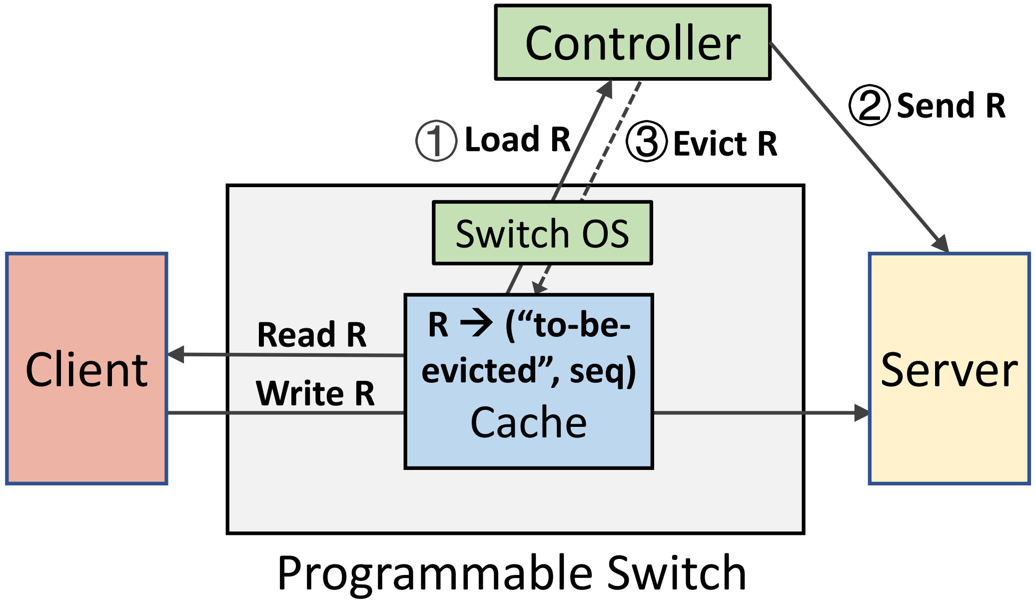
Problem of Cache Eviction

- Under write-back policy
  - Evicted record is latest yet not updated to server
  - Controller loads evicted record to server for persistent storage

- Subsequent writes arrive at switch during cache eviction
  - Processing without synchronization undermines availability
  - Synchronization by controller incurs large overhead

Available Cache Eviction

- ➢ Associate additional in-switch metadata to evicted record
  - Mark evicted record as “to-be-evicted”
  - Load evicted record to server before removing it from switch
  - Mark “to-be-evicted” record as “outdated” and forward writes to server
  - Process reads by switch if “latest” or server if “outdated”



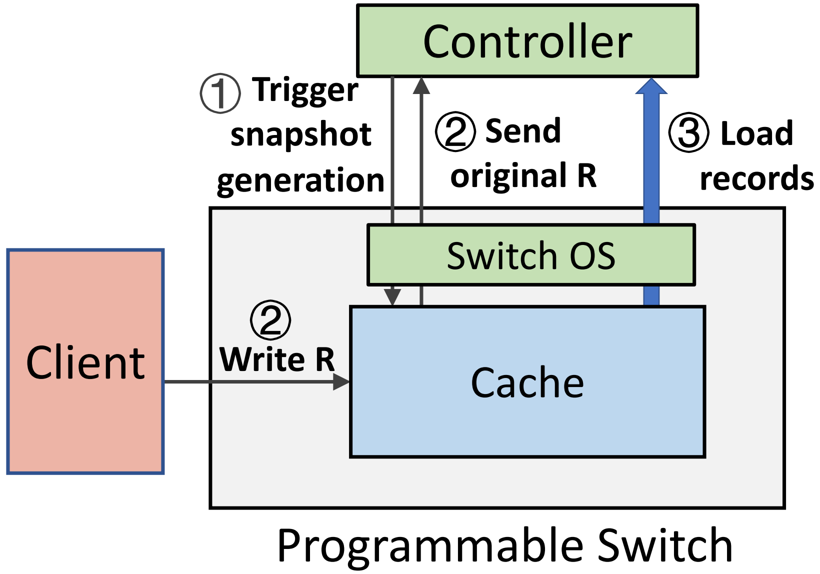
Problem of Reliability

- Under write-back policy
  - Cached records are latest yet not updated to servers
  - Latest in-switch records are lost after switch failures

- Controller loads cached records for snapshots
  - Subsequent writes arrive at switch during snapshot generation
  - Updating cache records incurs inconsistent snapshots

Crash-consistent Snapshot Generation

- Send original cached record for each first write
  - Controller replaces overwritten records for consistency
- Two-phase algorithm
  - Controller triggers snapshot generation
  - Controller loads cached records and switch sends original ones



Zero-loss Recovery

- Limitation of snapshot generation
  - Snapshot generation avoids data loss before the latest snapshot
  - Cached records after the latest snapshot are not protected
- Client-side record preservation
  - Clients preserve copies of cached records after the latest snapshot
  - Controller notifies clients to release the snapshotted records
- Replay-based recovery
  - Replay writes of the latest records to update servers
  - Replay admission decisions to recover in-switch cache

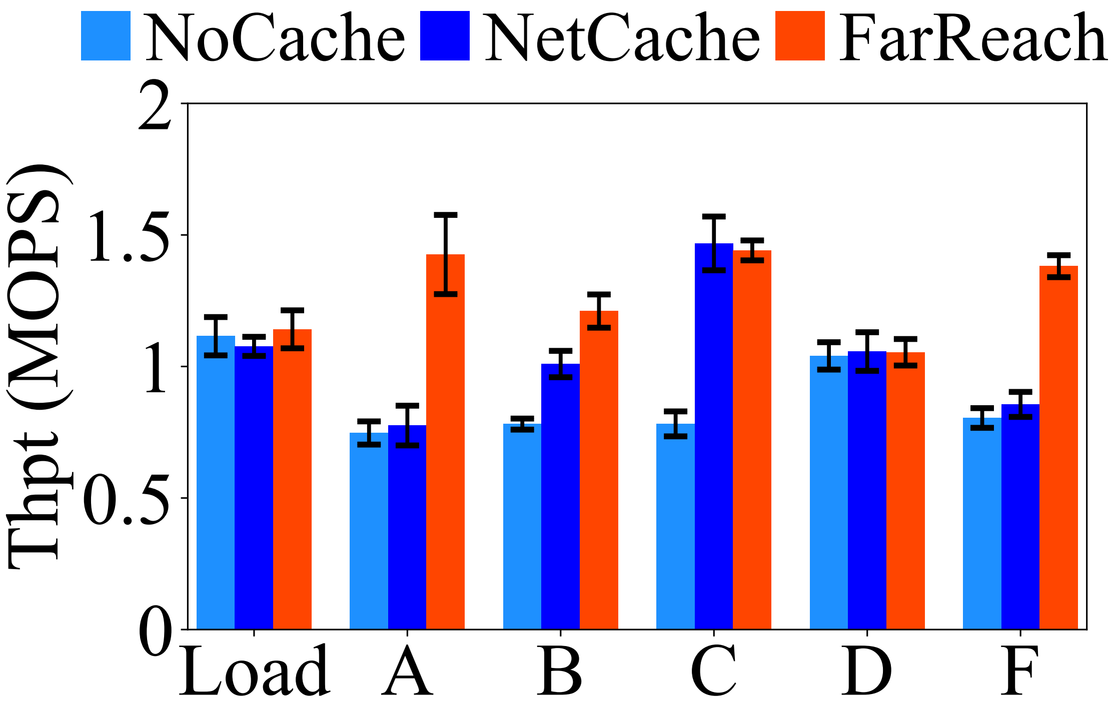
Evaluation

- Methodology
  - Simulate tens of servers by server rotation for server-side storage
  - Compile P4 in a Tofino switch for in-switch cache
  - Baselines: NoCache and NetCache [Jin et al., SOSP'17]

- Experiments
  - YCSB core workloads to evaluate throughput, latency, and scalability
  - Synthetic workloads to evaluate impact of different parameters
  - Performance of snapshot generation and crash recovery time
  - Hardware resource usage

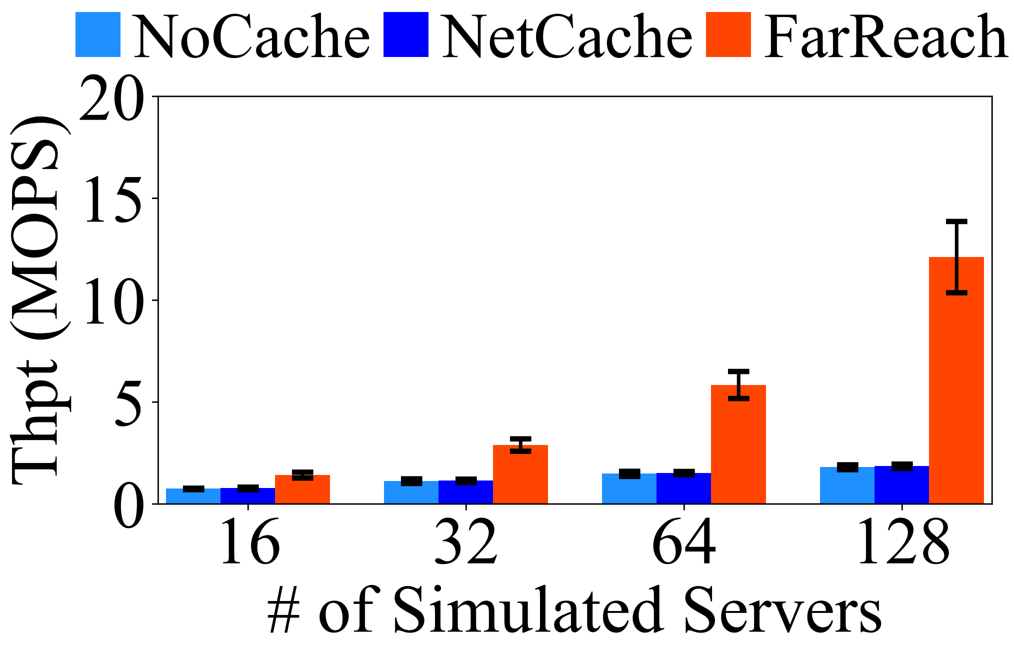
Throughput Analysis

- Simulate 16 servers by server rotation
- Larger throughput especially for workload A
  - In-switch write-back cache reduces server-side load



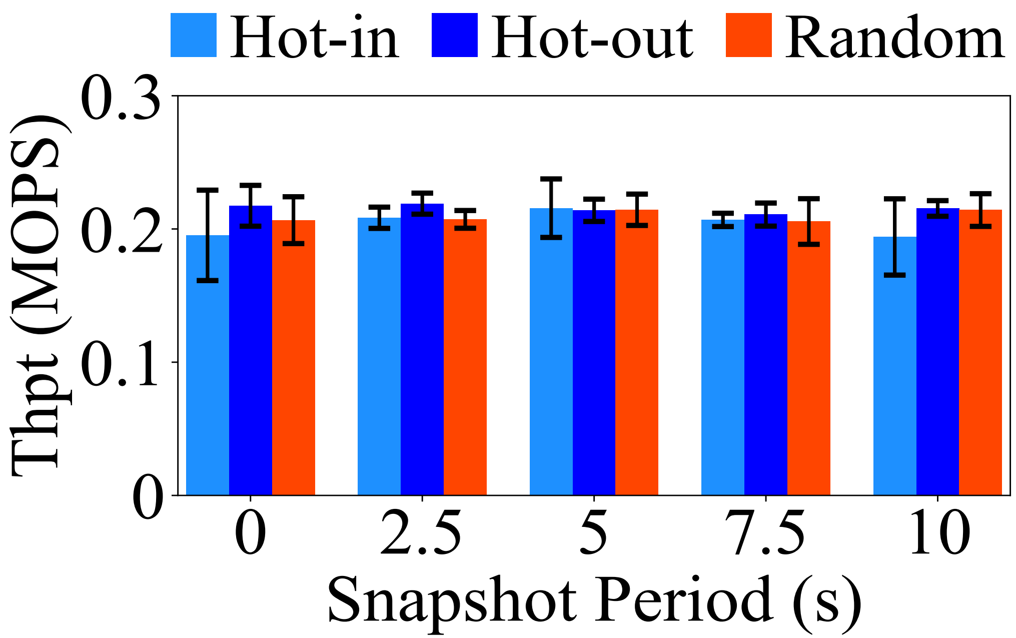
Scalability

- Use workload A (skewed and write-intensive)
  - Simulate 16 to 128 servers by server rotation
- Throughput gain is up to 6.6× under 128 simulated servers
  - In-switch write-back cache balances server-side load

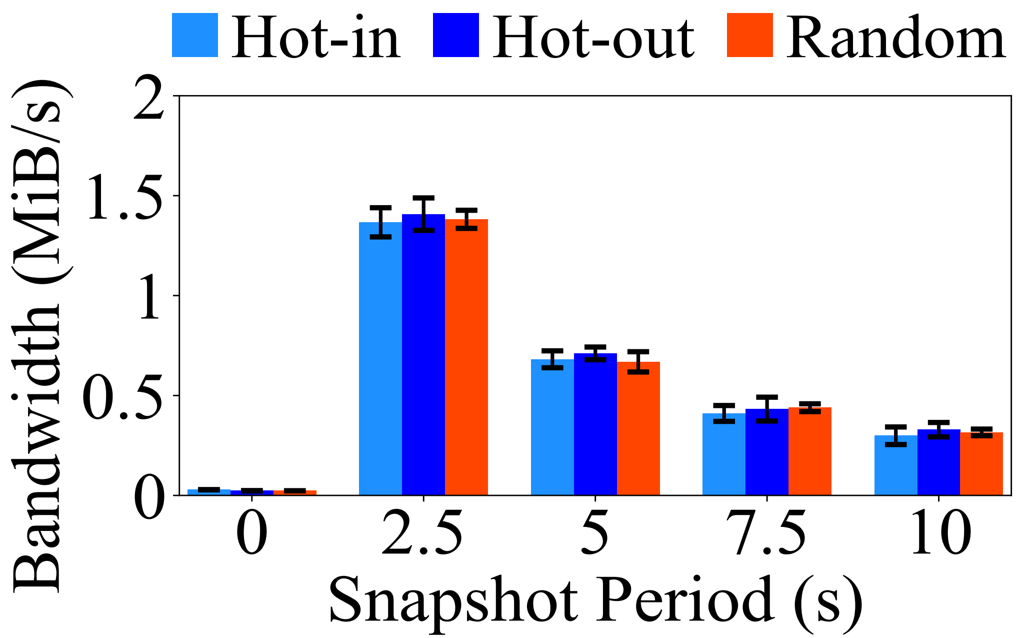


Performance of Snapshot Generation

- Dynamic workload patterns
  - Bandwidth includes snapshot generation and cache management
- Similar throughput and limited control-plane bandwidth



Throughput



Control-plane Bandwidth

Conclusion

- FarReach, a fast, available, and reliable in-switch write-back cache
  - Non-blocking cache admission
  - Available cache eviction
  - Crash-consistent snapshot generation with zero-loss recovery
- Tofino switch evaluation on YCSB and synthetic workloads
- Source code:
  - **http://adslab.cse.cuhk.edu.hk/software/farreach**

Thank You!
Q & A