Remus: High Availability via Asynchronous Virtual Machine Replication

Brendan Cully, Geoffrey Lefebvre, Dutch Meyer, Mike Feeley, Norm Hutchinson, and Andrew Warfield

Department of Computer Science,

The University of British Columbia

Presenter: Lei Xia

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Outline

- Motivation
- Approach
- Design and Implementation
- Evaluation
- Conclusion and Future work

Motivation

- It's hard and expensive to design highly available system to survive hardware failure
  - Using redundant component, special-purpose hardware.
  - Reengineering software to include complicated recovery logic.

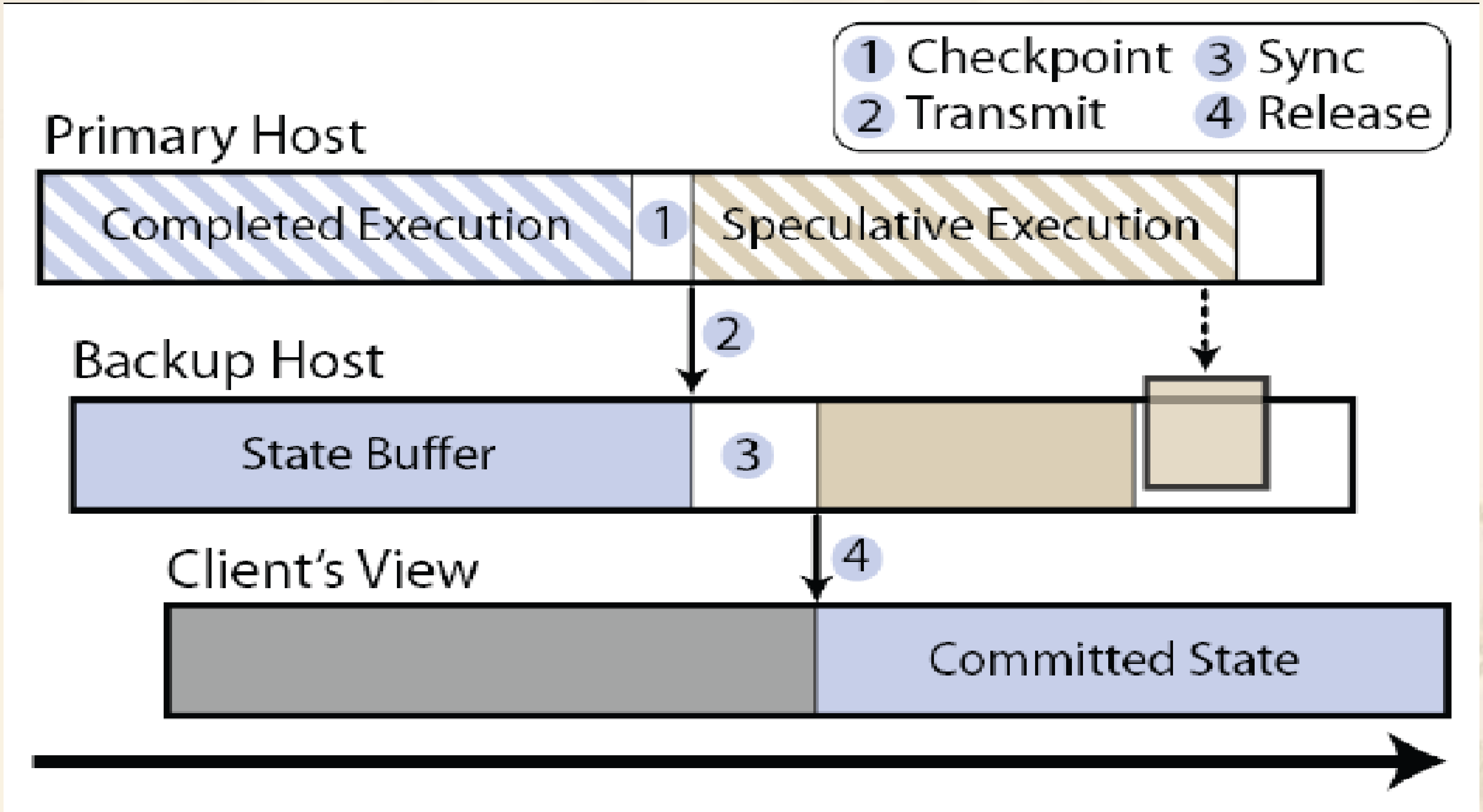
Motivation

- The goal is to provide high availability system, and it’s:
  - Generality
    - Regardless of applications and hardware
  - transparency
    - Without modification of OS and App.
  - Seamless hardware failure recovery
    - No externally visible state lost in case of single-host failure
    - Failure recovery should be fast

Approach

- VM-based whole system replication
  - Frequently checkpoint whole Virtual Machine state.
  - Protected VM and Backup VM is located in different Physical host.
- Speculative execution
  - We buffer state to *synchronous* backup later, and continue execution ahead of *synchronous* point.
- Asynchronous replication
  - Buffering output at the primary server allows replication to be preformed *asynchronously*
  - Primary VM execution is overlap state transmission

Speculative execution and replication in Remus



Design and Implementation

- Failure Model
  - The fail-stop failure of any single host is tolerable.
  - If both host fail, protected system's data will be left in a crash-consistent state.
  - No output will be made externally visible until the associated system state has been committed.

Design and Implementation

- Remus implementation is based on:
  - Xen's support for live migration to provide fine-grained checkpoints.
  - Two host machines is connected over redundant gigabit Ethernet connections.
- The virtual machine does not actually execute on the backup host until a failure occurs.

Remus: Architecture

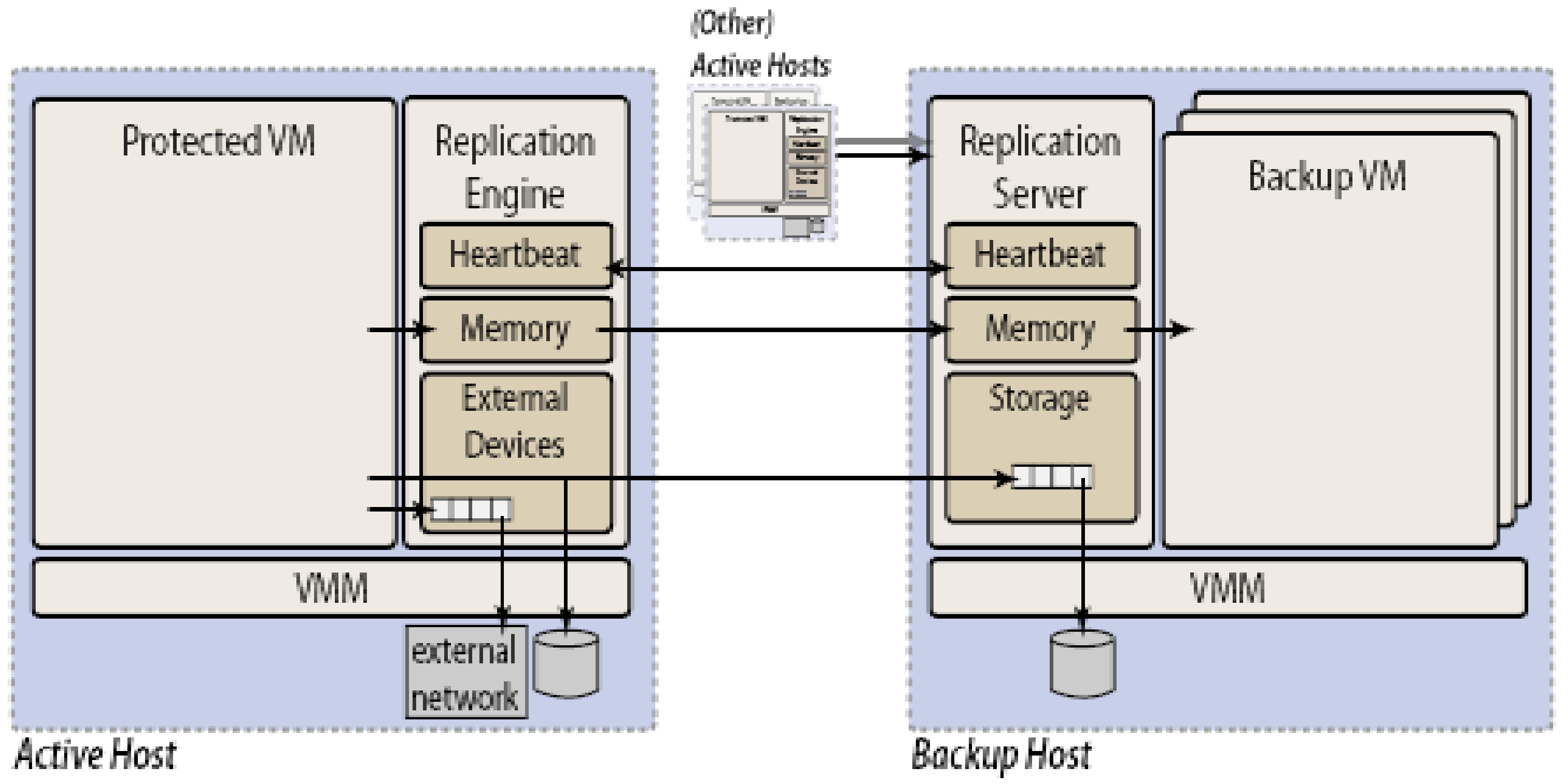


Figure 2: Remus: High-Level Architecture

Pipelined checkpoint

- Checkingpointing runs in high frequency.
  - Step 1: Pause the running VM and copy any changed state into a buffer.
  - Step 2: With state changes preserved in a buffer, VM is unpaused and speculative execution resumes.
  - Step 3: Buffered state is transmitted to the backup host.
  - Step 4: When complete state has been received, acknowledge to the primary.
  - Step 5: Finally, buffered network output is released.

Checkpoint Machine State

- CPU & memory state
  - Checkpointing is implemented above Xen's existing code for performing **live migration**.
- live migration
  - Technique by which a VM is relocated to another physical host with slight interruption.

Xen's live migration

- Stage 1. Memory is copied to the new location **while** the VM continues to run at the old location.
- Stage 2. During migration, writes to memory are intercepted, and dirty pages are copied to the new location in rounds.
- Stage 3. After a specified number of intervals, the guest is suspended and the remaining dirty page and CPU state is copied out. (final round, stop-and-copy)

- By hardware MMU, page protection is used to trap dirty page.
- Actually, Remus implements checkpointing as repeated executions of the final round of live migration.

Modification to Xen Live Migration

- Goal: 1) performance; 2) ensure a consistent image is always available at the remote location.
- Migration Enhancements
- Checkpoints support
- Asynchronous transmission
- Guest modification

Network buffering

- Most networks can not provide reliable data delivery.
  - Therefore, network applications use reliable protocols to deal with packet loss or duplication.
- This simplifies the network buffering problem: transmitted packets do not require replication.

Network buffering (cont'd)

- To ensure packet transition atomic and checkpoint consistency:
  - Outbound packets generated since the previous checkpoint are queued. And
  - Released until that checkpoint has been acknowledged by the backup site.
  - Inbound packets are delivered to host directly

Disk Buffering

- Requirements
  - All writes to disk in VM is configured to write though.
  - Recovery from single host failure
  - Preserve crash-consistent when both hosts fail.
- On-disk state don't change until the entire checkpoint has been received

Disk Buffering

- Maintaining complete mirror of active VM's disk on the backup host
  - Writes to storage are tracked and checkpointed
- All writes to active VM's disk are write through
  - Immediately applied to primary disk
  - Asynchronously mirrored to backup's memory buffer
  - No on-disk state changed until the entire checkpoint has been received

Disk Buffering

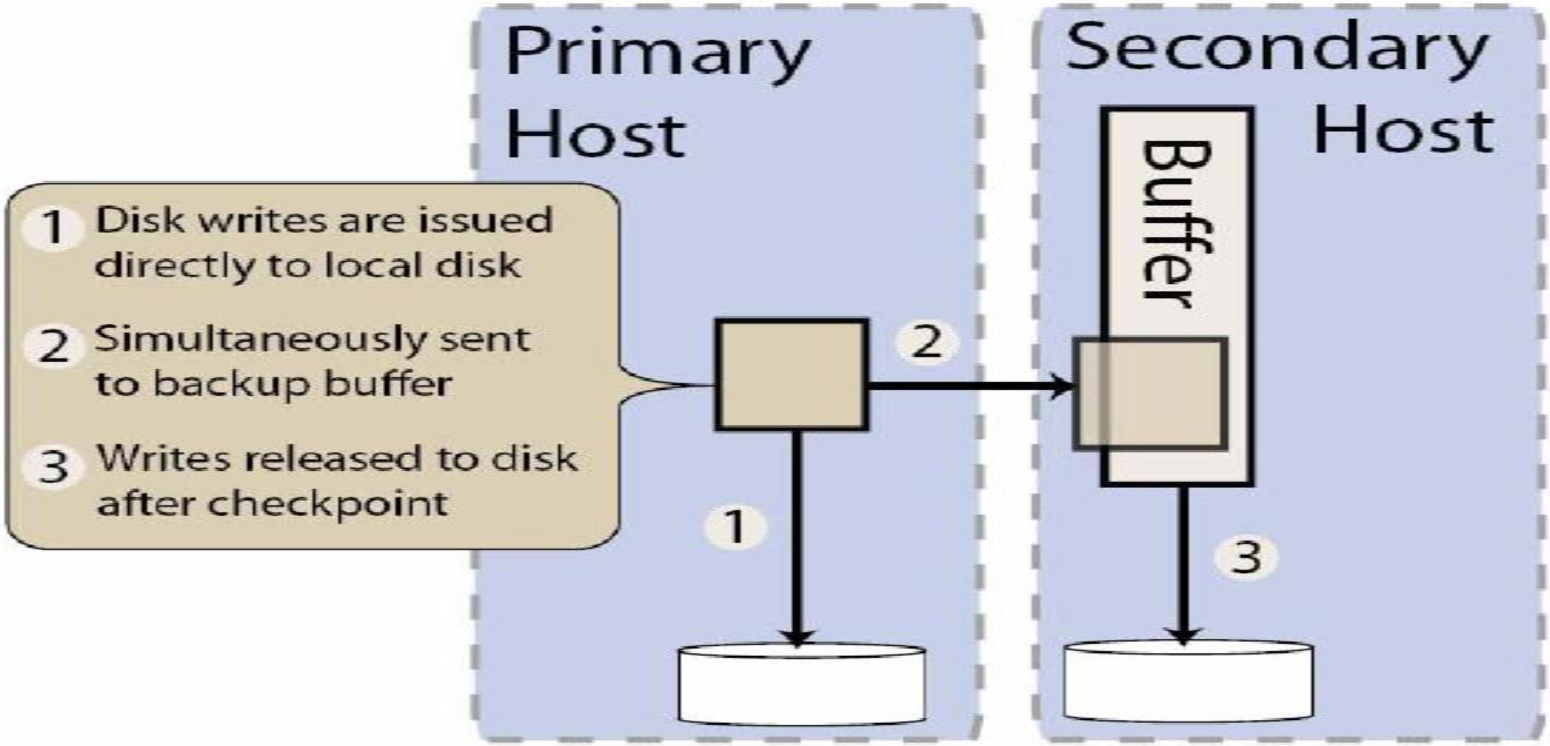


Figure 4: Disk write buffering in Remus.

Detecting Failure

- Use a simple failure detector directly integrated in the checkpointing stream
- Timeout event represent the host's failure.
  - a timeout of the backup responding to commit requests.
  - a timeout of new checkpoints being transmitted from the primary.

Evaluation

- Correctness
  - Kernel compiling with X11 client
  - 25 ms checkpoint
  - Every failure point, 1s delay on network, no inconsistency in backup disk image

Evaluation

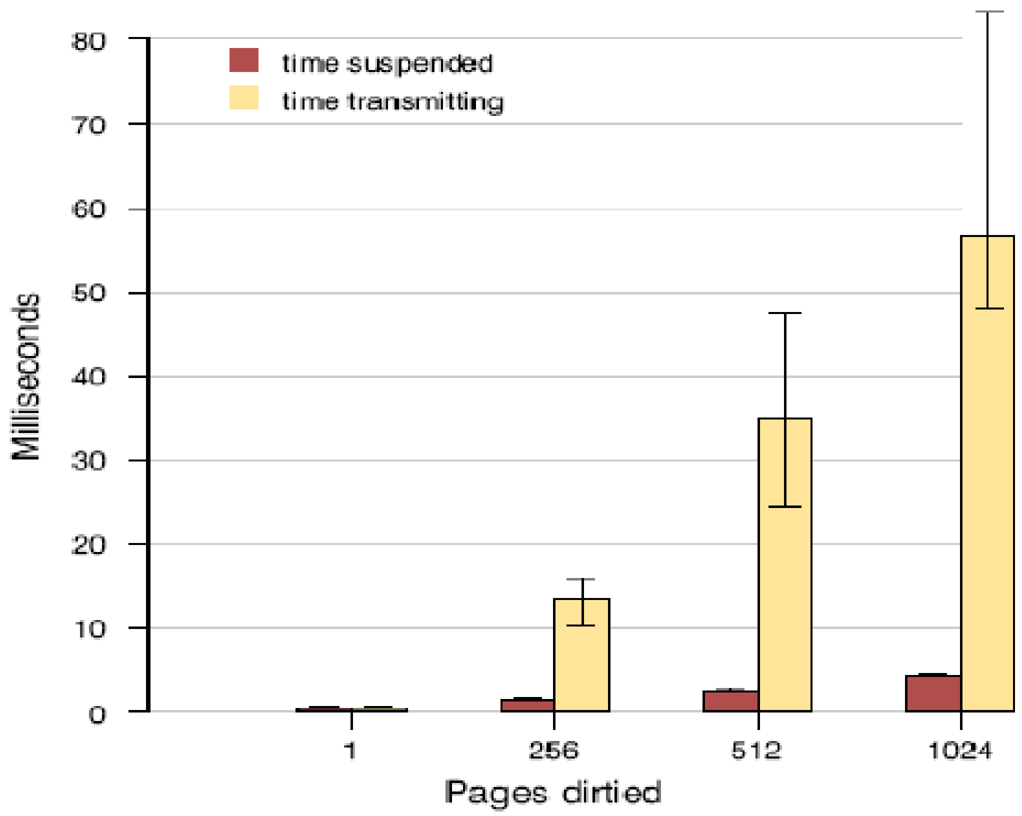


Figure 5: Checkpoint time relative to pages dirtied.

Evaluation (cont'd)

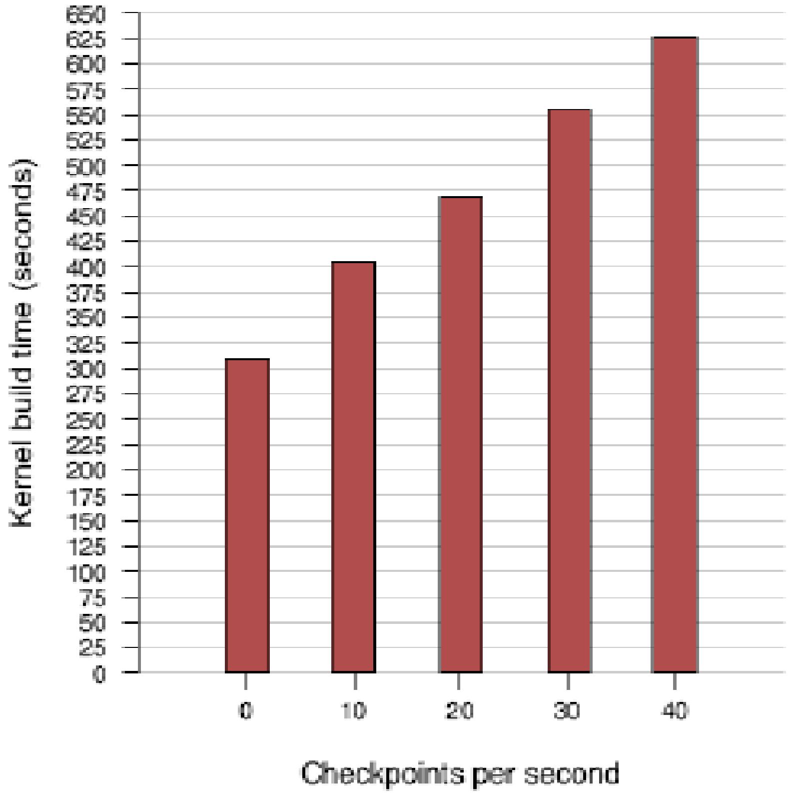


Figure 6: Kernel build time by checkpoint frequency.

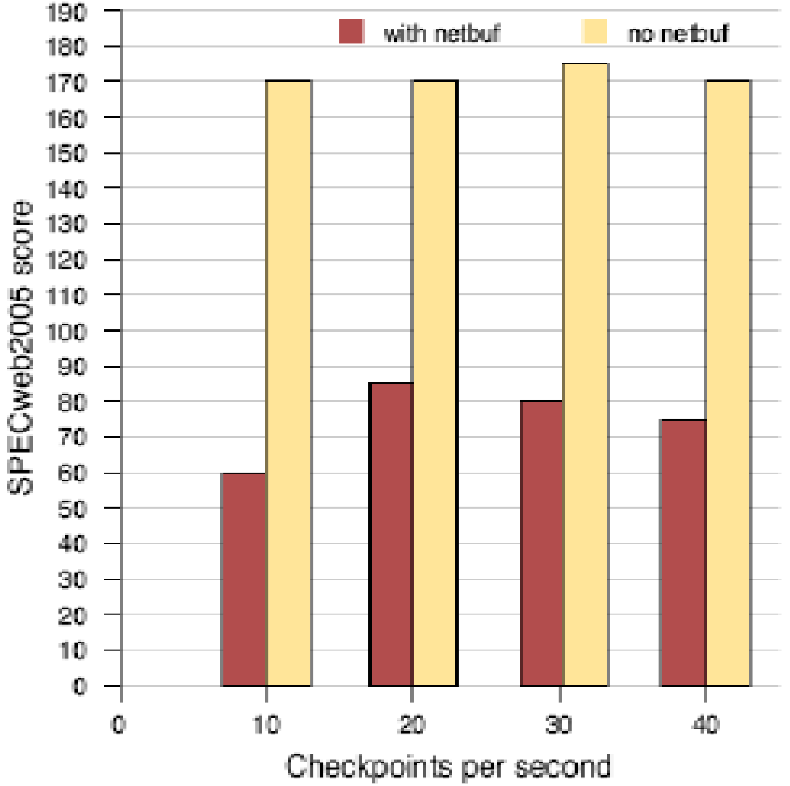


Figure 7: SPECweb scores by checkpoint frequency (native score: 305)

Evaluation (cont'd)

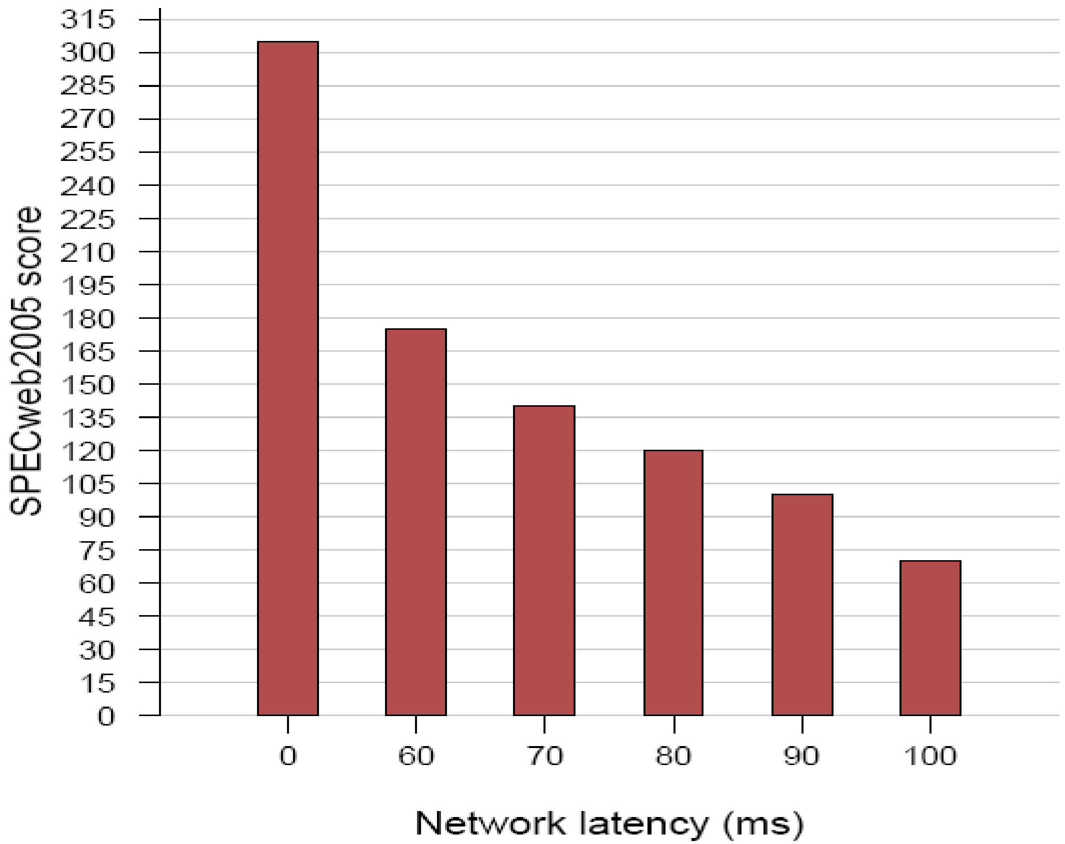


Figure 8: The effect of network delay on SPECweb performance.

Evaluation (cont'd)

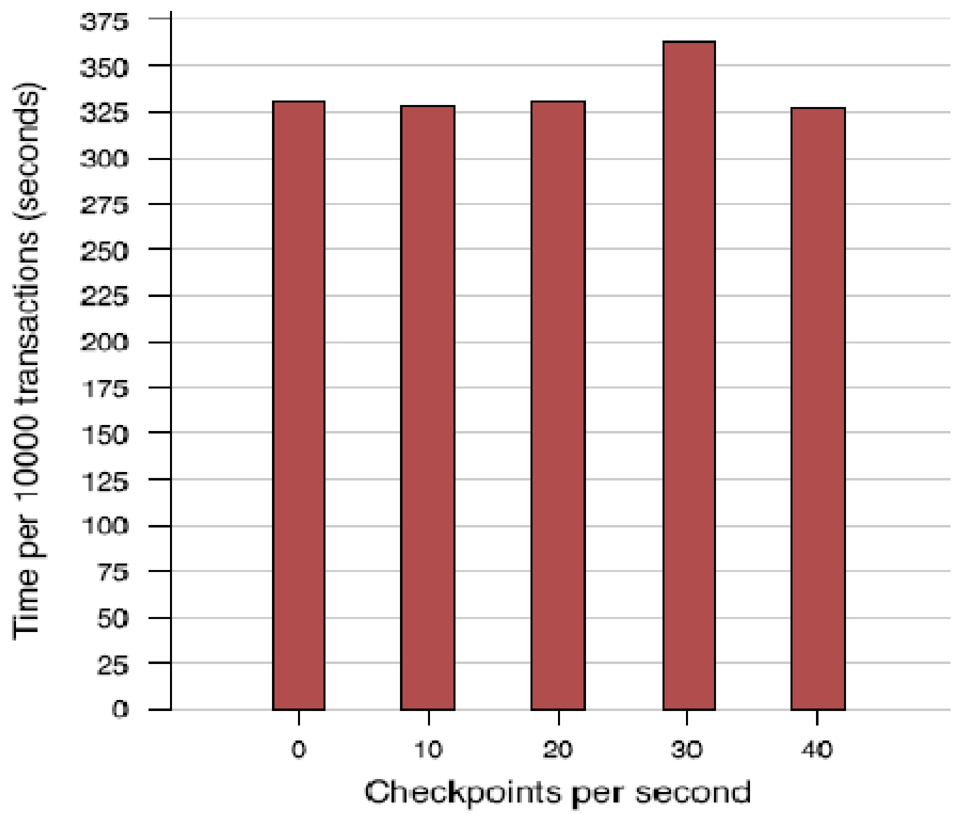


Figure 9: The effect of disk replication of Postmark performance.

Conclusion

- A VM-based software method to provide high availability to survive hardware failure, with low cost and transparency.

Limitations

- Outbound packet latency, lower network throughput
- Performance