Hypervisor-Based Fault-Tolerance

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Outline

- Introduction
- Replica Coordination Protocol
- Performance
- Conclusion and future work

Introduction

- We propose a software layer between the hardware and the operating system - **Hypervisor**.

- Our fault-tolerant computing system does not require modifications of hardware, operating system, or any application software.

Introduction

- What is Hypervisor?
  - *Virtual machines which* having the same instruction-set architecture as the hardware on which the hypervisor executes.
- We run protected VM in primary physical host and backup VM in backup physical host.
  - We keep these VMs sync in order for app (run in VM) to survive processor failure.

Introduction

- When primary hardware fails, the VM in backup harware will take over as soon as possible.

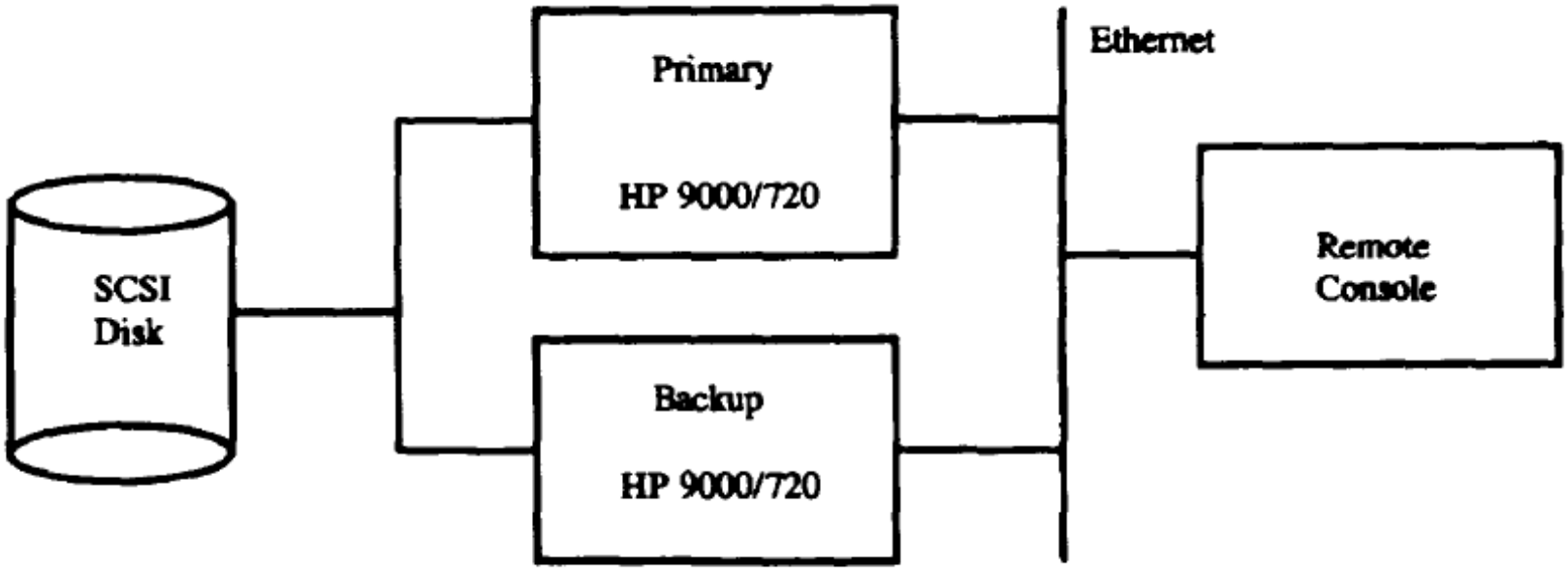


Fig. 1. The prototype.

Replica Coordination Protocol

- Idealistically, we hope primary VM is state machine, and every instruction is deterministic.
- Since we could make backup VM read the same sequence of instructions, in order to make backup VM reach the same state.
- But there is still some non-deterministic instruction to be made by VM.
  - See next slide.

Replica Coordination Protocol

- Deterministic instruction :
  - E.g. ADD, DIV.
  - As the same argument is given, the same result is produced.
- There is still some non-deterministic choice to make.
  - E.g. reading the time-of-day clock.
  - E.g. VM's interrupt.

Replica Coordination Protocol

- Our generalized assumption 1 :
  - Environment Instruction Assumption : VM is invoked to simulate when E.I is going to be execute.
  - What is Environment Instruction ?
    - E.g. reading time-of-day clock, reading disk block.
  - Actually E.I is only executed in primary, then result is transferred to backup.

Replica Coordination Protocol

- Our generalized assumption 2 :
  - Instruction Stream Interrupt Assumption :
    - A mechanism is available to invoke the VM when a specified point in the instruction stream is reached.
  - We could support this assumption by recovery register (HP's PA-RISC) which decrement each time an instruction done, and cause interrupt as content is zero.

Replica Coordination Protocol

- Our generalized assumption 2 :
  - Recovery register is to separate instruction stream into epochs.
  - In every epoch, primary VM buffer interrupts, and forward these to backup VM in the epoch's end.
  - Interrupts at backup VM are ignored.

Replica Coordination Protocol

- Scenario (primary) :
  - P0 : if primary VM execute Env. Instruction at pc
    - Send [E(p) , pc , Val] to backup and wait for ack.
  - P1 : if primary VM receives a interrupt
    - Buffer INT for delivery later.
  - P2 : if primary's epoch ends
    - Primary send to backup all buffered INT during E(p) and wait for ack.
    - Primary delivers all INT.
    - E(p) = E(p) +1 , and primary start epoch E(p) .

Replica Coordination Protocol

- Scenario (backup) :
  - P3 : if backup VM execute Env. Instruction at pc
    - Wait receipt of [E(b) , pc , Val] from primary.
    - If [E(b) , pc , Val] is received, then ack primary.
  - P4 : if backup VM receives a interrupt
    - It's ignored.
  - P5 : if epoch ends
    - Wait for all buffered INT from primary, if received, then ack primary.
    - Backup VM delivers all INT.
    - E(b) = E(b) +1 , and backup start epoch E(b) .

Replica Coordination Protocol

- If failure is detected (message timeout), backup VM execute Env. Instruction as if it's primary.
  - In next epoch, backup is promoted to primary.
- Unavoidably, INT might be lost when primary fails transfering INT to backup. (discussed later)

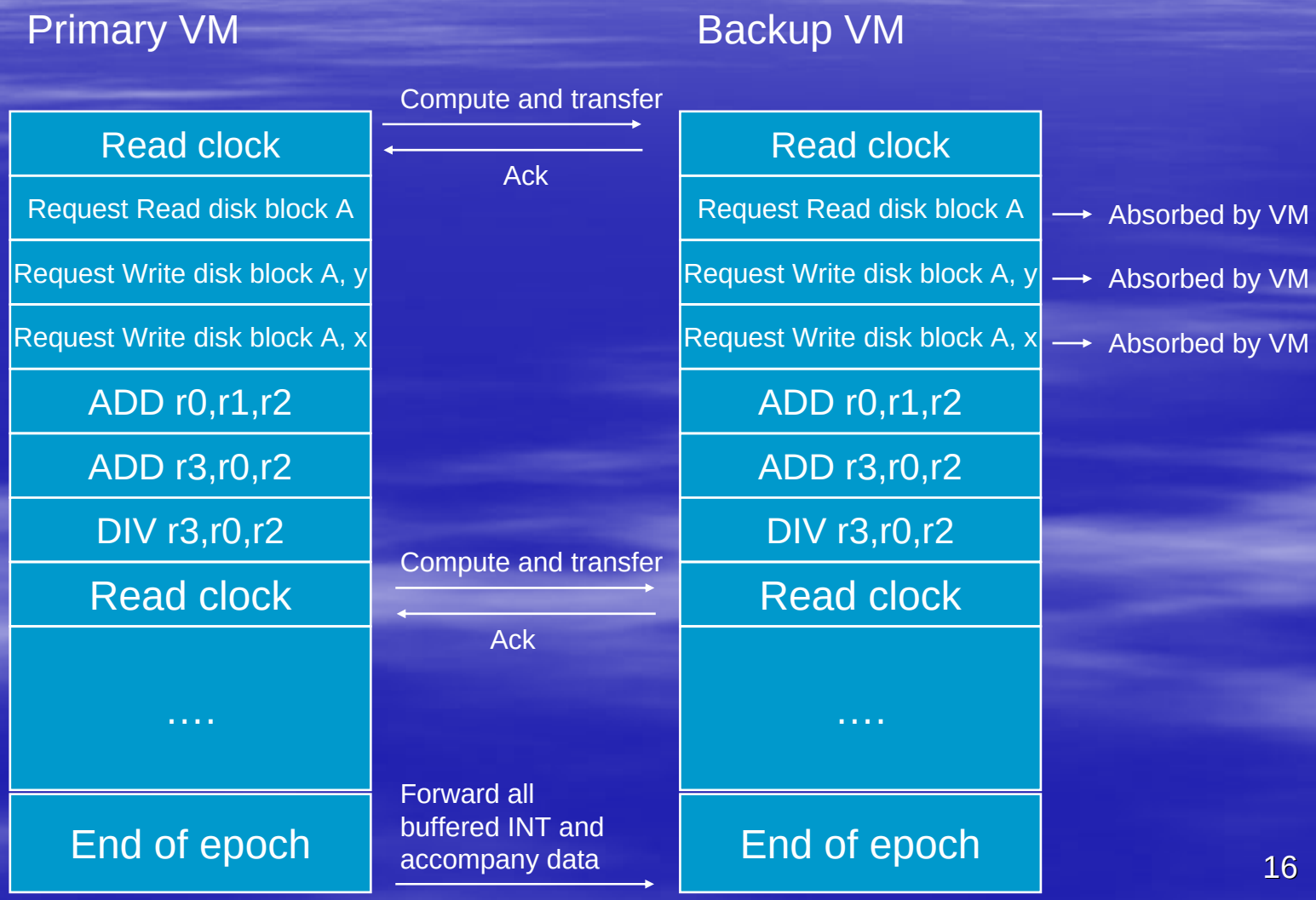
Replica Coordination Protocol

- Interaction with the environment
  - I/O instructions executed by a backup are absorbed by backup's VM.
  - Clock syn : at the end of epoch.
    - Make newly promoted primary are consistent with the failed primary.

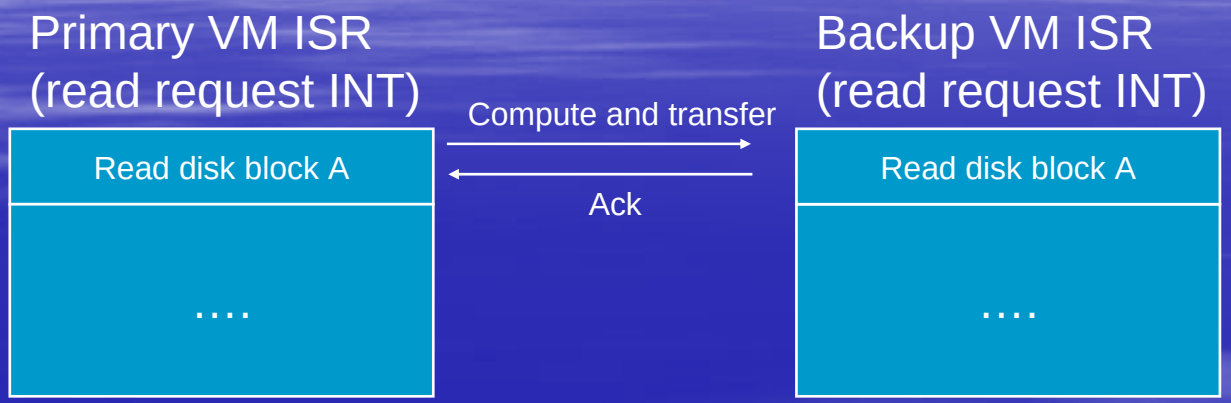
Replica Coordination Protocol

- Interaction with the environment (const.)
  - backup VM can tolerate not receiving interrupts buffered by the primary VM.
    - This newly promoted primary simply delivers “uncertain interrupts” for outstanding I/O operations.
  - For disks and networks, driver will reissue its last I/O instruction upon receiving an uncertain interrupt.
    - the state of a disk is insensitive to repetitions of I/O operation.
    - network protocols themselves send and ignore duplicate messages.

Protocol Example



Protocol Example, Const



Performance

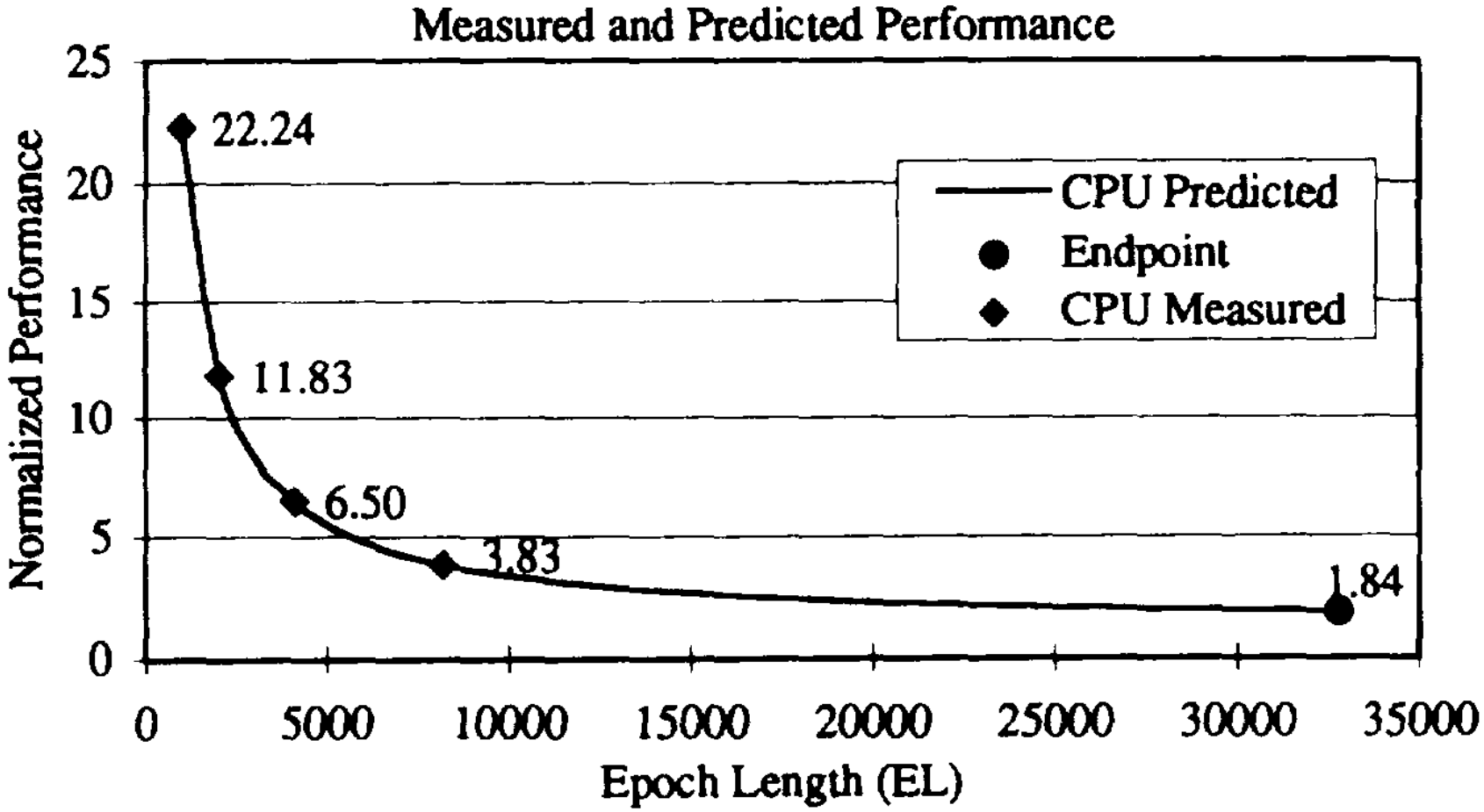


Fig. 2. CPU-intensive workload.

Performance

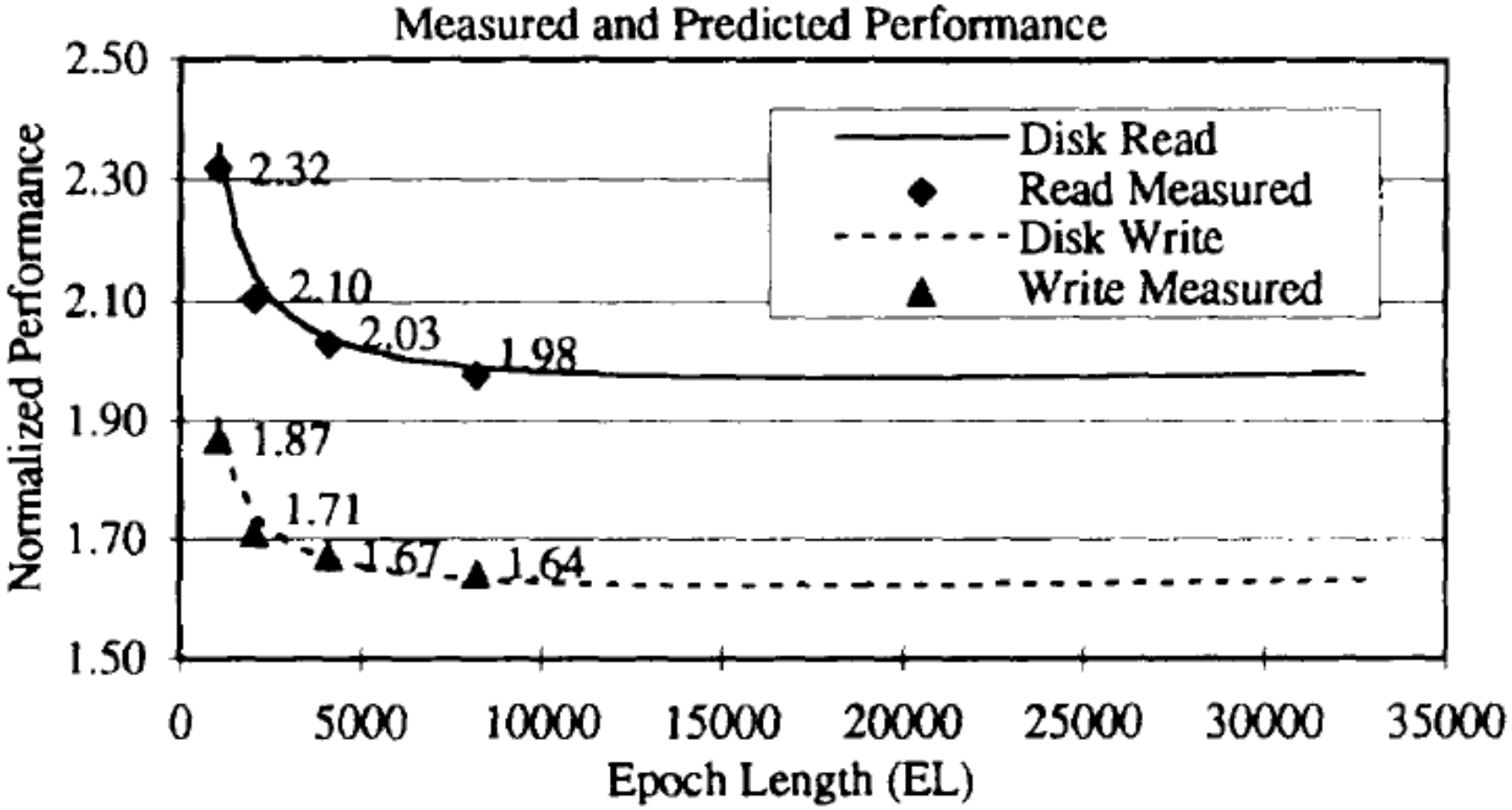


Fig. 3. Input/output options.

Performance

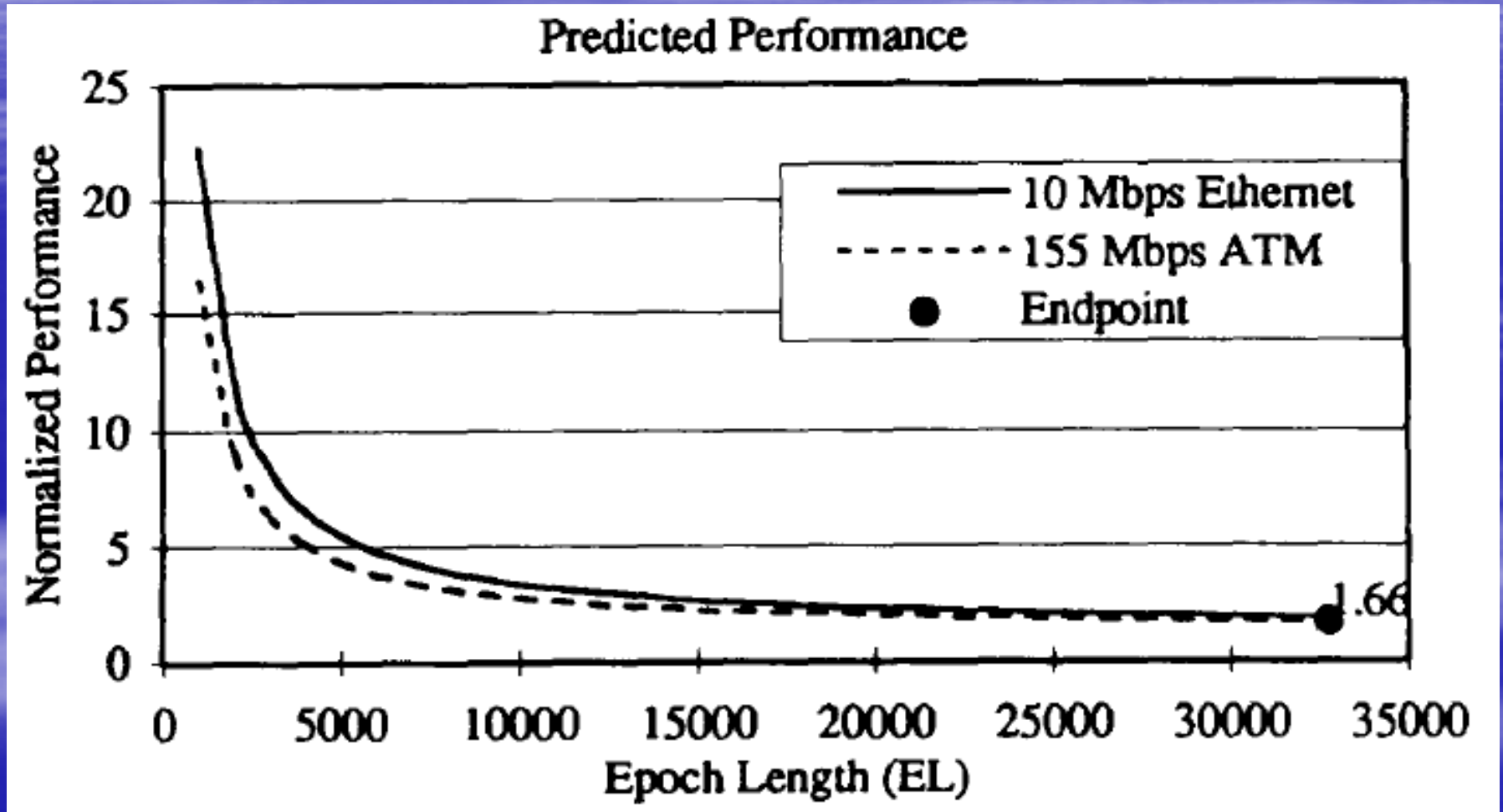


Fig. 4. Faster communication.

Conclusion and future work

- VM is not the only way to use our approach, for ex, one might modify microkernel.
- When time-to-market and cost is sensitive, our design is easier than the hardware-design (e.g.HP’s NonStop).