Virtualize Everything but Time

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Introduction

- **Clock synchronization, who cares?**
  - Network monitoring / Traffic analysis
  - Telecommunications Industry; Finance; Gaming, ...
  - Distributed `scheduling': timestamps instead of message passing
- **Status quo under Xen**
  - Based on *ntpd*, amplifies its flaws
  - Fails under live VM migration
- **We propose a new architecture**
  - Based on RADclock client synchronization solution
  - Robust, accurate, scalable
  - Enables *dependent clock* paradigm
  - Seamless migration

Key Idea

- **Each physical host has a single clock which never migrates**
- **Only a (stateless) clock read function migrates**

Para-Virtualization and Xen

- **Hypervisor**
  - minimal kernel managing physical resources
- **Para-virtualization**
  - Guest OS's have access to hypervisor via hypercalls
  - Fully-virtualized more complex, not addressed here
- **Focus on Xen**
  - But approach has general applicability !
  - Focus on Linux OS's (2.6.31.13 Xen pvops branch)
  - Guest OS's:
    - Dom0: privileged access to hardware devices
    - DomU: access managed by Dom0
  - Use Hypervisor 4.0 mainly

Hardware Counters

- **Clocks built on local hardware (oscillators → counters)**
  - HPET, ACPI, TSC
  - Counters imperfect, they drift (temperature driven)
  - Affected by OS
    - ticking rate
    - access latency
- **TSC (counts CPU cycles)**
  - Highest resolution and lowest latency - preferred! but..
  - May be unreliable
    - multi-core → multiple unsynchronised TSCs
    - power management → variable rate, including stopping !
- **HPET**
  - Reliable, but
  - Lower resolution, higher latency

Xen Clocksource

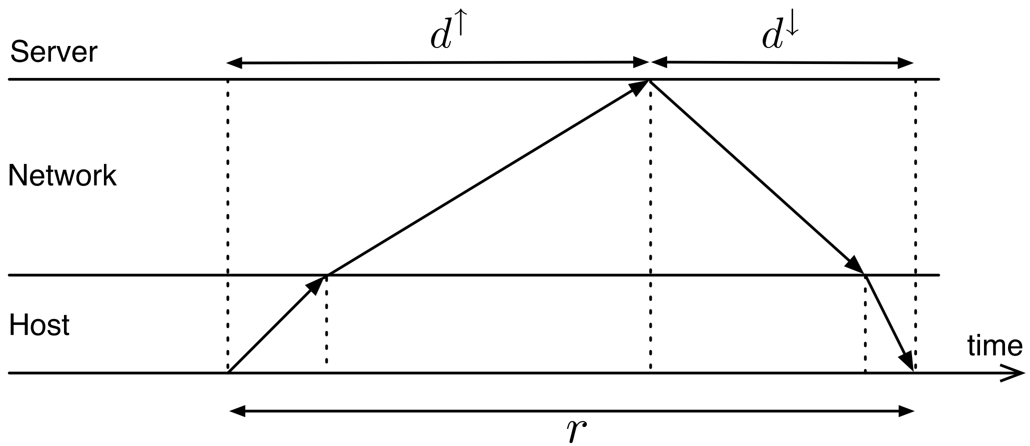
A hardware/software hybrid timer provided by the hypervisor

- **Purpose**
  - Combine reliability of HPET with low latency of TSC
  - Compensate for TSC unreliability
  - Provides 1GHz 64-bit counter

- **Performance of XCS versus HPET**
  - XCS performs well: low latency and high stability
  - HPET not that far behind, and a lot simpler

Clock Fundamentals

- Timekeeping and timestamping are distinct
- Raw timestamps and clock timestamps are distinct
- A scaled counter is not a good clock: drift !
- Purpose of clock sync algo is to correct for drift
- Network based sync is convenient, exchange timing packets:

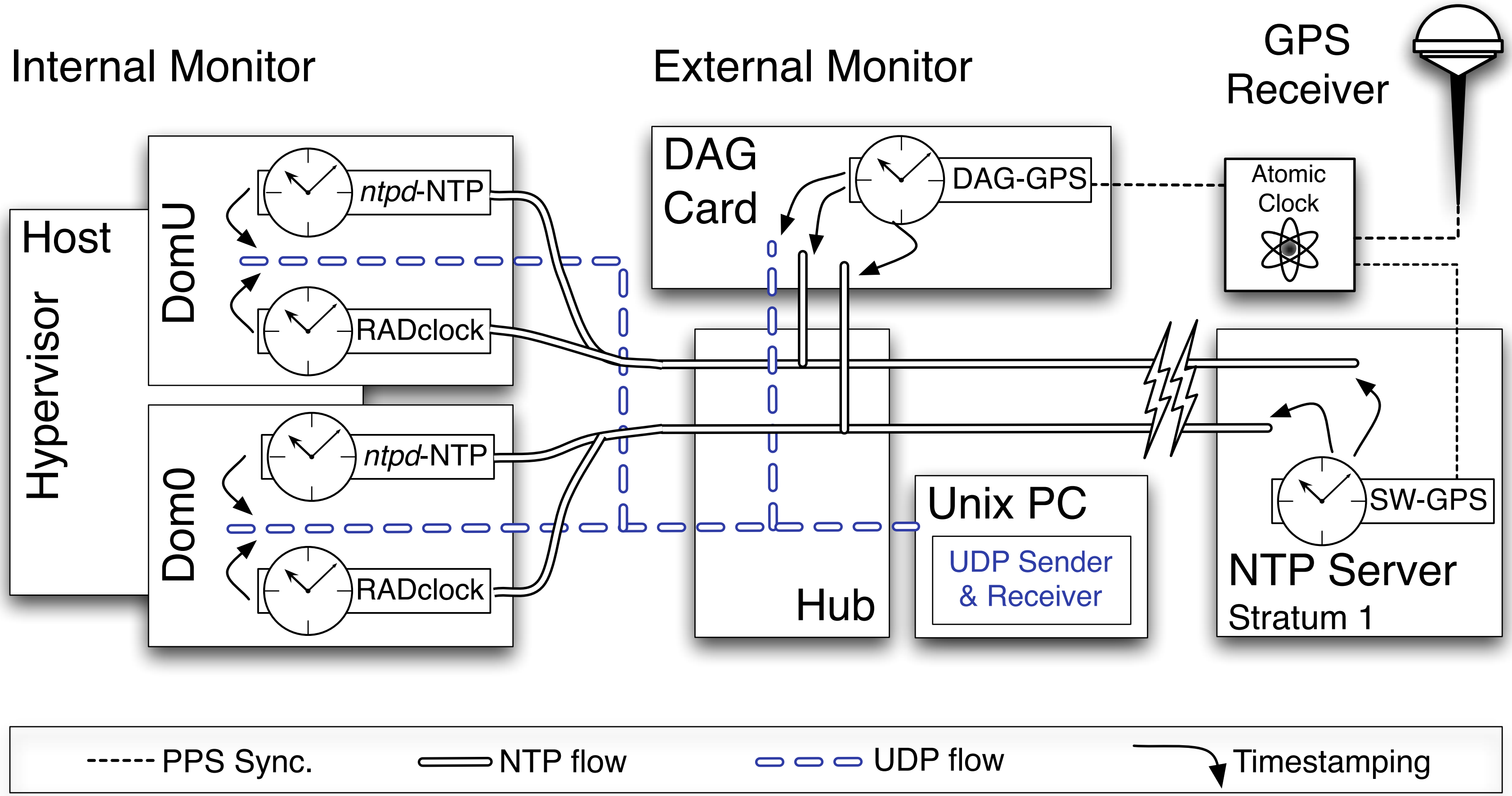


- **Two key problems**
  - Dealing with delay variability (complex, but possible)
  - Path asymmetry (simple, but impossible)

Synchronisation Algorithms

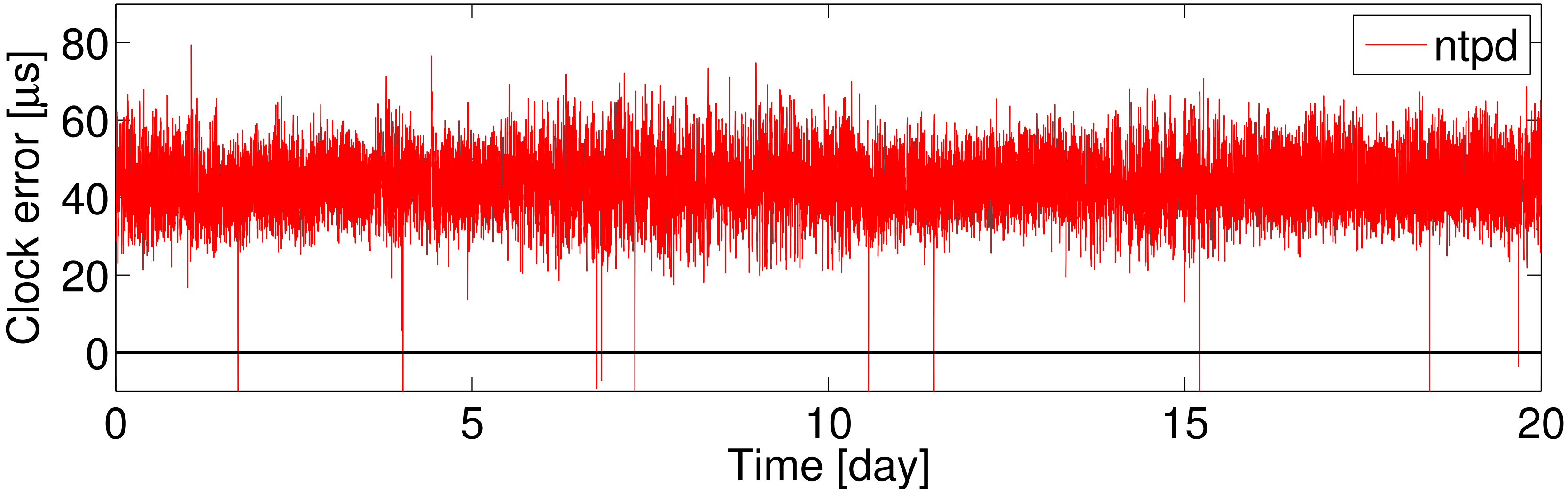
- **NTP (*ntpd*)**
  - Status Quo
  - Feedback based
    - Event timestamps are system clock stamps
    - Feedback controller (PLL,FLL) tries to lock onto rate
  - Intimate relationship with system clock (API, dynamics..)
  - In Xen, *ntpd* uses Xen Clocksource
- **RADclock** (Robust Absolute and Difference Clock)
  - Algo developed in 2004, extensively tested
  - Feedforward based
    - Event timestamps are raw stamps
    - Clock error estimates made and removed when clock read
  - `System clock' has no dynamics, just a function call
  - Can use any raw counter: here use HPET, Xen Clocksource

Experimental Methodology



Wots the problem? *ntpd* can perform well

- **Ideal Setup**
  - Quality Stratum-1 time-server
  - Client is on the same LAN, lightly loaded, barely any traffic
  - Constrained and small polling period: 16 sec



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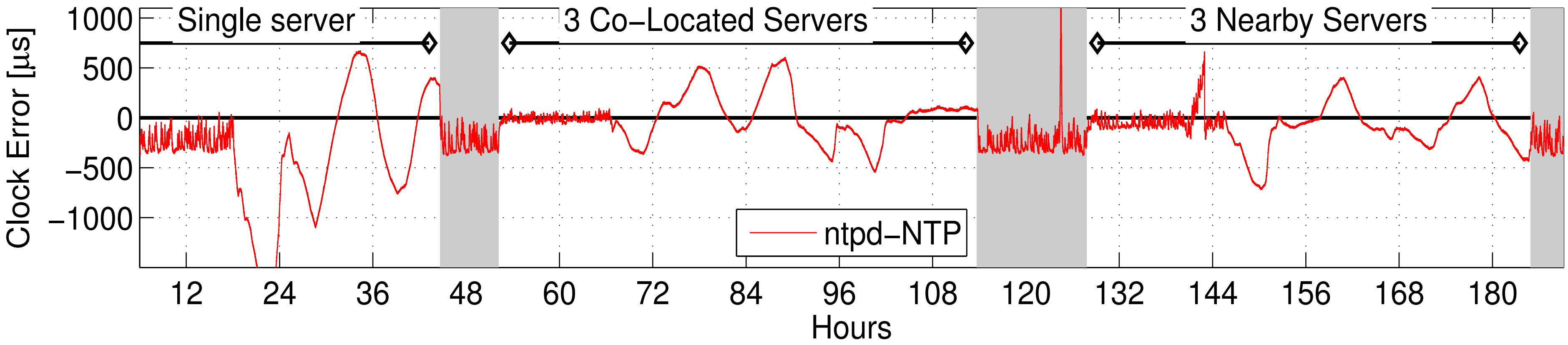
Or less well...

- **Different configuration (*ntpd* recommended!)**
  - Multiple servers
  - Relax constraint on polling period
  - Still no load, no traffic, high quality servers



When/Why? Loss of stability a complex function of parameters ⇒ unreliable

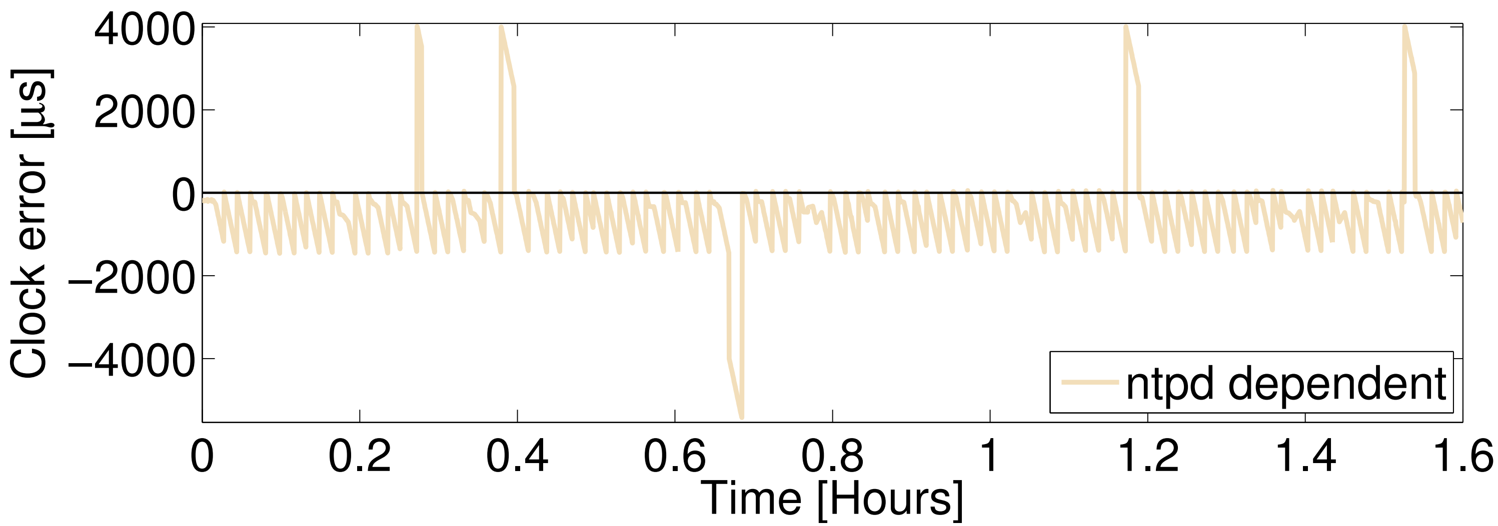
The Xen Context

- **Three examples of inadequacy of *ntpd* based solution**

1) Dependent *ntpd* clock
2) Independent *ntpd* clock
3) Migrating independent *ntpd* clock

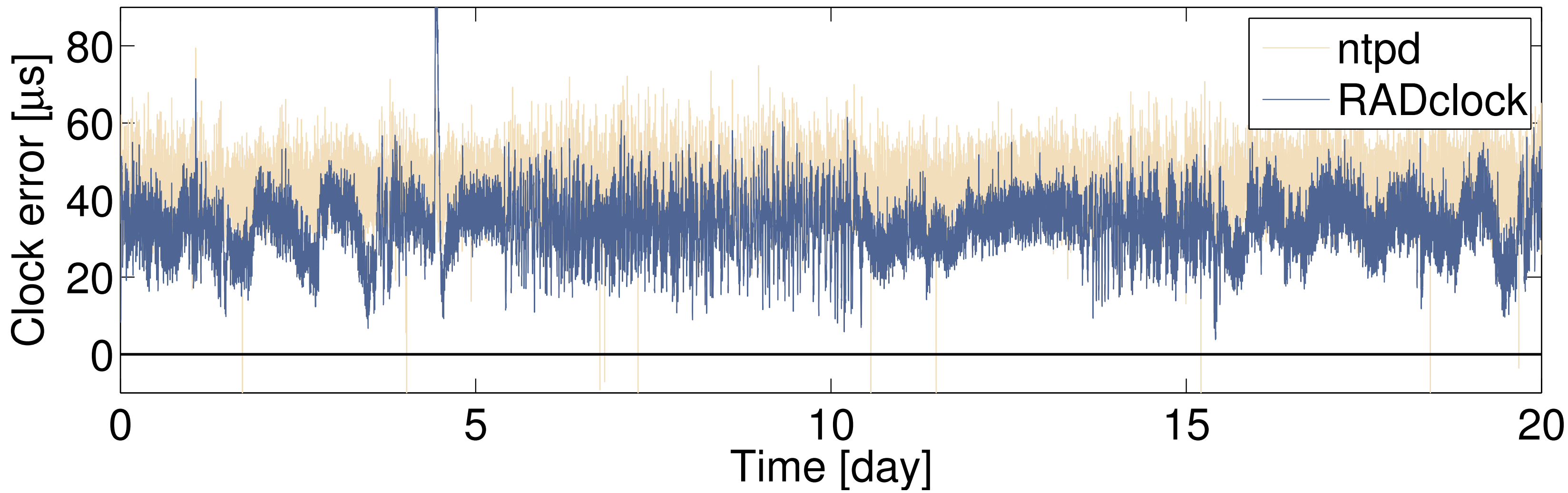
1) Dependent *ntpd* Clock

- **The Solution**
  - Only Dom0 runs *ntpd*
  - Periodically updates a `boot time' variable in hypervisor
  - DomU uses Xen Clocksource to interpolate
- **The Result** **(2.6.26 kernel)**



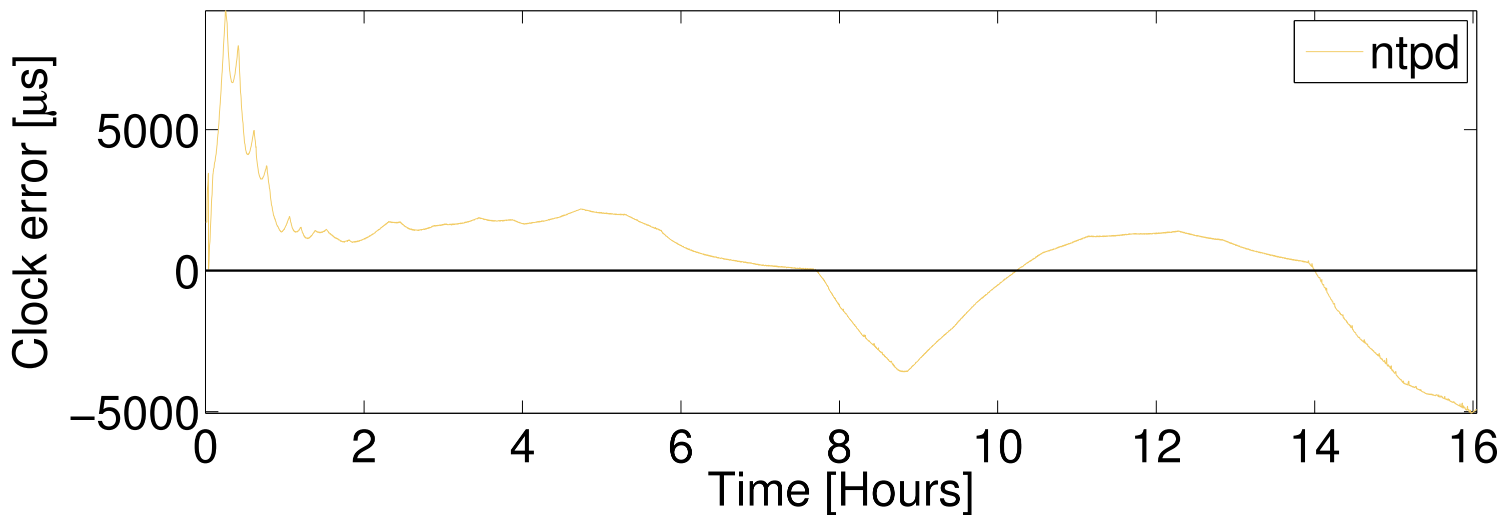
2) Independent *ntpd* Clock (current solution)

- **The Solution**
  - All guests run entirely separate *ntpd* daemons
  - Resource hungry
- **The Result**
  - When all is well, works as before but with a bit more noise
  - When works: (parallel comparison on Dom0, stratum-1 on LAN)



2) Independent *ntpd* Clock (current solution)

- **The Solution**
  - All guests run entirely separate *ntpd* daemons
  - Resource hungry
- **The Result**
  - Increased noise makes instability more likely
  - When fails: (DomU with some load, variable polling period, guest churn)



3) Migrating Independent *ntpd* Clock

- **The Solution**
  - Independent clock as before, migrates
  - Starts talking to new system clock, new counter
- **The Result**

Migration Shock!

More Soon

RADclock Architecture

Principles

- **Timestamping:**
  - raw counter reads, not clock reads
  - independent of the clock algorithm
- **Synchronization Algorithm:**
  - based on raw timestamps and server timestamps (feedforward)
  - estimates clock parameters and makes available
  - concentrated in a single module (in userland)
- **Clock Reading**
  - combines a raw timestamp with retrieved clock parameters
  - stateless

More Concretely

- **Timestamping**
  - read chosen counter, say HPET(t)
- **Sync Algorithm maintains:**
  - Period: a long term average (barely changes) ⇒ rate stability
  - K: sets origin to desired timescale (e.g. UTC)
  - E: estimate of error ⇒ updates on each stamp exchange
- **Clock Reading**
  - Absolute clock: $C_a(t) = \overline{\text{Period}} * \text{HPET}(t) + K - E(t)$
    - used for absolute, and differences above critical scale
  - Difference clock: $C_d(t_1,t_2) = \overline{\text{Period}} * \mathbf{(}\ \text{HPET}(t_2) - \text{HPET}(t_1)\ \mathbf{)}$
    - used for time differences under some critical time scale

Implementation

- **Timestamping `feedforward support'**
  - create cumulative and wide (64-bit) form of counter
  - make accessible from both kernel and user context
    - under Linux, modify Clocksource abstraction
- **Sync Algorithm**
  - Make clock parameters available via a user thread
- **Clock reading**
  - Read counter, retrieve clock data, compose
  - Fixed-point code to enable clock to be read from kernel

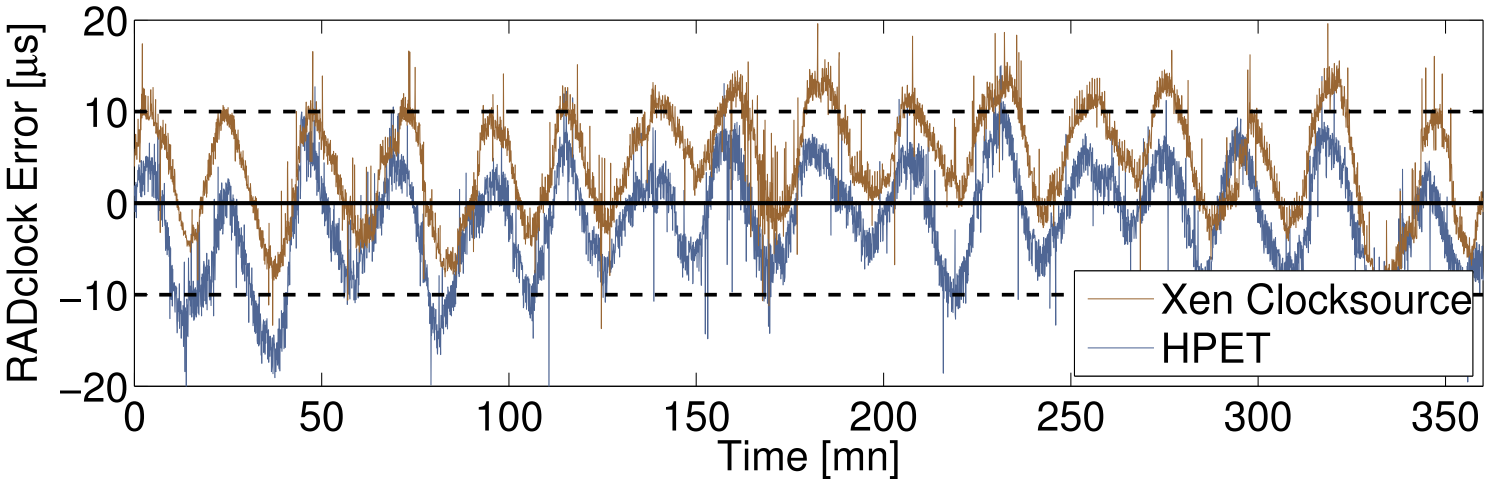
On Xen

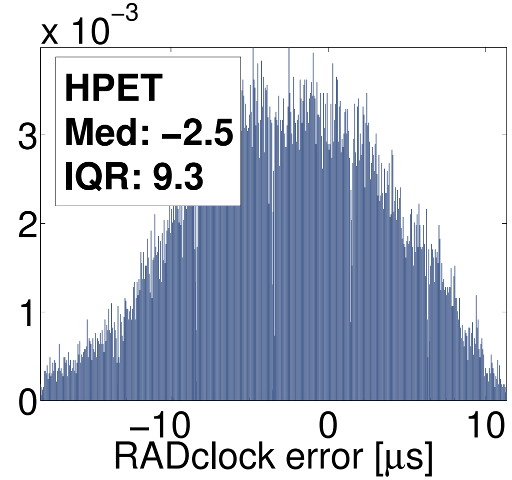
Feedforward paradigm a perfect match to para-virtualisation

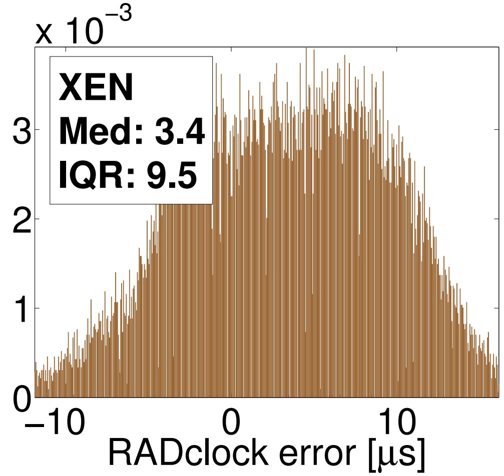
- **Dependent Clock now very natural**
  - Dom0 maintains a RADclock daemon, talks to timeserver
  - Makes Period, K, E available through Xenstore filesystem
  - Each DomU can just reads counter, retrieve clockdata, compose
- **All Guest Clocks identically the same, but:**
  - Small delay (~1ms) in Xenstore update
    - stale data possible but very unlikely
    - small impact
  - Latency to read counter higher on DomU
- **Support Needed**
  - Expose HPET to Clocksource in guest OSs
  - Add hypercall to access platform timer (HPET here)
  - Add read/right functions to access clockdata from Xenstore

Independent RADclock on Xen

- Concurrent test on two DomU's, separate NTP streams





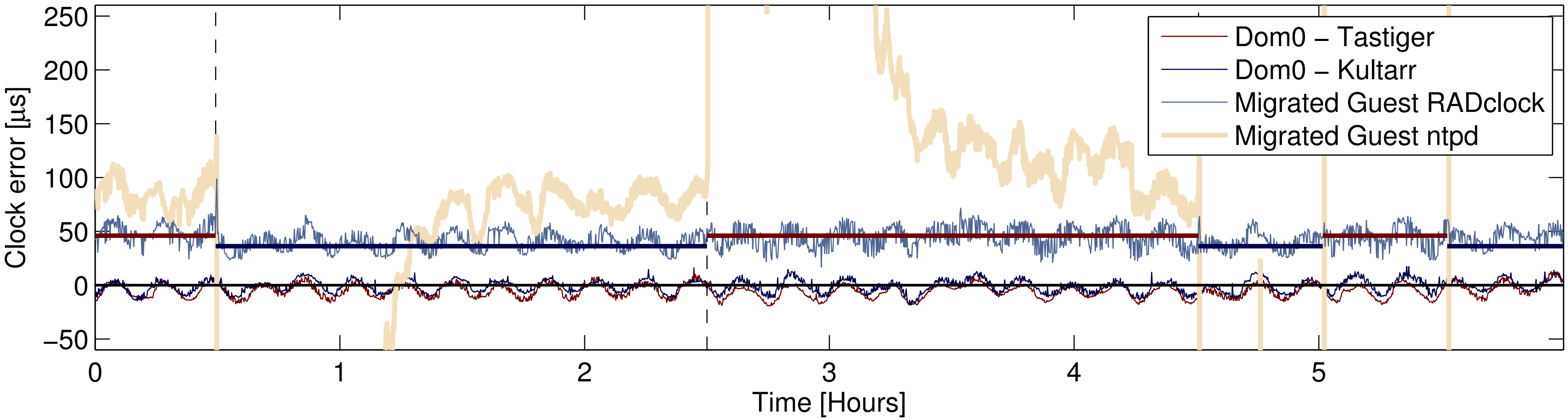


Migration On Xen

Feedforward paradigm a perfect match to migration

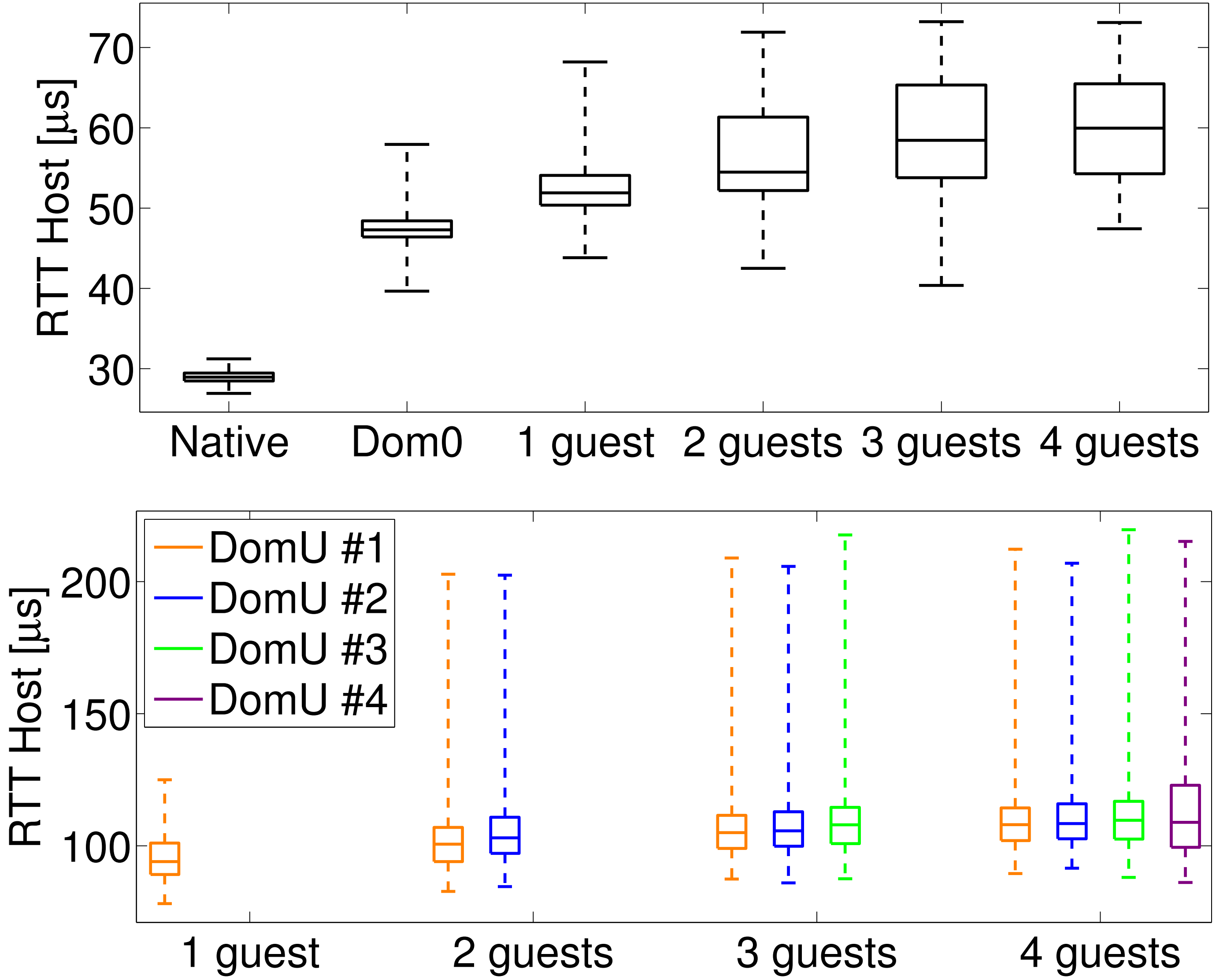
- **Clocks don't migrate, only a clock reading function does!**
  - Each Dom0 has its own RADclock daemon
  - DomU only ever calls a function, no state is migrated
- **Caveats**
  - Local copy of clockdata used to limit syscalls - needs refreshing
  - Host asymmetry will change, result in small clock jump
    - asymmetry effects different for Dom0 (hence clock itself) and DomU

Migration Comparison

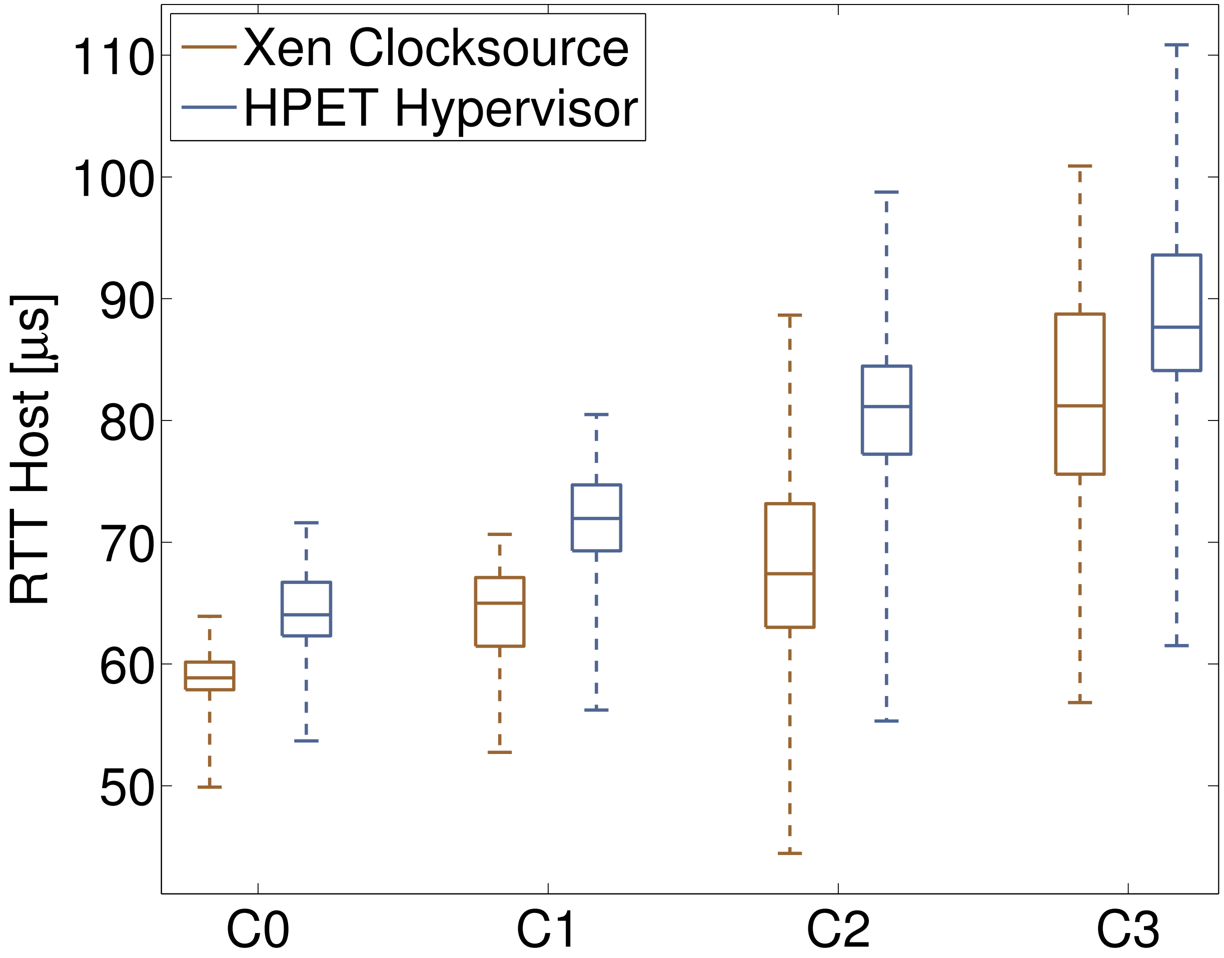


- **Setup**
  - Two machines, each Dom0 running a RADclock
  - One DomU migrates with a
    - dependent RADclock
    - independent *ntpd*

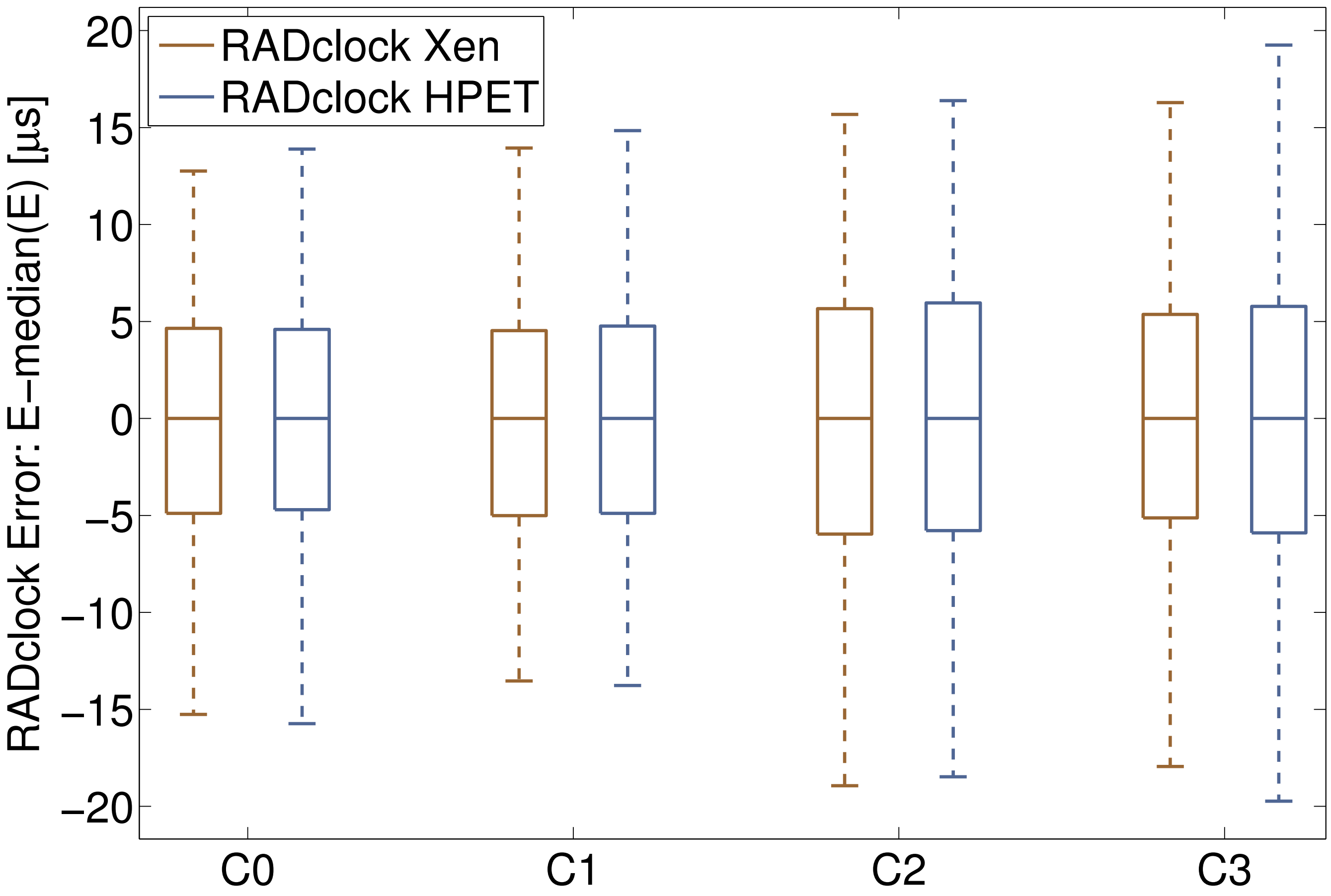
Noise Overhead of Xen and Guests



Noise Penalty Under C-States



Algo Performance Under C-States



Conclusion

- **Feed-Forward approach has many advantages**
  - Difference clock defined
  - Absolute clock can be made much more robust
  - Time can be replayed
  - Simpler kernel support
- **Good match to needs of para-virtualisation**
  - Enables clock dependent mode that works
  - Allows seamless live migration
- **RADclock project**
  - Aims to replace *ntpd*
  - Client and Server code
  - Packages for FreeBSD and Linux (Xen now supported)
  - http://www.cubinlab.ee.unimelb.edu.au/radclock/

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