Symmetricom

Leading the world in precise time solutions.

Delivering Sub-Microsecond Accurate Time to Linux Applications Around the World

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Agenda

- Precise Timing in Trading Applications
- The Four Sources of Time Error (w/ sample data)
- Using PTP for Precise Time Synchronization
- Solving The Problems (w/ sample data)
- Conclusions

Symmetricom at a Glance

Undisputed global leader of highly-precise timekeeping technology, instruments and solutions

- Headquarters in San Jose, California
- Publicly traded on NASDAQ (SYMM)
- Focused offerings for Communications, Government, Enterprise and Power Utility market segments
- Incumbency with major customers in over 100 countries
- Large ecosystem of partners including integrators, NEMs, test and silicon vendors

Our Leading & Diverse Customers

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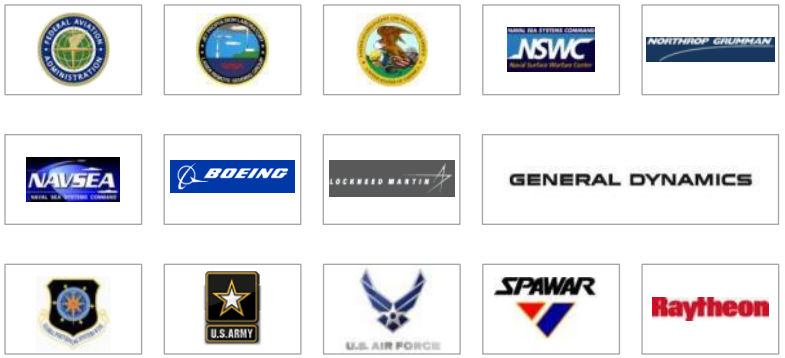
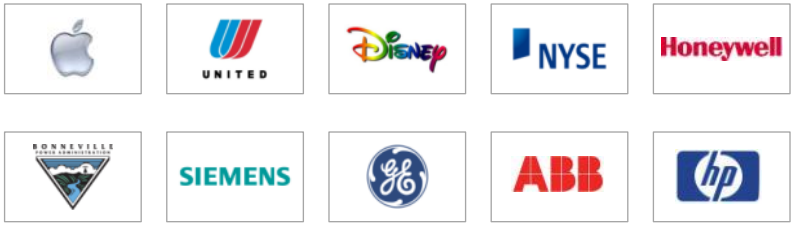
Communications

Government



Power

Enterprise



Precise Timing in Trading Applications

Optimized Algorithms = Optimal Financial Performance

- Accurate & precise time stamping of market data for historical archive
- Replay years of data in minutes
- Quickly re-optimize trading algorithms to changing conditions
- The better the time stamp now, the more useful the data will be in the future

Symmetricom timing

Continuous historical archive with accurate time stamps

Stock Exchange/ Execution Venue/ Trading Firms

Feed Handler
Receives market data stream, millions of messages per second

Order Handler
Places quotes, orders and handles acknowledgements

Trading Application Servers

Network Delay = Lost Opportunity

- Accurately synchronize server clocks and monitoring equipment to better identify trading system delays
- Optimize network/applications for lowest possible latency
- Identify and realize profitable, short-lived trading opportunities sooner

Symmetricom timing

Network Latency Monitoring Equipment

Stock Exchange/ Execution Venue/ Trading Firms

Feed Handler
Receives market data stream, millions of messages per second

Order Handler
Places quotes, orders and handles acknowledgements

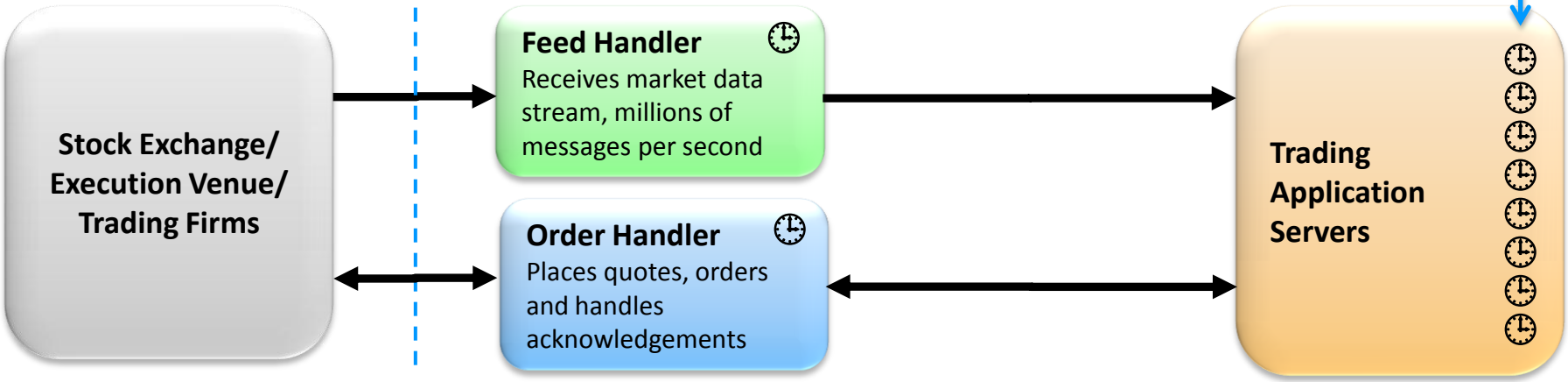
Trading Application Servers

Synchronization Errors = High Financial Risk

- Market data distributed across many servers handling very large & complex computations
- Accurate & precise time synchronization critical in:
  - Trade decision making/profits
  - Risk management/losses
  - Performance metrics

Symmetricom timing

Accurately and reliably synchronize clocks in servers in a single rack and in servers around the world



The Four Sources of Time Error

Packet Time Transfer Basics

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Accurate time transfer is all about….

- Correcting time **offsets** between clocks by exchanging timing packets
- Compensating for time packet transit **delays** between clocks
- Compensating for time packet transit delay **variation** (aka PDV, or packet arrival time jitter)

Sources of Time Offset Errors

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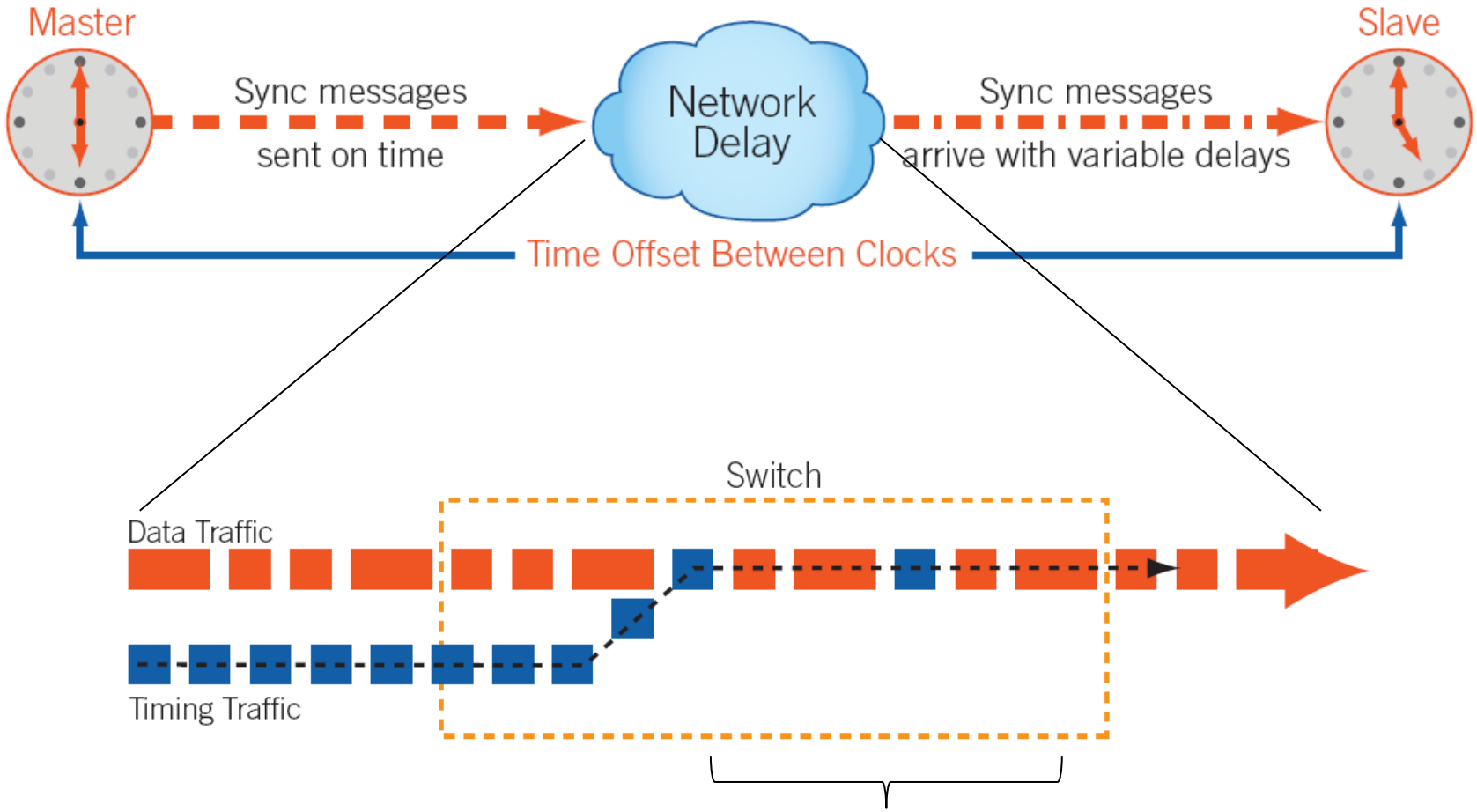
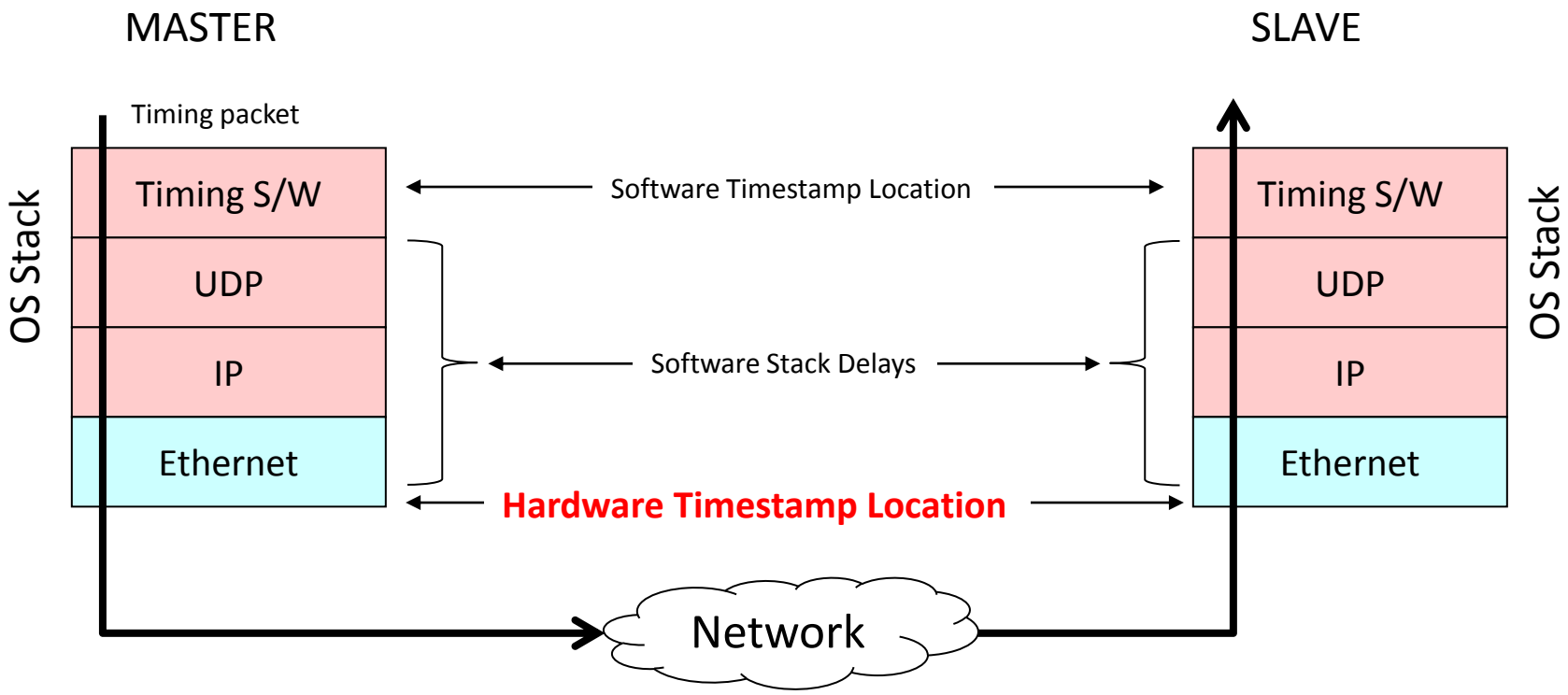
- Delays
  - Time transfer path delays
    - Network delays – queuing & delays inside switches
    - Linux stack delays
  - Linux clock call delays
- Clock instability
  - Inexpensive/unstable server oscillators
  - Temperature sensitivity

Network Path Delays



Delays not uniform and may exist in only one direction between master and slave

Linux Stack Delays



Hardware time stamping eliminates OS stack delays

Linux clock_gettime Call Delays

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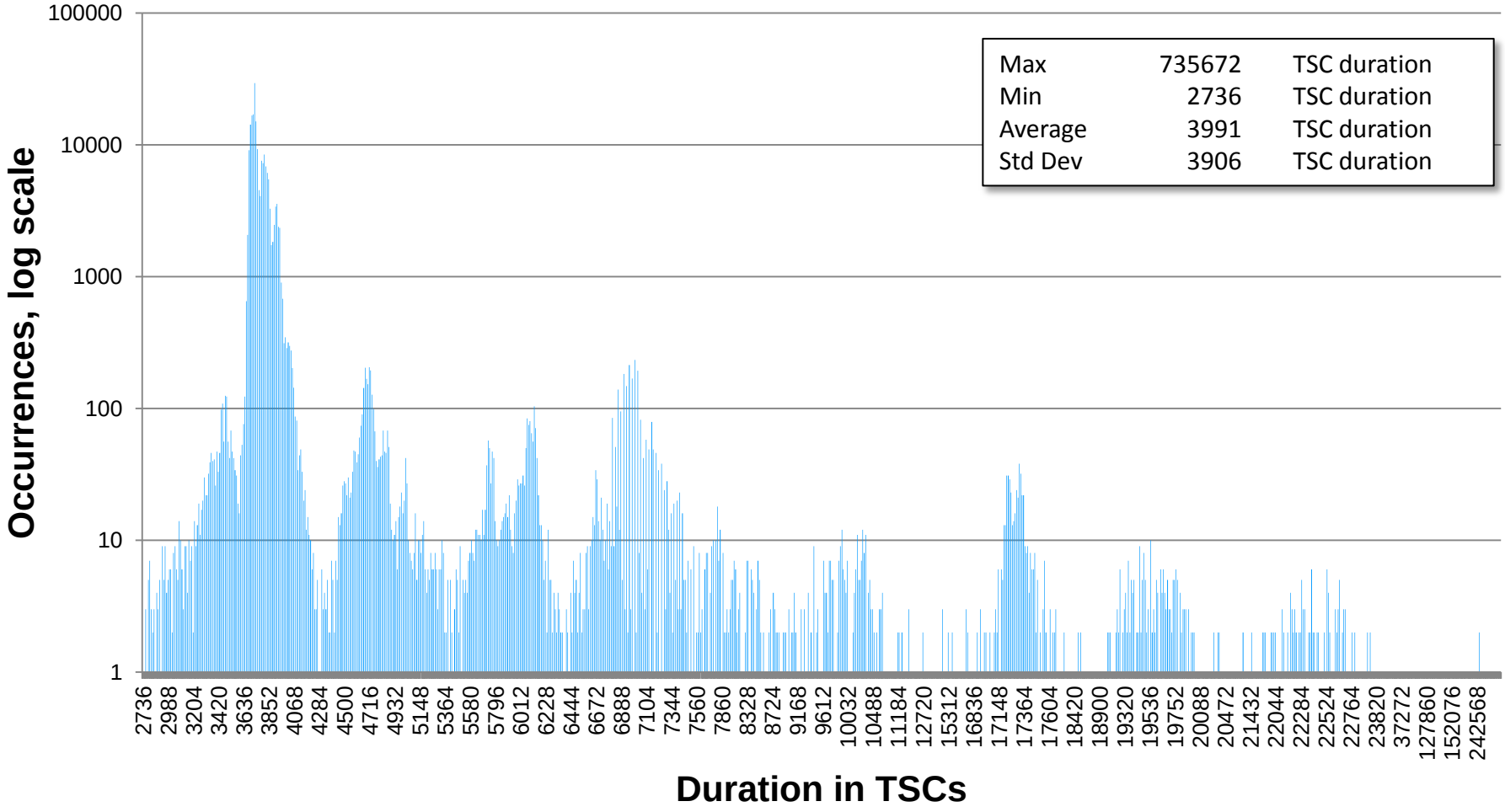
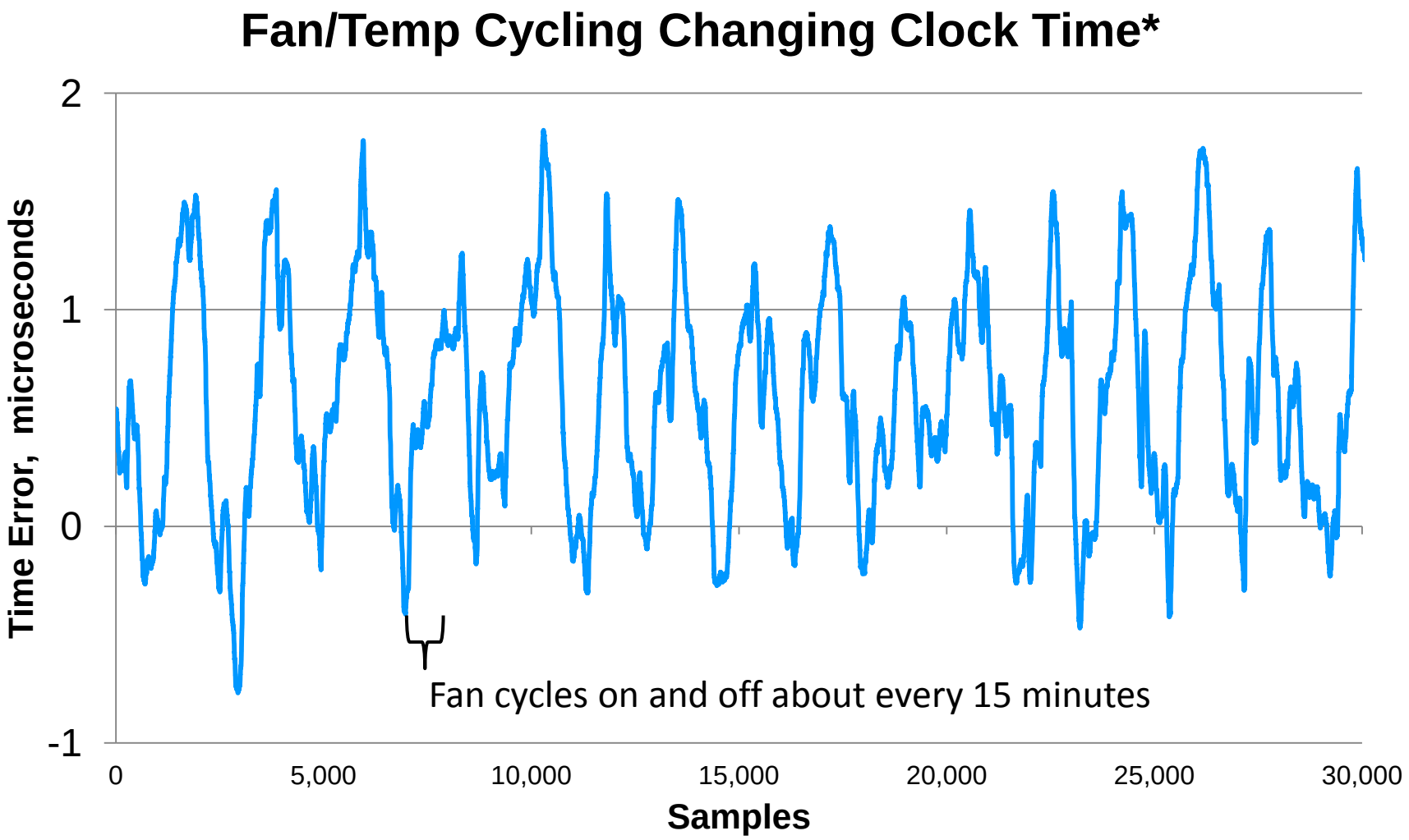
Histogram of Linux clock_gettime Call Duration in TSCs

(200,000 measurements)



Time Stamp Counter (TSC) representative of a certain number of CPU counter cycles

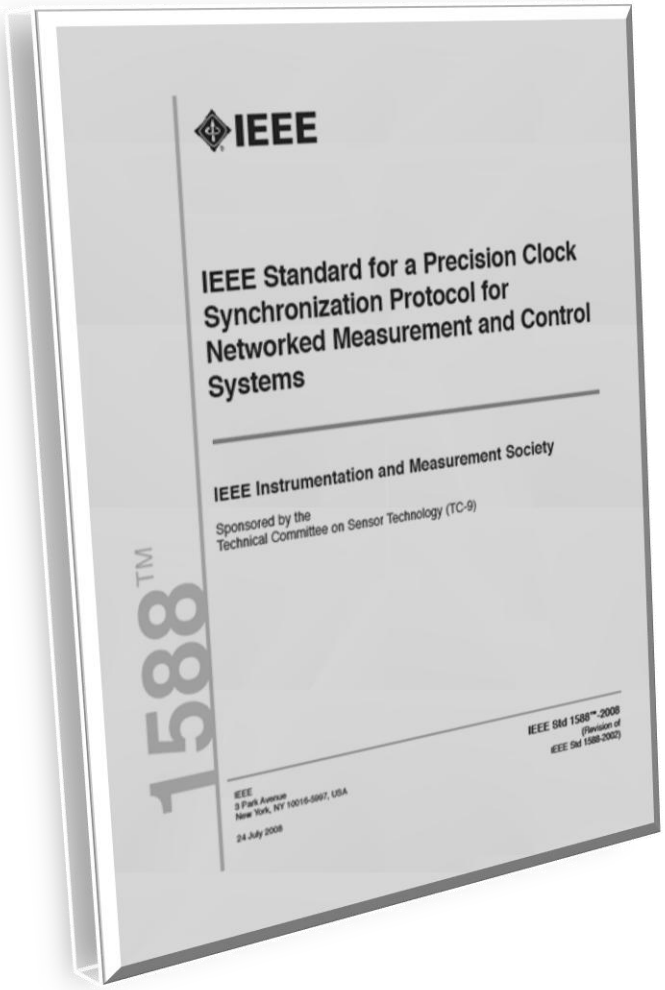
Server Oscillator Stability Errors



**This is on an unloaded server, errors worse on a server under load*

Using PTP for Precise Time Synchronization

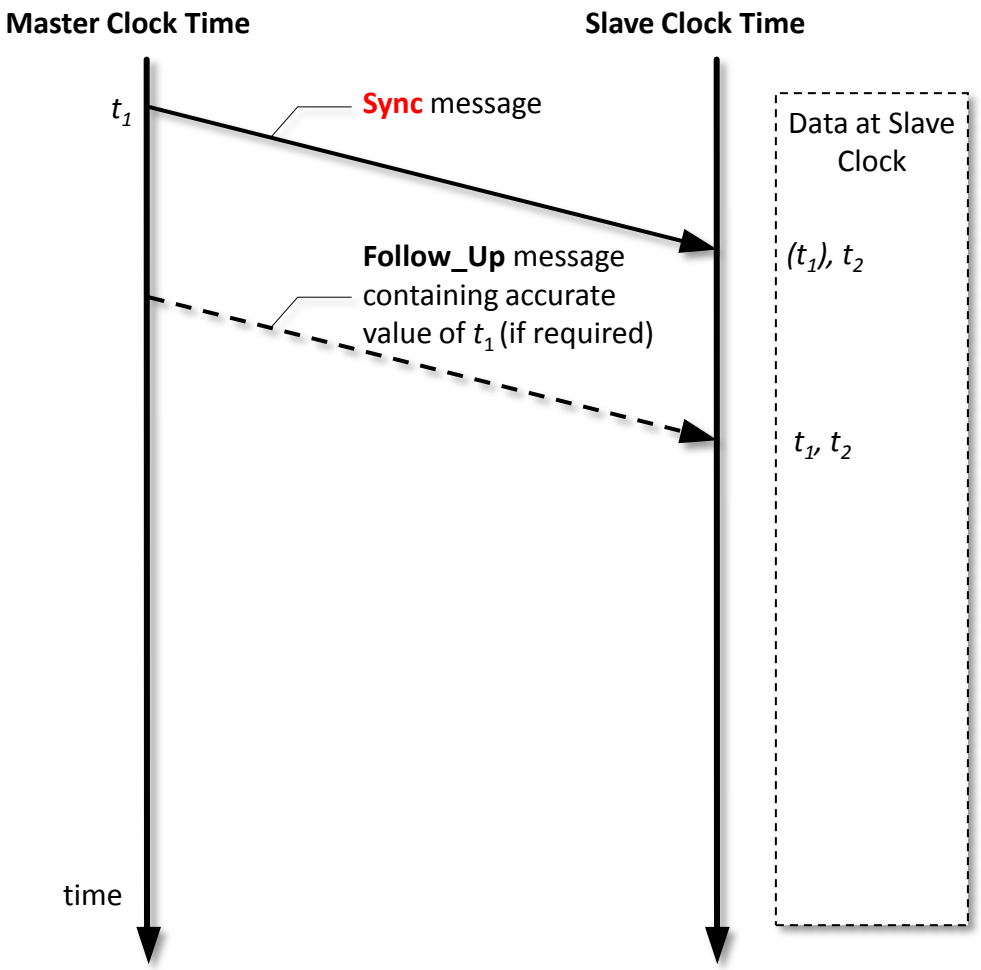
What is the Precision Time Protocol (PTP)?



- Protocol specification for distributing precise time over packet networks
- Defined in IEEE Standard 1588
  - First version (2002) targeted LAN applications
  - Second version (2008) expanded applicability to cover broader applications/networks
- Time is carried in “event messages” transmitted between a Grandmaster Clock and a Slave Clock
- Runs over Ethernet and/or IP networks
- Commonly referred to as:
  - PTP (Precision Time Protocol) or PTP v.2
  - IEEE1588-2008 or IEEE1588 v.2

PTP Packet Exchange

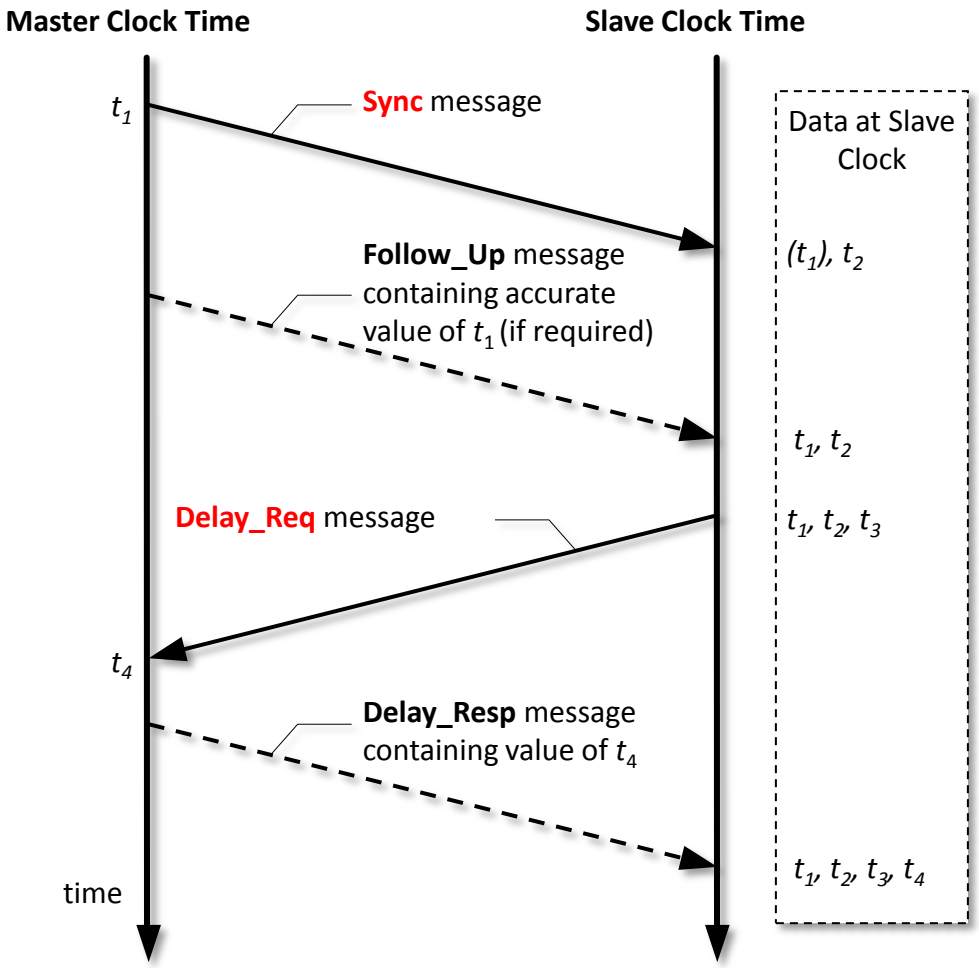
- PTP defines an exchange of time stamped messages over a packet network



- **Packet Exchange**: Master and Slave exchange time stamped *Sync* & *Delay_req* event messages

PTP Packet Exchange

- PTP defines an exchange of time stamped messages over a packet network



- **Packet Exchange**: Master and Slave exchange time stamped *Sync* & *Delay_req* event messages
- Four key timestamps are collected
- **Time offset** calculation requires all four timestamps:

$$SlaveTimeOffset = \frac{(t_1 - t_2) + (t_4 - t_3)}{2}$$

- assumes symmetric path delays
  (i.e. the forward path delay is equal to the reverse path delay)

Specific Benefits of PTP

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- Higher packet exchange rates…
  - Allows for improved packet filtering and clock steering with servo loops to overcome PTP packet arrival time jitter
- Hardware time stamping
  - Vendors have generally adopted hardware time stamping to eliminate OS stack delays
- What PTP is NOT…
  - No clock steering algorithms as part of the PTP standard
  - Clock steering algorithms are vendor supplied, results vary widely…

Solving the four sources of time error…

(network delays, stack delays, clock call delays, clock instability)

Symmetricom End-to-End Accurate and Reliable Timing Solution

GPS referenced SyncServer® S350 PTP Grandmaster for each venue

- Accurate to 50 nanoseconds to UTC
- Accurate time available around the planet

Network

Feed Handler, Order Handler, Trading Server

PTP Clock Card

- Superior clock hardware on PCIe bus compared to server clock
- Best possible time accuracy and precision

Time Client		Time Accuracy (microseconds)
PTP Software		Good (10's)
PTP Software+NIC		Better (<10)
PTP Clock Card-		Best (<1 !)

The Newest PTP Clock for High Speed Trading

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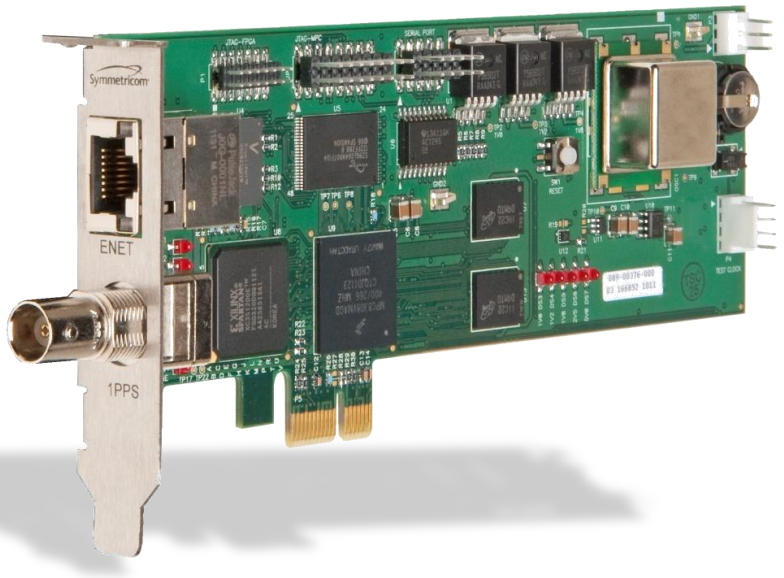
*Symmetricom **SyncPoint PCIe-1000** PTP Clock Card*
end-to-end nanosecond timing for high speed trading systems

Accuracy

- Ultra accurate PTP Clock Card
  (10 ns to a master in benchmark test)
- Absolute time accuracy at SW application
  ~600 ns to UTC

Speed

- Writes time directly to memory of host server
- Software can read time >1 million times per second and get monotonically advancing time



SyncPoint™ PCIe-1000 PTP Clock Card Advantages

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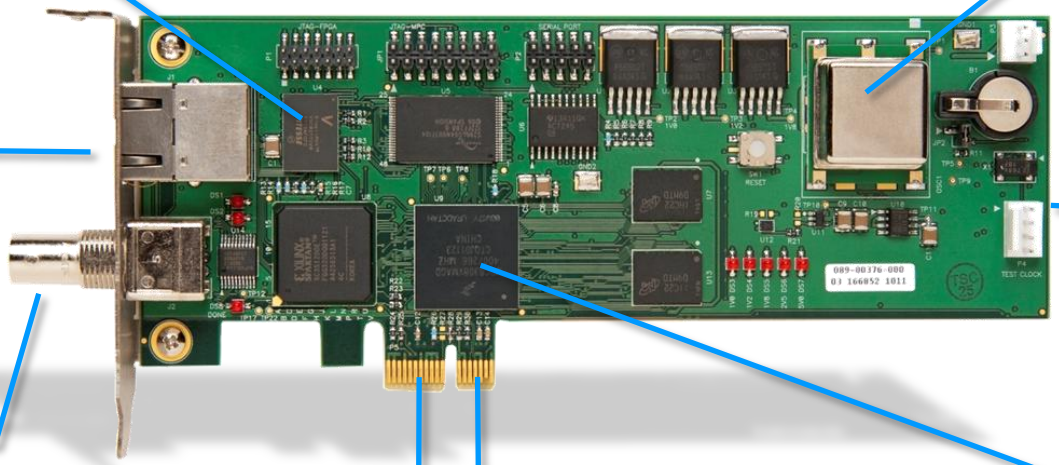
10 ns precision hardware time stamping eliminates server delay related errors

Gigabit Ethernet for easy interoperability with trading network

1PPS output to measure *real world* time accuracy to PTP grandmaster



High performance OCXO standard for very stable time during the trading day and server to server time sync

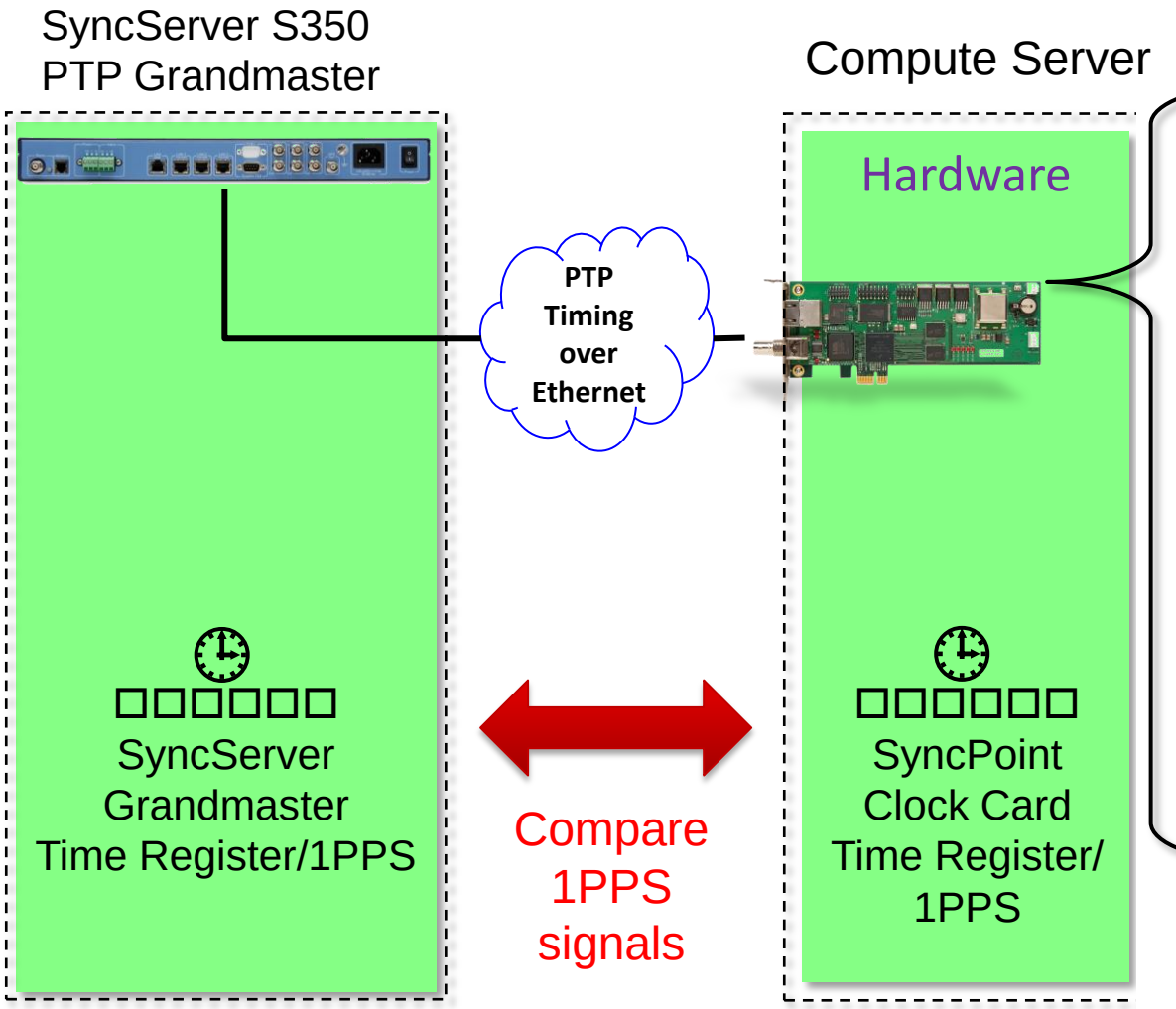
8 ns accuracy to PTP grandmaster is the best accuracy available today in a clock card. Great server to server sync.

State-of-the-art timing algorithms keeps time accurate over busy trading networks

Small x1 PCIe card fits any PCIe slot, not the most precious slots

Writes time directly to server memory to be read > 1million times per second

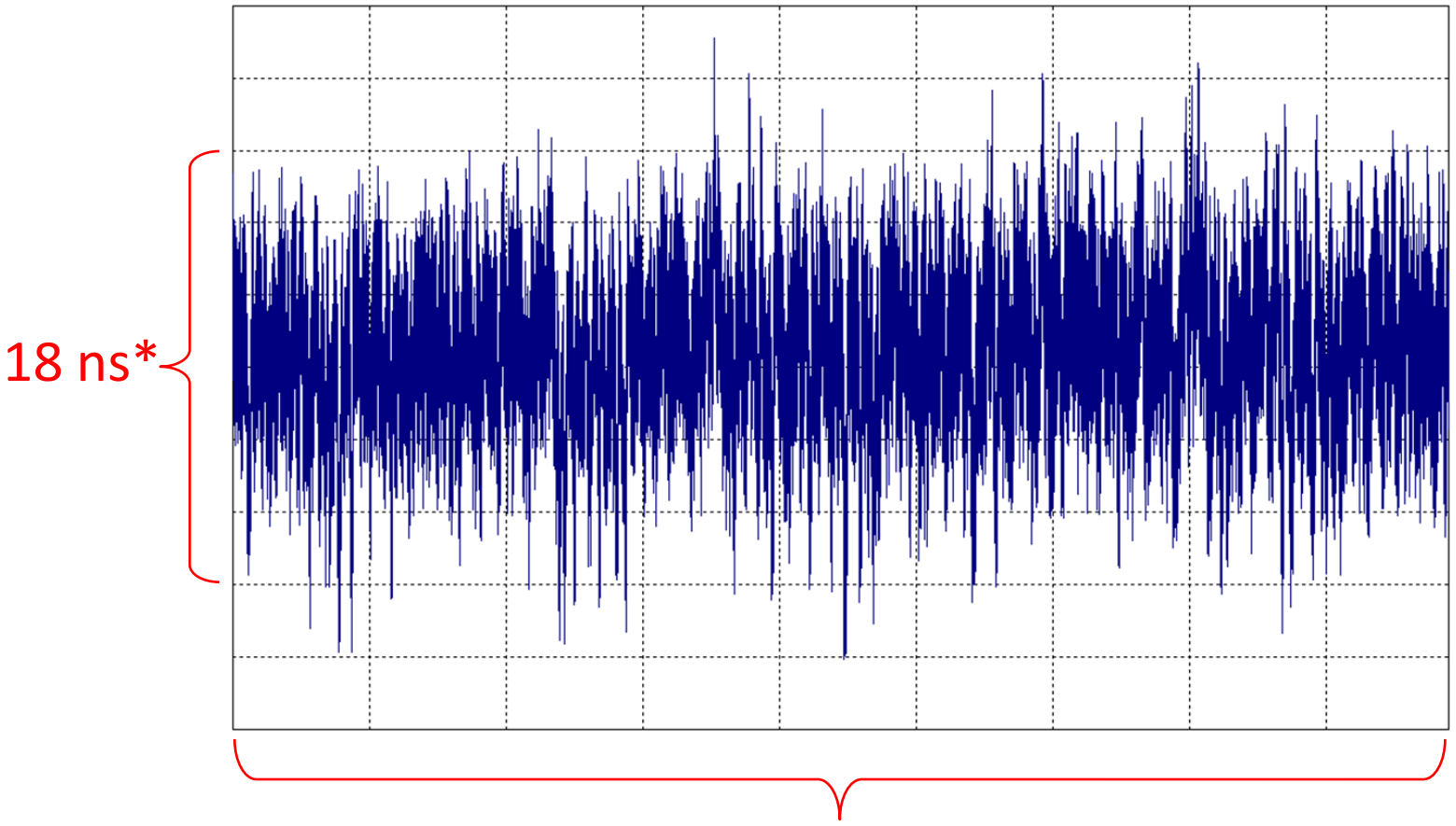
Solving Path Delays & Oscillator Instability



Advantages

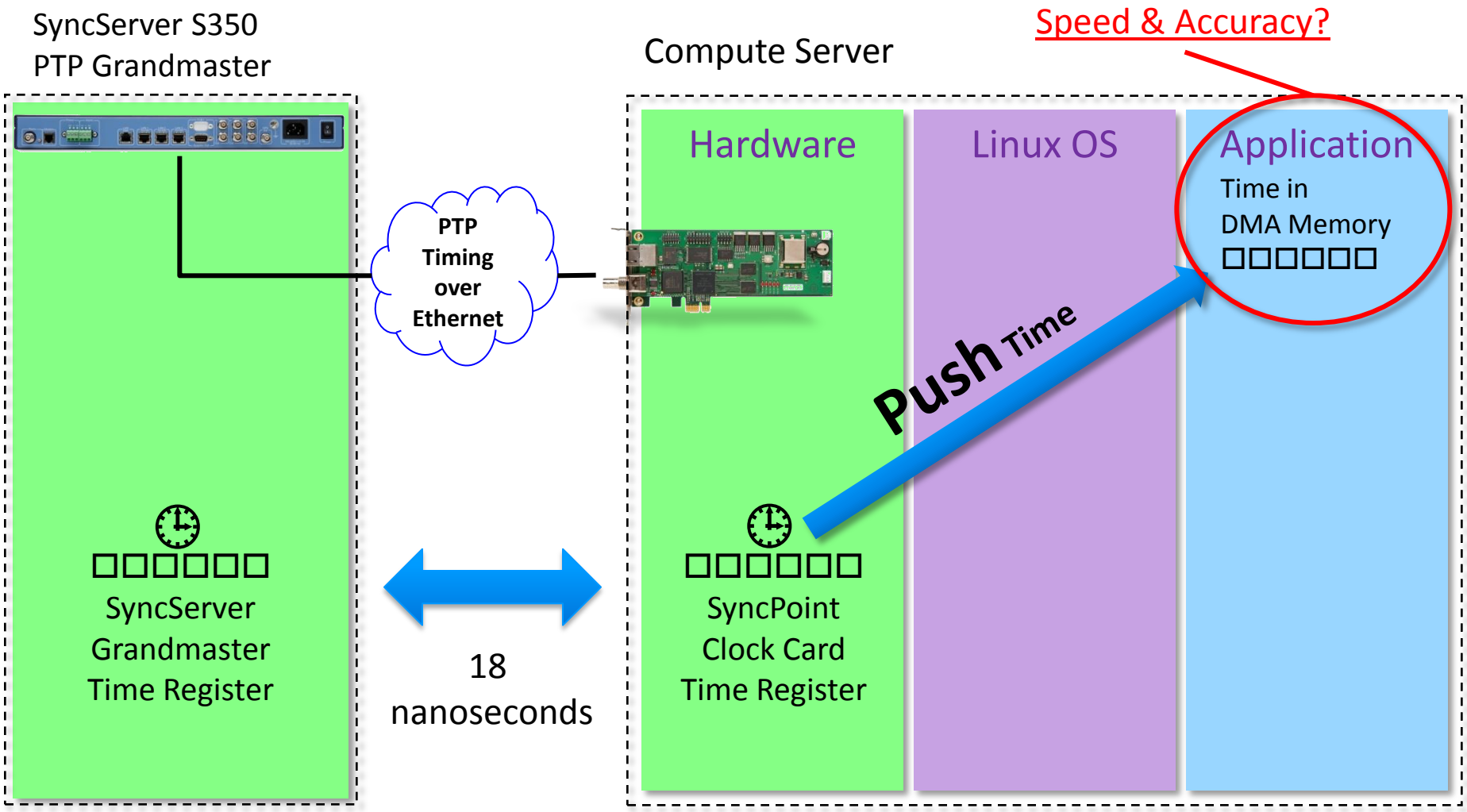
- Supports 32 PPS with packet pre filtering and excellent clock steering algorithms to overcome timing packet jitter
- OCXO for stable time base
- Hardware time stamping to eliminate OS stack delay

SyncServer to SyncPoint PCIe-1000 Accuracy

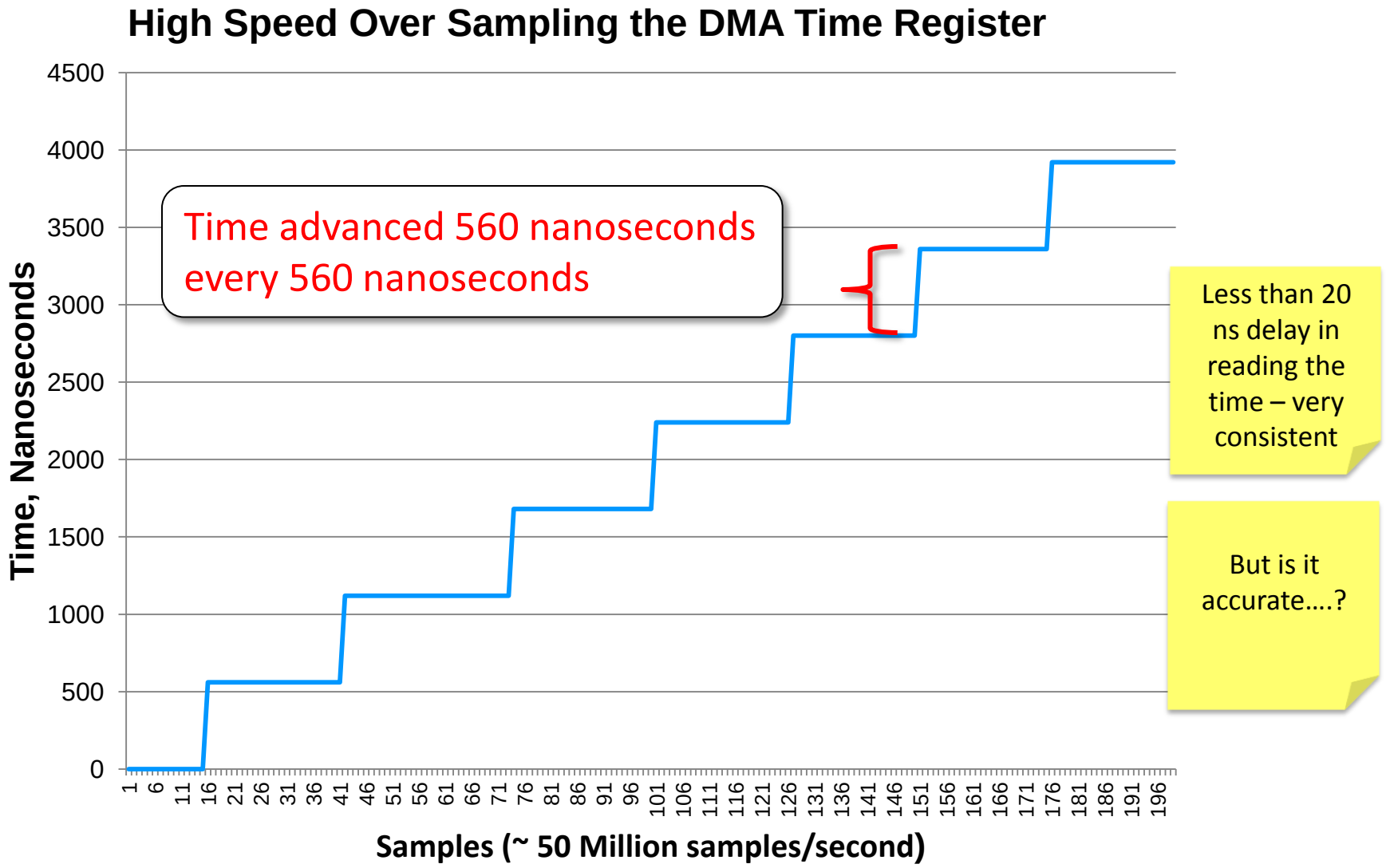


**benchmark test*

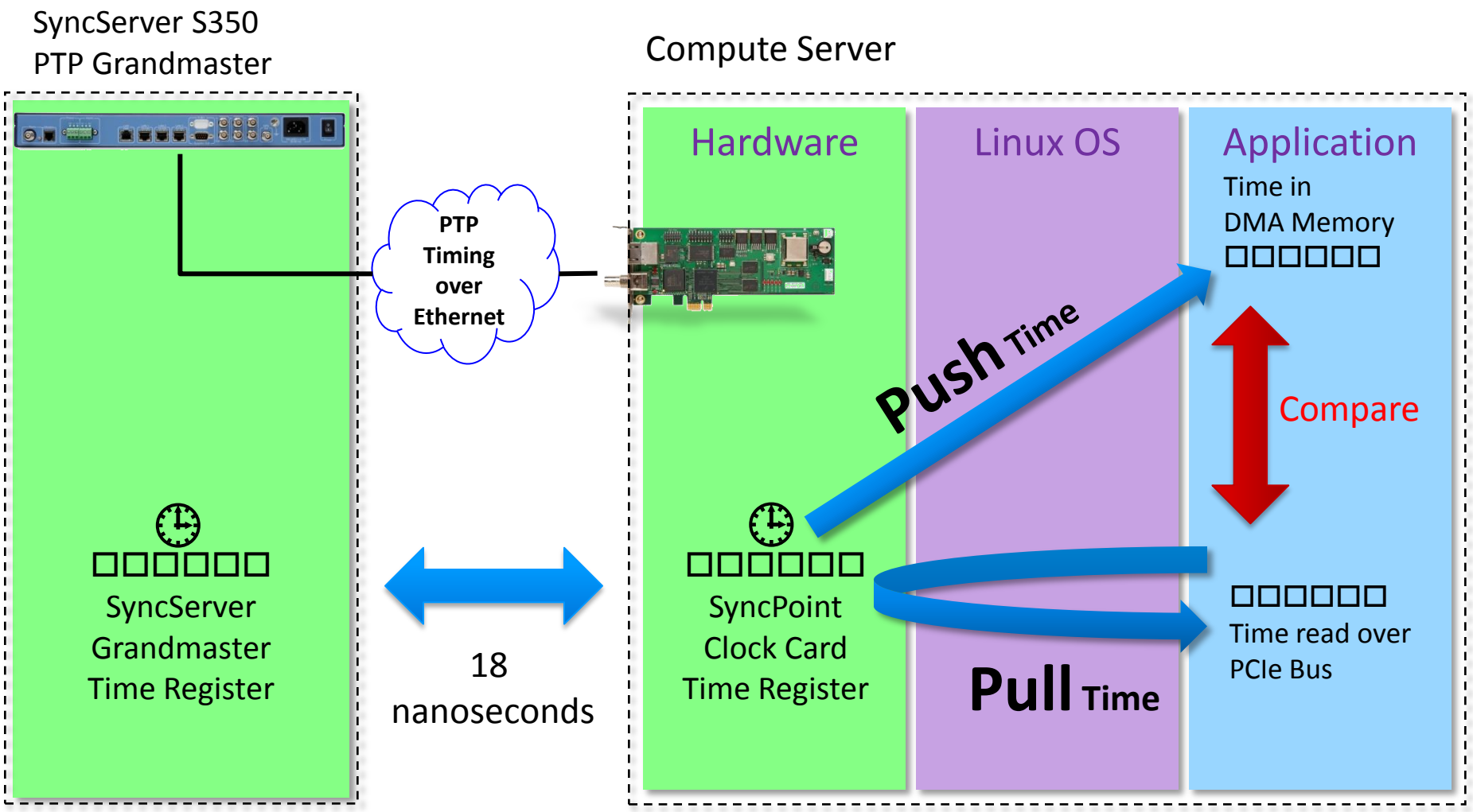
Moving Time To Memory



Oversampling Time from DMA Memory



How to Verify DMA Time Accuracy



Using “Happened-Before”* Analysis…

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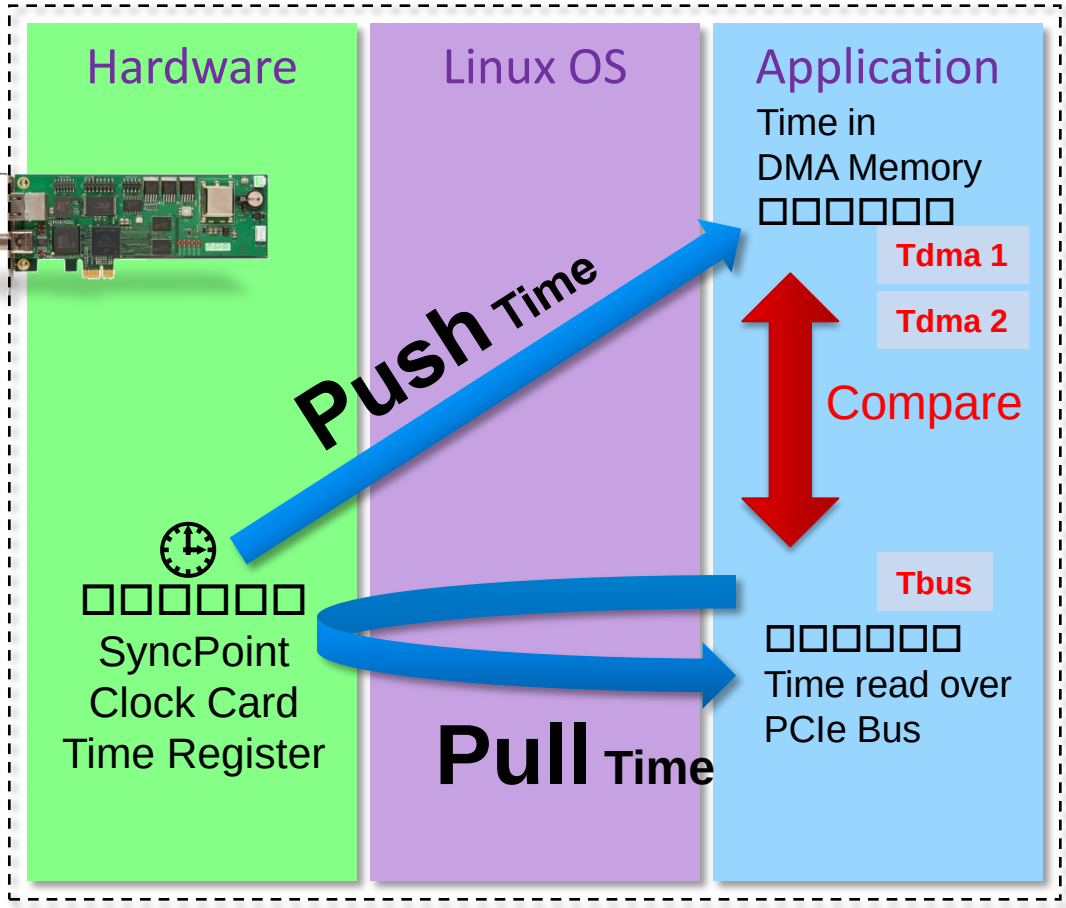
Compute Server



Process:

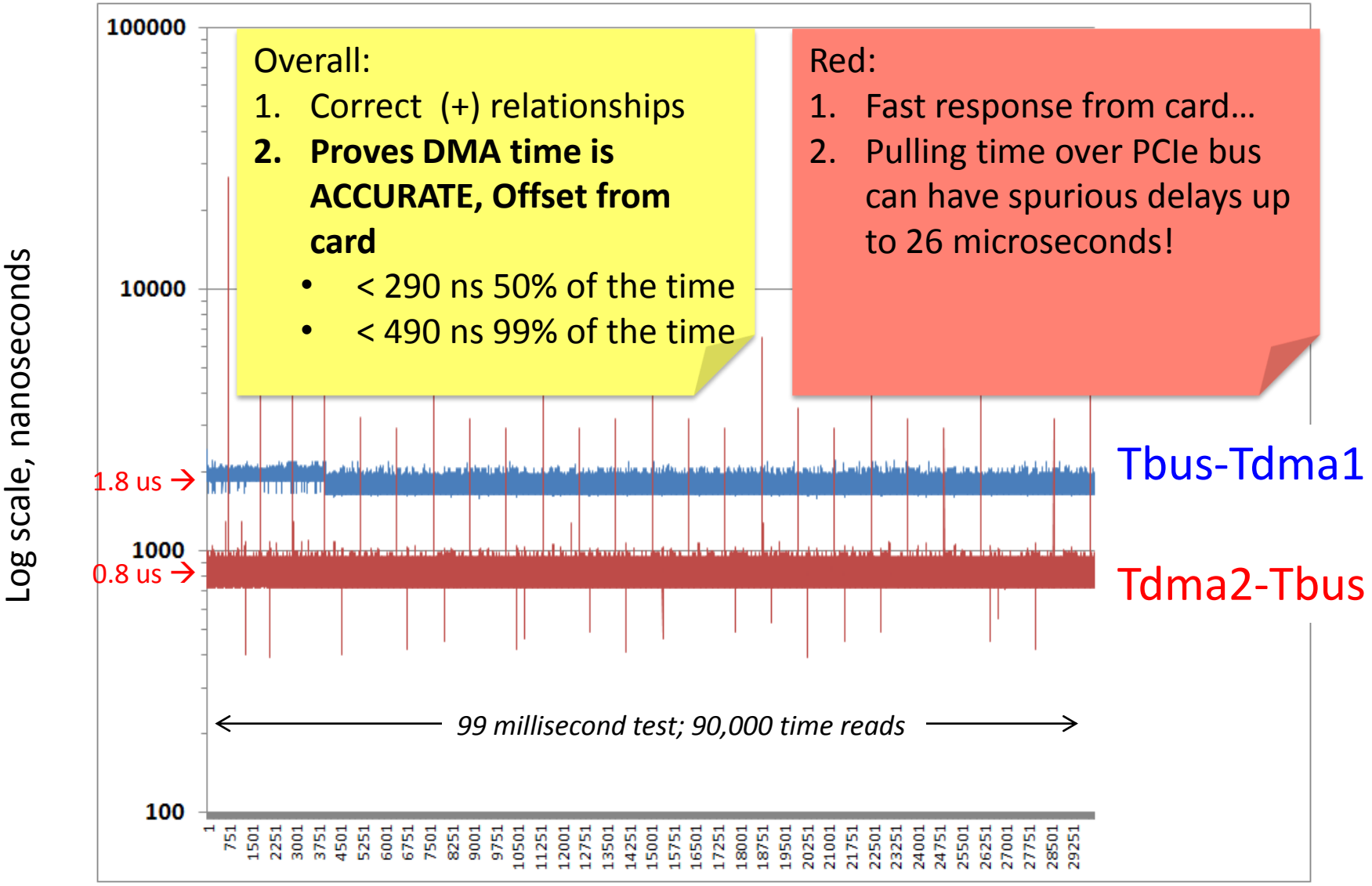
1. Read DMA Time: Tdma1
2. Pull PCIe Bus Time: Tbus
3. Read DMA Time: Tdma2

$$Tdma1 < Tbus < Tdma2$$

Compute delta times to verify time accuracy range of DMA time stamps

Time reads should be positively monotonic if registers synchronized

“Happened-Before” results…



The Four Timing Problems Solved

SyncServer S350
PTP Grandmaster

- Precise and Accurate time available globally via GPS
- Optional Atomic oscillator back-up

PTP Timing over Ethernet

Compute Server

SyncPoint PCIe-1000

- Technology to overcome network delays
- Stable OCXO time base
- Hardware time stamping eliminates OS stack delay

Linux OS

Application

Time in DMA Memory

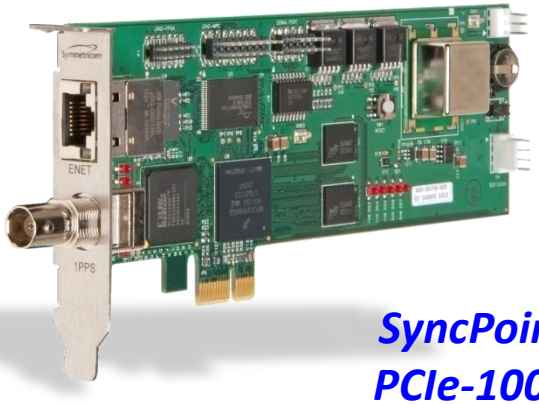
- Accurate and precise time available >1 million times per second

Conclusions

- Verified Symmetricom end-to-end accurate time to < 600 ns UTC to Linux applications using DMA time reads

SyncServer S350
PTP Grandmaster

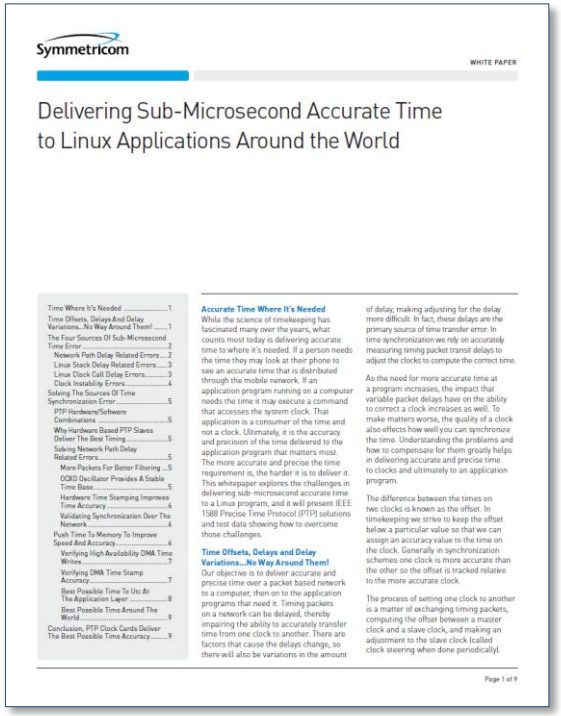
- SyncPoint PCIe-1000 PTP clock card with hardware time stamping, OCXO oscillator and DMA time writes…
  - Improves…
    - Time ***accuracy*** for Linux applications
    - Time ***availability*** for Linux applications
  - Reduces…
    - Network delay related errors
    - Stack delay related errors
    - Poor server clock related errors



SyncPoint
PCIe-1000
PTP Clock Card

Thank You

A link to the whitepaper will be sent to you



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WHITE PAPER

Delivering Sub-Microsecond Accurate Time to Linux Applications Around the World

Accurate Time Where It's Needed

While the science of timekeeping has fascinated many over the years, what counts most today is delivering accurate time to where it's needed. If a person needs the time they may look at their phone to see an accurate time that is distributed through the mobile network. If an application program running on a computer needs the time it may execute a command that accesses the system clock. That application is a consumer of the time and not a clock. Ultimately, it is the accuracy and precision of the time delivered to the application program that matters most. The more accurate and precise the time requirement is, the harder it is to deliver it. This whitepaper explores the challenges in delivering sub-microsecond accurate time to a Linux program, and it will present IEEE 1588 Precise Time Protocol (PTP) solutions and test data showing how to overcome those challenges.

Time Offsets, Delays and Delay Variations...No Way Around Them!

Our objective is to deliver accurate and precise time over a packet based network to a computer, then on to the application programs that need it. Timing packets on a network can be delayed, thereby impairing the ability to accurately transfer time from one clock to another. There are factors that cause the delays change, so there will also be variations in the amount of delay, making adjusting for the delay more difficult. In fact, these delays are the primary source of time transfer error. In time synchronization we rely on accurately measuring timing packet transit delays to adjust the clocks to compute the correct time.

As the need for more accurate time at a program increases, the impact that variable packet delays have on the ability to correct a clock increases as well. To make matters worse, the quality of a clock also effects how well you can synchronize the time. Understanding the problems and how to compensate for them greatly helps in delivering accurate and precise time to clocks and ultimately to an application program.

The difference between the times on two clocks is known as the offset. In timekeeping we strive to keep the offset below a particular value so that we can assign an accuracy value to the time on the clock. Generally in synchronization schemes one clock is more accurate than the other so the offset is tracked relative to the more accurate clock.

The process of setting one clock to another is a matter of exchanging timing packets, computing the offset between a master clock and a slave clock, and making an adjustment to the slave clock (called clock steering when done periodically).

Page 1 of 9

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