An Accurate and Scalable Clock Synchronization System for Commodity Networks

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Background and Motivation

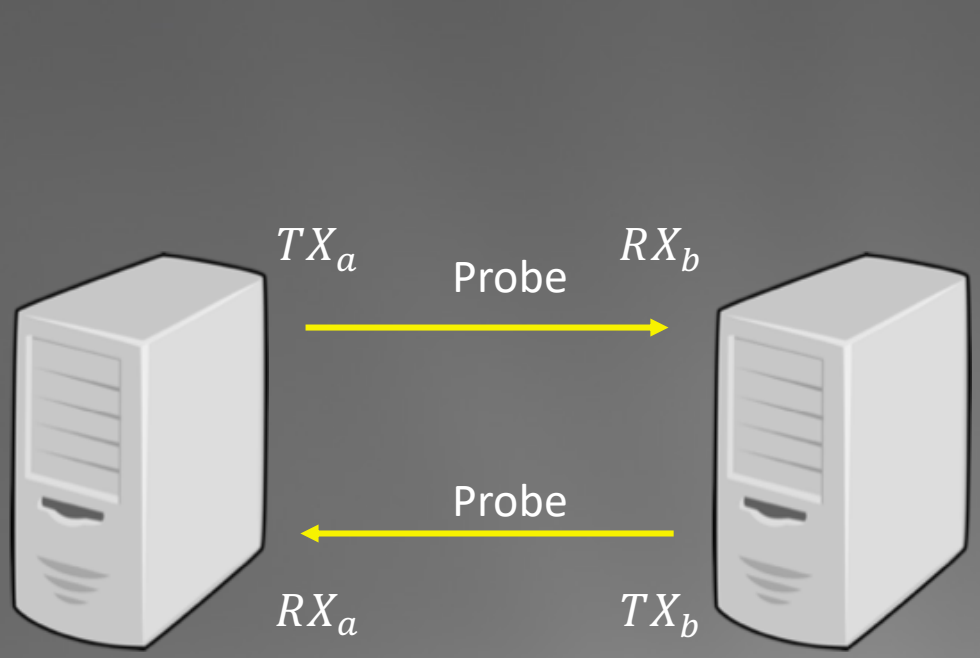
Synchronized clocks are fundamental to the operation of many distributed systems

- Distributed databases: improve performance and consistency
- Software-defined networking: enforce ordering of forwarding rule updates
- Financial systems: guarantee transaction execution order
- Network congestion control: TDMA-like flow scheduling (Fastpass)
- ……

Our goals:

- Synchronize clocks to 10s of nanoseconds in real-time and at scale
- Provide “accurate timestamping” as a fundamental primitive in data centers

Synchronizing clocks with probes



t

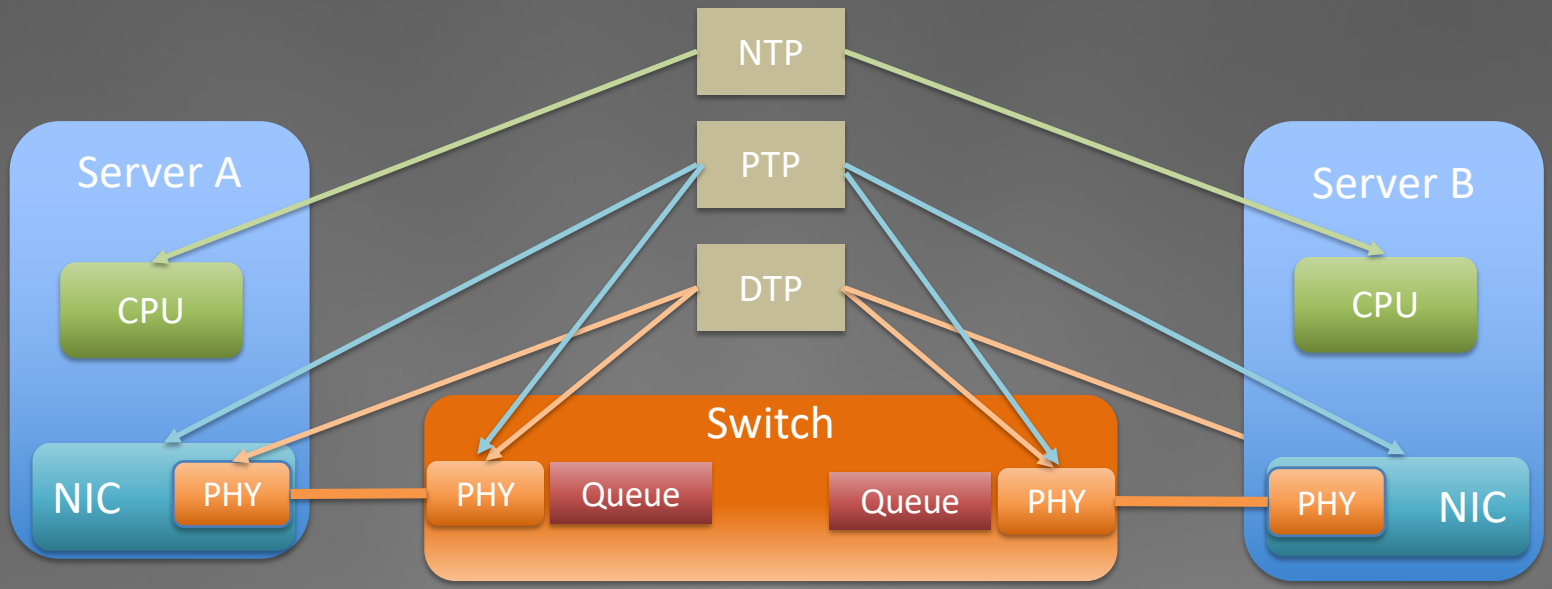
$t_a = t + \Delta t_a$

$t_b = t + \Delta t_b$

All methods of clock sync use these 4 timestamps; main differences:

1. Where to take timestamps?
2. How to process the timestamps?

Where to take timestamps



Huygens

- Uses NIC or CPU timestamps and, respectively, gets ns- and us-level sync accuracy
- *Does not need* timestamps from switches
- is a software-based approach

Huygens: Basic equations

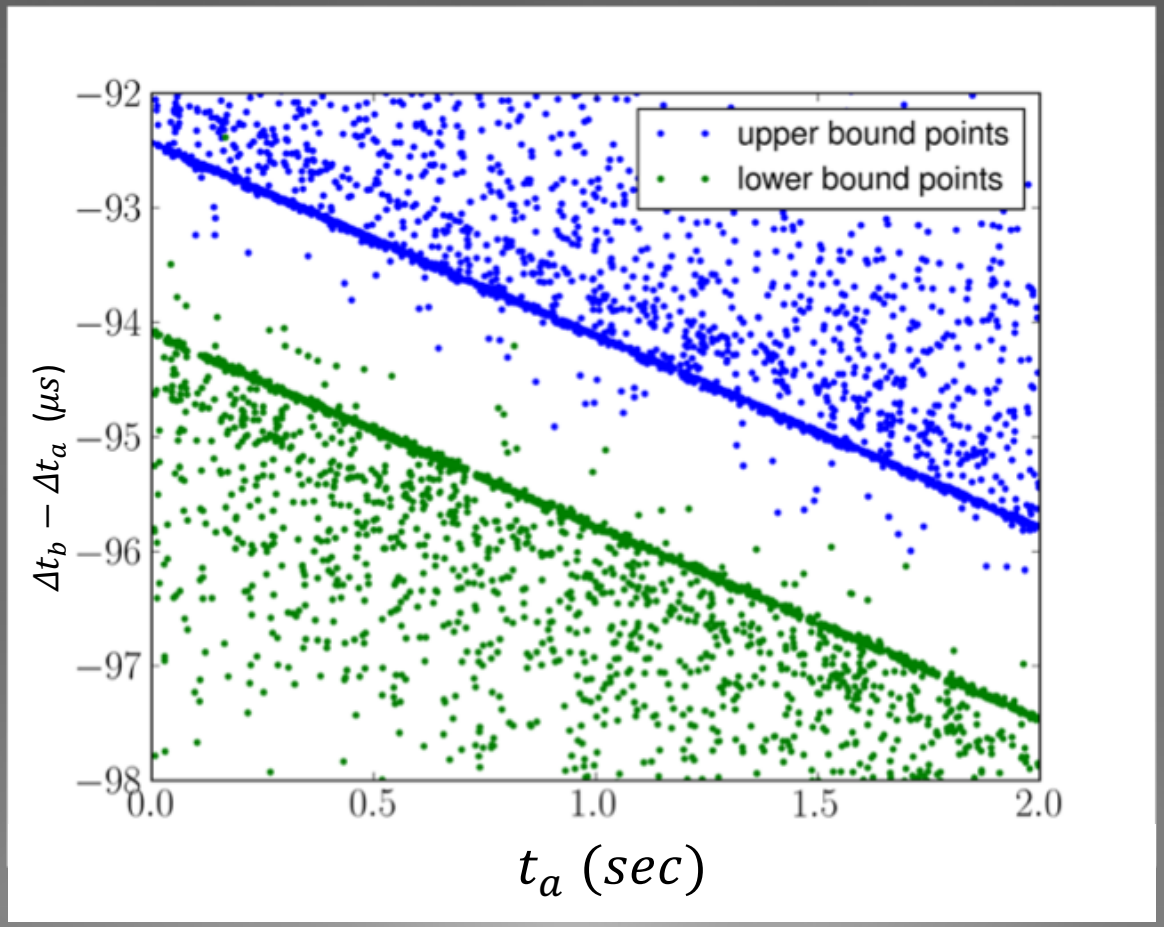
Probe from A to B:

- Receive time = transmit time + delay
- $RX_b - \Delta t_b = TX_a - \Delta t_a + Propogation\ and\ queueing\ delay$
- $\Delta t_b - \Delta t_a = RX_b - TX_a - Propogation\ and\ queueing\ delay$
- $\Delta t_b - \Delta t_a < RX_b - TX_a$

Probe from B to A:

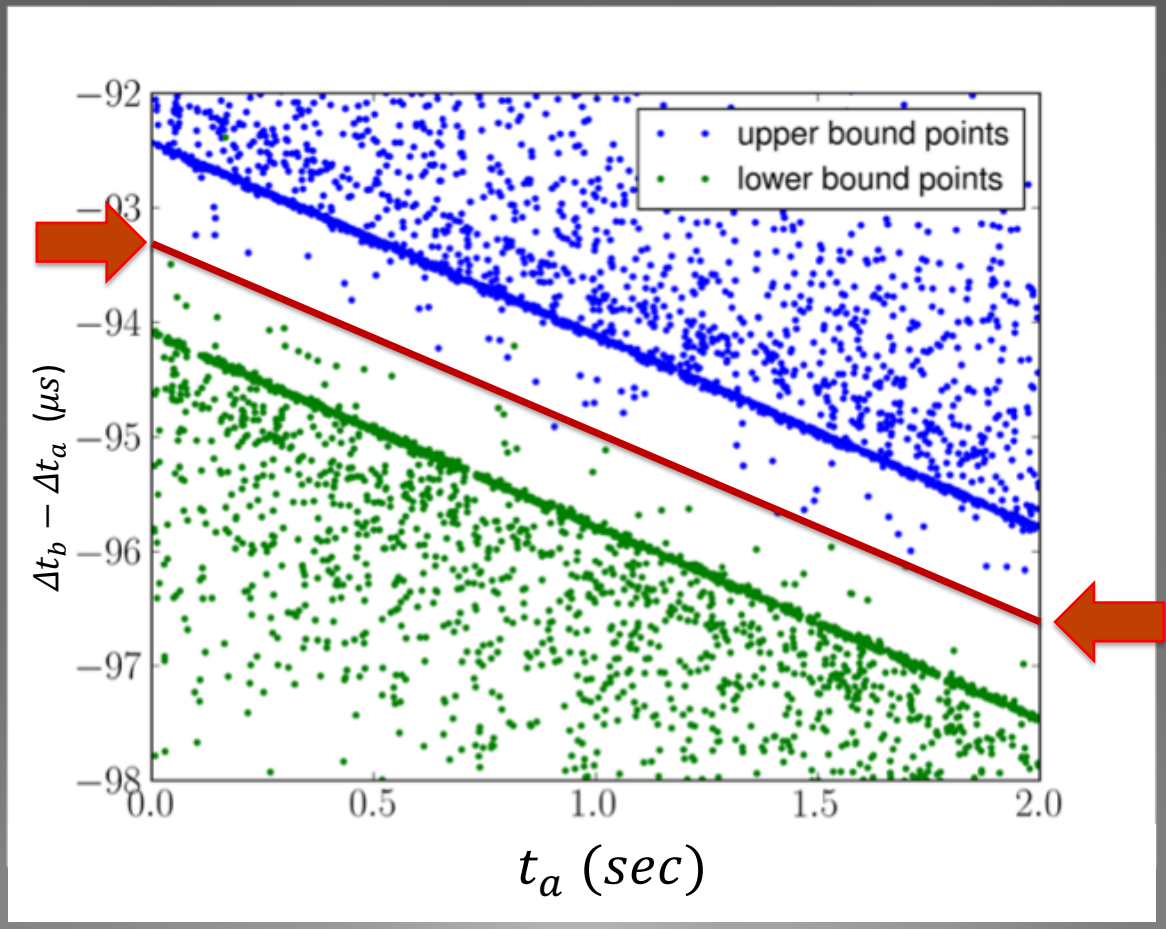
- $\Delta t_b - \Delta t_a > TX_b - RX_a$

Clock bounds over time: Google 40G testbed



Clock bounds over time: Google 40G testbed

Offset: -93.3 us

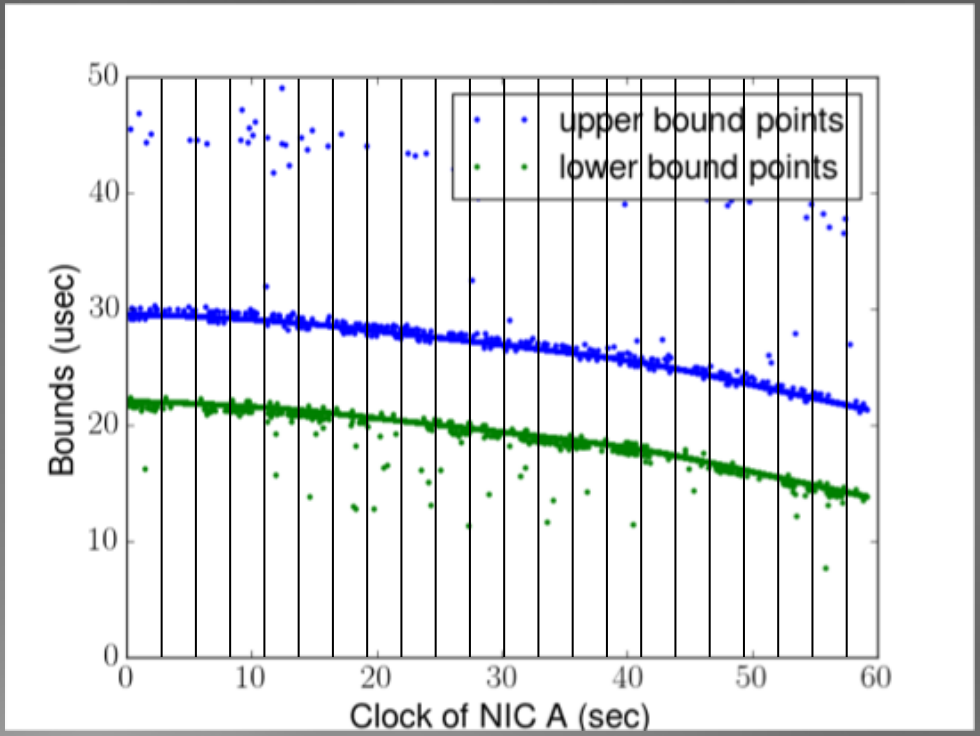


Offset: -96.6 us

Drift: -1.65 us/sec

Nonlinear clock drifts

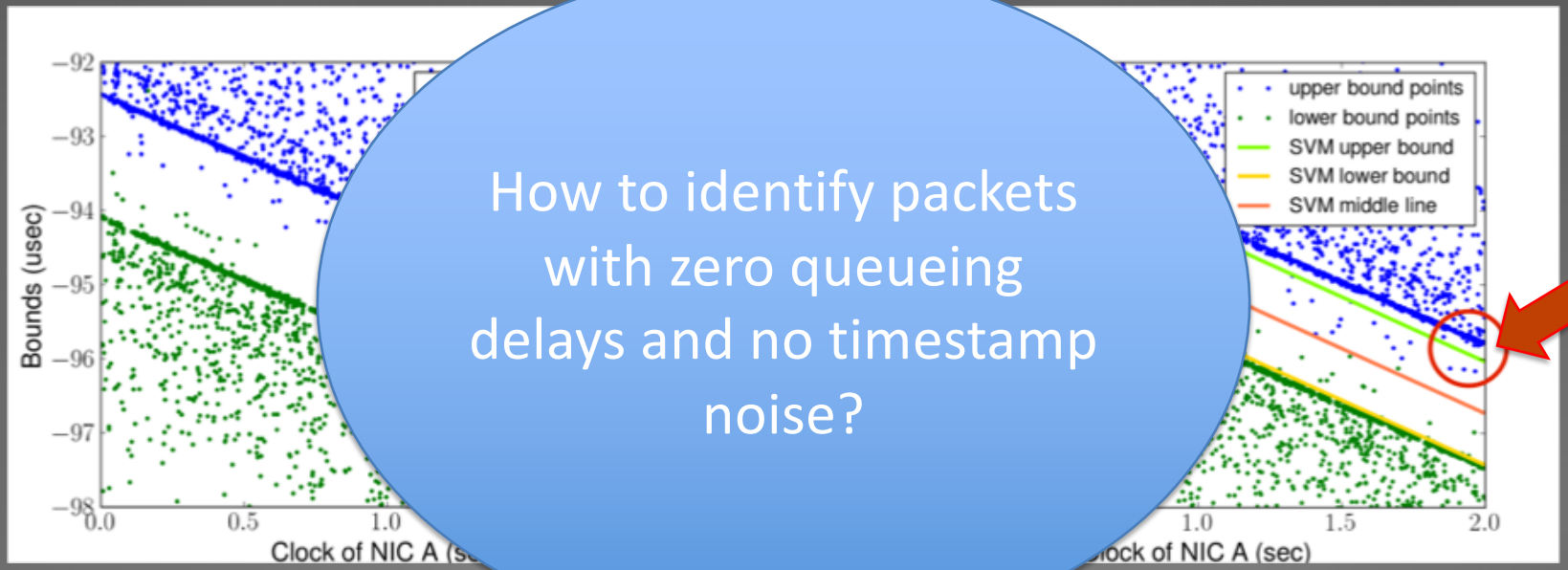
- Clock frequency varies over longer periods of time due to temperature variations
- Solution: Estimate clock offsets every 2-4 seconds since the frequency difference is nearly constant over these intervals



3 key ideas to find the red middle line

- Support vector machine
- Coded probes
- Network effect

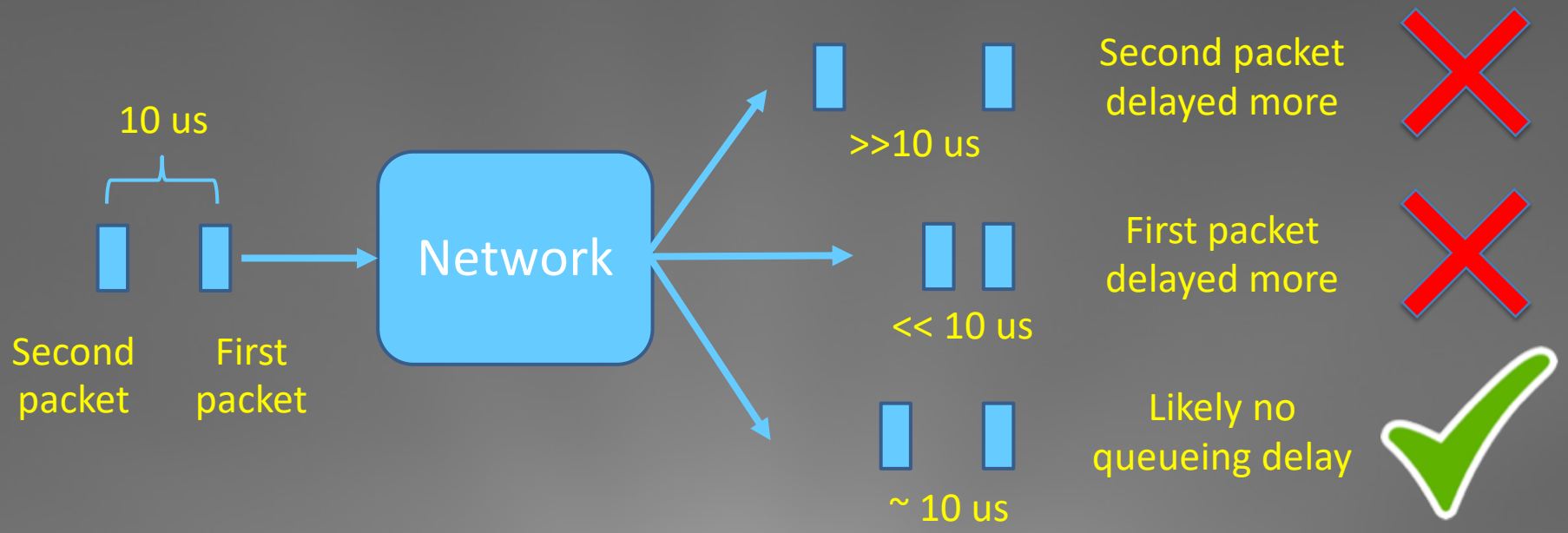
Syncing clocks with SVMs



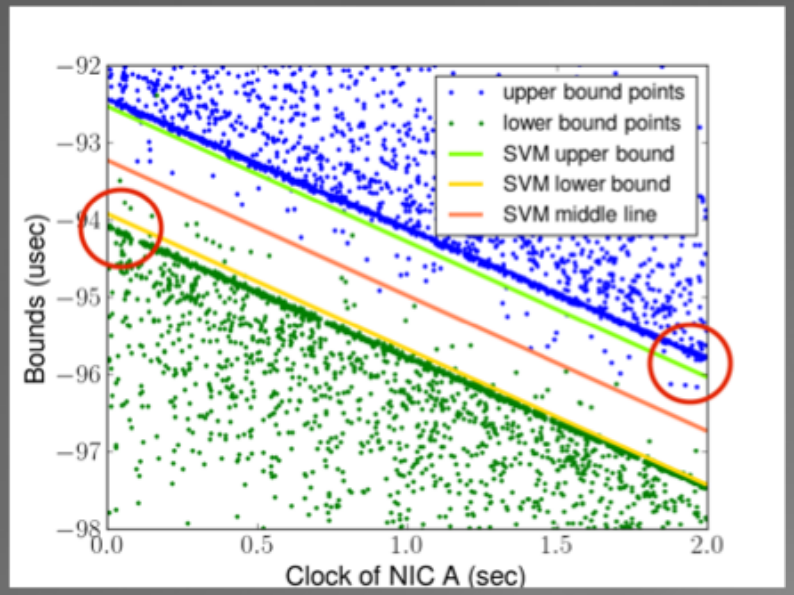
How to identify packets with zero queueing delays and no timestamp noise?

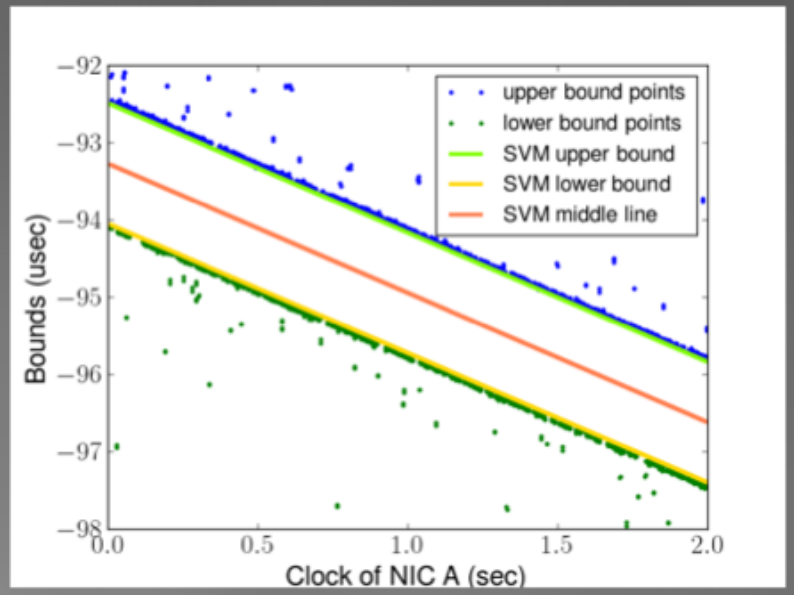
SVM achieves sync accuracy of 300~400 ns. Noisy timestamps cause synchronization errors!

Coded probes



Coded probes

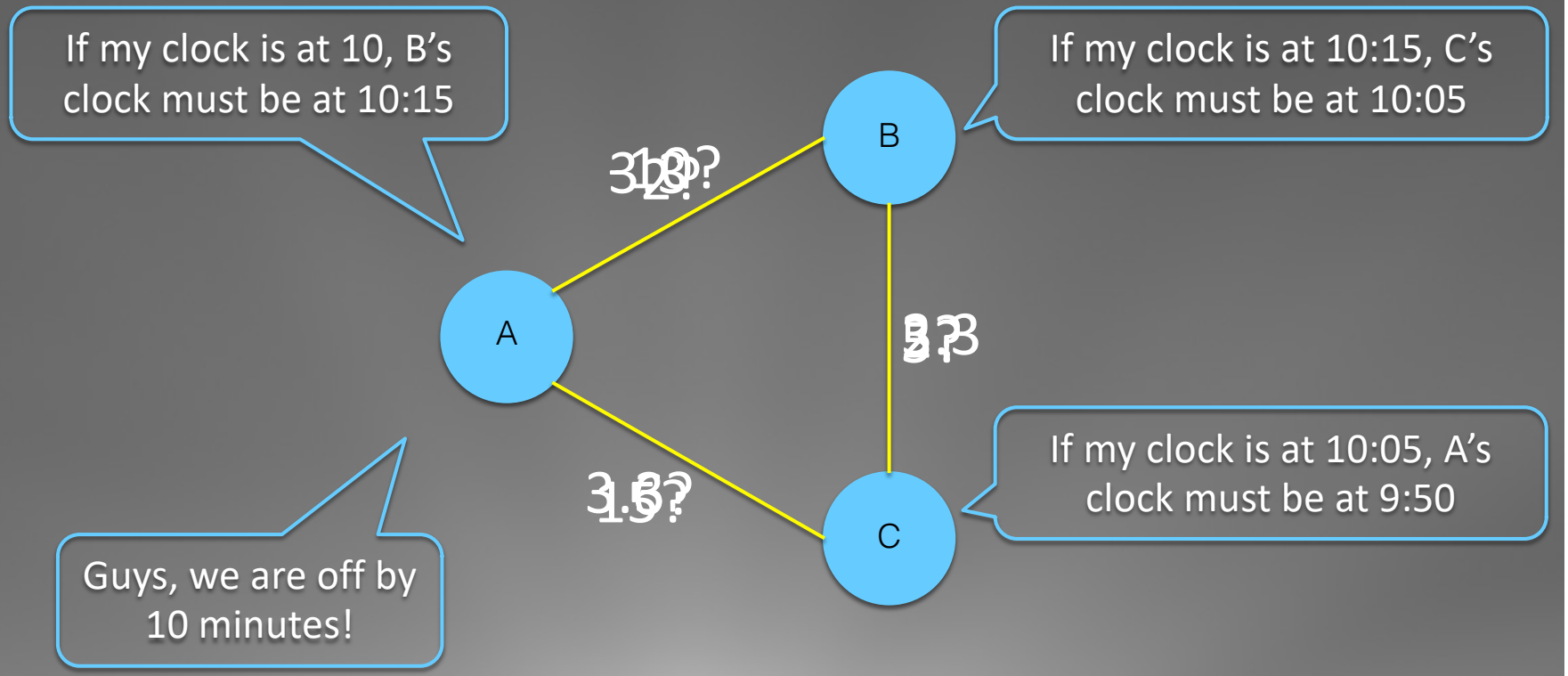




Empirically, coded probes filter out 90% of bad data and reduce the clock sync error by a factor of 4.

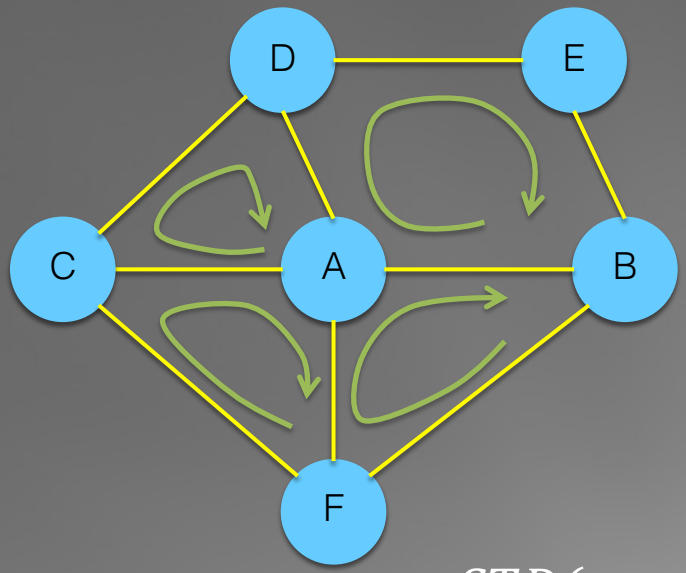
The network effect

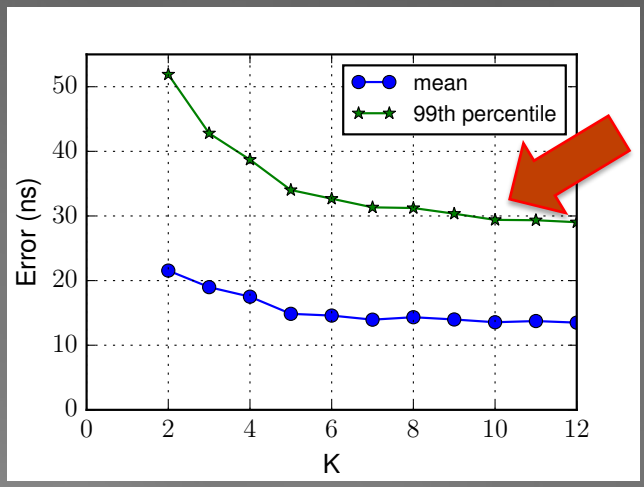
-- identifying the error



The network effect

-- fixing the error





$$STD(err\ after\ N.E.) \approx \frac{1}{\sqrt{K}} STD(err\ before\ N.E.)$$

Pilots and deployments

Google – Jupiter testbed

- 3-stage 40Gb/s Clos network
- 20 racks, 237 servers

A 10G-40G production network

- 5-stage Clos network

Stanford testbed

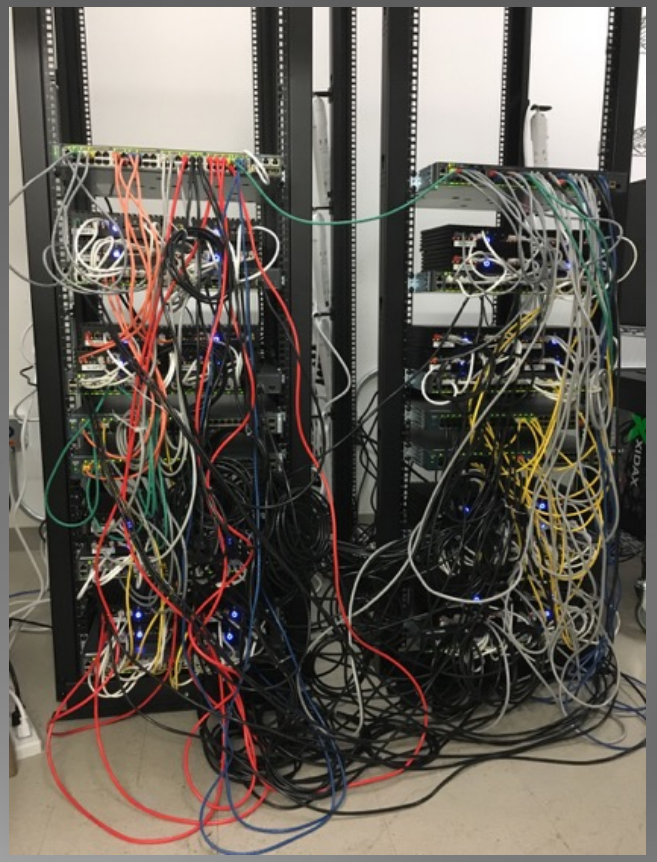
- 2-layer 1G network
- 8 racks, 128 servers
- Cisco 2960 and Cisco 3560 switches

Many financial firms

Stanford Testbed

Stanford

- 2-stage 1Gb/s Clos network
- 8 racks, 128 servers



NetFPGA verification

- Single NetFPGA acts as 4 independent NICs sharing the same clock
- Different NetFPGAs synced with I/O pins

Comparison with NTP

	NTP (with NIC timestamps)		Huygens	
	Mean abs. error	99th percentile abs. error	Mean abs. error	99th percentile abs. error
0% load	177.7 ns	558.8 ns	10.2 ns	18.5 ns
40% load	77,975 ns	347,638 ns	11.2 ns	22.0 ns
80% load	211,011 ns	778,070 us	14.3 ns	32.7 ns

Conclusion

- Huygens synchronizes
  - NIC clocks to within 10s of nanoseconds
  - CPU/VM/container clocks to within a few microseconds
- It is a software-based end-to-end system, and is lightweight and scalable (bandwidth, CPU overhead)
- Tick Tock Networks commercializing the tech
  - Contact hello@ticktocknetworks.com