

# On Explicit In-Band Measurement

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Based in part on ongoing work with Mark Allman (ICSI) and Rob Beverly (NPS)



measurement and architecture for a middleboxed internet

**measurement**

**architecture**

**experimentation**



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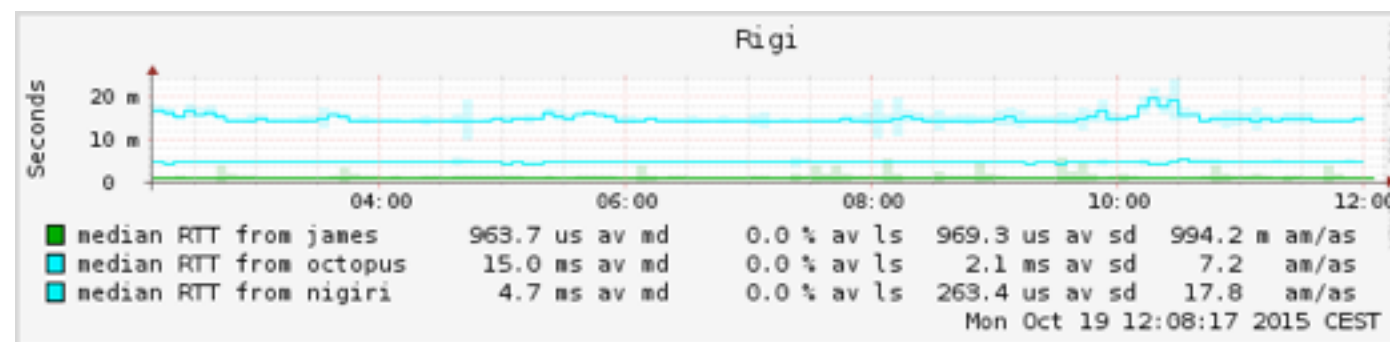
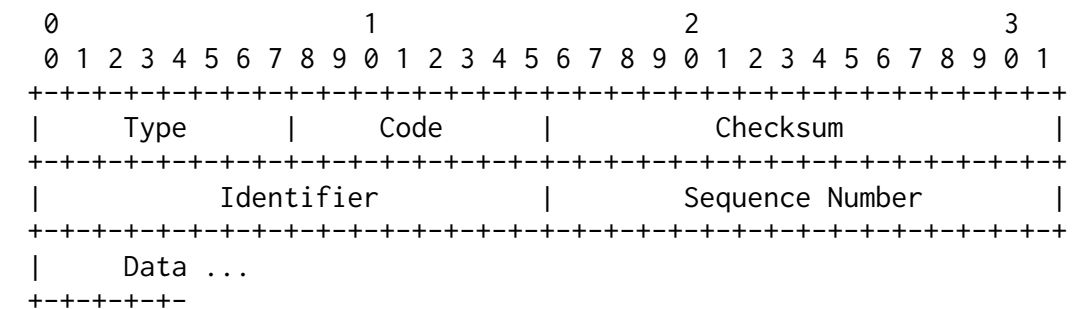
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# In the beginning...

- ...there was ping, and it was good.
  - (still the only explicit measurement facility in the stack.)
- Periodic measurement via cron
- Visualization and storage with rrdtool
- ~~Distributed measurement via telnet~~
- Distributed measurement via ssh
- Glue everything together with perl

Echo or Echo Reply Message



Actually, this is pretty much SmokePing.



# Everything after ping is a hack

- And even ping doesn't work that well:
  - ICMP blocked, different codepaths, ECMP routing.
- Traceroute: overload ICMP Time Exceeded messages to infer Layer 3 topology
  - Same problems as ping, but ECMP is worse.
- TCP throughput testing: how many bytes sent / sec?
  - Unreliable as an indication of network conditions [1].
- Netflow/IPFIX: watch the flows go by and measure
  - Passive RTT measurement [2] broken by ACK optimizations [3], etc.
  - Inflexible, low-rate sampling, even though we know better [9].



# Let's ask a different question...

- ***What if we had designed measurement into the stack as a first-order service?***
  - “Big five” metrics (loss, latency, jitter, rate, reordering) as socket properties, with transport MPI/API for access.
  - You don't need much more for QoE-relevant network metrics
  - Header fields explicitly defined for measurability
    - Constant-rate timestamps for latency/jitter
    - Transport-independent exposure of loss/reordering
    - Exposure in header allows passive as well as endpoint measurement
  - Detection of header manipulation (required for dynamic transport selection)
  - Explicit endpoint control over measurement exposure
- But we didn't, so ***how can we get there from here?***



# How close are we to the goal?

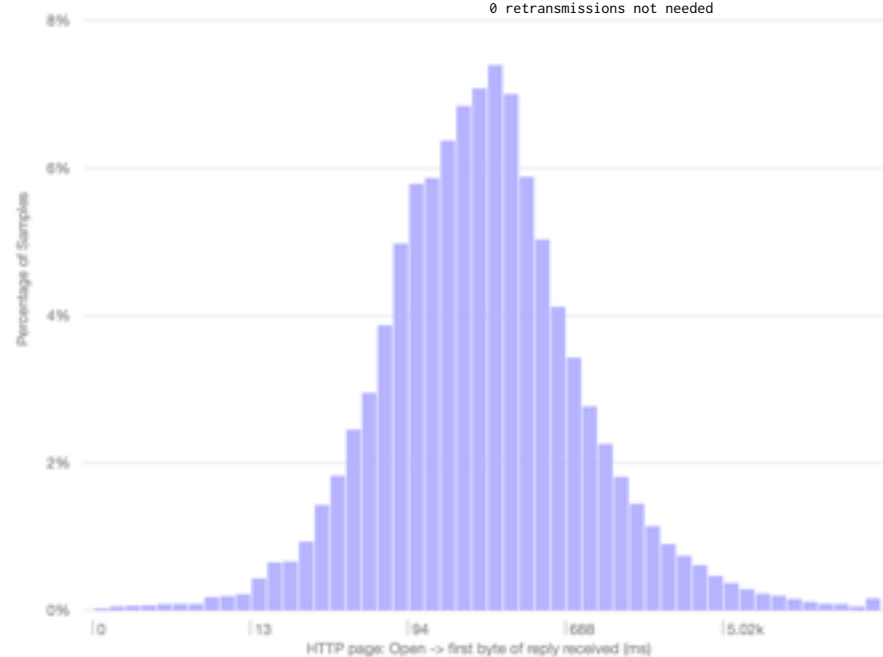
- TCP seq/ack number analysis for loss/reorder?
  - Always exposed, and roundly abused in the Internet
  - Only works with TCP
- TCP TSOPT timestamps for latency/jitter
  - Only works with TCP, enabled on about 30% of hosts
  - No application hooks for *explicit* enablement
  - Need heuristics to estimate sender clock rate
- Checksums provide poor header manipulation detection



# How close are we to the goal?

```
% netstat -s -p tcp
tcp:
136072 packets sent
 36226 data packets (12605543 bytes)
 52 data packets (19892 bytes) retransmitted
 1 resend initiated by MTU discovery
 86569 ack-only packets (49 delayed)
 0 URG only packets
 0 window probe packets
 7894 window update packets
 5277 control packets
 0 data packets sent after flow control
 6 checksummed in software
   6 segments (339 bytes) over IPv4
   0 segments (0 bytes) over IPv6
164742 packets received
 34764 acks (for 12593499 bytes)
 1246 duplicate acks
 0 acks for unsent data
 143462 packets (152392523 bytes) received in-sequence
 62 completely duplicate packets (49185 bytes)
 0 old duplicate packets
 0 received packets dropped due to low memory
 0 packets with some dup. data (0 bytes duped)
 434 out-of-order packets (532085 bytes)
 0 packets (0 bytes) of data after window
 0 window probes
 19 window update packets
 286 packets received after close
 0 bad resets
 0 discarded for bad checksums
 6 checksummed in software
   6 segments (496 bytes) over IPv4
   0 segments (0 bytes) over IPv6
 0 discarded for bad header offset fields
 0 discarded because packet too short
2736 connection requests
 9 connection accepts
 0 bad connection attempts
 0 listen queue overflows
2611 connections established (including accepts)

2823 connections closed (including 50 drops)
 96 connections updated cached RTT on close
 96 connections updated cached RTT variance on close
 5 connections updated cached ssthresh on close
 0 embryonic connections dropped
 70310 segments updated rtt (of 31390 attempts)
 83 retransmit timeouts
 0 connections dropped by rexmit timeout
 0 connections dropped after retransmitting FIN
 0 persist timeouts
 0 connections dropped by persist timeout
 40 keepalive timeouts
 40 keepalive probes sent
 0 connections dropped by keepalive
 78 correct ACK header predictions
 126450 correct data packet header predictions
 28 SACK recovery episodes
 2 segment rexmits in SACK recovery episodes
 1454 byte rexmits in SACK recovery episodes
 69 SACK options (SACK blocks) received
 303 SACK options (SACK blocks) sent
 0 SACK scoreboard overflow
 0 LRO coalesced packets
 0 times LRO flow table was full
 0 collisions in LRO flow table
 0 times LRO coalesced 2 packets
 0 times LRO coalesced 3 or 4 packets
 0 times LRO coalesced 5 or more packets
 0 limited transmits done
 28 early retransmits done
 1 time cumulative ack advanced along with SACK
 0 probe timeouts
 0 times retransmit timeout triggered after probe
 0 times fast recovery after tail loss
 0 times recovered last packet
1606 connections negotiated ECN
 0 times congestion notification was sent using ECE
 21 times CWR was sent in response to ECE
 0 times packet reordering was detected on a connection
 0 times transmitted packets were reordered
 0 times fast recovery was delayed to handle reordering
 0 times retransmission was avoided by delaying recovery
 0 retransmissions not needed
```

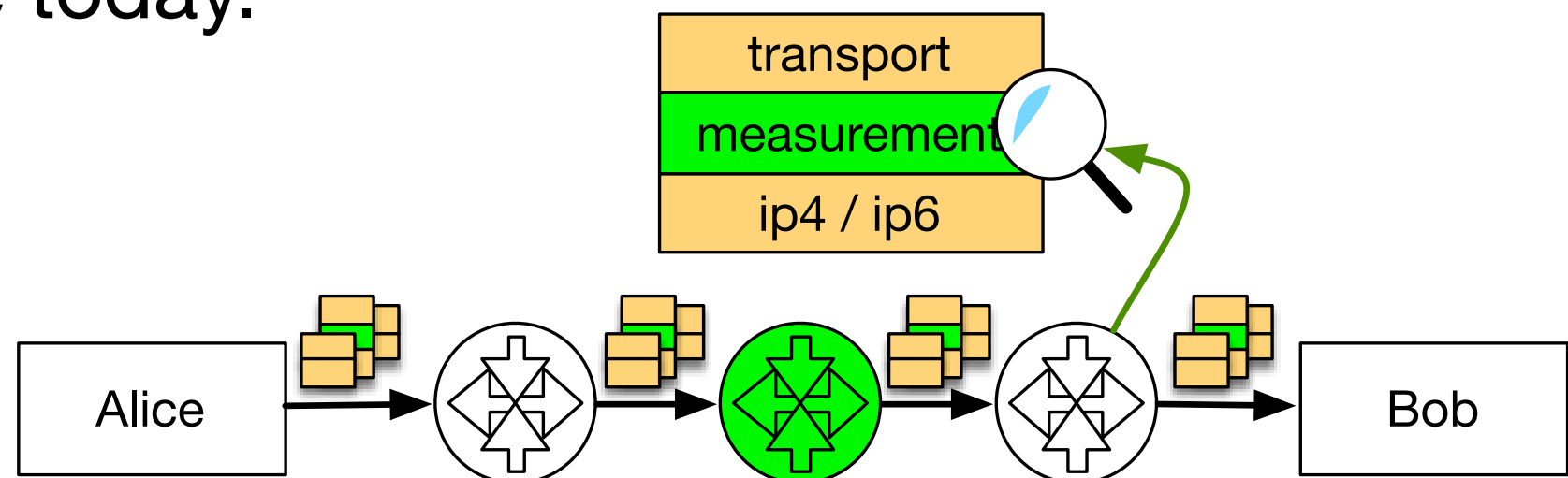


- Modern networking stacks are heavily instrumented
- `netstat -s -p tcp` on OSX yields 82 event counters.
- Application instrumentation also includes collection
- e.g. [telemetry.mozilla.org](https://telemetry.mozilla.org)
- Phase 1: generalizing and standardizing access to data we already have.
- e.g. mPlane [4]



# A Measurement Layer

- Phase 2: define a “measurement layer” for explicit exposure of information as part of **normal protocol exchanges**.
- e.g. IPv6 PDM DO [5], HICCUPS [6].
- You don’t have to instrument every packet, every endpoint, or every router to get *much* better information than we have today.





# A Measurement Layer

- Insight: shifting the burden to analysis-time **reduces the runtime burden.**
- Cumulative nonce ( $n_{tx}, \sum n_{rx}$ ) added to each / sample of packets [8] allows loss rate estimation.
- Timestamp echo ( $t_{tx}, t_{rx}, t_{\Delta rx}$ ) with constant-rate clock [7] and remote delta allows latency and jitter estimation.
- Protected header hash echo ( $h_{tx}, h_{rx}$ ) allows detection of header manipulation [6].
  - Shared-secret protected hashes allow secure detection by endpoints
  - Unprotected hashes detect only accidents
- Insight: Each of these can work at **low sampling rates for large flows.**
  - How much smarter can we be for less than one bit per packet?





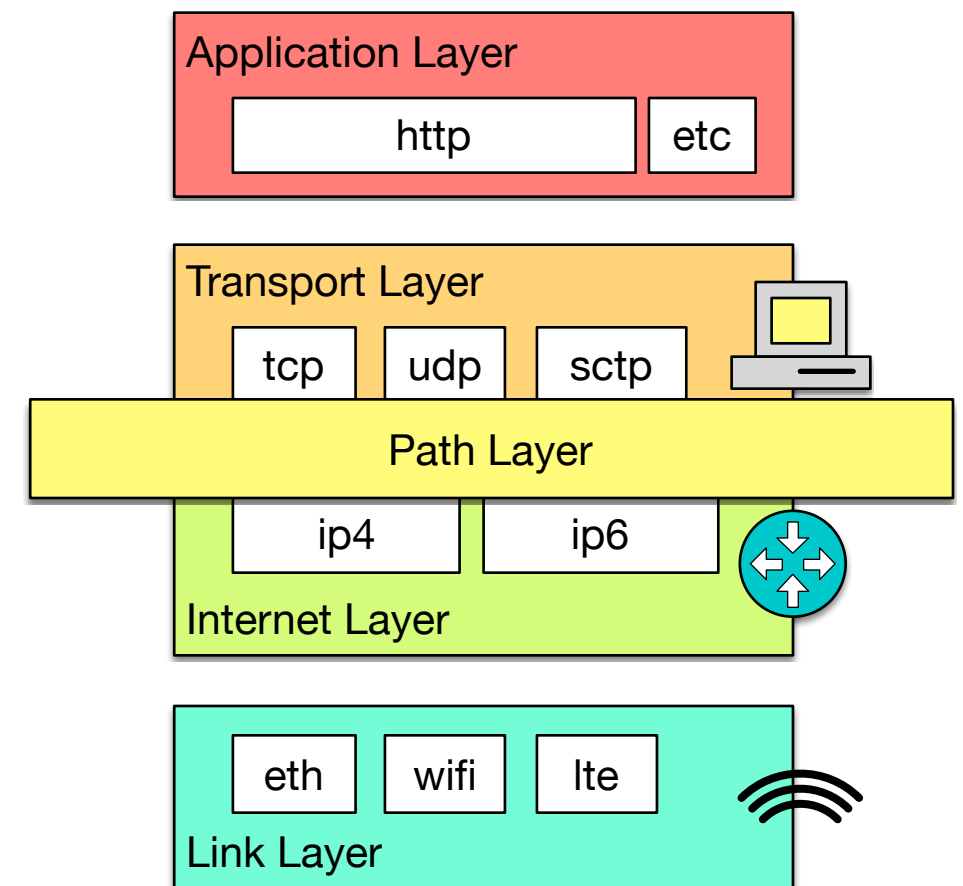
# Sounds great. Let's do it!

- Now we just have to find the bits...
- IPv6 Destination Options?
  - not very deployable, may be nearing deprecation, v6 only.
- IPv4 options?
  - even less deployable, v4 only.
- in the TCP header?
  - Options hard to deploy, TCP only, measurement not properly layer 4.
  - HICCUPS reclaimed a few bits from the header itself
- ***Adding new layers to the stack is hard.***



# Adding new layers to the stack for fun and profit

- Our “measurement layer” is a special case of a more general problem:
  - Internet layer is hop-by-hop, stateless
  - Transport layer is end-to-end, stateful
  - Where do all of the complex, stateful, not necessarily end-to-end functions we’ve built go?
- Since we already have a “***path layer***”, let’s make it explicit:
  - Encryption of transport layer and above to enforce end-to-end-ness
  - Explicit exposure from endpoints to the path of appropriate information





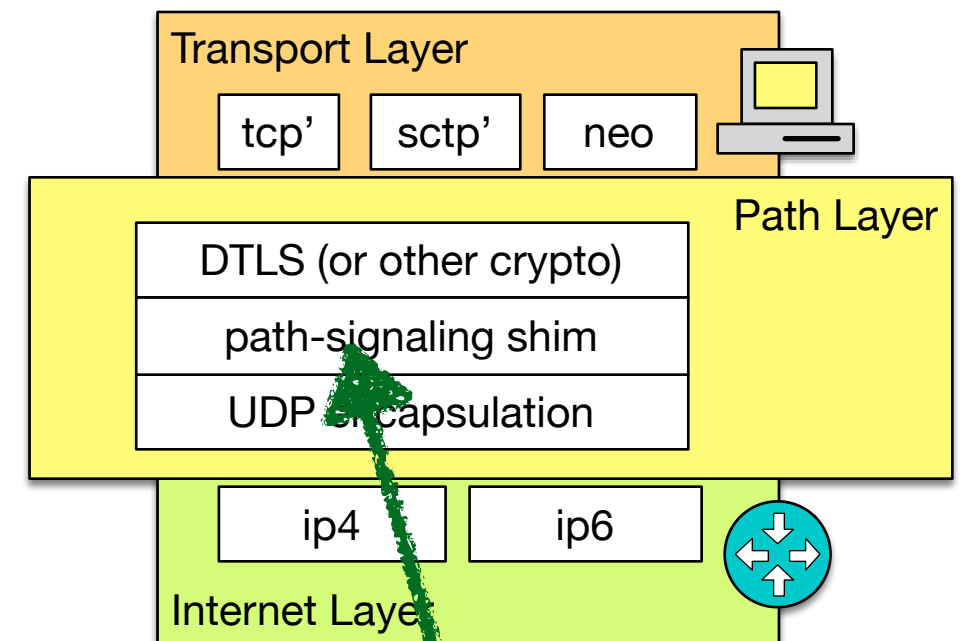
# How to implement a path layer

- You can't add a new layer that today's routers won't route.
  - NAT: hard\* to deploy protocols other than TCP or UDP
- Need to support userland implementation for experimentation and early deployment.
- Conclusion: “path layer” headers as shim over UDP
  - Initial findings: 3-6% of Internet hosts may have broken or no UDP connectivity, so we'll need a backup.
  - Define path layer headers so that other future encapsulations (e.g. IPv6 DO) are possible?



# Path layer requirements

- Exposure to the path of information the endpoints decide the path needs
- Cryptographic protection of the rest of the transport layer
- Packets grouping for property binding, on-path state management
- Efficient per-packet signaling
- Integrity protection for exposed headers, allowing modification with endpoint permission
- Protection against trivial abuse of UDP
- Work in progress: draft-trammell-spud-req



measurement  
goes here

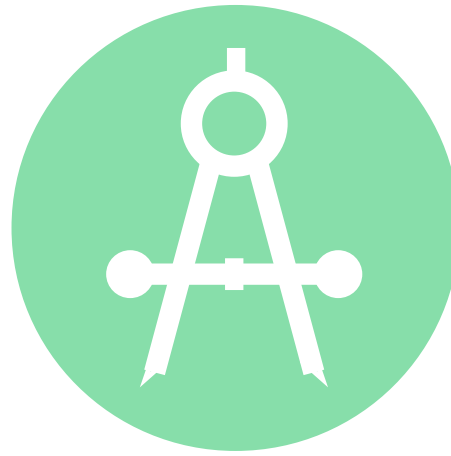
# The MAMI Project

Measurement and Architecture for a Middleboxed Internet



**measurement**

of deployed middleboxes



**architecture**

for middlebox cooperation



**experimentation**

of use case applicability  
and deployability

- Strong interaction with relevant standards organizations for impact on deployment
- FIRE testbed (MONROE) support for measurement as well as experimentation, especially on mobile broadband access networks
- Learn more at <http://mami-project.eu/>

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## In conclusion...



- Two steps to put measurement where it belongs in the stack:
  1. better access to instrumentation we already have
  2. build a layer to expose information explicitly intended for measurement to amplify our ability to measure.
- Adding a layer to the stack for middlebox cooperation gives us the ability to deploy step 2.
  - We believe this is possible atop UDP encapsulation.
  - Work in progress: watch IETF SPUD, MAPRG; [mami-project.eu](http://mami-project.eu).
- Questions? <{trammell, mirja.kuehlewind}@tik.ee.eth.ch>

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# References



- [1] draft-ietf-ippm-model-based-metrics (IETF IPPM WG Internet-Draft)
- [2] Trammell et al “On Inline Data Integrity Signals for Passive Measurement”, TMA 2014
- [3] Ding et al “TCP Stretch Acknowledgements and Timestamps: Findings and Implications for Passive RTT Measurement”, Comput. Commun. Rev. 45(3), Jul. 2015.
- [4] draft-trammell-mplane-protocol (IETF individual Internet-Draft)
- [5] draft-ietf-ippm-6man-pdm (IETF IPPM WG Internet-Draft)
- [6] Craven et al “A middlebox-cooperative TCP for a non end-to-end Internet”, SIGCOMM 2014.
- [7] draft-trammell-tcpm-timestamp-interval (IETF individual Internet-Draft)
- [8] Savage et al “TCP congestion control with a misbehaving router”, Comput. Comm. Rev. 29(5), Oct. 1999.
- [9] Estan et al “Building a better NetFlow”, SIGCOMM 2004.

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# Backup

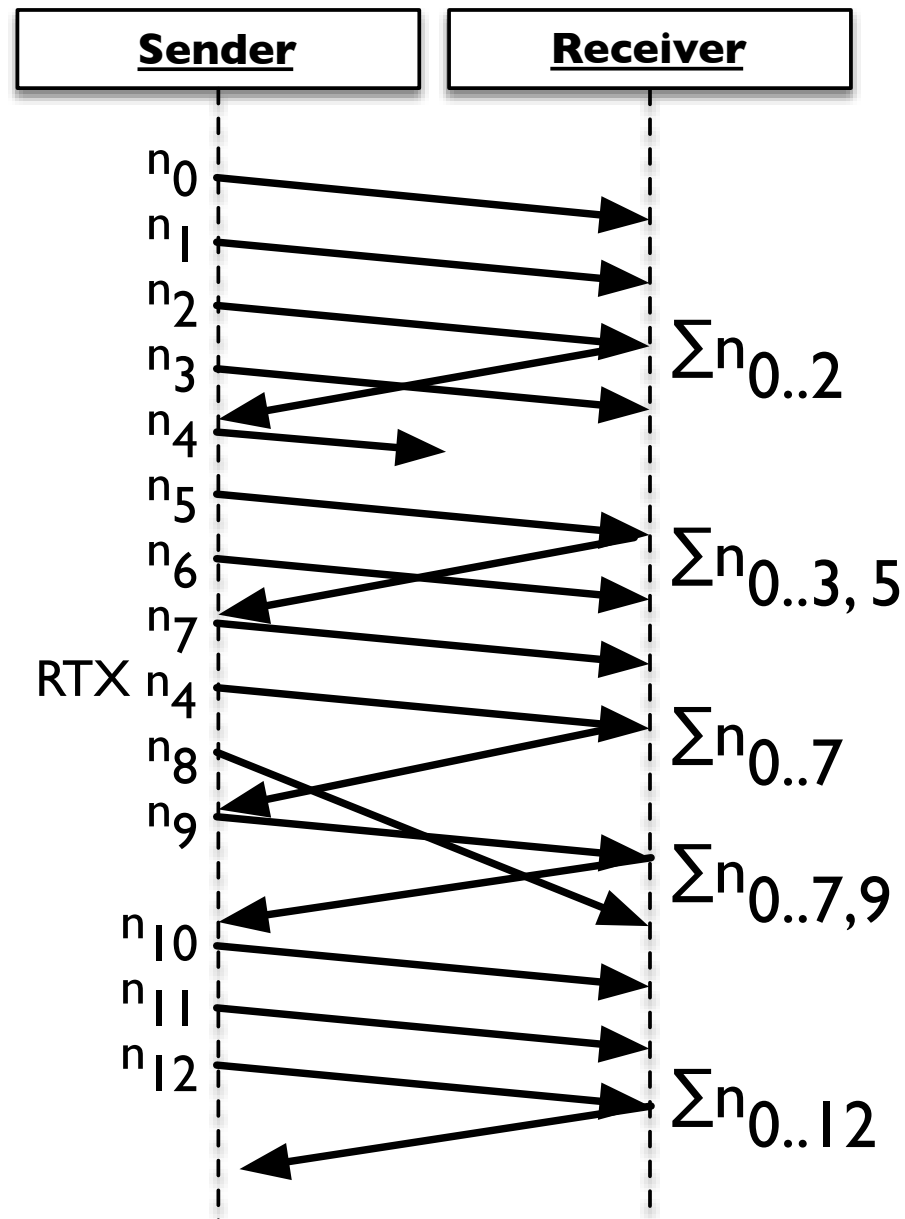






# Measurement Primitives Illustrated

## Cumulative Nonce



## Delta Timestamp Echo

