

On Explicit In-Band Measurement

Brian Trammell and Mirja Kühlewind, ETH Zürich

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



measurement and architecture for a middleboxed internet

measurement

architecture

experimentation



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 688421. The opinions expressed and arguments employed reflect only the authors' view. The European Commission is not responsible for any use that may be made of that information.



Supported by the Swiss State Secretariat for Education, Research and Innovation under contract number 15.0268. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Swiss Government.

In the beginning...





In the beginning...

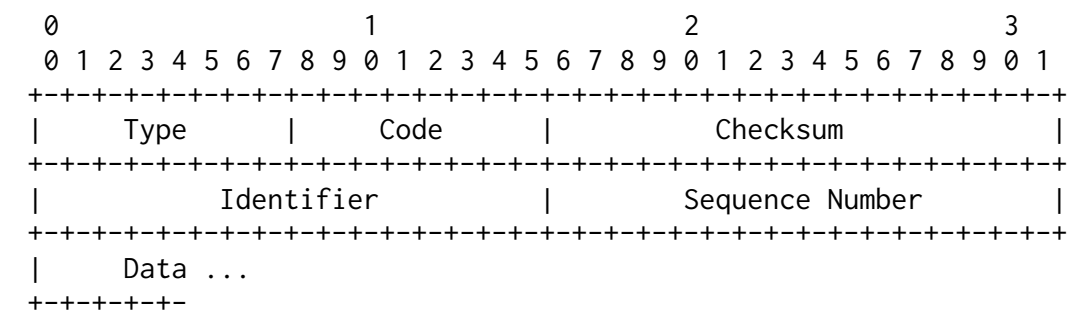
- ...there was ping, and it was good.



In the beginning...

- ...there was ping, and it was good.

Echo or Echo Reply Message

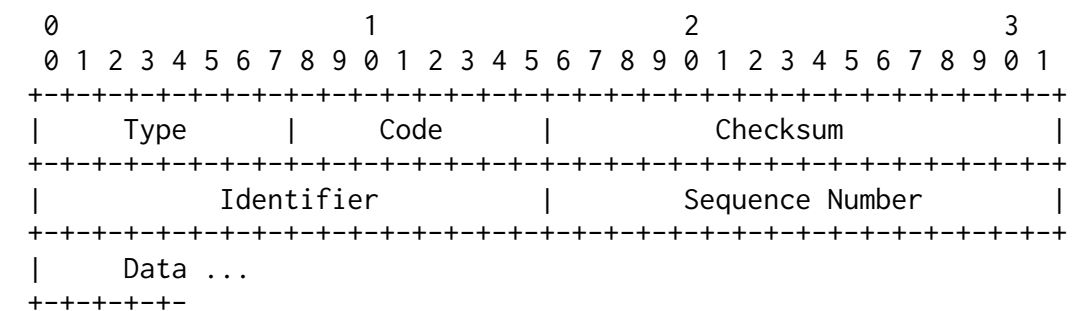




In the beginning...

- ...there was ping, and it was good.
- (still the only explicit measurement facility in the stack.)

Echo or Echo Reply Message

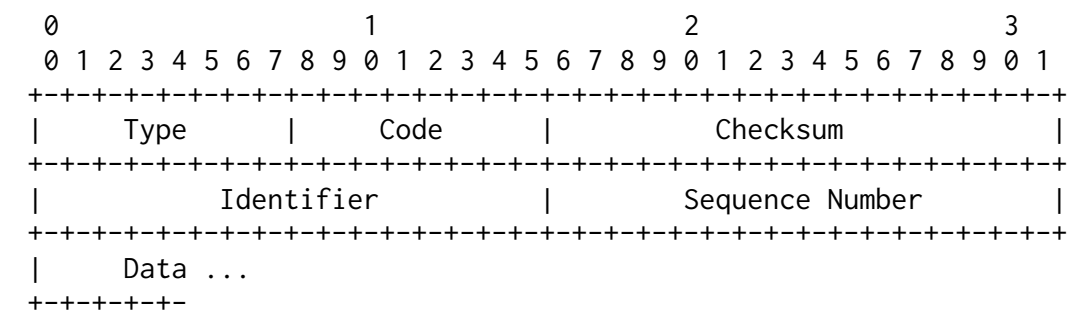




In the beginning...

- ...there was ping, and it was good.
 - (still the only explicit measurement facility in the stack.)
- Periodic measurement via cron

Echo or Echo Reply Message

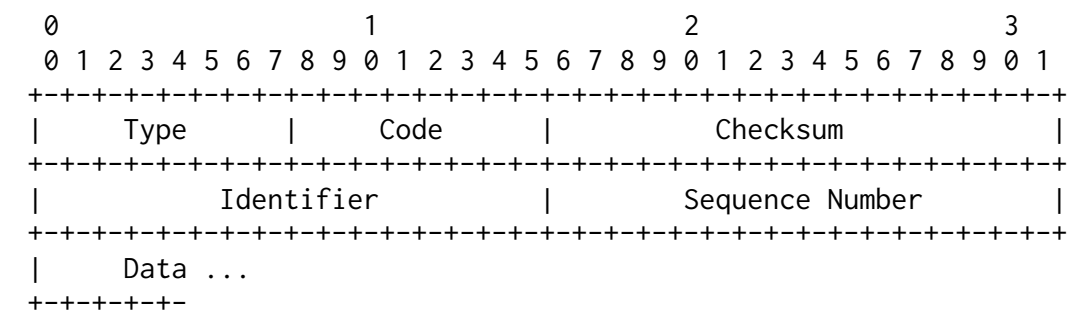




In the beginning...

- ...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

Echo or Echo Reply Message

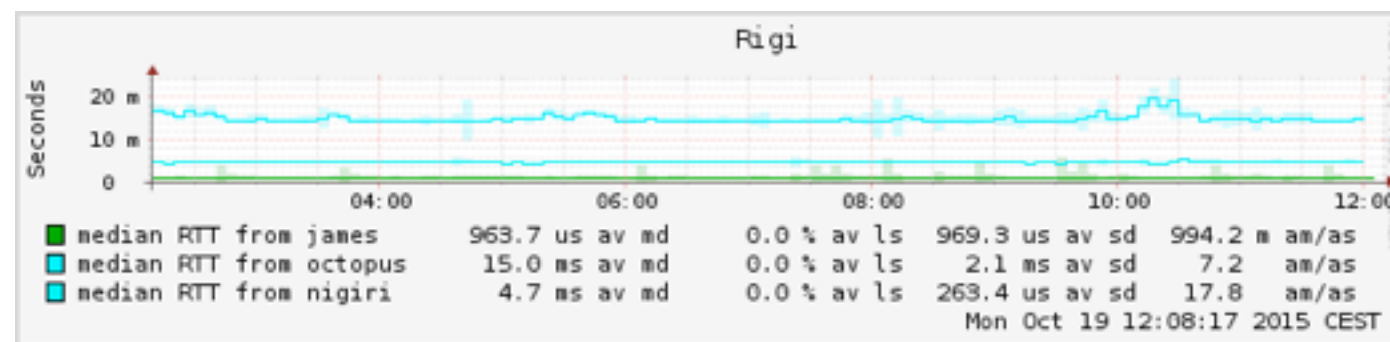
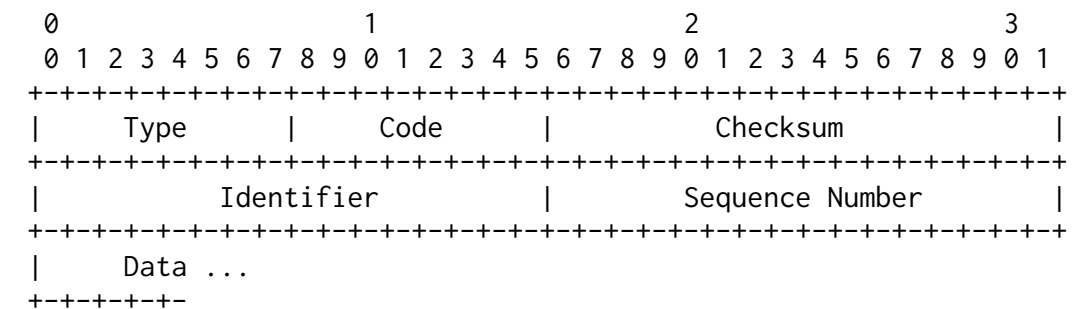




In the beginning...

- ...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

Echo or Echo Reply Message

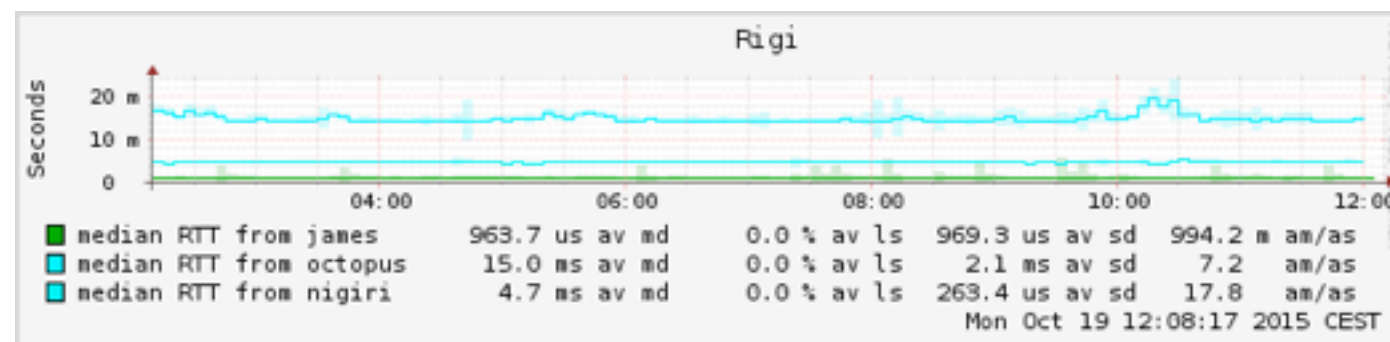
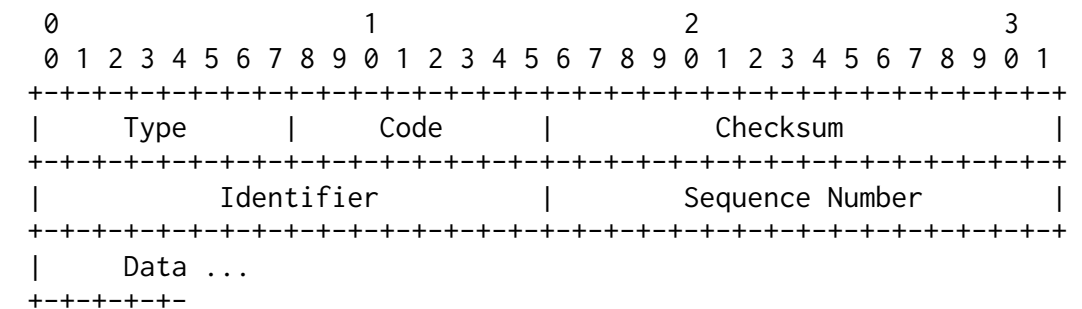




In the beginning...

- ...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

Echo or Echo Reply Message

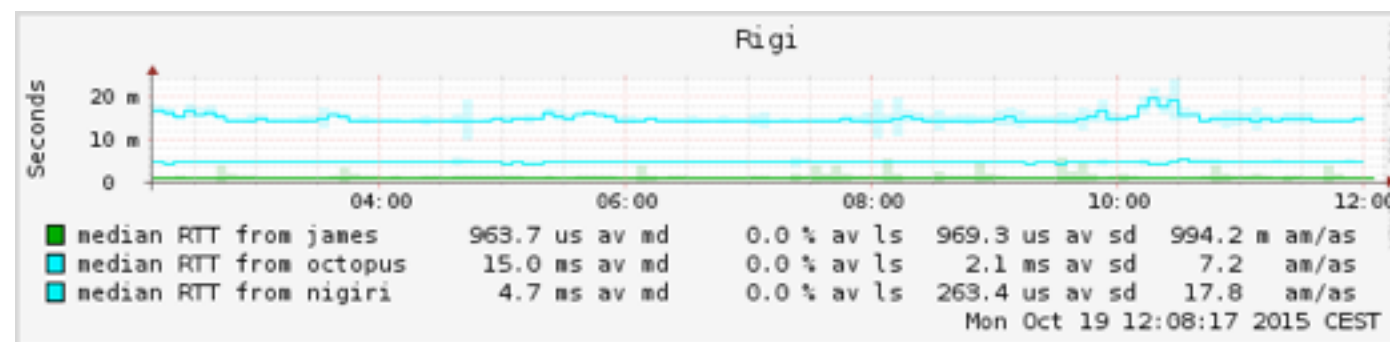
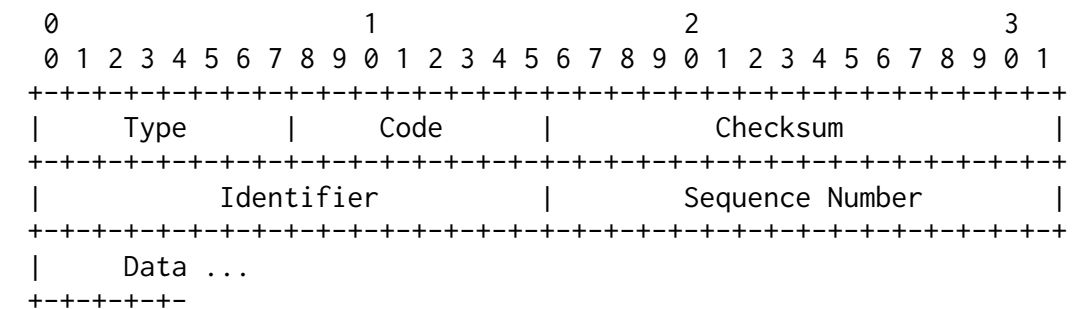




In the beginning...

- ...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~~

Echo or Echo Reply Message

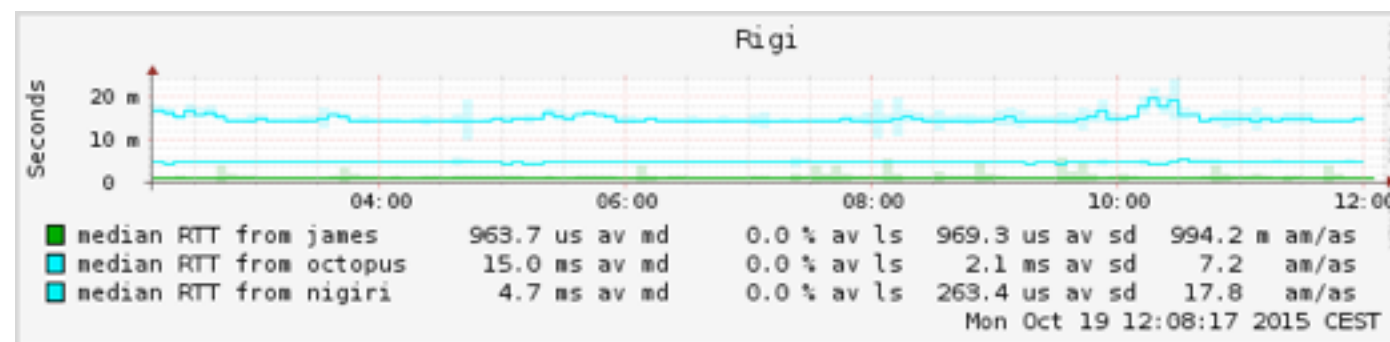
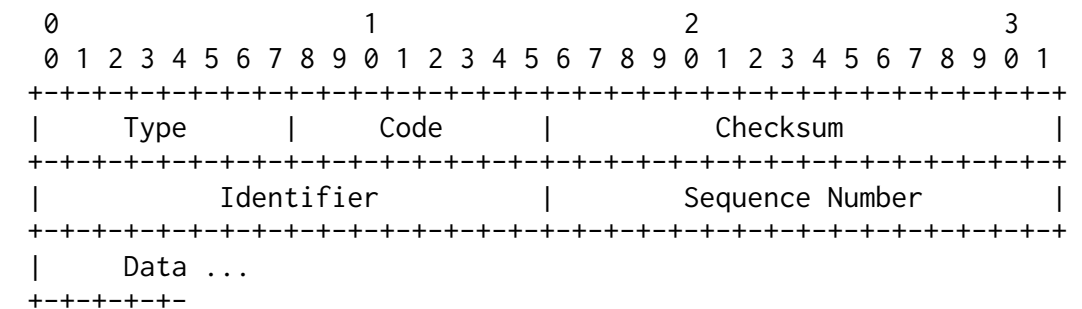




In the beginning...

- ...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

Echo or Echo Reply Message

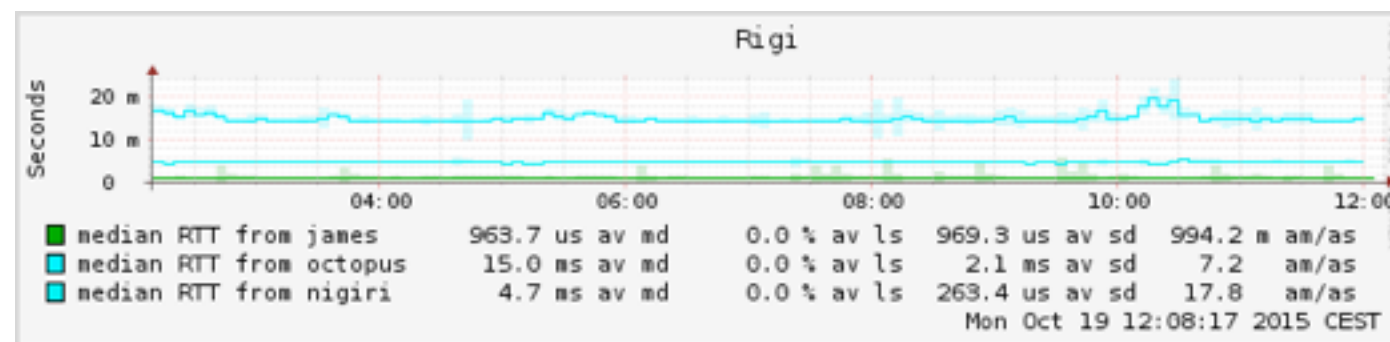
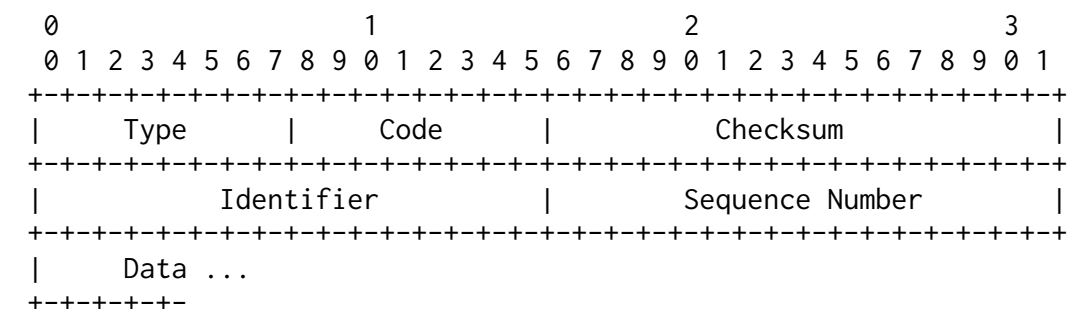




In the beginning...

- ...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

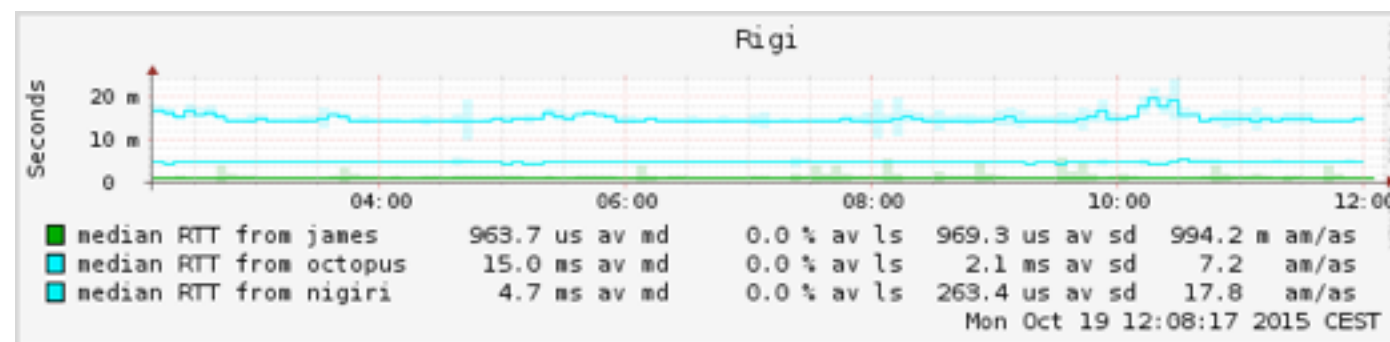
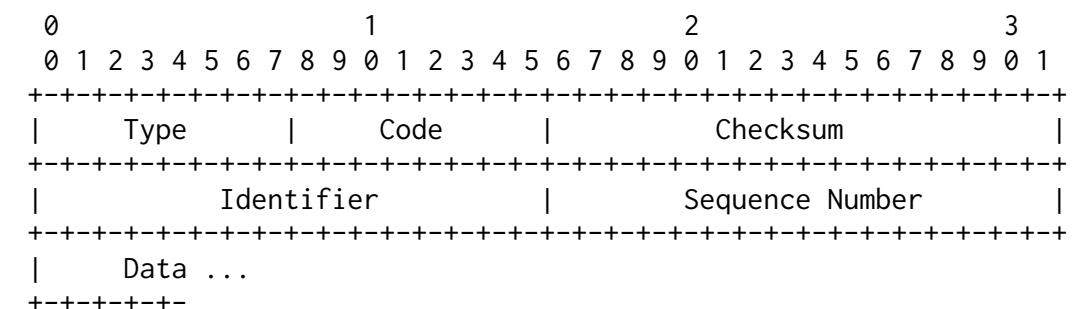




In the beginning...

- ...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?

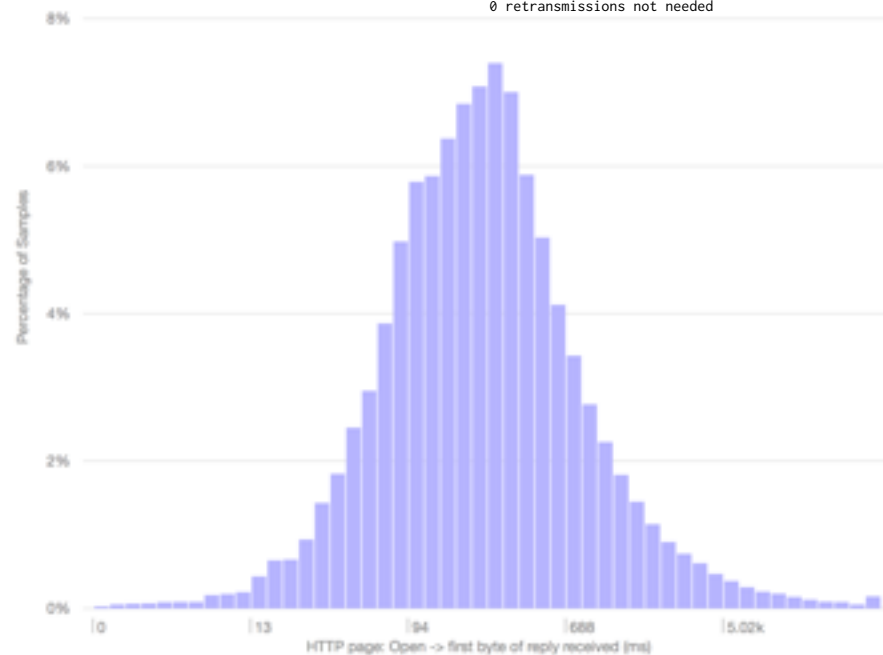
- TCP seq/ack number analysis for loss/reorder?
 - Always exposed, and roundly abused in the Internet
 - Only works with TCP
- TCP TSOPT timestamps for latency/jitter
 - Only works with TCP, enabled on about 30% of hosts
 - No application hooks for *explicit* enablement
 - Need heuristics to estimate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

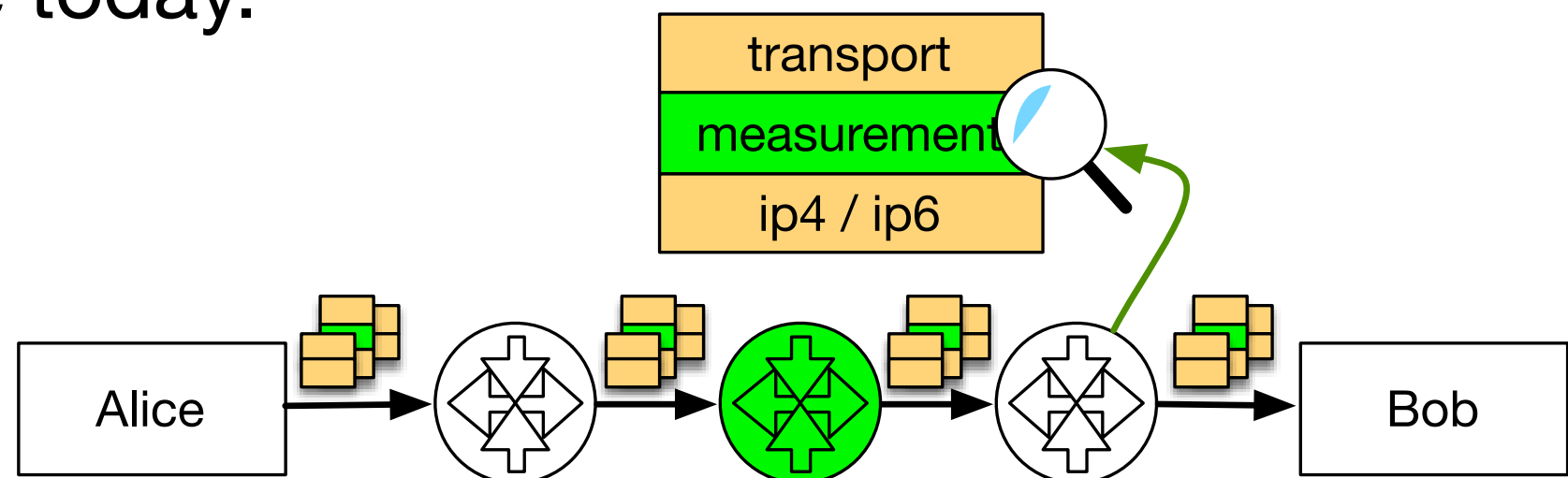


- Modern networking stacks are heavily instrumented
- `netstat -s -p tcp` on OSX yields 82 event counters.
- Application instrumentation also includes collection
- e.g. telemetry.mozilla.org
- Phase 1: generalizing and standardizing access to data we already have.
- e.g. mPlane [4]



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!





Sounds great. Let's do it!

- Now we just have to find the bits...



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.



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.



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



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

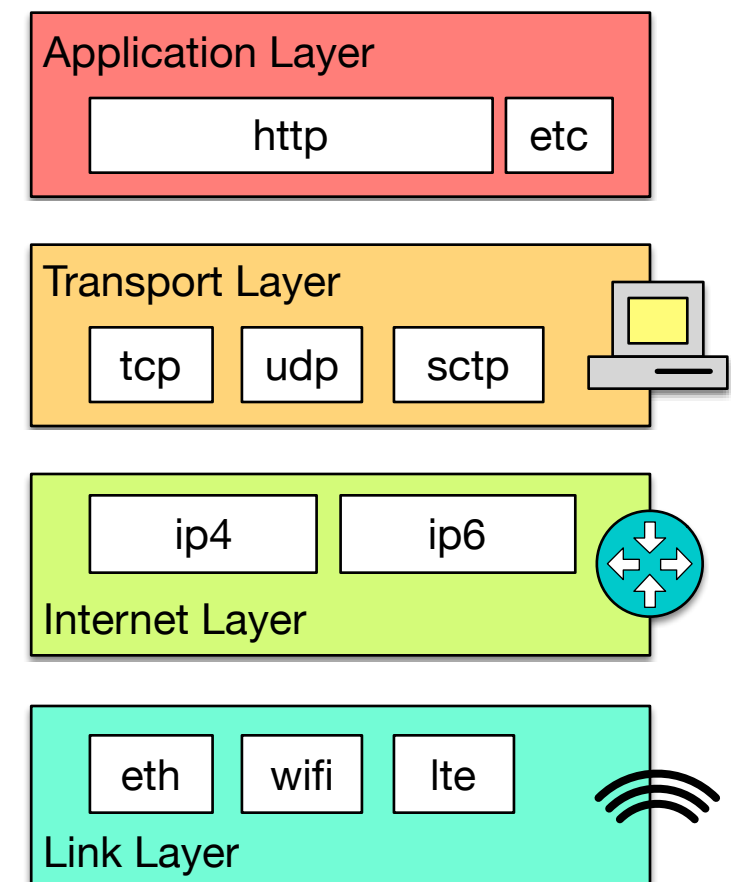


Sounds great. Let's do it!

- 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.***



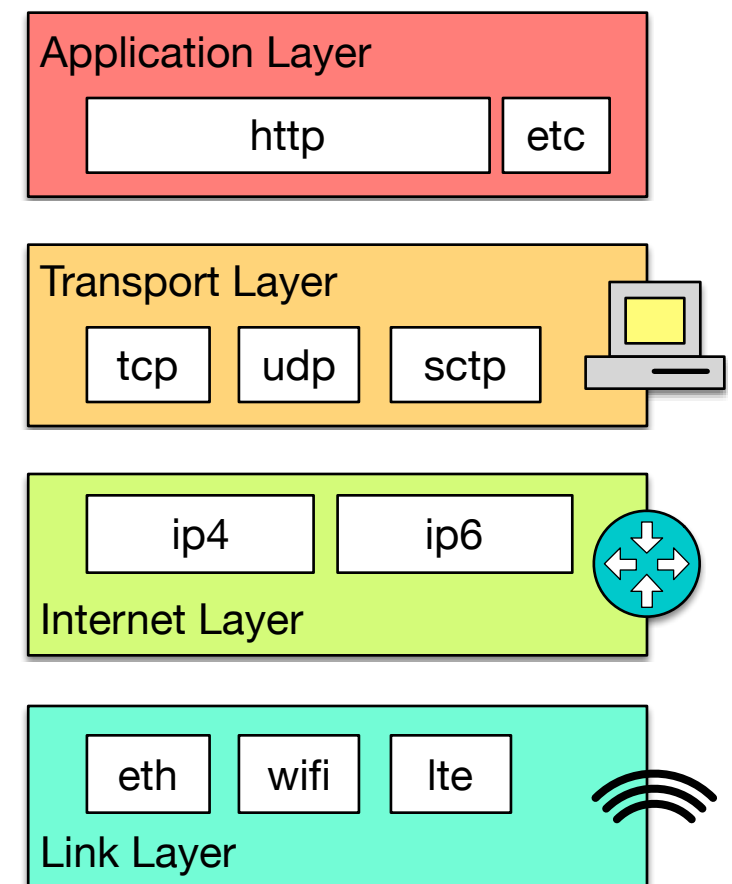
Adding new layers to the stack for fun and profit





Adding new layers to the stack for fun and profit

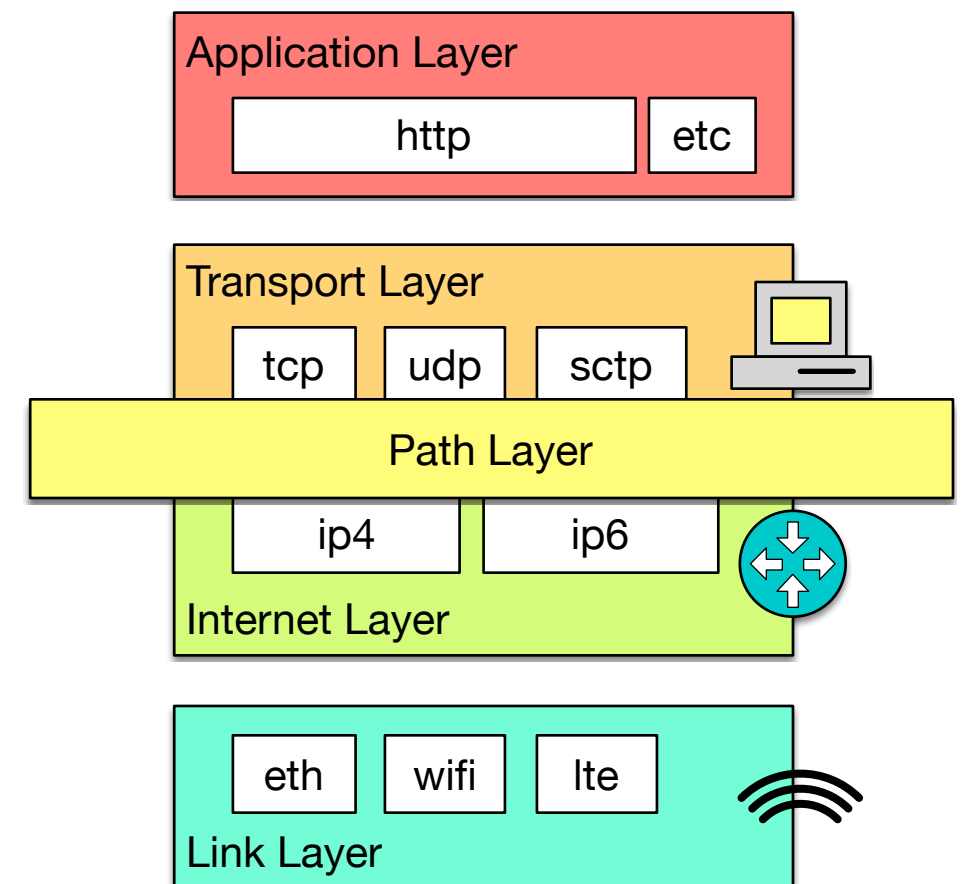
- Our “measurement layer” is a special case of a more general problem:
 - Internet layer is hop-by-hop, stateless
 - Transport layer is end-to-end, stateful
 - Where do all of the complex, stateful, not necessarily end-to-end functions we’ve built go?





Adding new layers to the stack for fun and profit

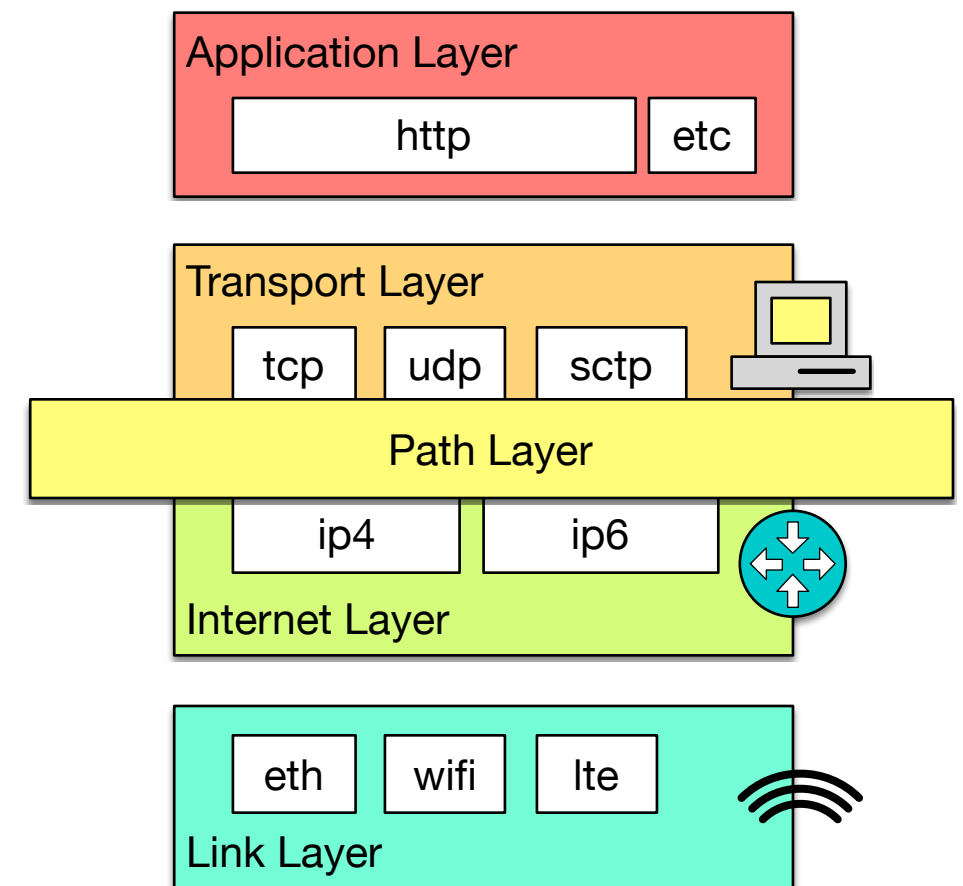
- Our “measurement layer” is a special case of a more general problem:
 - Internet layer is hop-by-hop, stateless
 - Transport layer is end-to-end, stateful
 - Where do all of the complex, stateful, not necessarily end-to-end functions we’ve built go?





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





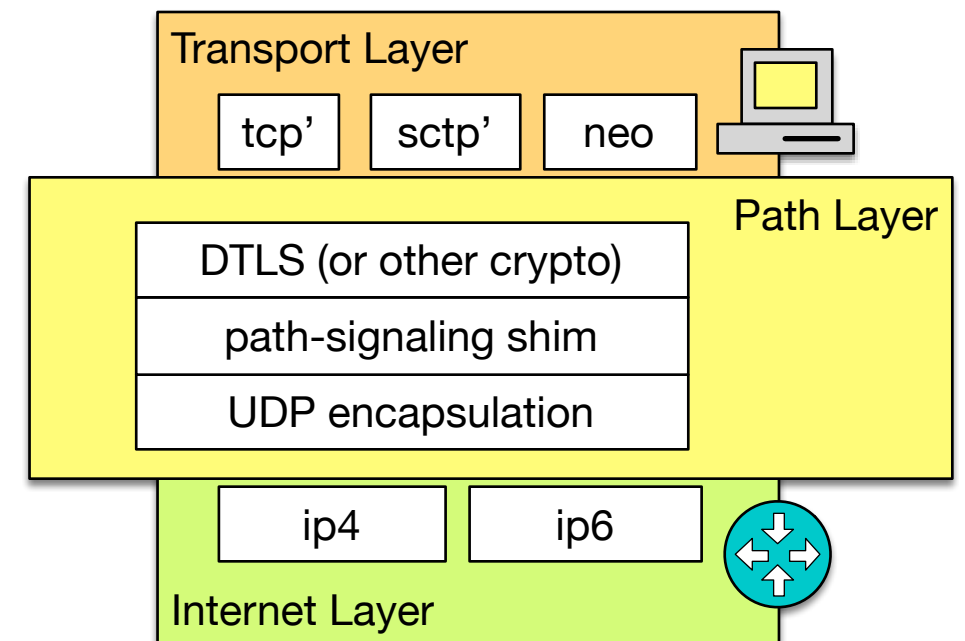
How to implement a path layer

- 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

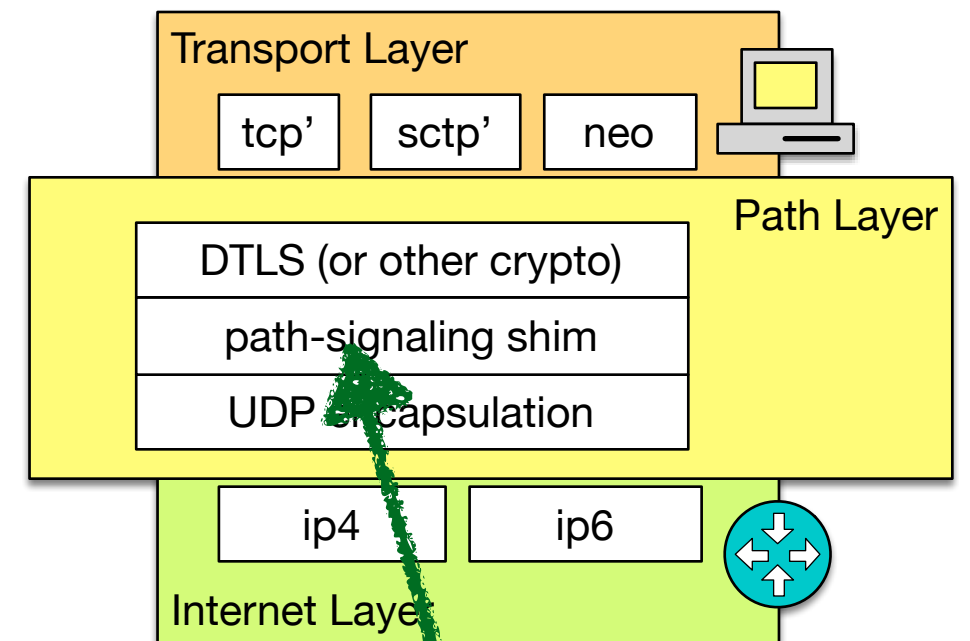
- Exposure to the path of information the endpoints decide the path needs
- Cryptographic protection of the rest of the transport layer
- Packets grouping for property binding, on-path state management
- Efficient per-packet signaling
- Integrity protection for exposed headers, allowing modification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





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

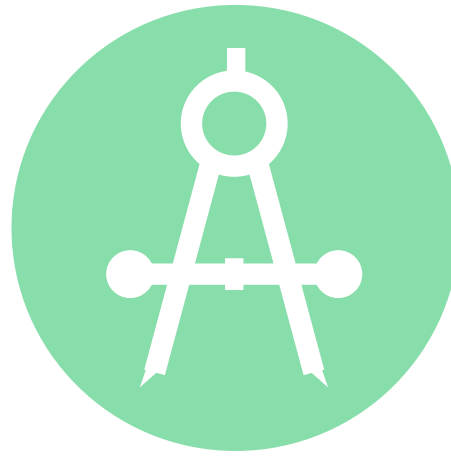
The MAMI Project

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/>

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.
- Questions? <{trammell, mirja.kuehlewind}@tik.ee.eth.ch>

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.

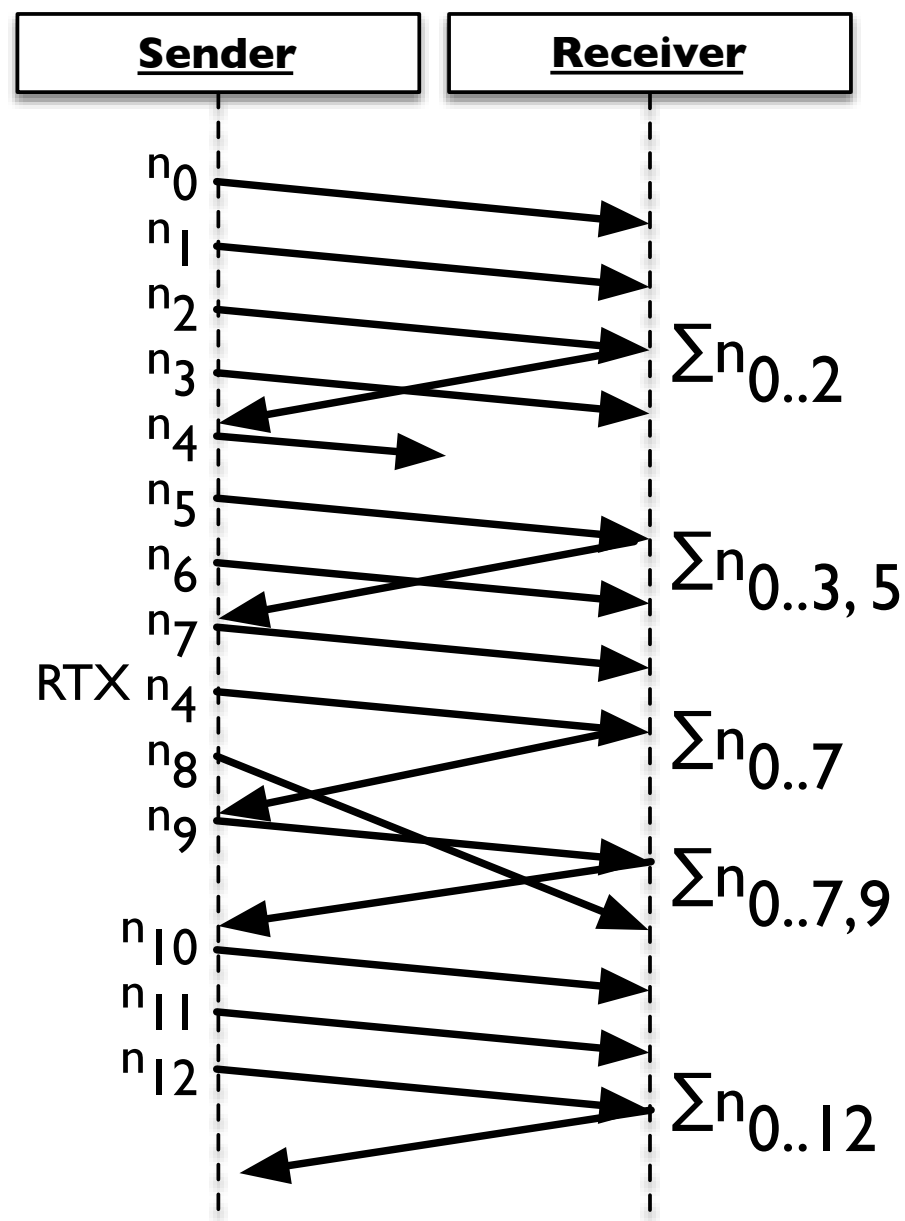
Backup





Measurement Primitives Illustrated

Cumulative Nonce



Delta Timestamp Echo

