On Explicit In-Band Measurement

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

mami

measurement and architecture for a middleboxed internet

measurement architecture experimentation

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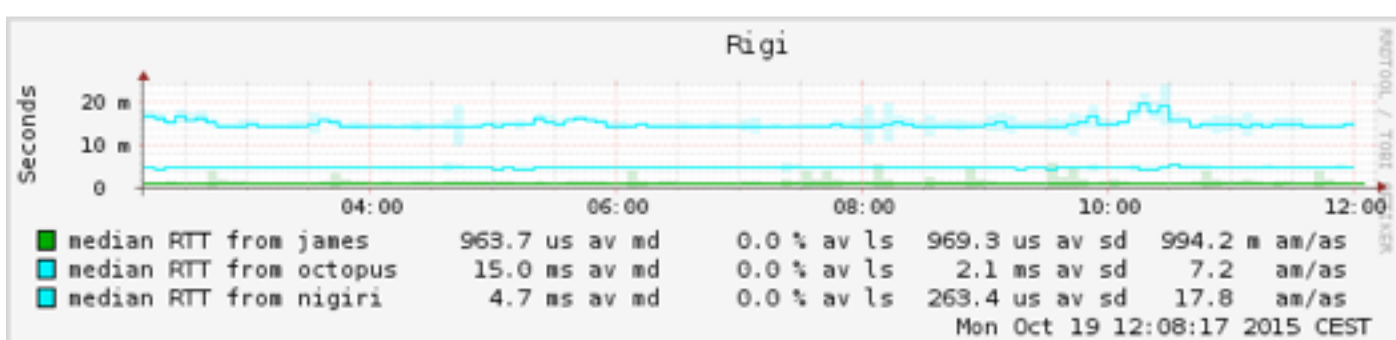
In the beginning…

- …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

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Identifier          |        Sequence Number        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Data ...
+-+-+-+-+-
```



- Actually, this is pretty much SmokePing.

Today's talk

- A couple of questions:
  - what if we'd designed measurement as a first-order service of the protocol stack?
  - how far from that ideal are we, really?
- A proposed answer:
  - design a measurement layer into the stack
  - use deployable technologies to make it work
- Some shameless promotion:
  - H2020 MAMI project, working to make this a reality

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…

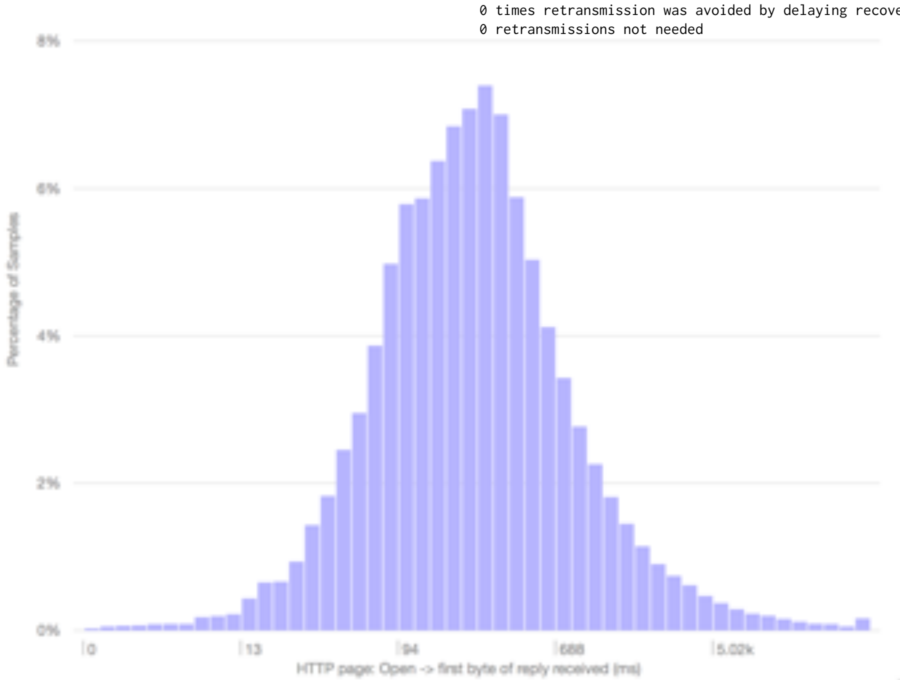
- ***What if we had designed measurement into the stack as a first-order service?***
  - "Big five" metrics (loss, latency, jitter, rate, reordering) as socket properties, with transport MPI/API for access.
    - You don't need much more for QoE-relevant network metrics
  - Header fields explicitly defined 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?

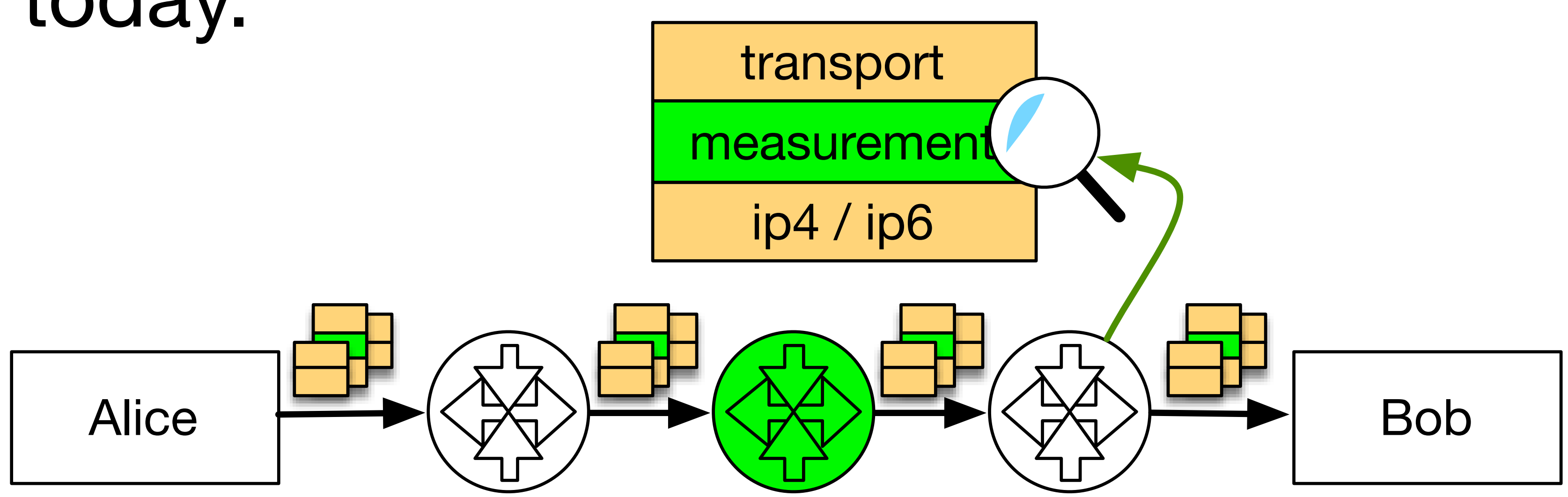
```
% netstat -s -p tcp
tcp:
    136072 packets sent
        36226 data packets (12605543 bytes)
        52 data packets (19892 bytes) retransmitted
        1 resend initiated by MTU discovery
        86569 ack-only packets (49 delayed)
        0 URG only packets
        0 window probe packets
        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?

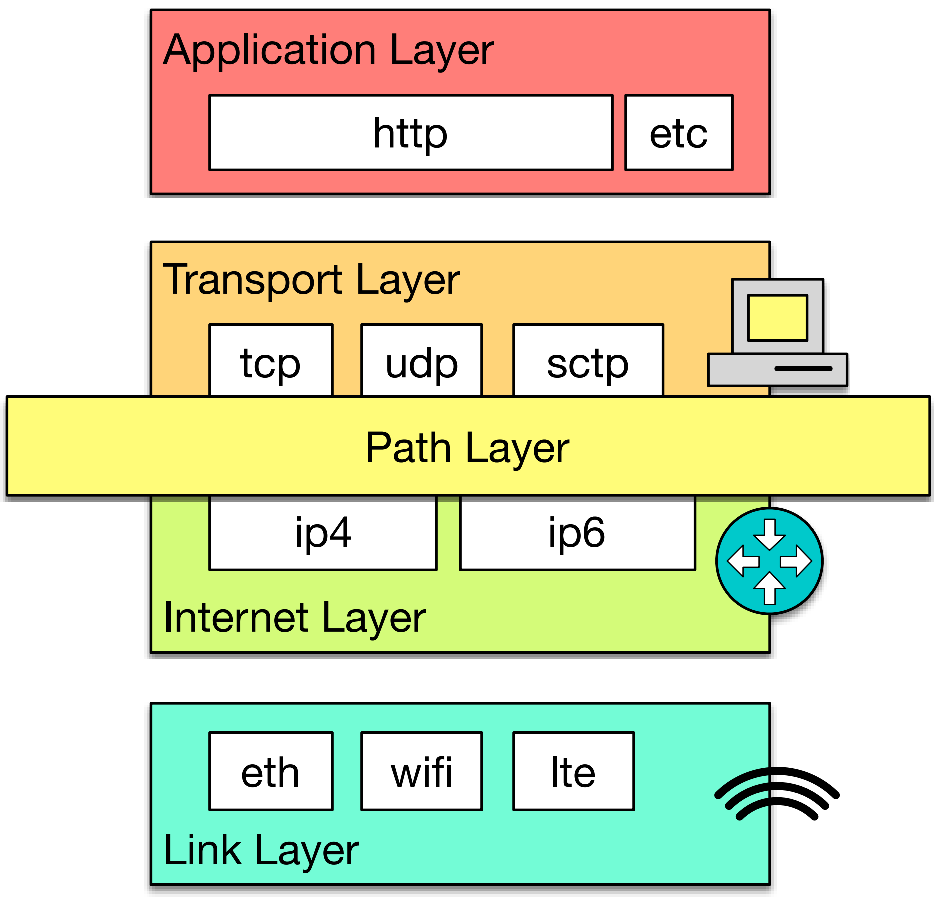
Sounds great. Let's do it!

- 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

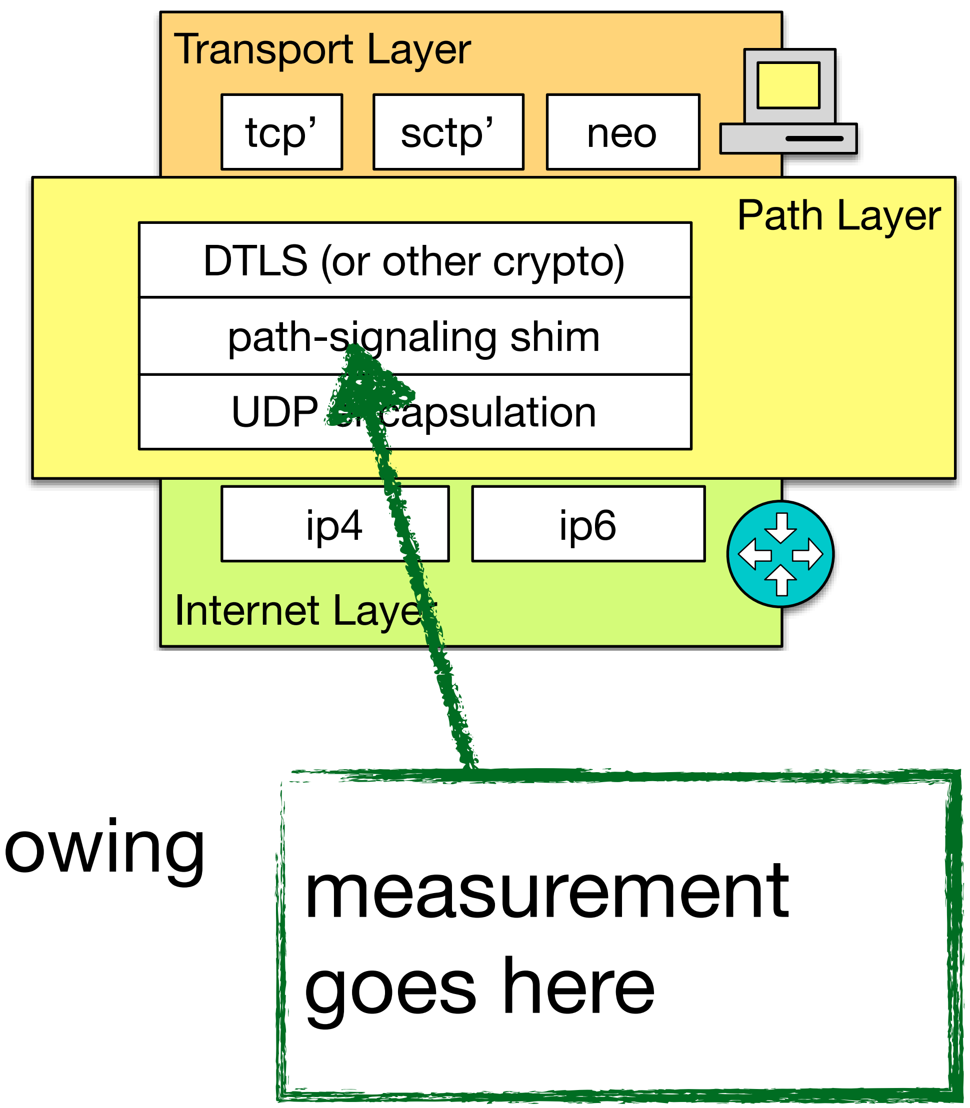


How to implement a path layer

- 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?

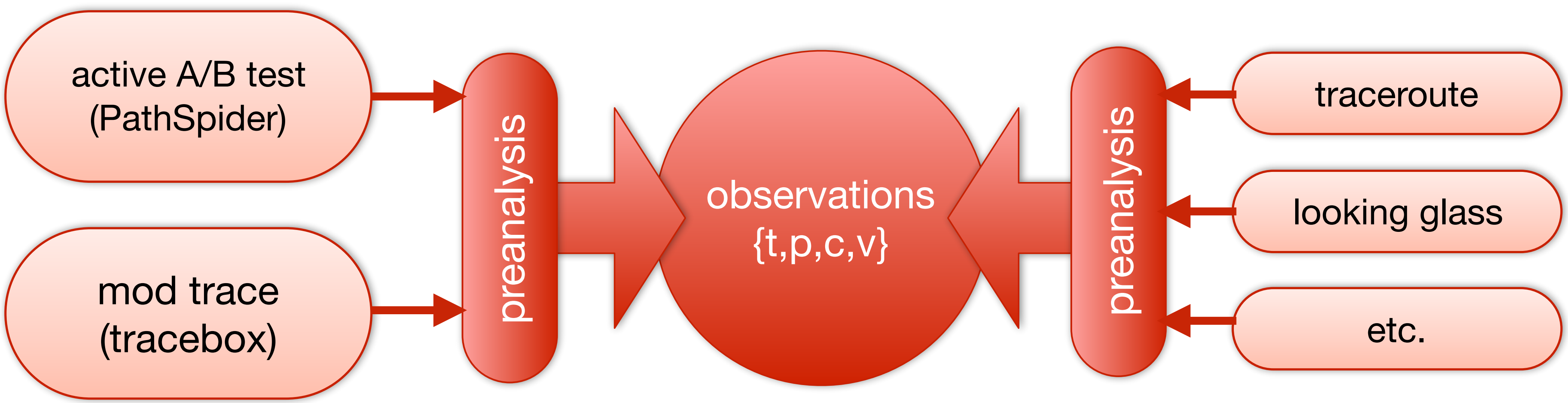
Path layer requirements

- 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



Answering the path layer deployability question: a Path Transparency Observatory

- UDP encapsulation sounds great, but decisions about deployment need data.
- Solution: observatory (public release end 2016) to derive common ***observations*** about *conditions* on a given *path* at a given *time*
- Combining disparate measurements leads to better insight
  - e.g. own measurement data, traceroutes, BGP, traces



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>

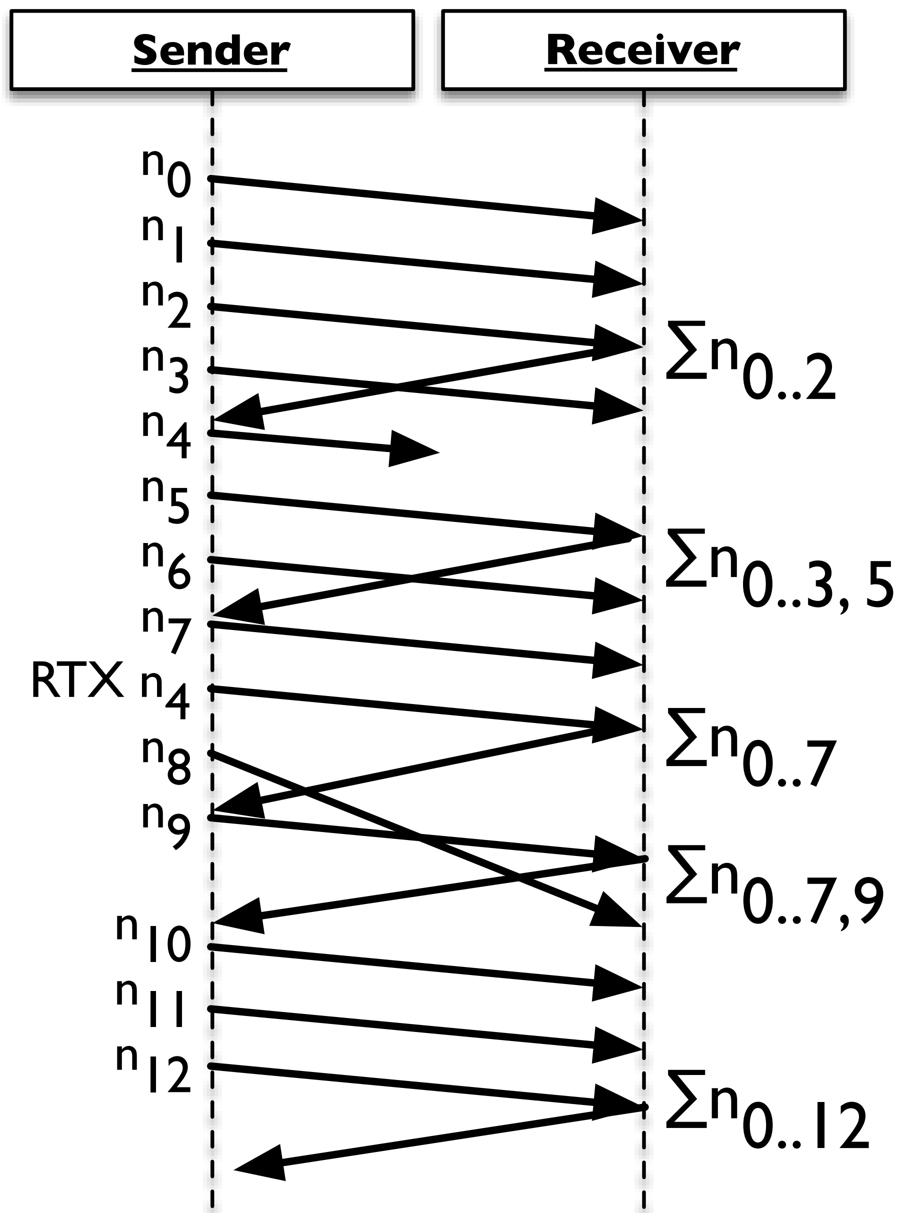
References

- [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