# What if we'd designed measurement as a first-order service?

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measurement and architecture for a middleboxed internet

measurement | architecture | experimentation

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# Overview

- Network measurement is hard.
  - Which tool? What to measure? How often?
- Getting it right is even harder.
  - *„Wer misst, misst Mist“* *misst=measure & Mist=bullshit
- Why is it so hard?
  - “Big five” metrics (loss, latency, jitter, rate, reordering)
- How hard can it be?
  - Path layer providing explicit in-band measurement!

# Example: latency/RTT

- Ping?
  - IMCP often blocked
  - Differential Treatment possible
- 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

# Example: Loss/reordering

- TCP throughput testing… is hard to get right [1]
  - High network load and unwanted interference
- Ping Mesh?
  - Overhead is not applicable for Internet measurement
  - Do we really measure what we want to measure?
- TCP seq/ack number analysis for loss/reorder?
  - Always exposed, and roundly abused in the Internet
  - Only works with TCP

# 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.

- Passive measurement, e.g. Netflow/IPFIX:
  - Passive RTT measurement [2] broken by ACK optimizations [3], etc.
  - Inflexible, low-rate sampling, even though we know better [4].

# What do we really need?

- “Big five” metrics: loss, latency, jitter, rate, reordering
  - as socket properties, with API for access
  - exposed to the network, explicitly for measurability

- Transport-independent header fields explicitly defined for measurability
  - Constant-rate timestamps for latency/jitter
  - Exposure of loss/reordering
  - Detection of header manipulation (required for dynamic transport selection)
- Explicit endpoint control over measurement exposure
- Exposure in header allows passive as well as endpoint measurement

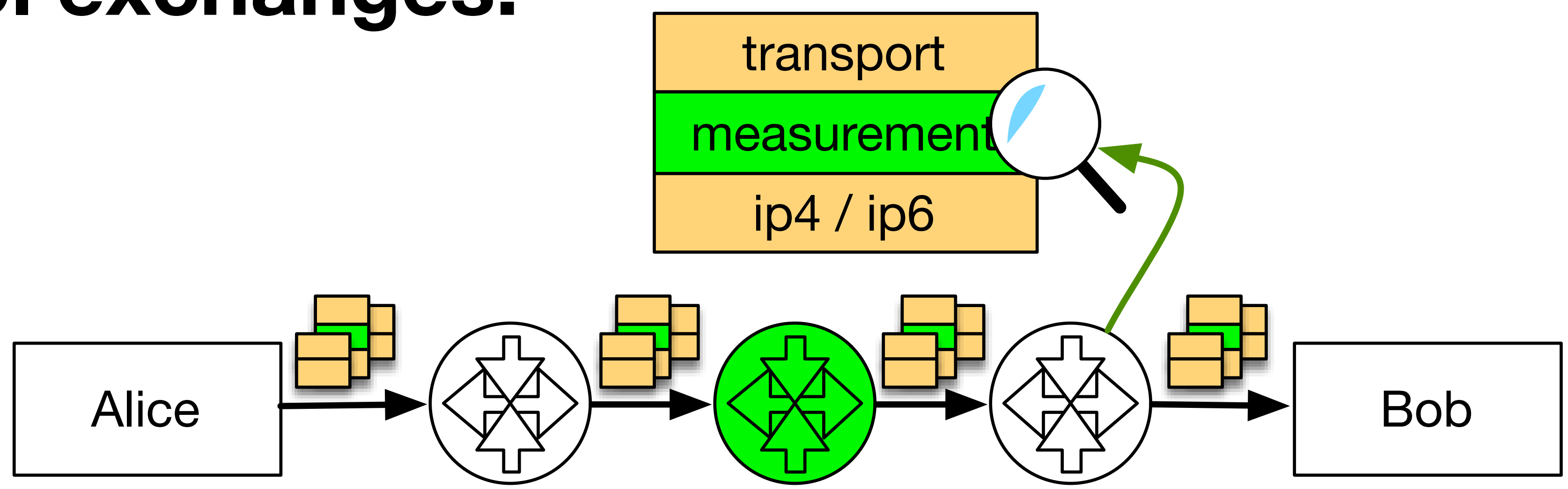
# Sounds great. Let's do it!

Now we just have to find the bits…

- IPv6 Destination Options [5]?
  - not very deployable, may be nearing deprecation, v6 only.
- IPv4 options?
  - even less deployable, v4 only.
- in the TCP header?
  - TCP only; options hard to deploy
  - HICCUPS [6] reclaimed a few bits from the header itself

# A Measurement Layer

… for explicit exposure of information as part of **normal protocol exchanges!**




➡ You don't have to instrument every packet, every endpoint, or every router to get *much* better information than we have today.

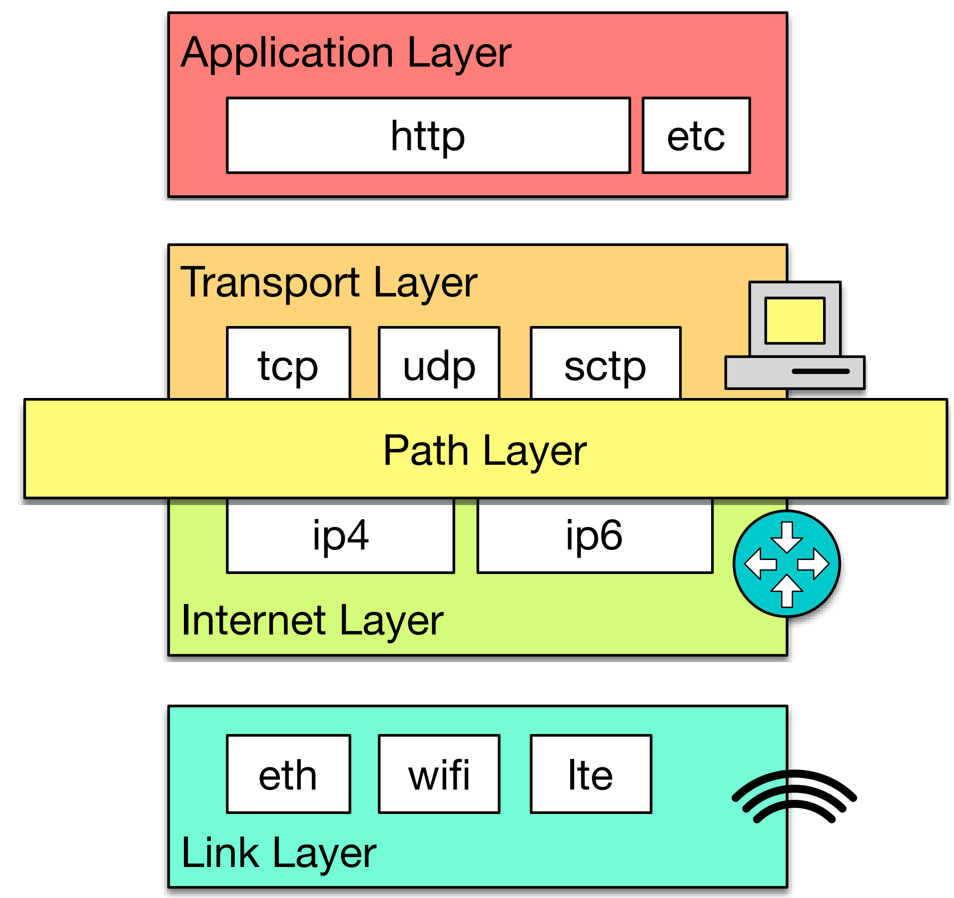
# Adding new layers to the stack for fun and profit

Our “measurement layer” is a special case of a more general problem [7]:

- Where do all of the complex, stateful, not necessarily end-to-end functions we’ve built go?

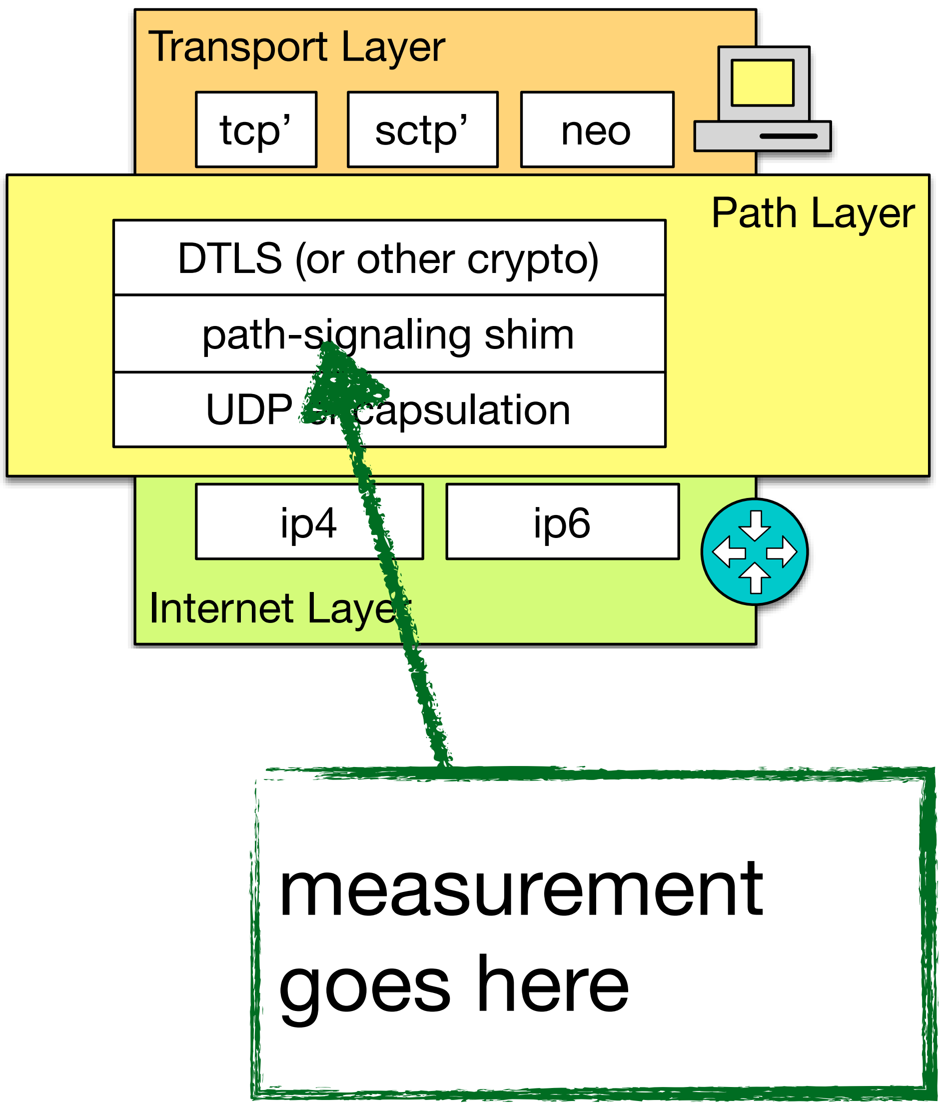
Solution: “**Path layer**”

- Encryption of transport layer and above to enforce end-to-end-ness
- Explicit exposure from endpoints to the path of appropriate information



# Path layer requirements

- 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 [8], spud@ietf.org



# Will it deploy?

- You can't add a new layer that today's routers won't route.
  - NAT: hard* to deploy protocols other than TCP or UDP

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.
- See presentation by Brian Trammell in MAT WG

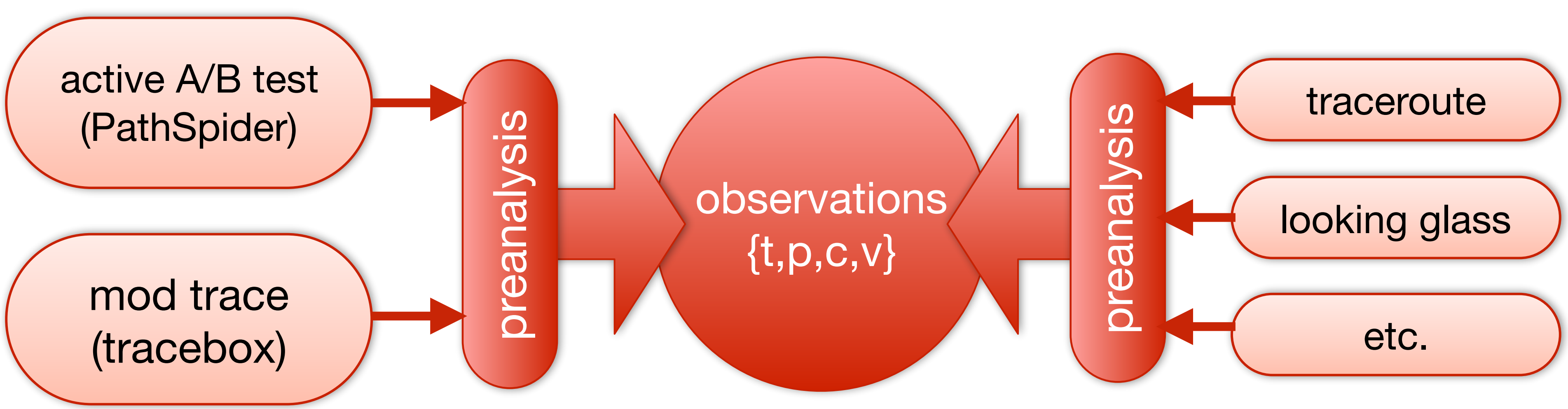
# Conculsion

- Yes, measurement is hard.
- Let's make it better!

**Missing:**
**Path layer for explicit exposure of traffic and measurement information**

# Path Transparency Observatory

- Observatory (public release end 2016) to derive common ***observations*** about *conditions* on a given *path* at a given *time*
  - Active measurements, made by the project
  - External measurements (e.g. traceroutes, BGP, traces)
- Combining disparate measurements leads to better insight
  - How likely is it that a certain path impairment impacts my traffic?




Follow http://mami-project.eu for updates on data model & availability!

# 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] Estan et al “Building a better NetFlow”, SIGCOMM 2004.

[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-kuehlewind-spud-use-cases (IETF individual Internet-draft)

[8] draft-trammell-spud-req (IETF individual Internet-draft)

# Backup

# The MAMI Project

## Measurement and Architecture for a Middleboxed Internet

**measurement**
of deployed middleboxes

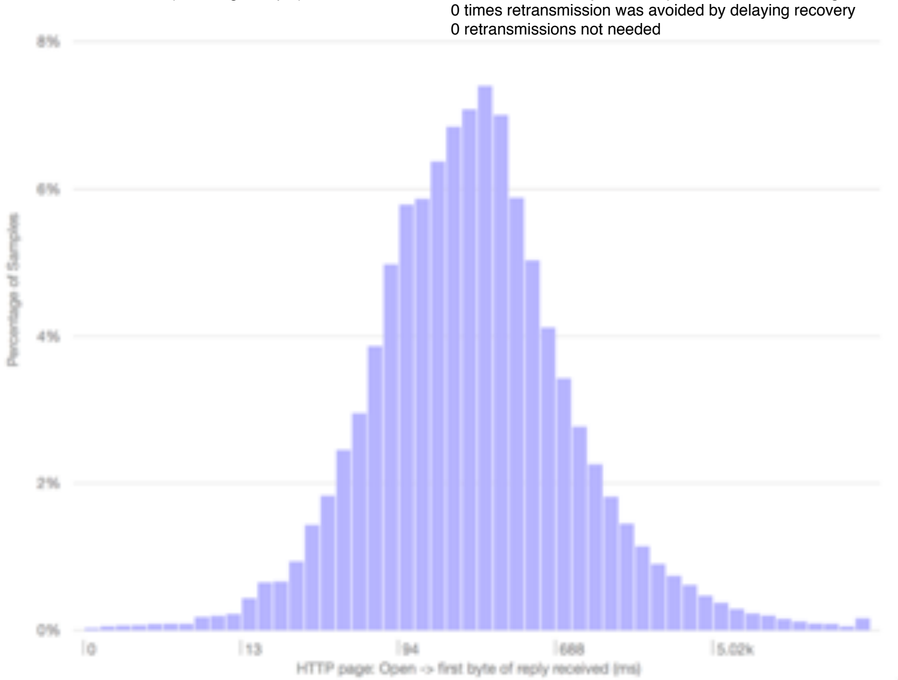
**architecture**
for middlebox cooperation

**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/**

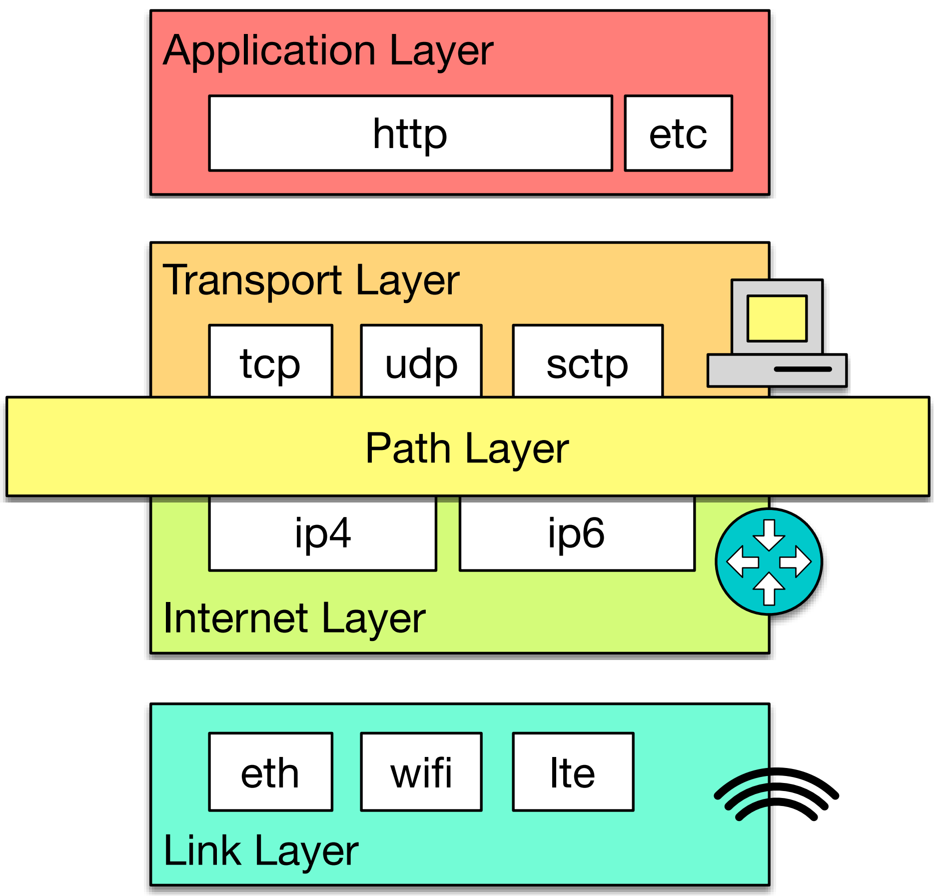
# How close are we to the goal?

```
% 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](telemetry.mozilla.org)
- Phase 1: generalizing and standardizing access to data we already have.
    - e.g. mPlane [4]

# Why a new shim layer?




- Transport layer: end-to-end sockets
  - flow information
  - stateful and ... g at the ...
- ... handling
  - ... rmation
  - ... and simple processing in the middle

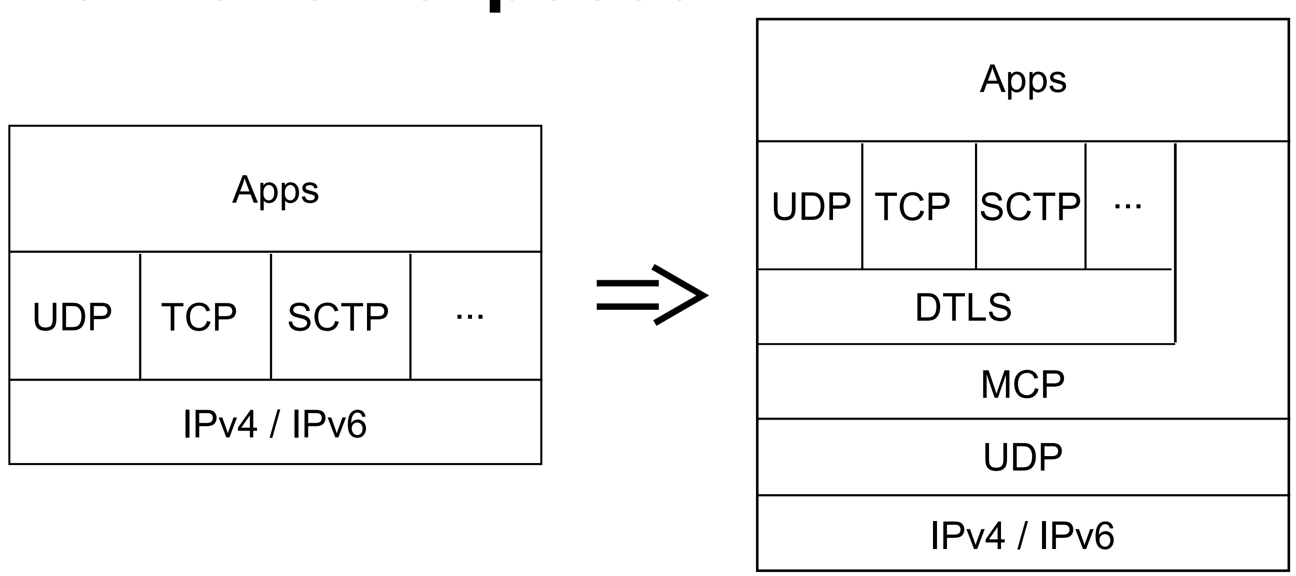
**Missing: Per-flow information for stateful in-network functions**

➡ **Path layer** for explicit cooperation with middleboxes instead of implicit assumptions

# Implementing an Explicit Path Interface

- Application can directly indicate requirements to path layer
- Transport can use the path layer to expose parts of its functionality/ intentions to the network
- *Middlebox Cooperation protocol* (MCP) signals these information appropriately to on-path middleboxes

➡ **Minimize the information exposed!**



# How to implement a new path layer?

- Transport-layer **encapsulation over UDP**
  - Need ports for NAT
  - Impossible to deploy with new protocol number across the Internet
  - Userspace (and kernelspace) implementation possible
- **Magic number** for easy recognition, protection against reflection
- **Flags** for “SYN/ACK” condition for state decision delegation to endpoint
  - All traffic bidirectional
  - Data in first packet possible
- Signals fit in a single packet (**no segmentation or reliability**)
- **Checksum** for error detection, cryptographic integrity checks available

# Why should I trust what you say about your flows?

- **Default**: *trust but verify*
  - declarative signaling: **no** negotiation, **no** guarantees
  - the best way to prevent cheating is to make it useless to do so
  - minimize the information exposed!

- Leverage existing trust relationships for higher-assurance declarations
  - e.g. your enterprise firewall, access network middleboxes, etc.

# 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?