Overview of framework additions:

Clock issues, “wire time.”

Singletons, samples, statistics.

Self-consistency.

Avoiding “stochastic” metrics.

Packets of “Type P”.

Internet addresses vs. hostnames.

“Well-formed” packets.

Clock issues:

Follow NTP (RFC 1305) terminology when possible:
“offset,” “skew,” “drift.”

Resolution: smallest unit by which the clock's time is updated.

Additional notion: “relative” offset/skew/drift between two clocks.

Two clocks can be highly synchronized but highly inaccurate!

Often synchronization more important than accuracy, if little absolute skew.

Clock issues, con't:

Independent synchronization preferable to NTP, which depends on network properties & emphasizes absolute accuracy.

Skew can be crucial when comparing clocks: 0.01% skew over ten minutes gives an error of 60 msec.

“Wire time”:

Distinguish between when a packet enters/leaves the network vs. when it's “seen” by the host.

Wire arrival time: first time at which any/all bits have arrived on a link.

Wire exit time: first time at which all/any bits have completed transmission.

“Wire time”, con't:

Host times are easy to measure. Wire times are often more essential.

Prefer definitions in terms of wire time, when appropriate.

Packet filters can help for measuring wire time.

Singletons, samples, and statistics:

Singleton metric: defined as a single (atomic) instance.

Sample metric: a collection of distinct singletons.

Statistical metric: derived from a sample metric via statistics.

Gathering samples:

Periodic sampling can suffer from aliasing effects; predictability; and synchronization.

Prefer random additive sampling, each interval drawn from distribution $G(t)$.

Ideal: Poisson sampling ($G(t) = 1 - e^{-\lambda t}$).
Equivalent: <u>uniform</u> sampling of N samples over time ΔT.

Framework discusses some subtleties for accurate Poisson sampling.

Self-consistency:

Part of measurement calibration is testing for self-consistency. Applies both to the measured values, and the <u>process itself</u>.

Example of measurement consistency: RTT should always be > 0 (and $>$ OTT if available).

Example of process consistency: do the Poisson sampling times actually have exponential spacing between them? Do their wire times?

Defining statistical distributions:

Use standard definition of “empirical distribution function” (EDF):

$F(x) =$ fraction of all observations that were $\leq x$.

Preferred to histograms, which lose information.

“Percentile”: smallest x such that $F(x) \geq$ given percentage.

“Median”: if odd number of samples, 50%tile, otherwise average of middle two values.

(C code for EDF goodness-of-fit based on Anderson-Darling test forthcoming.)

Avoiding “stochastic” metrics:

It's often tempting to define metrics in terms of probability. E.g., packet loss as “probability p that a packet was not be delivered by the network.”

Such definitions often carry with them inappropriate assumptions about the network's behavior.

Prefer deterministic definitions, e.g., “proportion k/n of packets not delivered by the network.”

Avoiding “stochastic” metrics, con't:

Highlights need to define sampling interval.

Avoids assuming network elements behave in a probabilistic fashion.

Stochastic <u>models</u> by which metrics are interpreted are fine!

Packets of “Type P”:

Many metrics yield different values depending on the type of the packets to which they are applied.

Generic notion: “Type P” packet.

For some metrics, P might be explicitly spelled out (“TCP-HTTP”), partially spelled out (a payload of B octets) or left generic.

Useful future work: ways to determine classes of equivalent packet types. (E.g., “all TCP traffic is routed identically.”)

Internet addresses vs. hostnames:

Observation: multi-homing makes Internet hostnames potentially ambiguous.

Fix: instead, define metrics when appropriate in terms of IP addresses.

“Well-formed” packets:

Unless otherwise stated, assume metrics are for “well-formed” packets:

- correct IP header length
- valid IPV4 header, header length $\geq$ 5, valid checksum
- not a fragment
- correct source and destination addresses
- sufficient or maximum TTL
- no IP options
- if transport header present, it's valid too

(Also define “minimal IP packet from A to B”.)