

# Measuring Network Quality for End-Users, 2021

*An Internet Architecture Board virtual workshop*

Day 3

# Agenda

## Synthesis 1

- 14:00 Chairs' Intro
- 14:10 Szilvester Nadas, Balasz Varga, Luis M. Contreras, Sandor Laki. Incentive-based Traffic Management and QoS Measurements.
- 14:17 Satadal Sengupta, Hyojoon Kim, Jennifer Rexford. Fine-Grained RTT Monitoring Inside the Network.
- 14:24 Al Morton. Dream-Pipe or Pipe-Dream: What Do Users Want (and how can we assure it)?
- 14:31 Discussion

## Synthesis 2

- 15:00 Kalevi Kilkki, Benjamin Finley. In Search of Lost QoS.
- 15:07 Neil Davies, Peter Thompson. Quality Attenuation as a framework for measuring and evaluating end-user network experiences.
- 15:14 Mingrui Zhang, Vidhi Goel, Lisong Xu. User-perceived latency to measure CCAs.
- 15:21 Discussion
- 16:00 Break

## Synthesis 3

- 16:10 Christoph Paasch, Randal Meyer, Stuart Cheshire, Omer Shapira. Responsiveness under working conditions.
- 16:17 Bob Briscoe, Greg White, Vidhi Goel, Koen De Schepper. A single common metric to characterize varying packet delay.
- 16:24 Christoph Paasch, Kristen McIntyre, Randall Meyer, Stuart Cheshire, Omer Shapira. An end-user approach to the Internet Score.
- 16:31 Discussion

## Recap

- 17:00 - Parking lot and follow-up planning.
- 18:00 - Fin.

# Incentive-Based Traffic Management and QoS Measurements

Szilveszter Nádas, Balázs Varga, Luis M. Contreras, Sándor Laki



# Traffic Management: Mechanisms, algorithms and strategies

- Choose the right **mechanisms** depending on the congestion duration
- For each mechanism there are alternative **algorithms**
  - E.g. different TCP Congestion Control Algorithms
- **Strategies** are harmonized sets of algorithms
  - 1, more, or 0 for each mechanism
  - E.g. Best Effort Internet access – minimal harmonization
- Updating a single algorithm has limited impact, consider also updating the strategy
  - An update might even break the harmonization of strategies (e.g. a new TCP CCA vs. a new AQM)
- Is it possible to have a Strategy for the Internet with richer SLA and more meaningful measurements?
  - Where is the place of measurements in this? How does it cooperate with the rest of the algorithms?

Congestion  
duration

Long

Short

**Mechanism** controlling the  
congestion

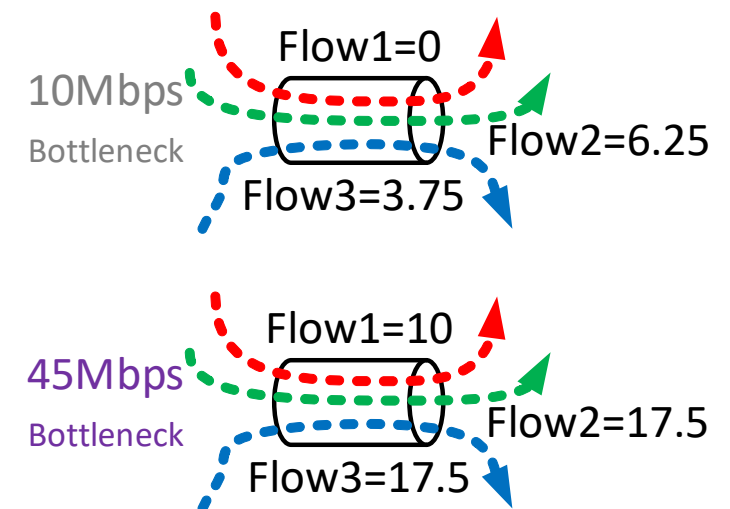
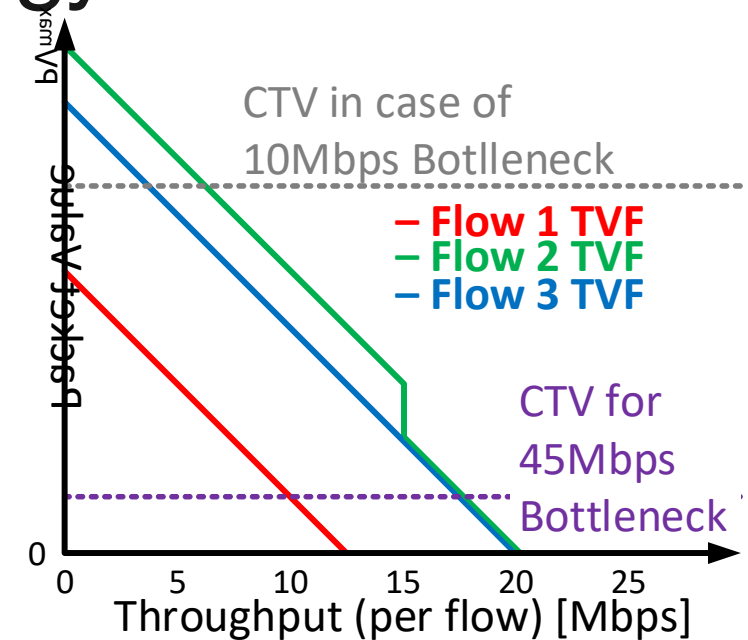
Usage Policy, SLA  
Network Dimensioning  
Admission Control  
Load Balancing  
Content Adaptation  
Congestion Control  
Resource Sharing Control  
AQM and Scheduling



# Incentive Based Core-Stateless QoS strategy

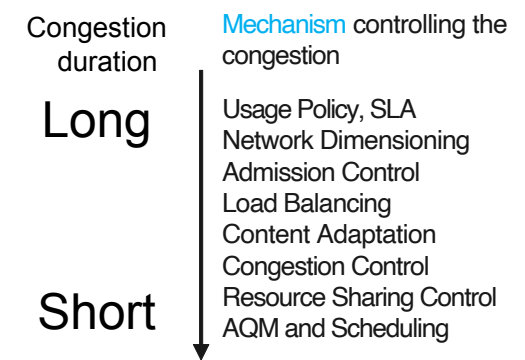
## Per Packet Value (PPV) [ppv.elte.hu](http://ppv.elte.hu)

- Resource sharing policies are expressed by Throughput Value Functions
- The TVF is encoded by marking a Packet Value on each packet
  - Different flows may have the same policy (same TVF, but separate packet marker)
- Scheduling and AQM works only by maximizing the transmitted Value
  - No flow identification or policy knowledge is needed at the bottleneck
- Congestion Threshold Value (CTV) is a rich congestion measure
  - For a single resource or for a network path
- Packets with Value less than the CTV are dropped
- CTV helps in harmonizing the algorithms of Traffic Management
  - E.g. Load Balancing, Network Dimensioning
- CTV can be measured by the end-user



# Conclusion

## Incentive-Based Traffic Management and QoS Measurements



- We argue that meaningful QoS measurements shall be supported by the Traffic Management Strategy
  - Measurement shall be considered during the design of the TM algorithms including the usage policy
- Using a rich congestion measure both for the measurements and for harmonizing the algorithms of the TM strategy looks a promising way forward (e.g. the Incentive Based Core-Stateless QoS strategy)
- The simplicity of the Internet and the “Best Effort Internet access” strategy was a key success factor
  - Most developed QoS solutions are not used, especially not end-to-end
  - Session based QoS is extremely unlikely to happen over the Internet
- Incentives are proposed as pieces of information usable to make Traffic Management decisions
  - It is intended to be lightweight and not session based
  - It shall enable more detailed SLAs (Service Level Agreements) over the Internet

# Fine-Grained RTT Monitoring Inside the Network

*Satadal (Sata) Sengupta, Hyojoon Kim, Jennifer Rexford*



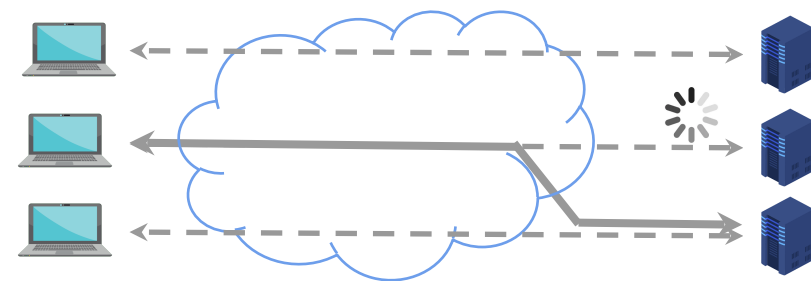
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## RTT is an important QoE metric

- RTT relates directly to TCP throughput
- Influences video QoE, page load time, etc.
- Crucial for latency-sensitive applications, e.g., interactive video, algorithmic trading, online gaming

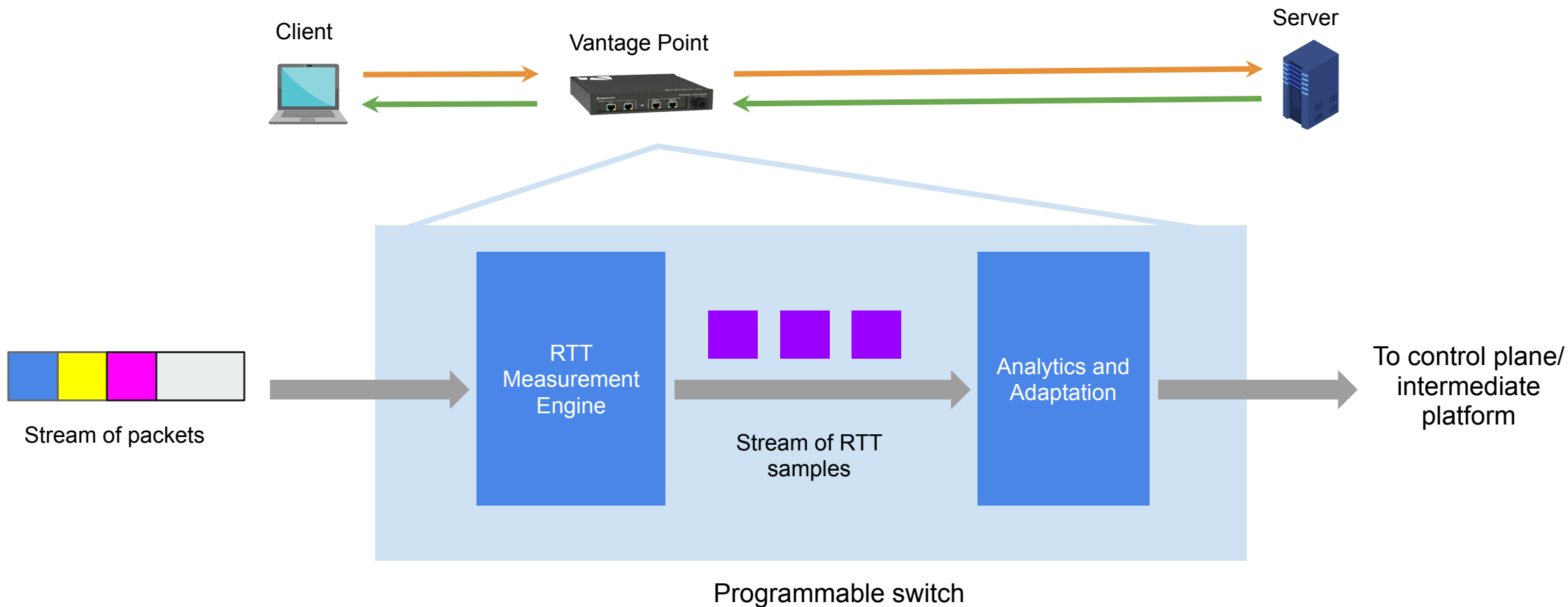
## The case for real-time, fine-grained RTT

- Select CDN replica with lower latency
- Detect and mitigate diminishing video QoE
- Latency-aware hand-offs in WiFi network



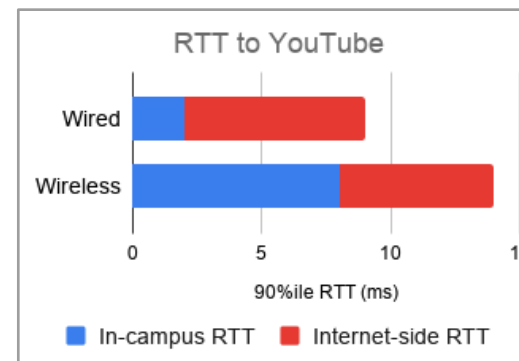
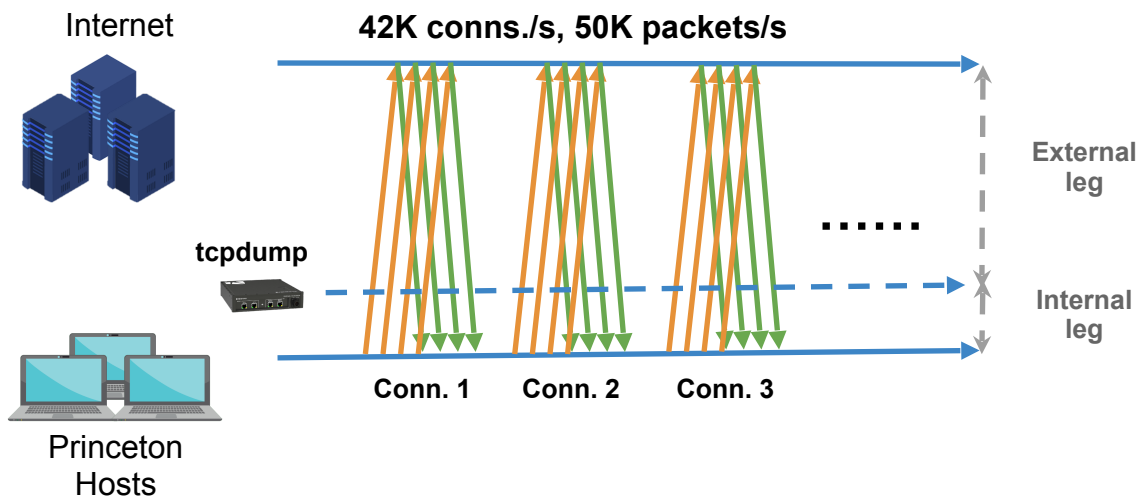
Anycast-based CDN replica selection

# P4RTT: RTT Monitoring and Network Adaptation



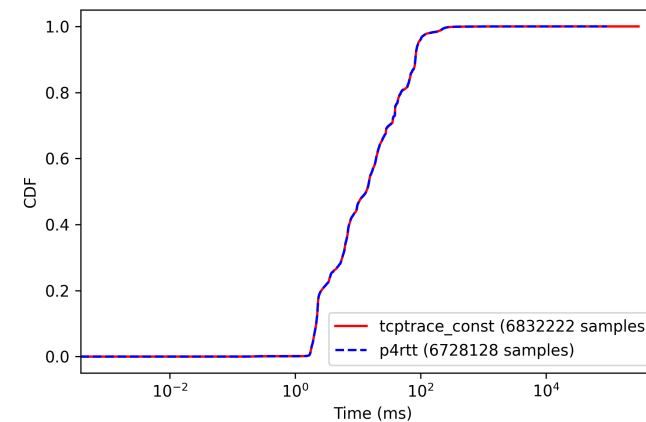
- **Technique:** Match data packets with ACKs; continuous RTT samples
- **Trade-off:** Vagaries of TCP traffic vs. resource constraints of high-speed data plane
- **Advantages:** Constant space impl. (vs. tcptrace), accurate & fine-grained (vs. TCP TS-based methods)

# Preliminary Evaluation on Campus Dataset [IRB+PADR approved study]



Impact of wired vs. wireless infrastructure on 90%ile RTT to YouTube

- **Baseline:** *tcptrace\_const*
- **Prototype:** In P4 for Intel Tofino
- **Faithful simulation:** *pyP4RTT* in Python
- **Early result:** 98% of samples collected, similar RTT dist.



Performance comparison vs. baseline

**Future directions:** Deploy P4RTT to campus testbed; test network adaptation; include QUIC?

# DREAM-PIPE OR PIPE-DREAM: WHAT DO USERS WANT (AND HOW CAN WE ASSURE IT)?

AL MORTON

(I-D WITH REFERENCES)

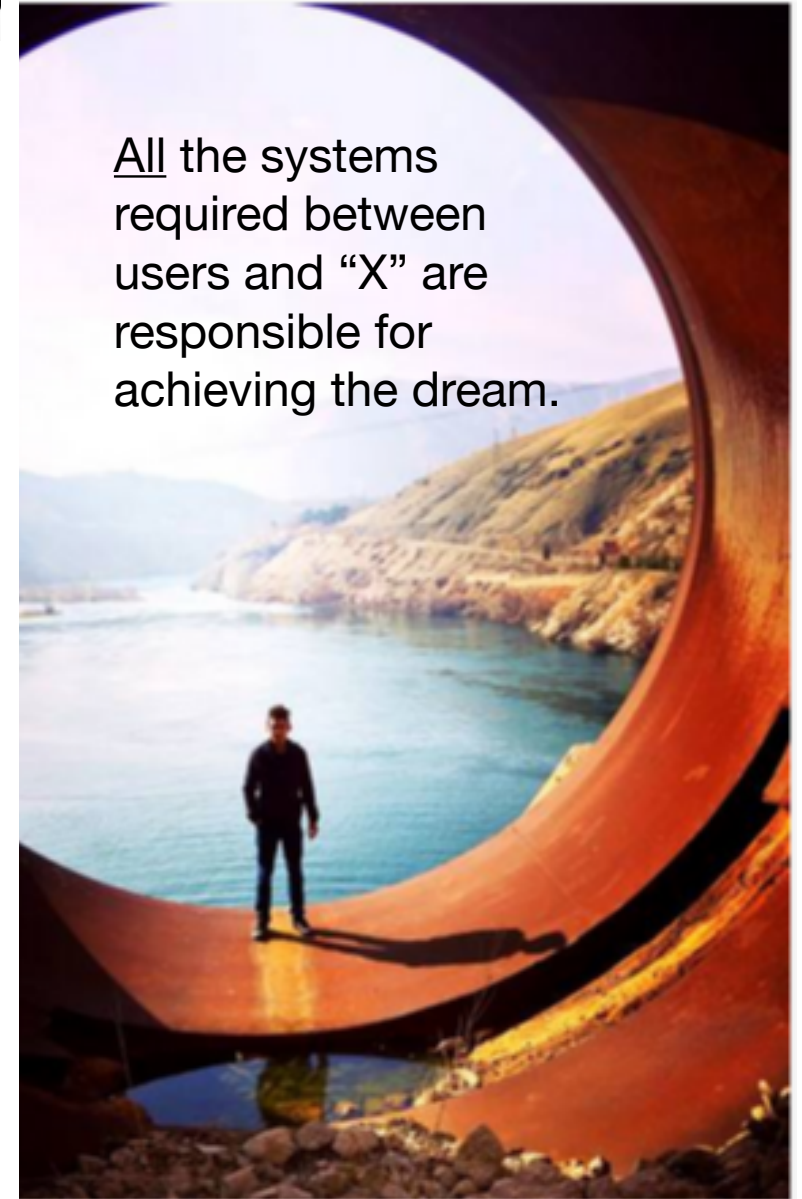
## User's Dream Pipe:

- Available always when needed
- Sufficient Capacity when needed
- No apparent loss
- No apparent latency (both low and consistent latency)
- Unlikely for all apps, w/o qualifiers, AOE (Pipe-Dream)

## Survey of UK Users late 2020:

- Want what they don't have!
- Reliability every-where/-one
- More Capacity in Rural Areas
- Their ISP to bundle Sec/Pri
- But no mention of Latency...

All the systems required between users and "X" are responsible for achieving the dream.





# METRIC HIERARCHY: FUNDAMENTAL – DERIVED – SINGLE FIGURE OF MERIT

## ■ IPPM WG: 7 Fundamental Metrics

- Intrinsic value: assess net properties (they don't go away)
- Singleton, Sample, Statistic Metrics
- Use them to create additional metrics called Derived Metrics

## ■ Most common **Derived Metrics**:

- Delay Variation: two forms PDV & IPDV
- Selection Function: compare 2 delays

## ■ Other Derived Metrics:

- Reliability/Availability (loss over time)
- Matt Mathis' MBM (loss and RTT)
- Y.1540 Stream Block (like BLER for pkts, # of losses in a set of pkts)
- Max IP-Layer Capacity (loss, RTT PDV, others), approximately the metric that ISPs advertise ("Up to X Mbps"), has a calibration "ground truth"

## ■ Structure for Metric Standards

- Clear Metric Definition, Method of Measurement, and Stream Definition
- Flexible input factors: **Parameters**
- But **Nail-down** the Parameters when describing Measurements! See the Performance Metrics Registry.

## ■ Reporting Results:

- Include a Frame of Reference! (like bottleneck link properties: Max Theo. FR)
- Make interpretation as easy as possible: Gauges with red-line

## ■ **Figure of Merit** combines many metrics

- Strength/weaknesses of a single number, but people like simplicity!
- Objective interpretation of packet measurements using models derived from Subjective testing (ground truth)



## WRAP-UP: PROPOSALS

### ■ **New Derived Metric:**

Number of Users Supported on ISP Access

- Gigabit access (~ Dream Pipe?):
  - >bps than a single user consumes today
  - Some Advertisements citing #of users or whole household
  - Benefits for latency and delay var.
- But: need def. of Standard User's streams for # of apps, or app streams
  - Changes over time, must be registered, can't argue about it for a year...

### ■ **OLD Derived Metric(s): (not new&shiny)**

Connectivity, Availability, Reliability

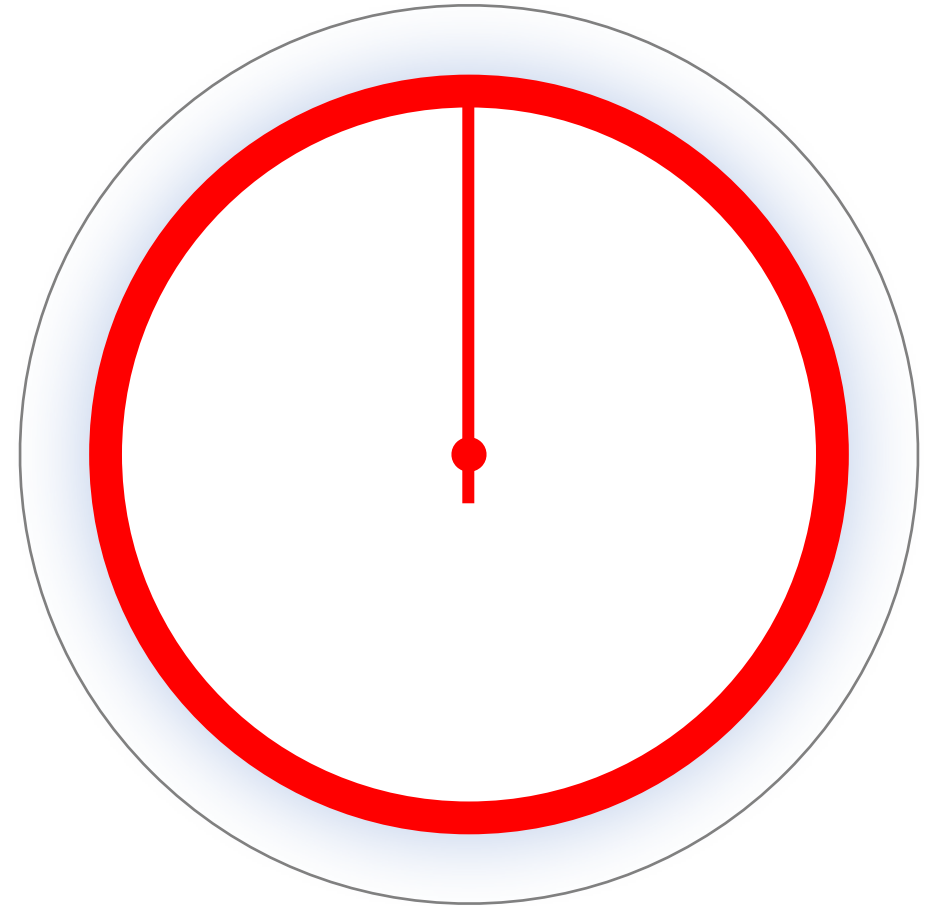
- COVID-19 made this category more evident to households, as the hub for all comms.
- Can be measured point2point (standards)
- Derive from Loss (and a matrix of point2point measurements?)
- Measurement Systems require Connectivity to begin their work but need to record when measurement set-up fails!
  - Could be the most important info!

# Discussion

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# In Search of Lost QoS

**K. Kilkki & B. Finley**

Aalto University, Espoo, Finland

kalevi.kilkki@aalto.fi

text available at <https://arxiv.org/abs/1901.06867>

- » QoS has been studied and developed 30 years with a fixed mindset
  - » The task of the network is to satisfy the **QoS requirements** of different entities
    - Entity = application, user, connection, flow, session, equipment, ...
  
- » In reality, the usage of QoS mechanisms has remained limited
  - » Usually: Best effort & overprovisioning with no or very little QoS
  
- » **Is there any other approach?**

# Proposal: Incentive-based QoS

## » Network

- Provides rules and (QoS) mechanisms that create incentives for applications and users to behave in a way that is beneficial to the users and the network during congestion

## » Users and applications

- Free to use the network and the mechanisms as they wish
  - depending on their needs (bit rate, delay, packet loss ratio & reliability)

## » A possible technical solution

- 2 delay classes: freely selectable, but low delay comes with a “penalty”
- 6 priority levels: Low bit rate  $\Rightarrow$  high priority  $\Rightarrow$  low packet loss ratio

## » Requires common agreement and standardization

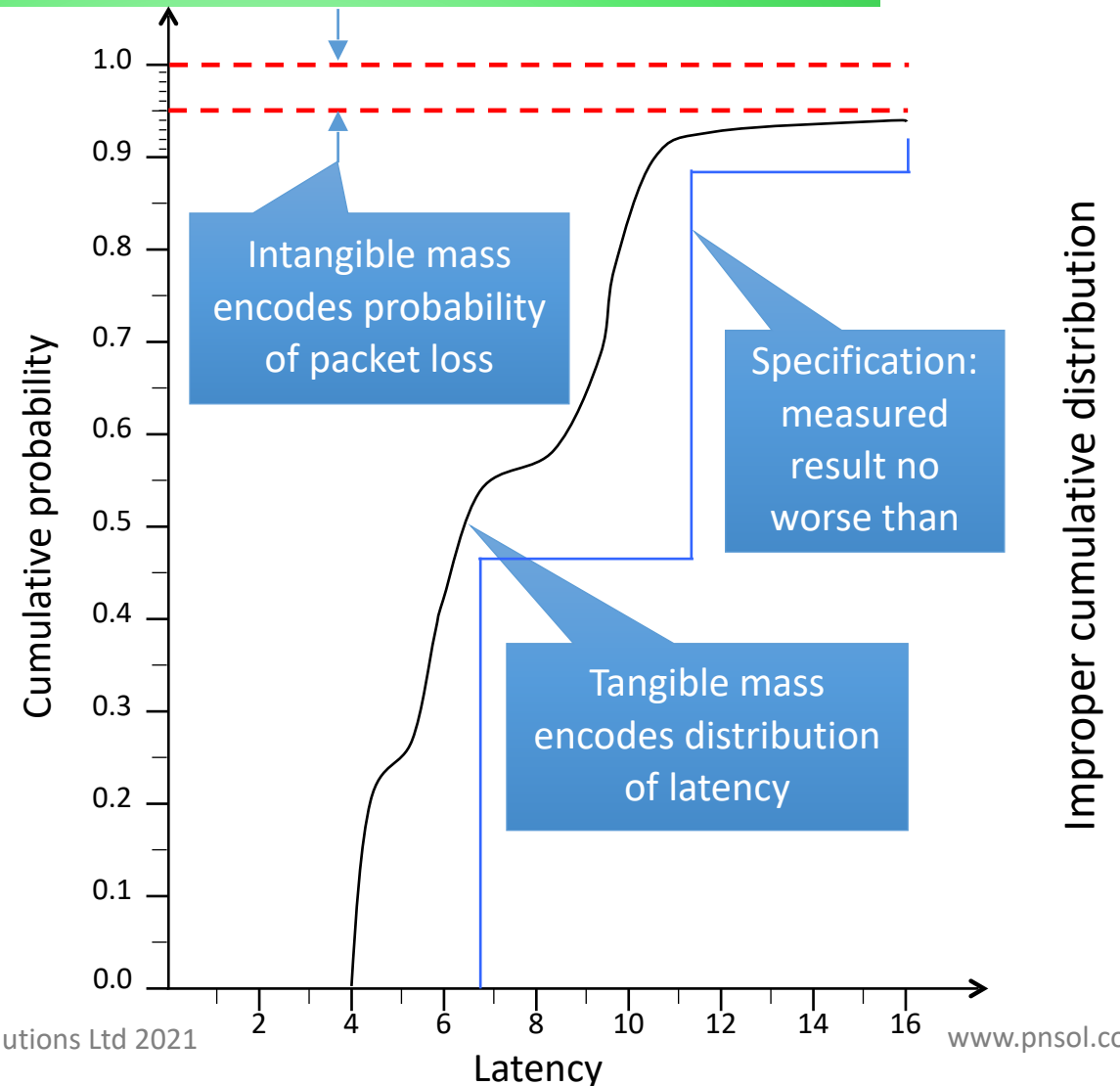


# Measuring Network Impact on Application Outcomes Using Quality Attenuation

Neil Davies, Peter Thompson (Predictable Network Solutions Ltd.),  
Gavin Young, Jonathan Newton (Vodafone Group PLC),  
Bjørn Ivar Teigen, Magnus Olden (Domos AS)

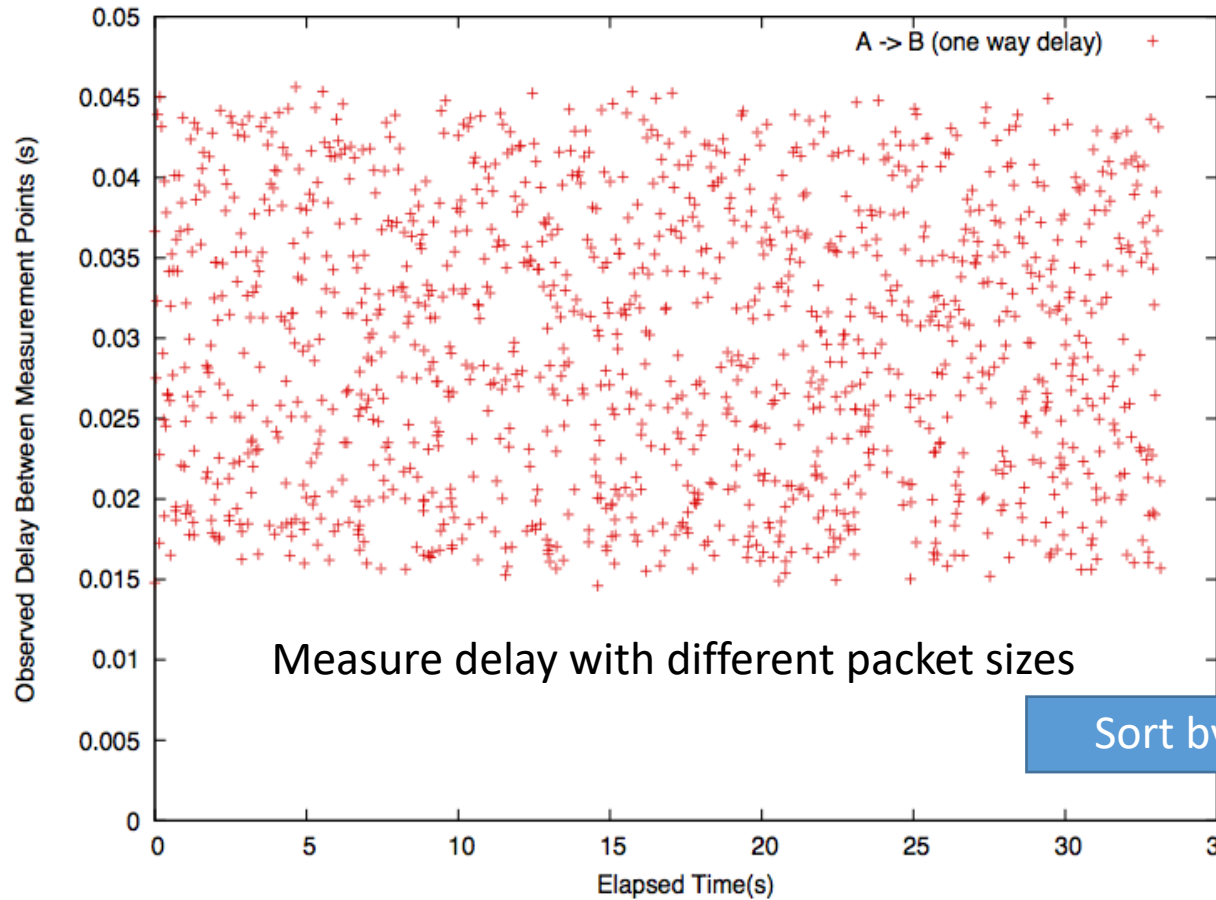
# Loss and delay must be considered together

- Quality attenuation ( $\Delta Q$ ) is the combination of both
- Need to measure full distribution not averages
- This is what applications “see”
  - What their protocols react to
  - Different applications/protocols are sensitive to different aspects
  - No single moment or centile can work for all
- Can specify application requirement as a bounding distribution

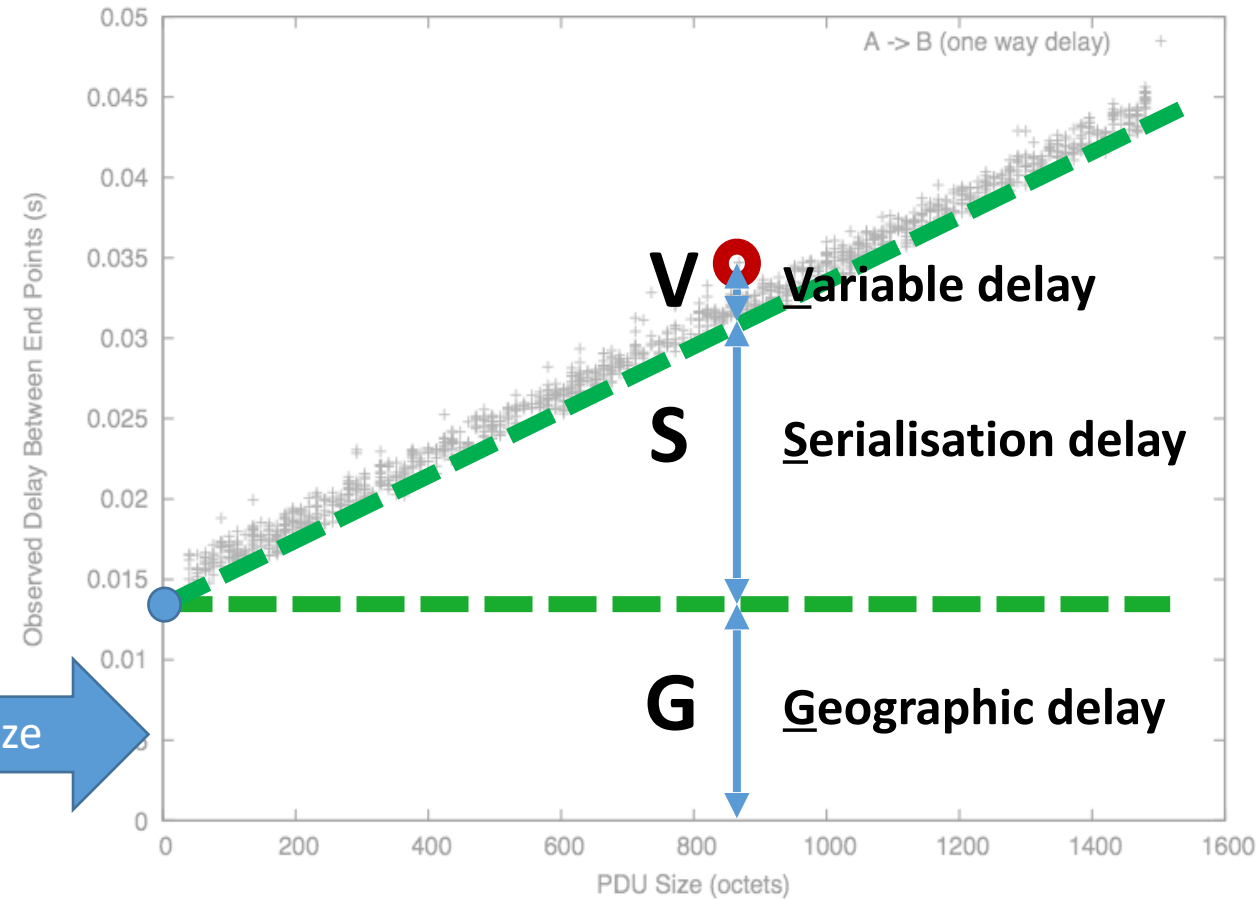




# Decouple static from load-related issues



Sort by size

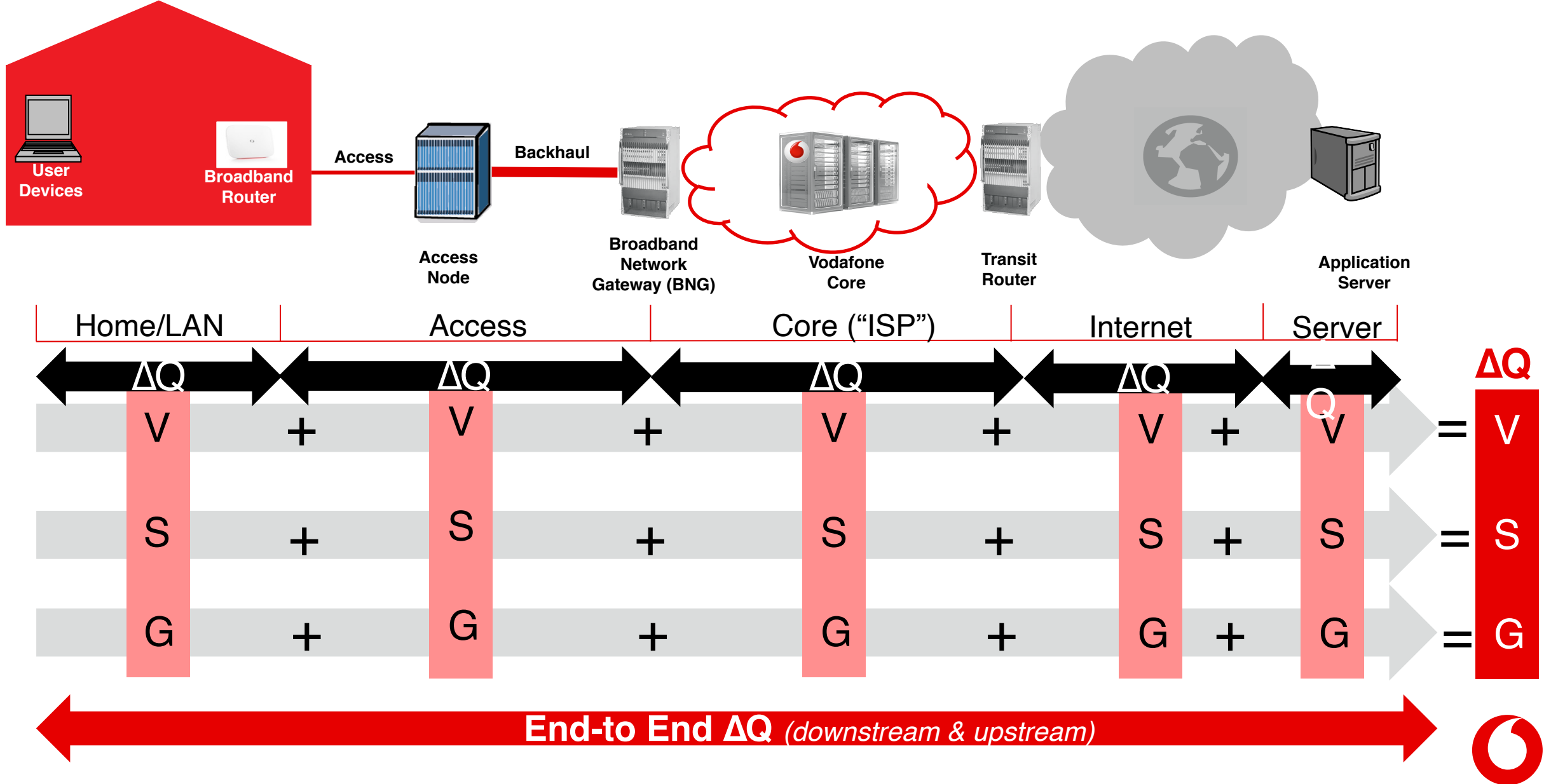


Quality attenuation can be broken into component elements highlighting different factors:

G and S are independent of load – V captures contention effects



# Composable Measurement Across the Digital Delivery Chain



# User-Perceived Latency to Measure Congestion Control Algorithms (CCAs)

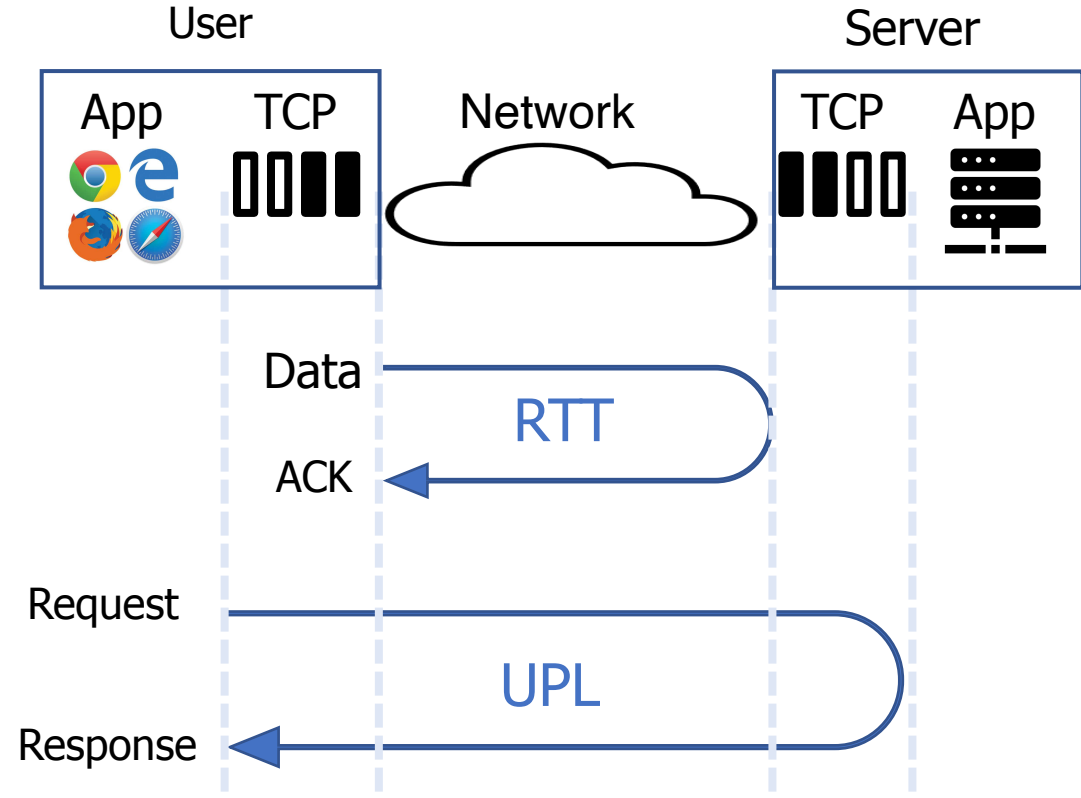
Mingrui Zhang @ University of Nebraska-Lincoln

Vidhi Goel @ Apple

Lisong Xu @ University of Nebraska-Lincoln

# CCA Latency Metrics

Metrics	Current: Round-Trip Time (RTT)	Proposed: User-Perceived Latency (UPL)
Definition	from Departure of TCP Data to Arrival of TCP ACK	from Departure of User Request to Arrival of User Response
Delays measured	delay inside the network	delay inside the network and at the hosts



# Experiment results: UPL and RTT

- Setup:

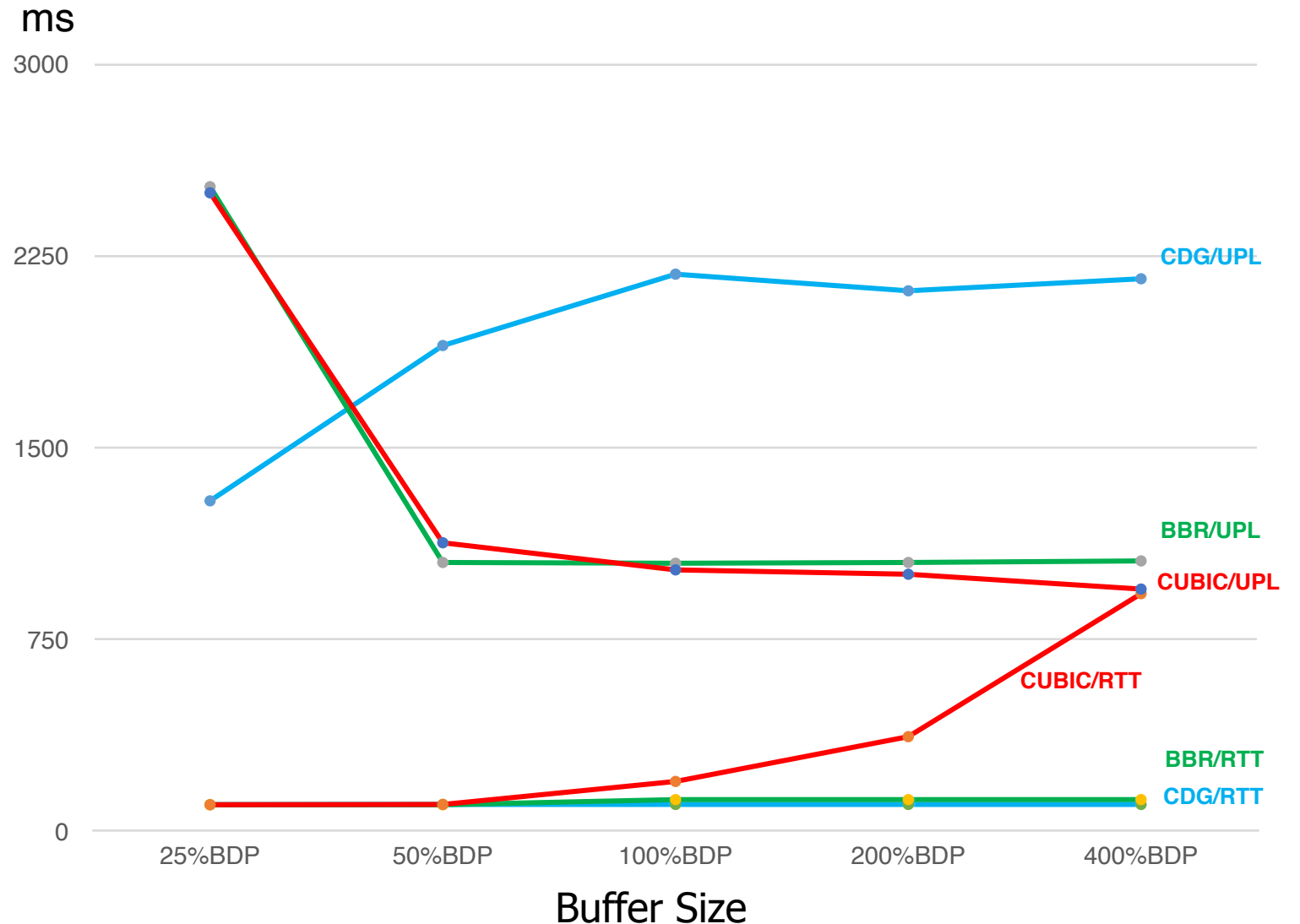
- TCP (Kernel 5.11): CUBIC, BBR, CDG
- Bottleneck: 10Mbps, 100ms RTT
- Cross Traffic: 1Mbps UDP bi-dir
- request=1Byte, response=1MBytes

- Result:

- RTT is not a good indication of the latency perceived by the user

- Propose:

- UPL, in addition to RTT

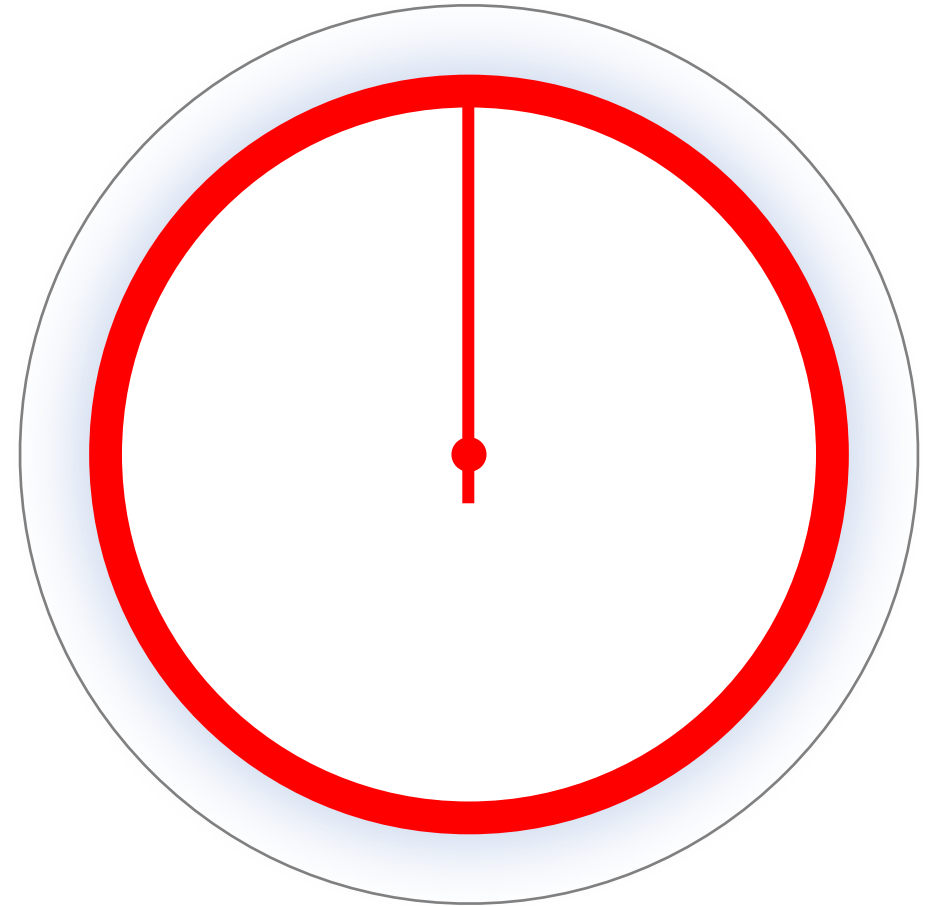


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# Responsiveness under Working Conditions

## *draft-cpaasch-ippm-responsiveness*

*C. Paasch, R. Meyer, S. Cheshire, O. Shapira*

### Problem #1

- 10+ years of Bufferbloat
- Still very widespread
- Need to raise awareness & tools
  - End-user as forcing-function
  - Forcing-function creates market incentive
  - Easy usable tools to measure *"bufferbloat"*

### Problem #2

- What is *"bufferbloat"*
- ICMP-ping, UDP-ping, TCP request/response, H3 ?
- How to *"load"* the network ?
- Huge differences in existing tools
  - DSLReports, Fast.com, waveform,...
- Need for a standardized metric of *"Responsiveness under working conditions"*

# Responsiveness under working conditions

*draft-cpaasch-ippm-responsiveness*

- Responsiveness for the end-user
  - Use modern protocols (HTTP/2, HTTP/3, TLS, ...)
  - Measure all stages of the connections (DNS, TCP-handshake, TLS, ...)
  - User-friendliness
- Creating **stable** working conditions (*harder than you might think*)
  - Multiple H2 bulk-transfers ramping up gradually.
- Measuring Responsiveness
  - HTTP/2 GET request on load-bearing connections
  - Separate short-lived parallel HTTP/2 GET requests

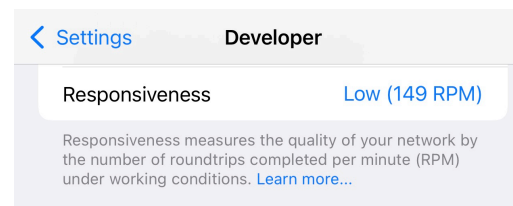
# Responsiveness Metric & Tool

*draft-cpaasch-ippm-responsiveness*

- Round-trips per Minute (RPM)
  - Higher is better
  - Integer range from low tens (> 1 second of latency) to a few thousand (less than 50 ms of latency)
  - Nice analogy to car engine's "revolutions per minute"

• `/usr/bin/networkQuality` in macOS beta

• Responsiveness UI in iOS beta



```
$ networkQuality
==== SUMMARY ====
Upload capacity: 191.175 Mbps
Download capacity: 275.957 Mbps
Upload flows: 20
Download flows: 12
Responsiveness: High (3047 RPM)
```



# A Single Common Metric to Characterize Varying Packet Delay

Bob Briscoe, Independent <ietf@bobbriscoe.net>  
Koen De Schepper, **NOKIA** Bell Labs <koen.de\_schepper@nokia.com>  
Greg White, **CableLabs**® <g.white@CableLabs.com>  
Vidhi Goel, Apple <Vidhi\_Goel@Apple.com>

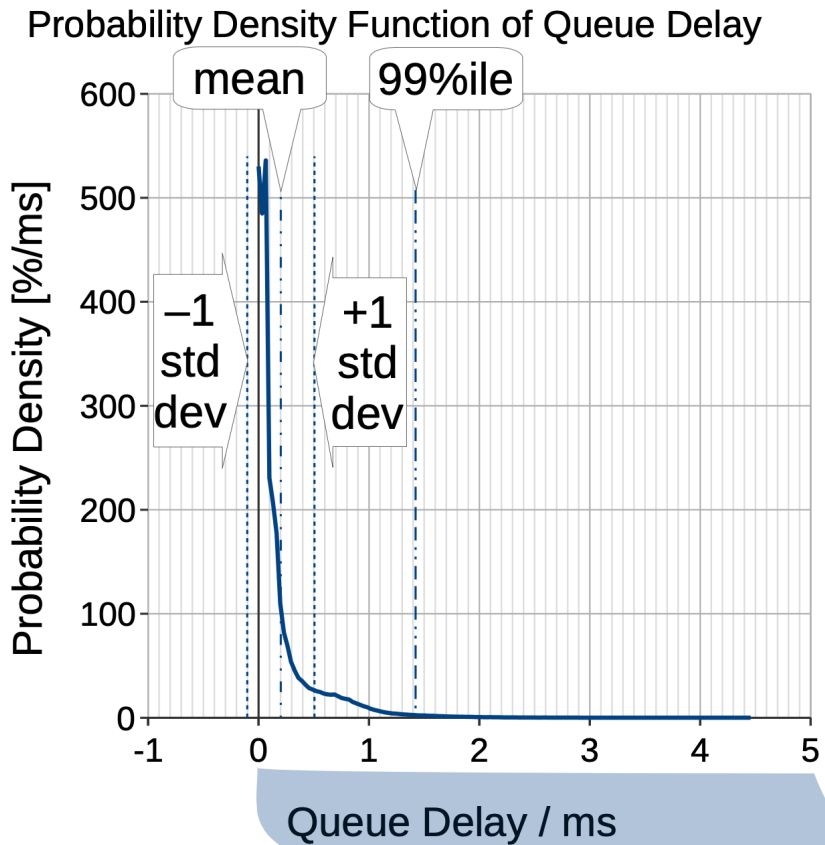


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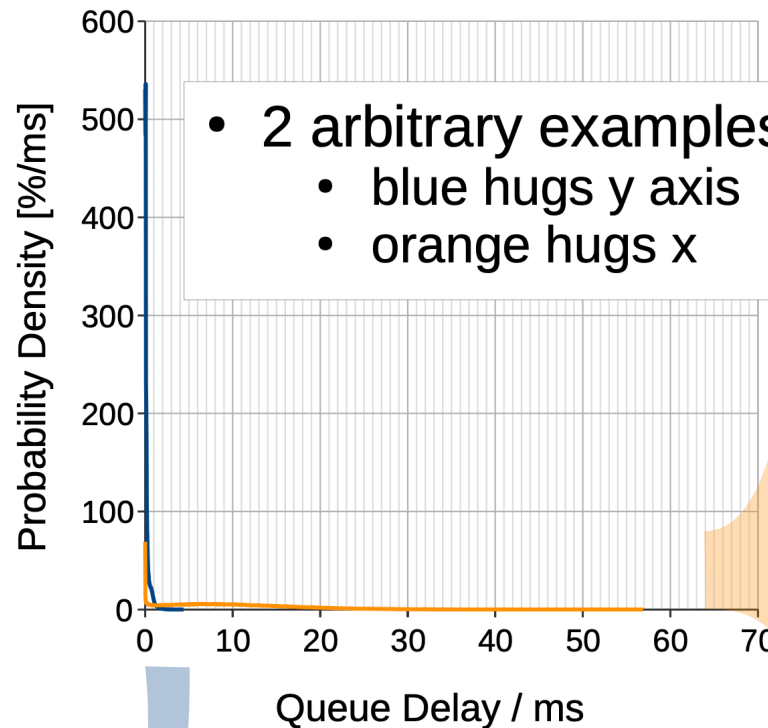
# Which metric best characterizes the experience of varying packet delay?

mean	0.2 ms
std dev	0.3 ms
median	0.07 ms
99%ile	1.4 ms

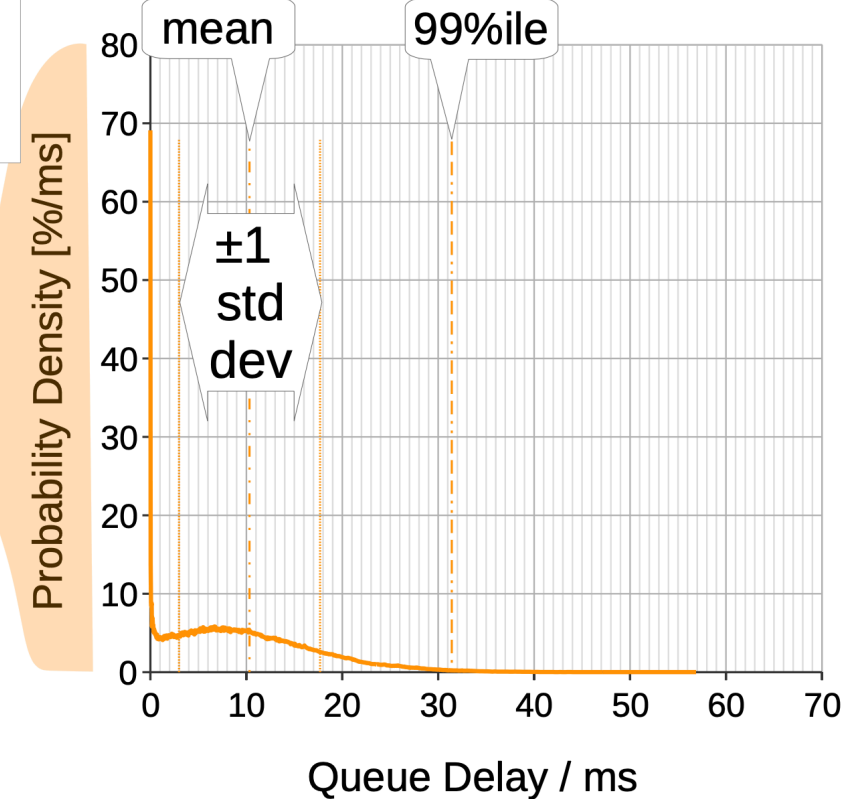
mean	10 ms
std dev	7 ms
median	9 ms
99%ile	31 ms



Probability Density Function of Queue Delay

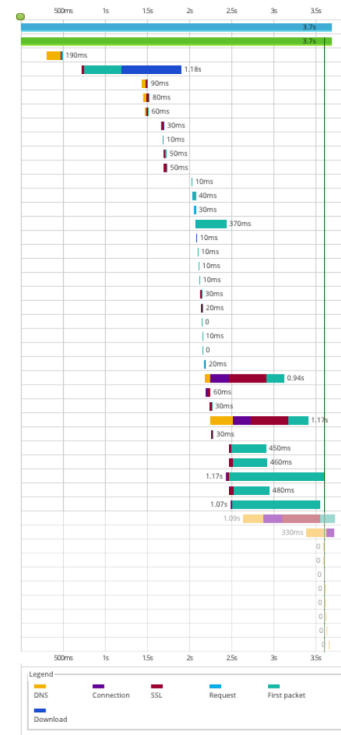


Probability Density Function of Queue Delay



# mean or median are distractions

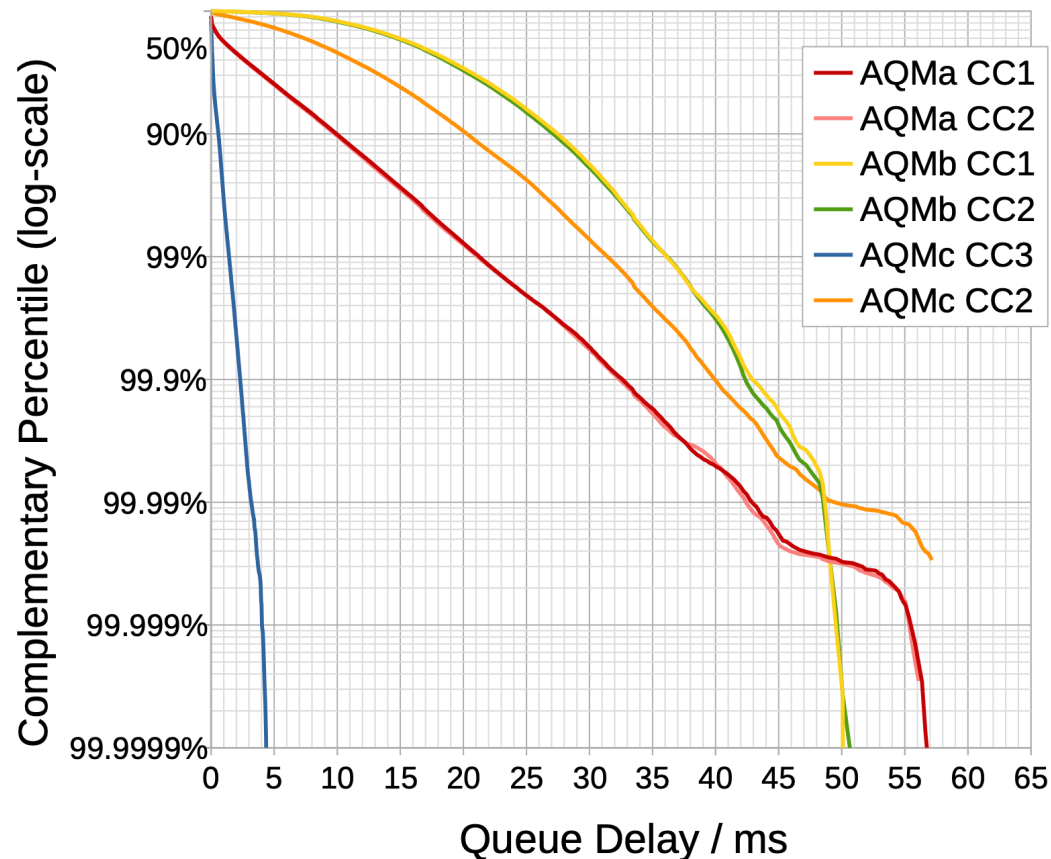
- Real time
  - play-out after median delay would discard 50% of packets
- TCP short flows (e.g. web/RPC)
  - wait for straggler packets to deliver to app in order
- Multiple streams/objects (e.g. http2/quic, webrtc)
  - even if no protocol sequence, typically inter-object dependencies in the app logic
- **Generalization (mostly true):**
  - **the user experiences the delay delivering the assembled product, not the pieces**
- Nearly all packet delay distributions are asymmetric with a long-tail
  - mean, median, standard deviation, etc. all characterize the irrelevant body, not the tail
- **Proposal: Standardize at least one high percentile to enable comparisons...**



# Which high percentile?

## Queue Delay CCDFs

120 Mb/s link rate, 10 ms base RTT



- Not too high
  - otherwise too slow to calculate accurately
  - but high enough to reflect typical delay experience
- Strawman: 99%ile
  - can apps conceal 1% discard well?
- IETF (ippm): appropriate body to forge consensus
  - interested? arguments against?

*“The IETF is good at setting standards when there is only one choice”*  
Spencer Dawkins?

## Clarifications

- not saying won't need to specify what, where and how\* as well
  - that's for each scenario, whereas the present question is for all scenarios
- not saying you shouldn't specify other percentiles as well or ideally a whole log-scale CCDF
  - as long as we have one common metric for comparisons

\* 1-way/2-way; layer7/4; at queue/e2e; capacity; RTT; load pattern; etc

# An end-user approach to an Internet Score

Christoph Paasch, Kristen McIntyre, Omer Shapira, Randall Meyer, Stuart Cheshire  
Apple, Inc.

# The case for an end-user “*Internet Score*”

- It’s not all about Throughput !
- Responsiveness, Jitter, Protocol conformance, ... (and many more)
- Too many different metrics for end-users to understand
- Some users/use-cases have different focus (e.g., Gaming vs Video Streaming)
- Proposal:
  - Define Internet Score for different use-cases as measure of Network Quality

# Network Properties

- Goodput
- Latency
  - Idle - not actively being used
  - Working - actively used
    - ability to multitask
- Protocol Conformance
  - existing and future - ECN, IPv6, Wi-Fi security

# Internet Score

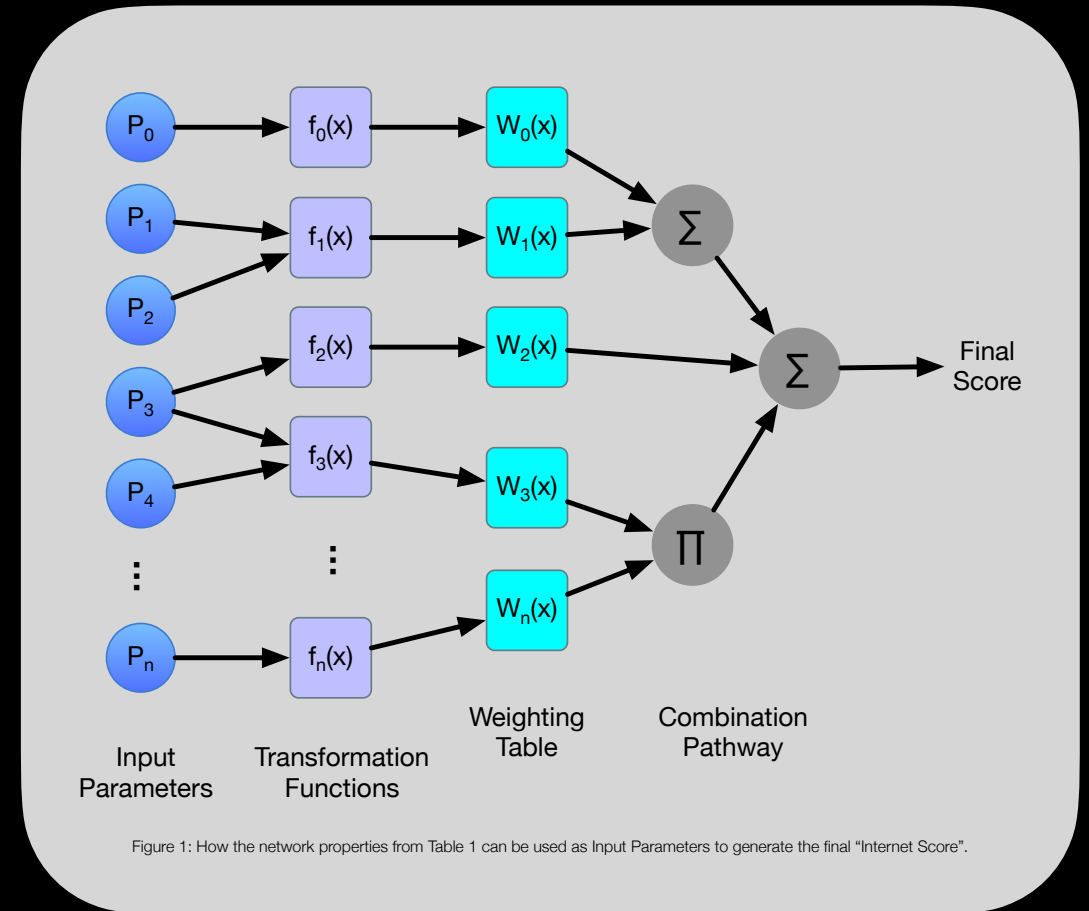
- 'Quality' and 'Utility' metric
- Single positive small-ish, dimensionless number
  - higher is better
  - no upper bound
- Correlation to user experience
- Mediated by a 'weighting table' composed of functions
  - future relevance - protocols come and go

# Our proposal: Synthetic Score

## Scalable into the future

- Transform input parameters and combine
- Pass through transformation functions
- Apply the weighting table as appropriate
- Combine as appropriate to make the Internet Score

### Linear and Nonlinear transformations



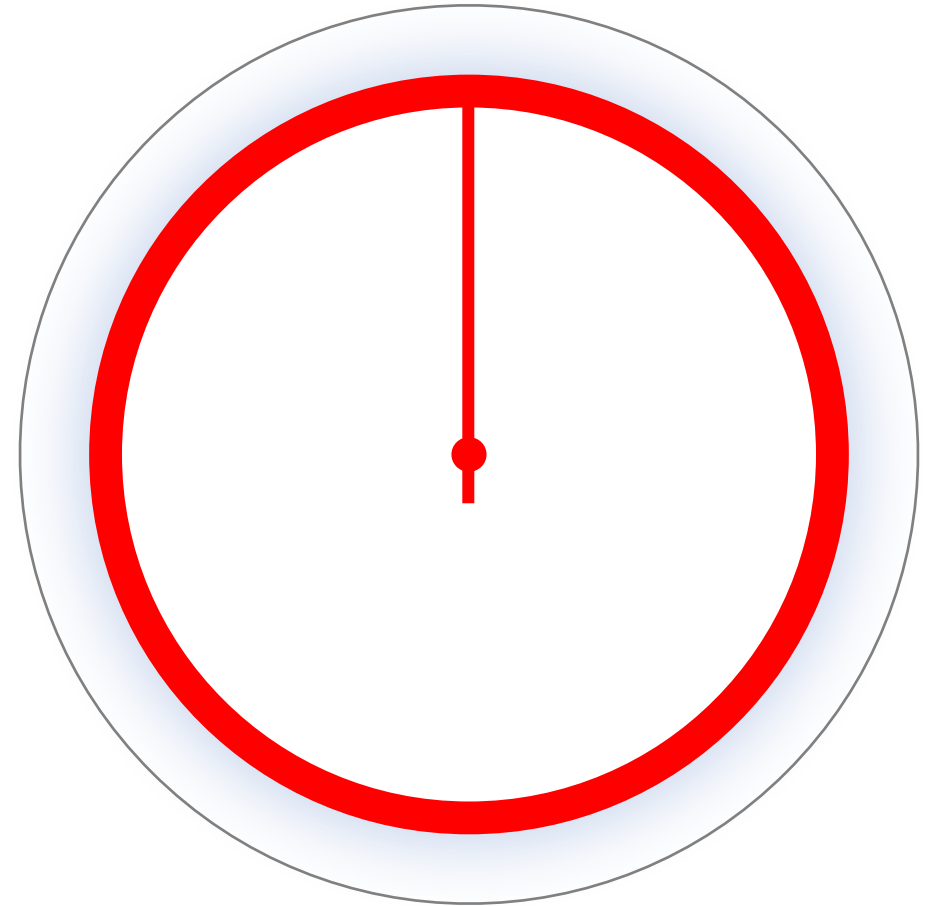


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What's next?

**FIN**