

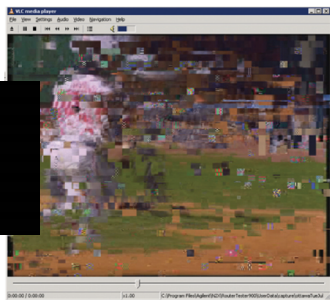
Residential Internet Performance Measurements: The Future is Passive

Renata Teixeira

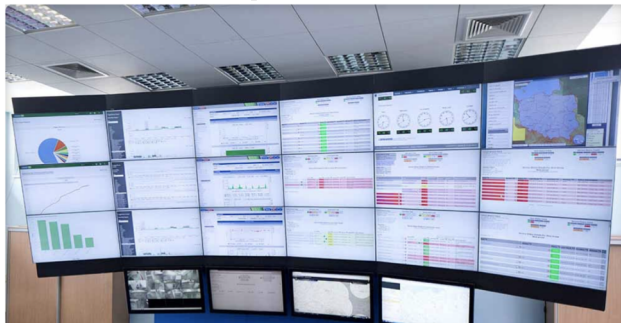
Director of Research at Inria, Paris
Visiting Scholar at Stanford University

Measuring residential Internet performance is crucial

- Home users



- ISPs, content providers



- Regulators, policymakers

Eighth Measuring Broadband America Fixed Broadband Report

A Report on Consumer Fixed Broadband Performance
in the United States



Federal Communications Commission

How to measure Internet access performance?

- Which metrics should we measure?
- How to measure them?

Many “speed tests”, but what do they measure?

- Access ISP performance?
- WiFi in the home?
- Bulk transfer capacity? Access capacity?
- Do these measurements match application performance?

Speed \neq application performance



Xfinity xFi Speed Test

Download speed

327.3 Mbps



Your Internet speed is

310 Mbps

Outline

- Cofounding factors of home network performance
- Metrics and measurement method
- From speed to quality of experience
- Final thoughts on Internet measurements

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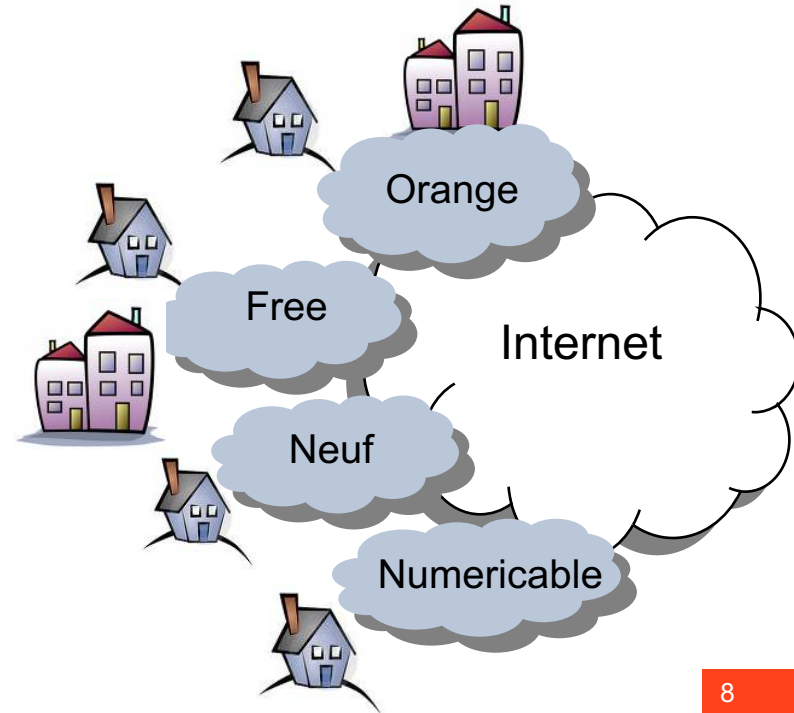
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Are users getting what they paid for?

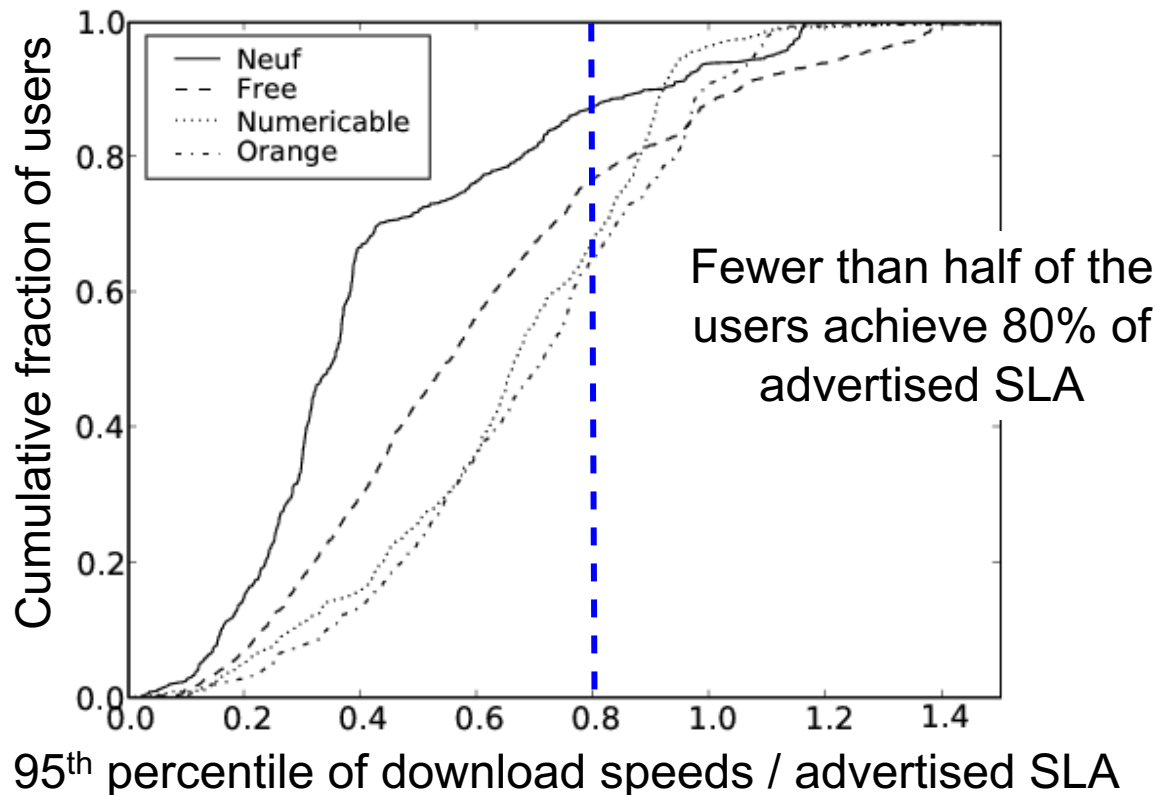
- In 2009: dataset with > 10K home users



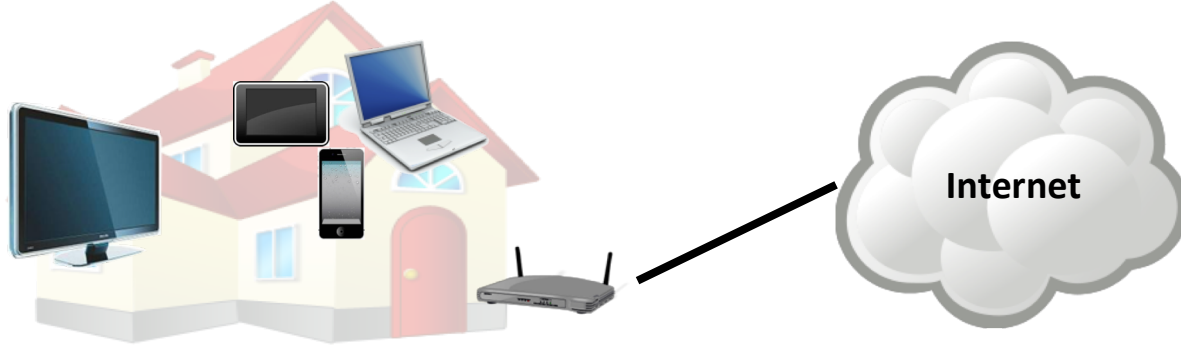
- Reports quality of ISPs in France
- Clients on home computers
 - Pings
 - FTP download/upload
 - Metadata: ISP, SLA, and city



Grenouille's users rarely got advertised speeds

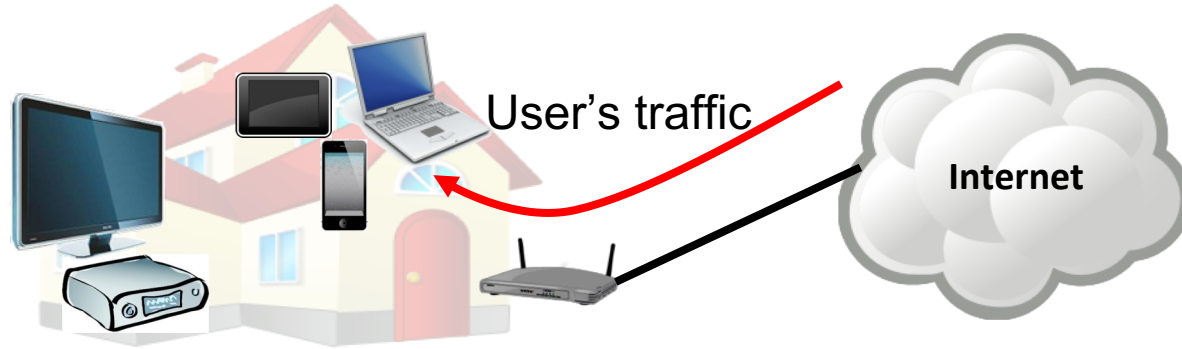


Many confounding factors



- Home network: WiFi, cross traffic
- Server location
- Test method

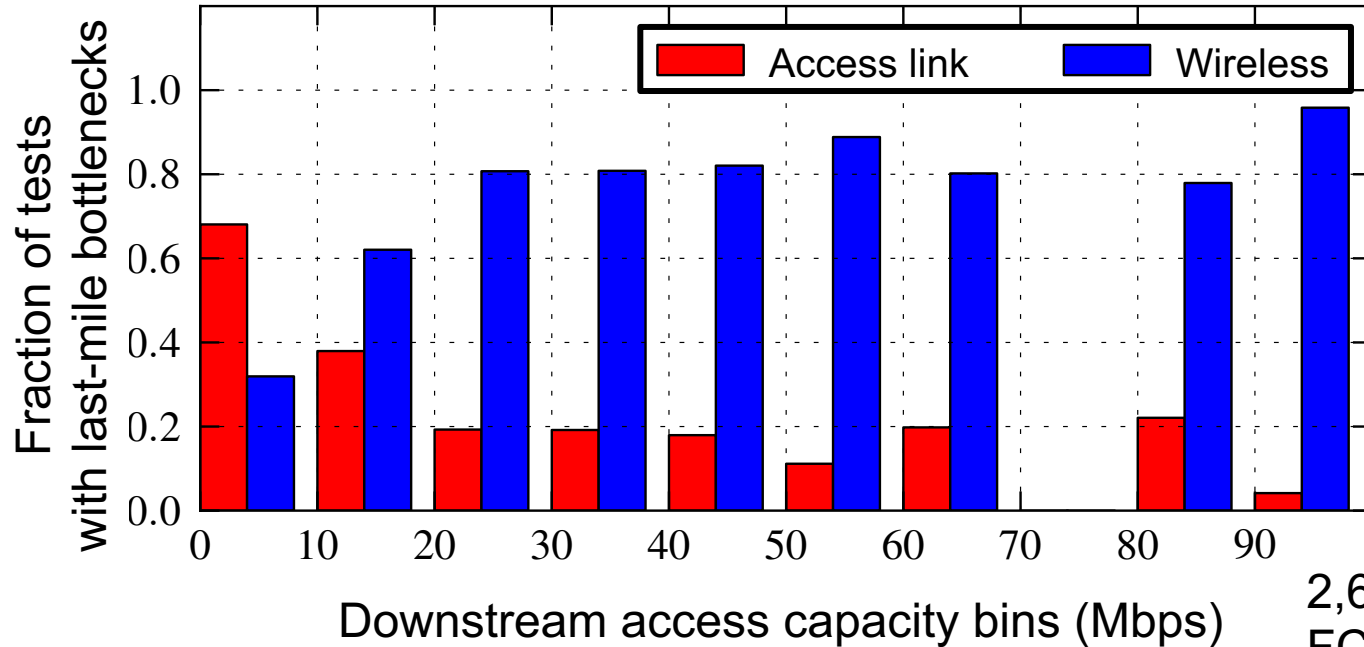
Are throughput bottlenecks in the access ISP or the home WiFi?



- Home or Access (HoA) algorithm
 - Inspect packets traversing the home router
 - Packet inter-arrival time to detect access bottlenecks
 - RTT in home to detect wireless bottlenecks

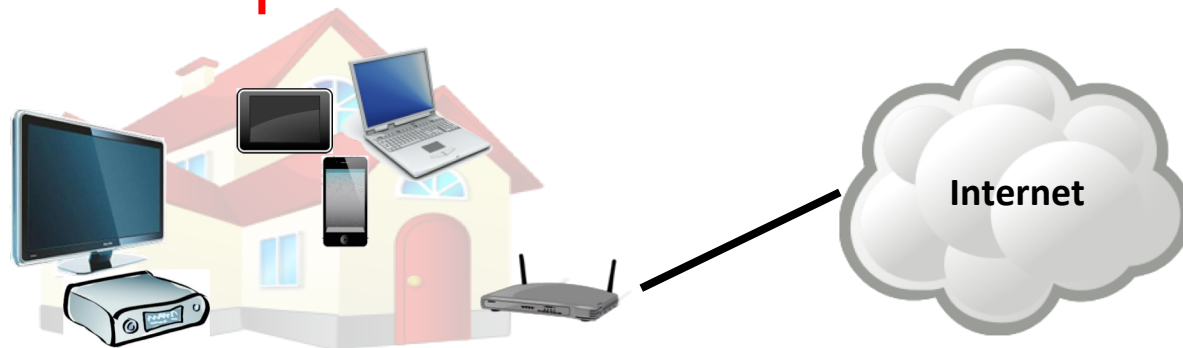
S. Sundaresan, N. Feamster, R. Teixeira. *Home Network or Access Link? Locating LastMile Downstream Throughput Bottlenecks*. PAM'16.

Prevalence of last-mile bottlenecks



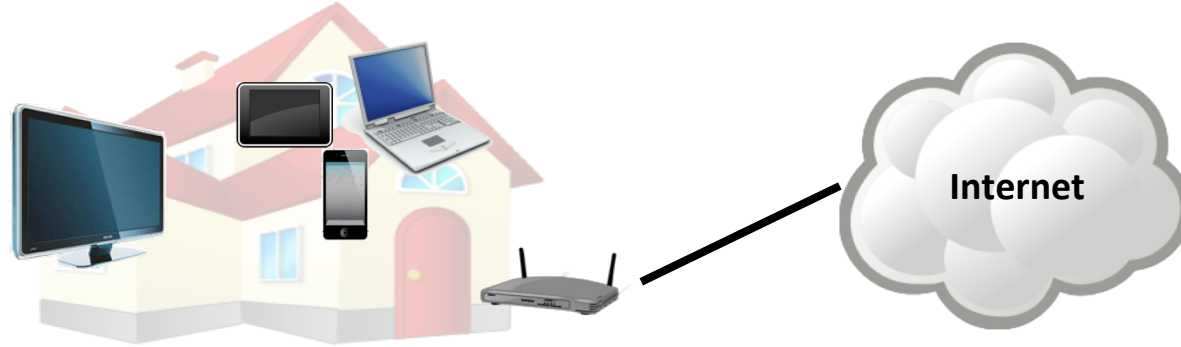
2,652 homes in
FCC, Nov 2014

How to reduce the effect of the home network on speed measurements?



- End-hosts
 - Test affected by home network
- Home router
 - Direct measurement of access link

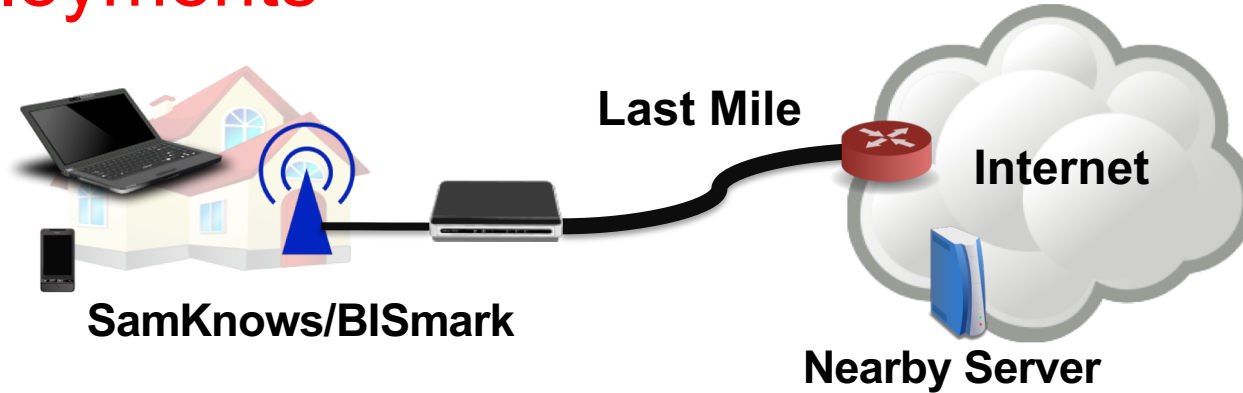
Idea: Measure from home router



- 👍 Ideally placed between home devices and Internet
- 👍 Always on
- 👎 Requires deploying infrastructure

S. Sundaresan, W. de Donato, N. Feamster, R. Teixeira, S. Crawford, A. Pescapé. *Broadband Internet Performance: A View From the Gateway*. ACM SIGCOMM'11.

Deployments



- Breadth: The FCC/SamKnows study
 - 7,800 gateways, 18 ISPs, multiple service plans
- Depth: The BISmark study
 - 120+ gateways in 28 countries worldwide, periodic and on-demand measurements

Lessons on the effect of home network on speed

- Home network can bottleneck end-to-end throughput
 - Homes with $> 20\text{Mbps}$ most often bottlenecked on WiFi
- Better to measure access speed from home router

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Speed metrics

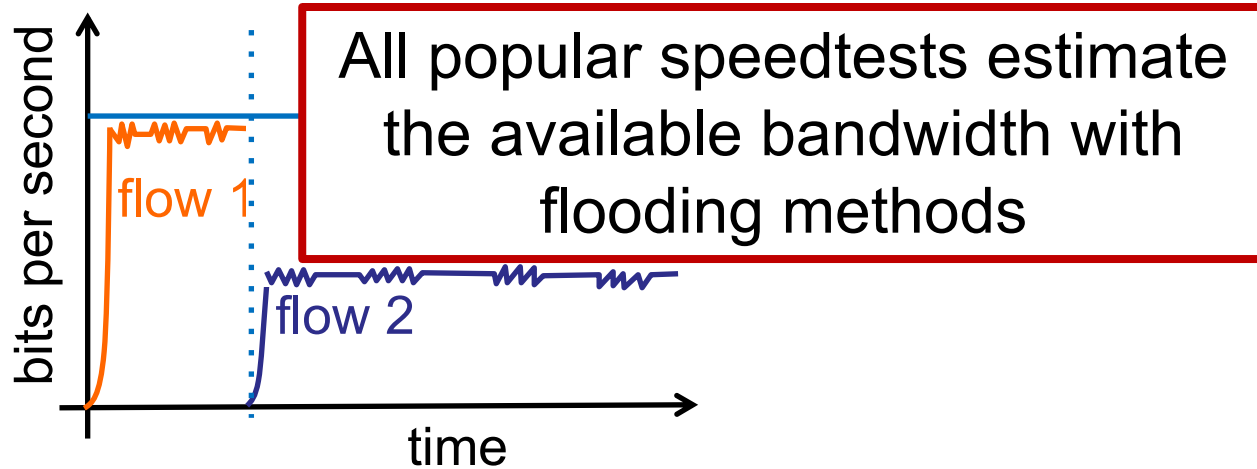
- Capacity
 - Maximum IP-layer rate of maximum-sized packets
- Available bandwidth
 - Maximum unused capacity
- Bulk transfer capacity
 - Throughput of single TCP connection during bulk transfer

Approaches to measure available bandwidth

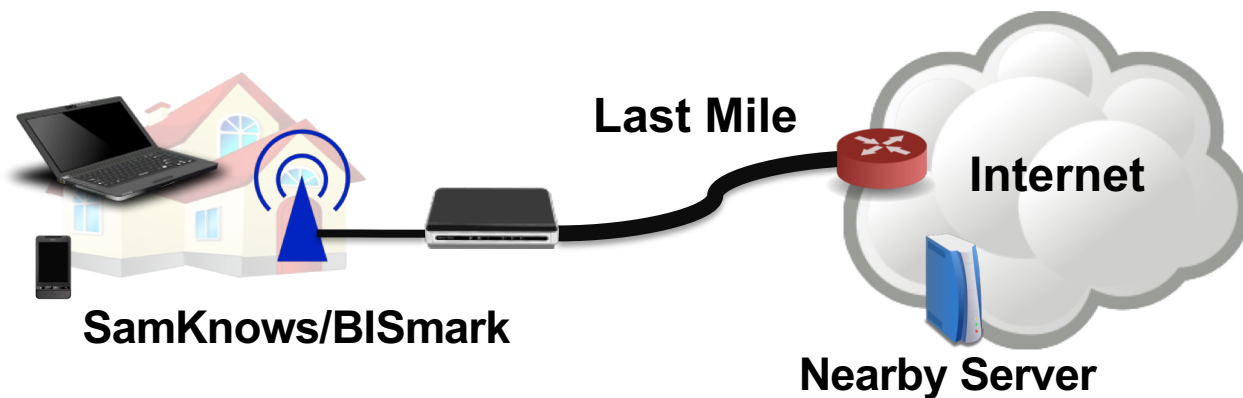
- Flooding
 - Large parallel TCP transfers & post-processing
 - 👍 Measures the effective available bandwidth
 - 👎 Large overhead
- Advanced probing
 - Trains or pairs of probes with varying sizes/spacing
 - 👍 Lower overhead
 - 👎 Assumptions may not always hold

Available bandwidth \neq what is available for new connections

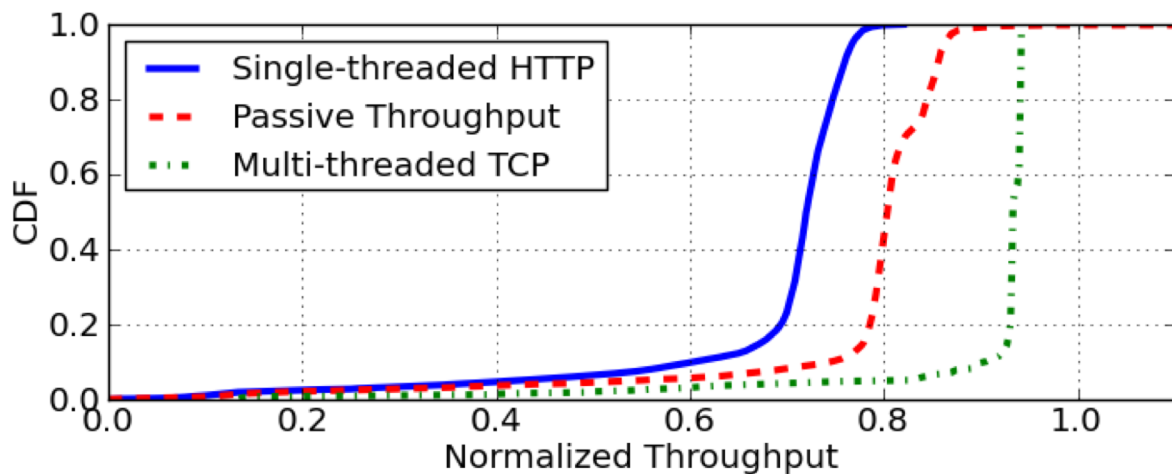
- Cross traffic is often elastic



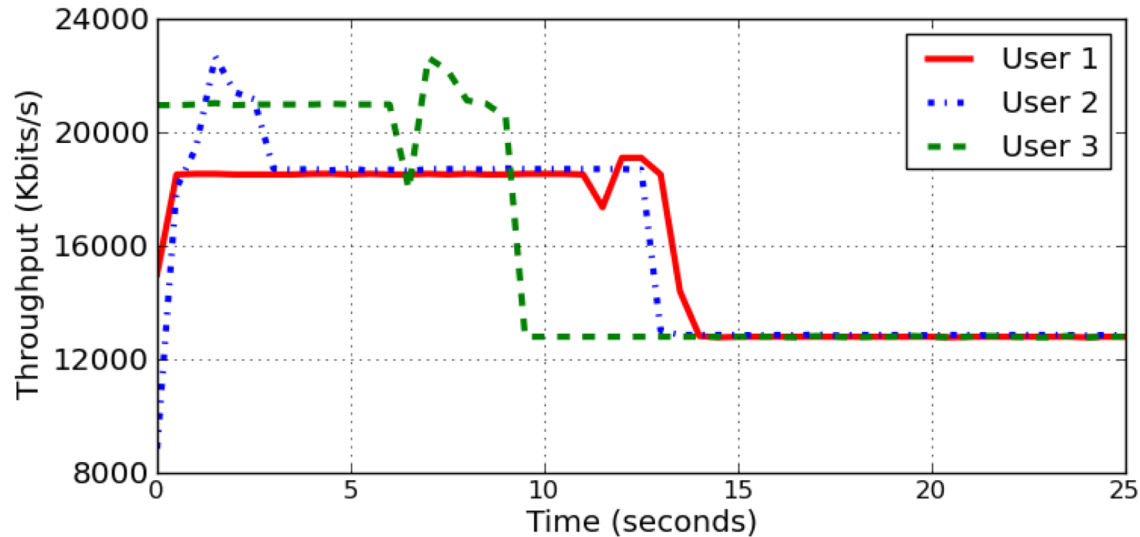
Measuring access speed with flooding methods from home routers



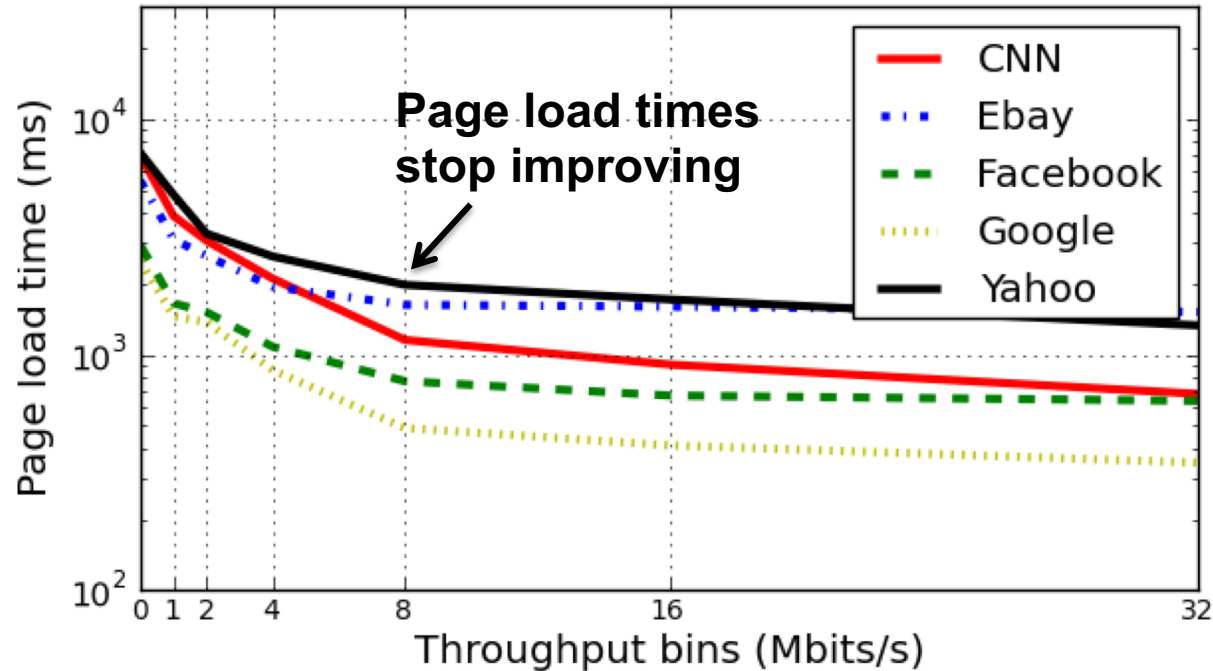
Different methods measure different speed metrics



Short-term throughput different from sustainable throughput

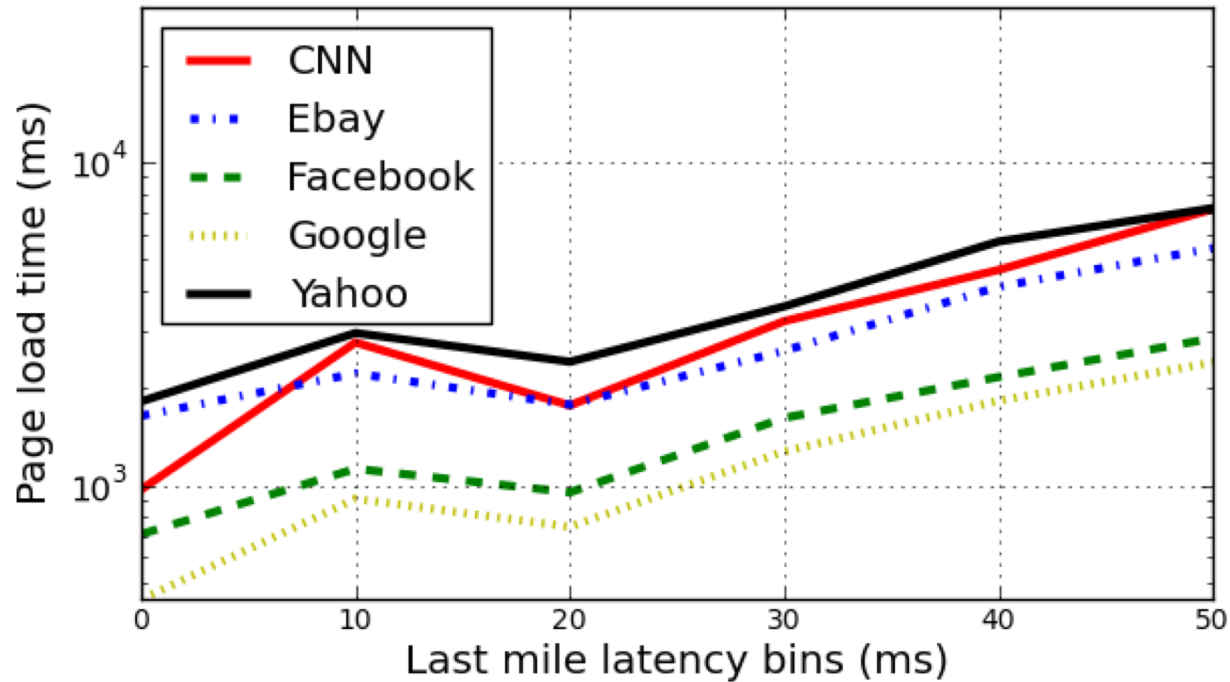


Page load times stop improving above about 8-16 Mbit/s

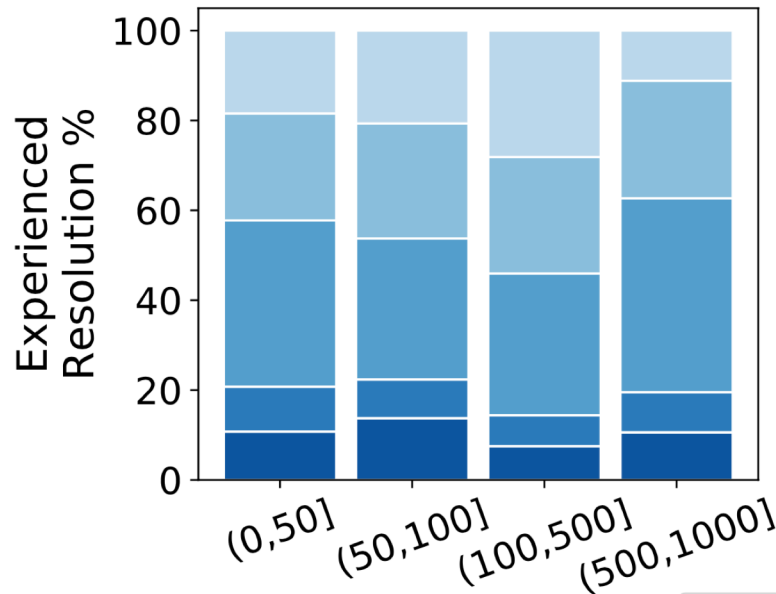


S. Sundaresan, N. Feamster, R. Teixeira, N. Magharei. *Measuring and Mitigating Web Performance Bottlenecks in Broadband Access Networks*. IMC'13

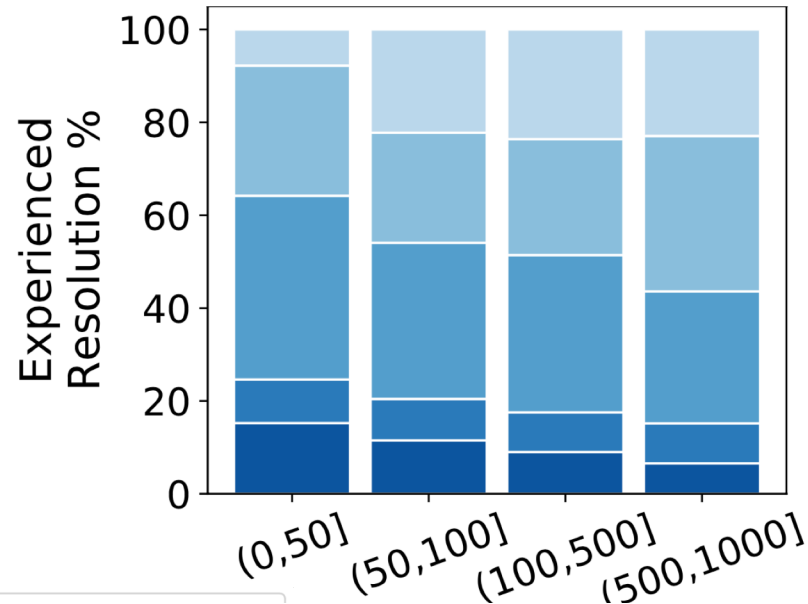
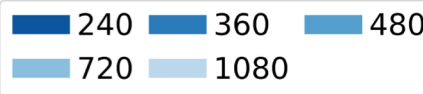
Last-mile latency matters



Video resolution depends on factors other than speed



Nominal Speed



95th% active throughput

F. Bronzino, P. Schmitt, S. Ayoubi, G. Martins, R. Teixeira, N. Feamster. *Inferring Streaming Video Quality from Encrypted Traffic: Practical Models and Deployment Experience*. Sigmetrics'20

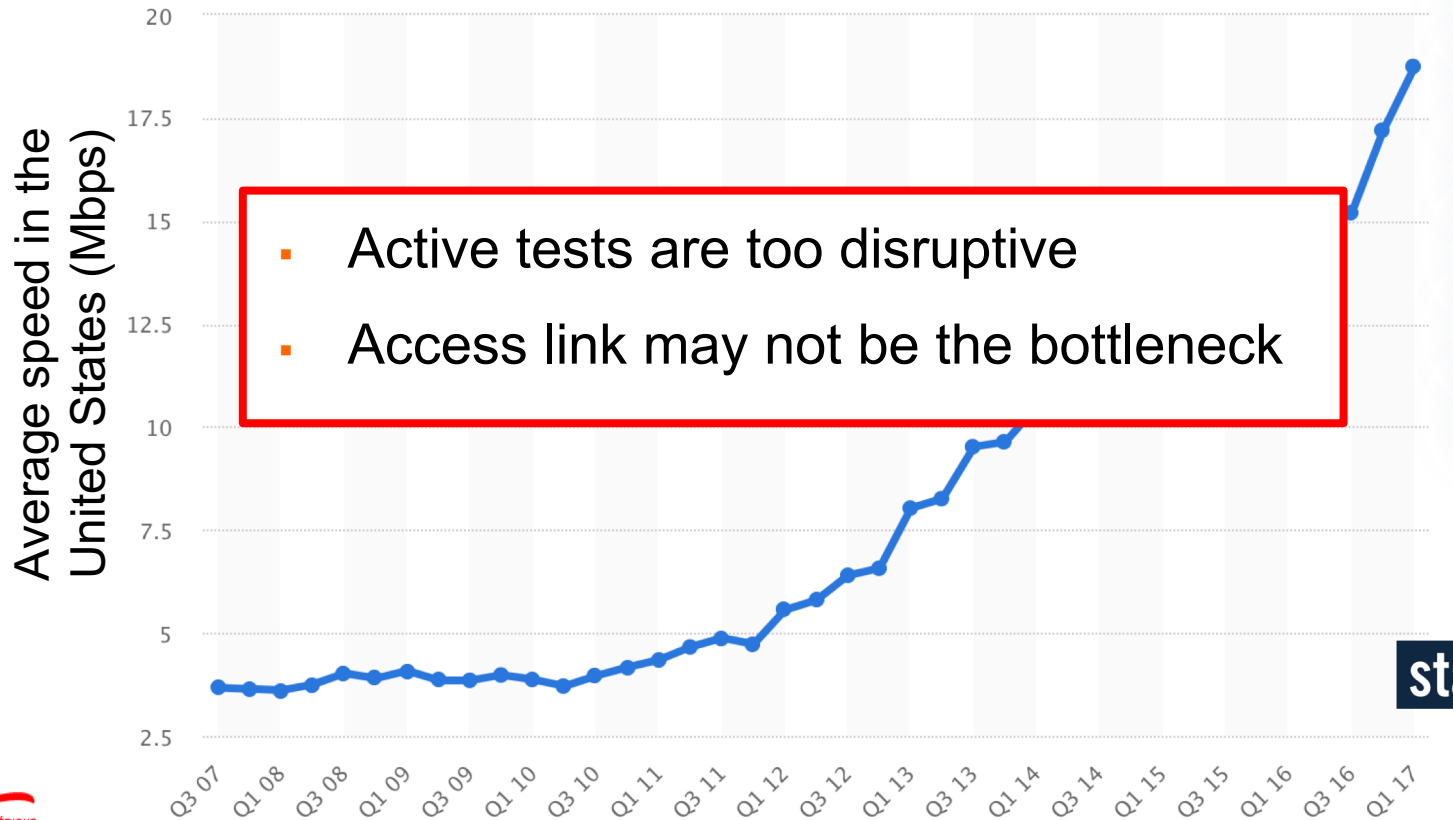
Lessons on measuring access performance

- A single metric of speed may not be sufficient
 - Short-term versus sustained
 - Consistency over time
- Speed is not enough
 - Web: Latency becomes bottleneck beyond 16 Mbps
 - Video: some correlation with access throughput, but many other factors
 - Eg., device, content, video streaming decisions

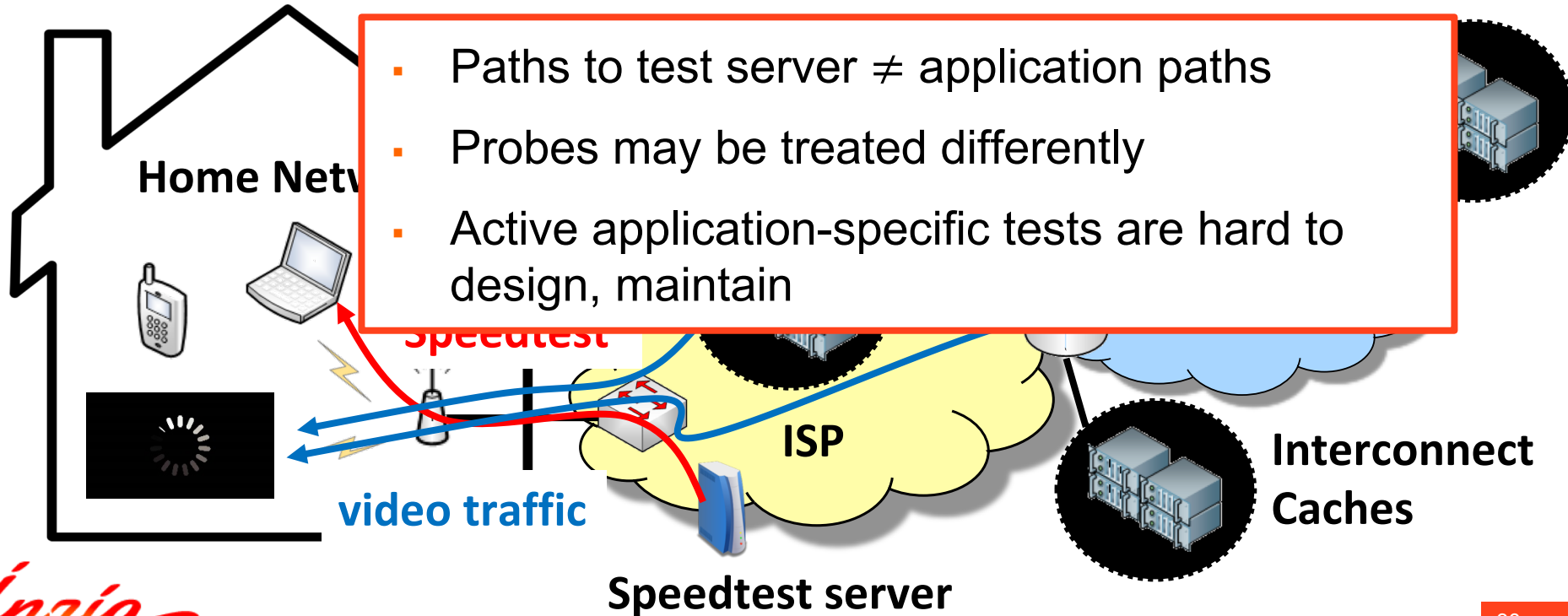
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Access networks are getting faster



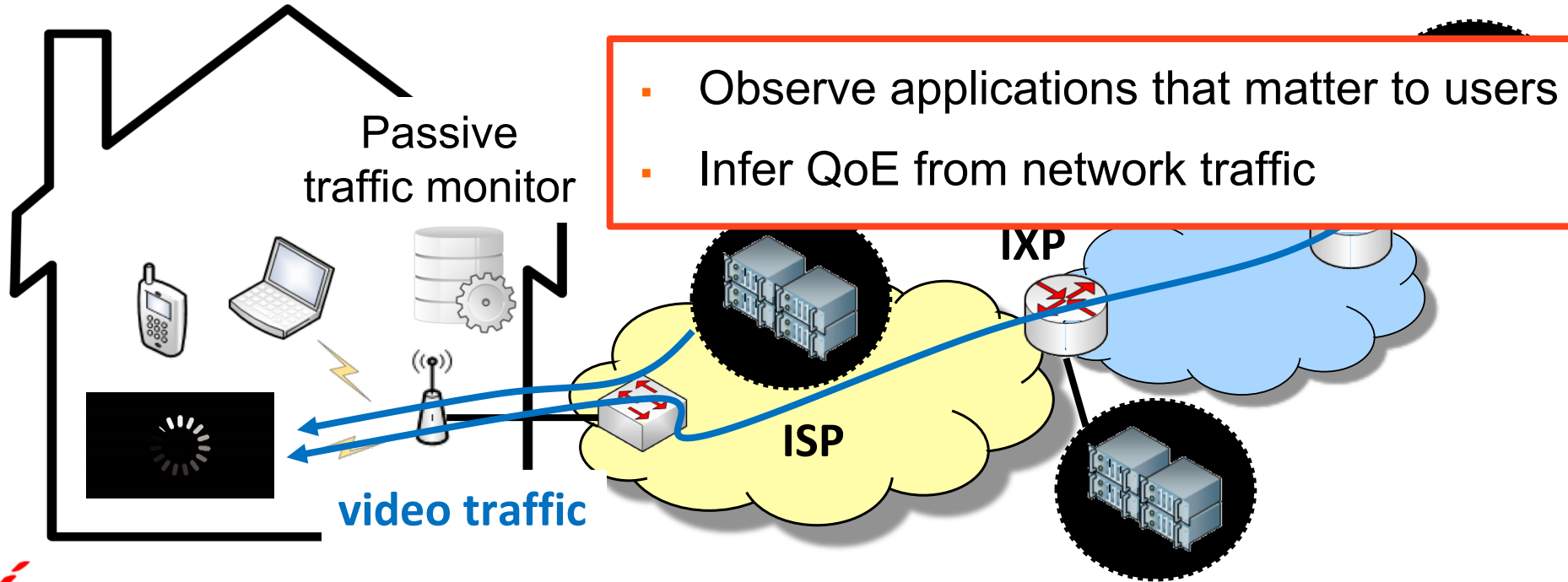
Applications are complex, distributed, adaptive





Active measurements have reached their limit

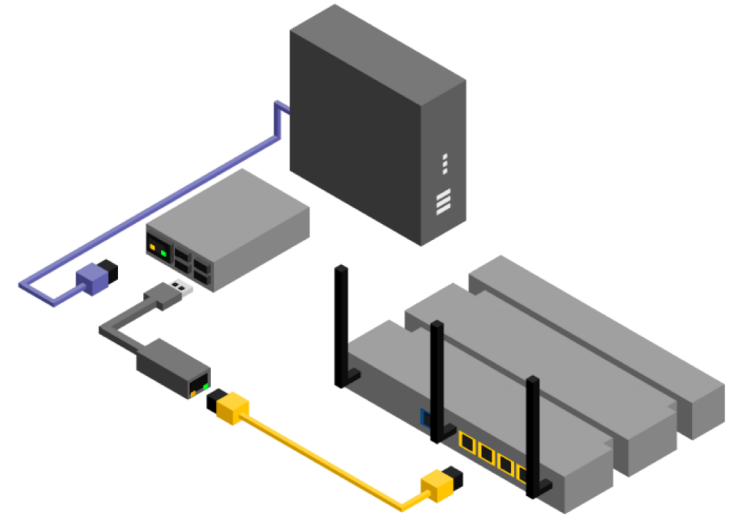
From active speed tests to passive Quality of Experience (QoE) inference



Video quality with Network Microscope

- Implemented for low-cost devices
 - Raspberry Pi, Odroid
- Inference of video quality from encrypted network traffic
- Pilot home deployment
 - ~10 in Paris
 - ~60 in the US

THE WALL STREET JOURNAL.



F. Bronzino, P. Schmitt, S. Ayoubi, G. Martins, R. Teixeira, N. Feamster. *Inferring Streaming Video Quality from Encrypted Traffic: Practical Models and Deployment Experience*. Sigmetrics'20

Advantages of passive QoE inference

- Captures all factors that matter
 - Access speed
 - Latency
 - Peering
 - Connectivity to services
- Adapted to individual households

Open problems

- Bottleneck identification: Is the access ISP the performance bottleneck?
- What should ISPs advertise?
- What to present to users?

Summary

- Residential Internet performance measurements should focus on QoE instead of speed
- Passive measurements are better to capture QoE
- As networks and usage evolve, measurements need to evolve

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Networks are evolving

- In-network programmability and load balancing
 - Harder to make active probes follow application paths
- Explosion of connected devices and IPv6
 - Internet-wide active probing prohibitive
- Link speeds keep increasing
 - Passive per packet measurements more challenging

Applications and users are evolving

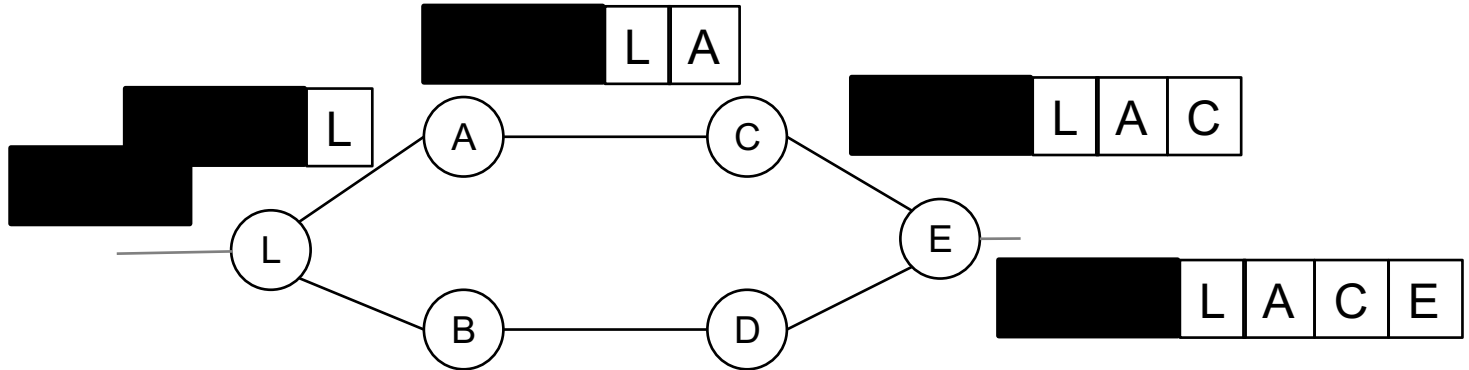
- Concerns over privacy
 - Passive measurements face restrictions
- Traffic is more often encrypted
 - Prevents deep-packet inspection
- Content everywhere
 - Shorter paths over fewer domains

Opportunity: Leveraging advances in statistical learning

- What can we infer from encrypted traffic?
 - Application and device type identification
 - Application performance
 - Security threats
- Research challenges
 - Lack of labeled datasets
 - Co-design of measurements and inference

Opportunity: Programmable data planes

- In-band Network Telemetry (INT)
 - Enables new measurement capabilities at switches



- What to measure?
- How to scale INT?

Concluding remarks

- Internet measurements: The future is passive
- A number of interesting research challenges
 - Mapping of network performance to QoE
 - Scalability
 - Coverage for Internet-wide analyses

Thanks!