HOPS @ IETF94:
Access Networks – Dormant Middleboxes

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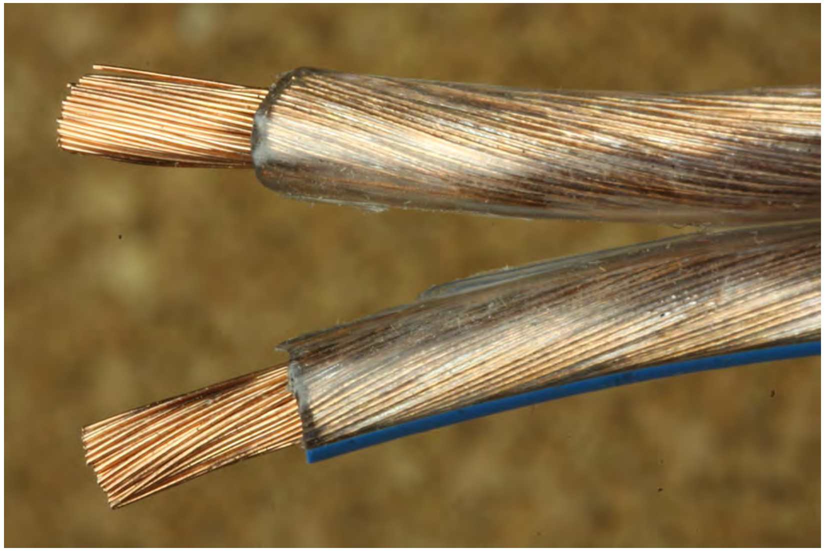
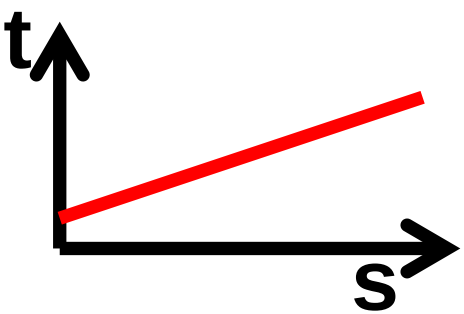
Motivation

- Commonly used **network abstraction**
  - **Networks are stateless copper wires**
  - **Silent** assumption

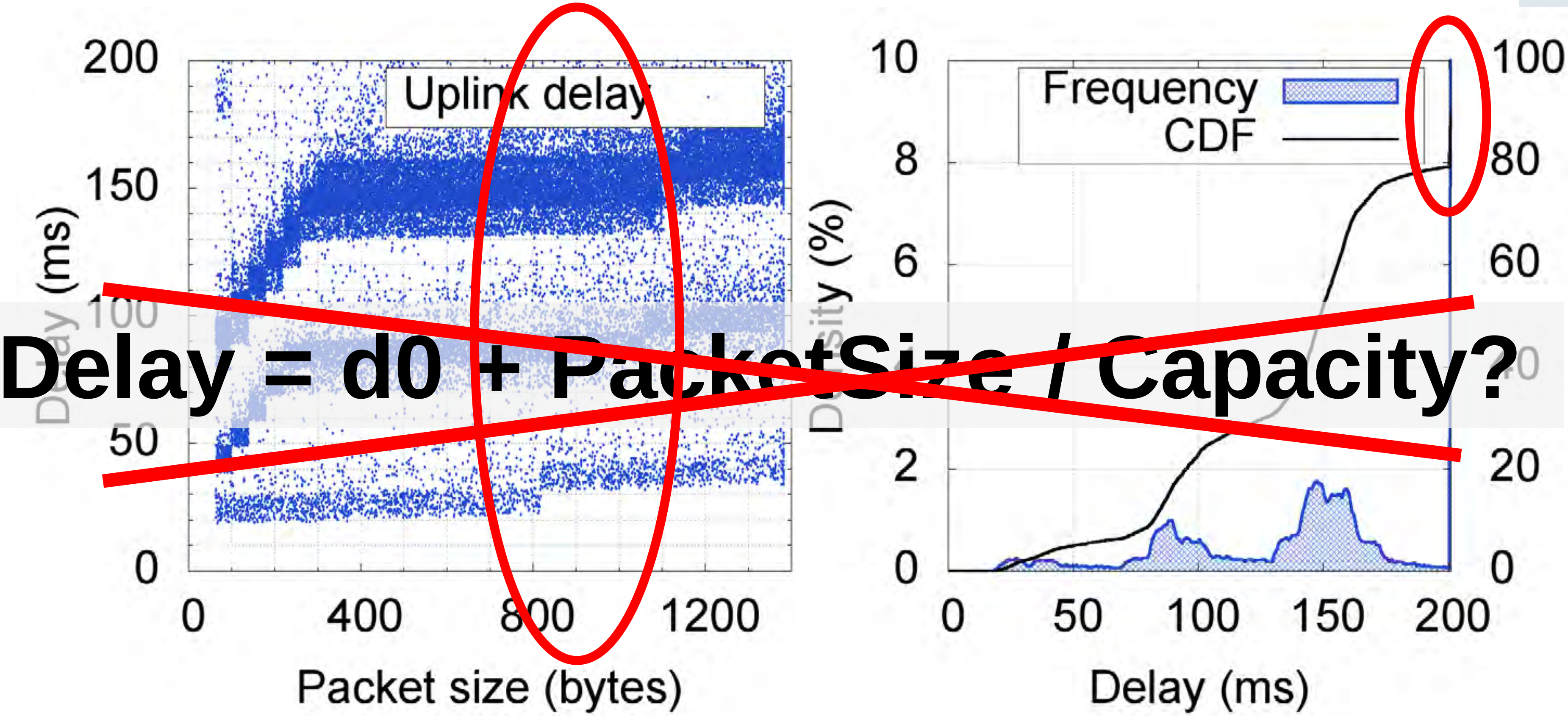




Delay = d_0 + PacketSize / LinkCapacity

Source: http://commons.wikimedia.org/wiki/File%3ALautsprecherkabel_Makro_nah.jpg

Delay in Today‘s 3G Networks (HSPA)



~~**Delay = d0 + PacketSize / Capacity?**~~

Measurement details: HSPA network, uplink one-way delay, 50K samples, size 64-1400 bytes (uniform), inter-packet delay 100-5000 ms (total 36 hrs)

Additional Challenges

- **Network delay** has decreased
  - Wireless and wired networks
  - Previously obscured uncertainty factors contribute to delay
- Economy focus as main driver (vendors, operators):
  1. **Overall network capacity optimization**
  2. **Software-dominated networks**

Problem wrt. Middleboxes:

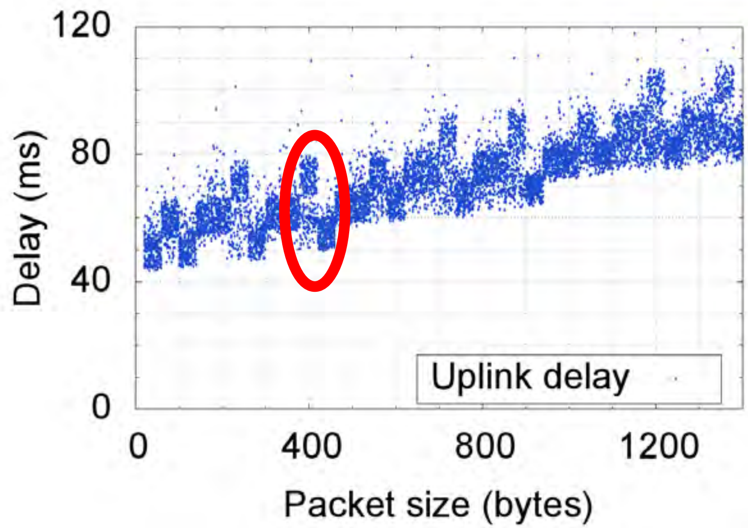
„Optimization“ depends on session-awareness and session-state in networks at layers below IP

Statement

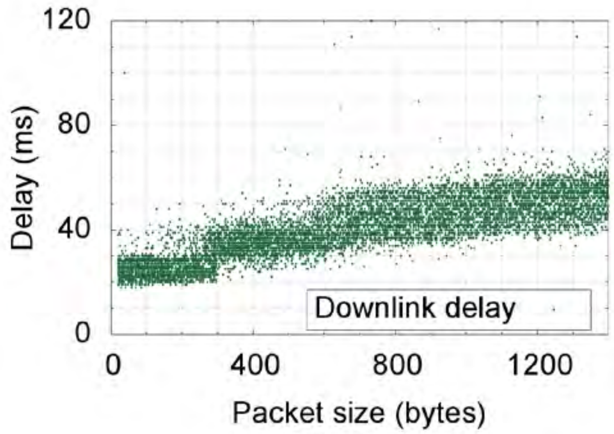
- Many Access **Networks** are dormant middleboxes
  - On-demand capacity allocation
    - Capacity depends on traffic history
  - Store session state
    - Per-terminal or per-flow (PDP context)
    - Visible in terms of timing
    - **Currently** not visible in value domain
- Middlebox: **time**-domain vs. **value** domain
  - Session-awareness is main prerequisite for middlebox
  - Session state enables easy migration from time domain to value domain
- Examples of Strange Access Network Delay „Patterns“

Access Network Delay Patterns

- **Packet-based scheduling and processing**
  - Packets with larger payload may (deterministically!) experience lower delay than smaller packets

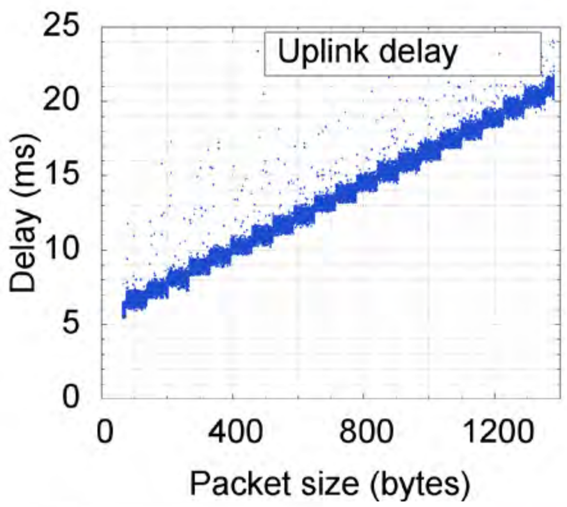


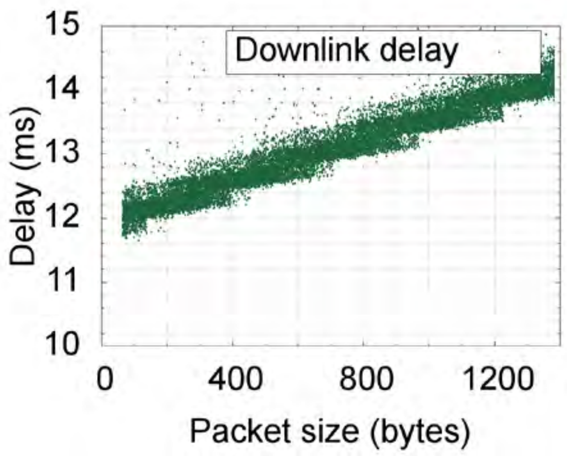
- **Asymmetric links**
  - Access links: distinct capacities and characteristics for uplink and for downlink (fixed, wireless)



Access Network Delay Patterns (ctd.)

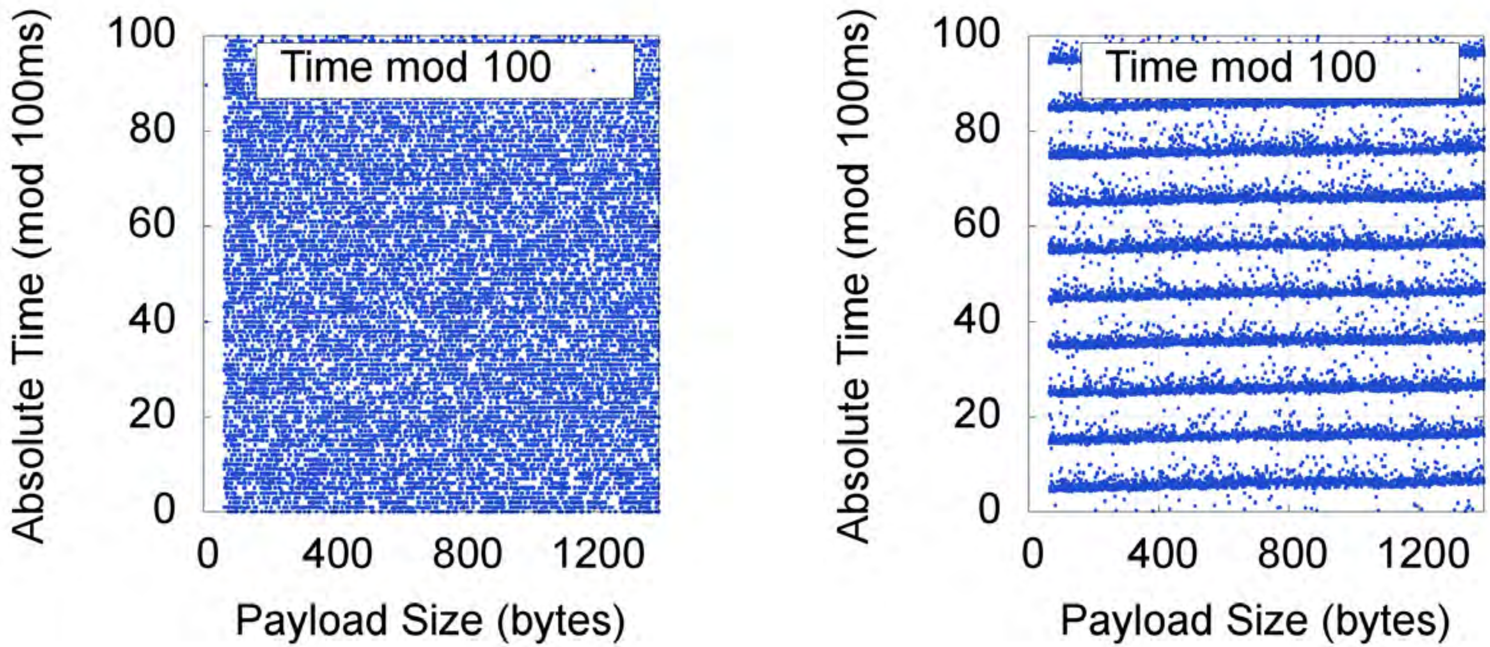
- **Asymmetric links**
  - Delay NOT necessarily proportional to link capacity!
  - Example: VDSL (fixed access)
    - **768 kb/s** uplink, **8Mb/s** downlink
    - Uplink delay for 64 byte packets: approx. 6ms
    - Downlink delay: approx 12ms
  - **Reason**: Provider activated **interleaving** on downlink
    - Overhead for single (sporadic) packet like sensor reading?





Access Network Timing

- **State and history**: time-slotted links

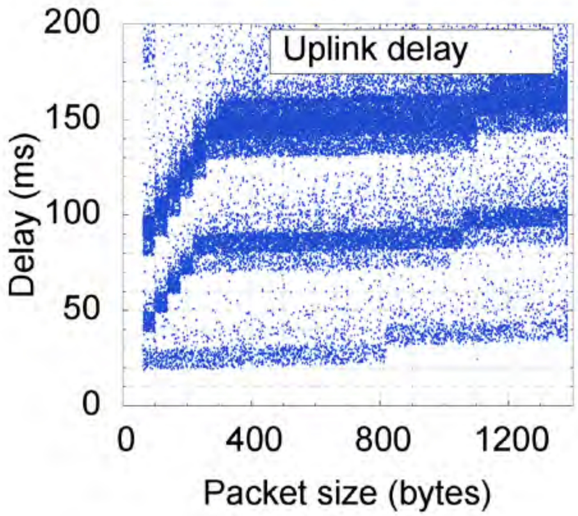


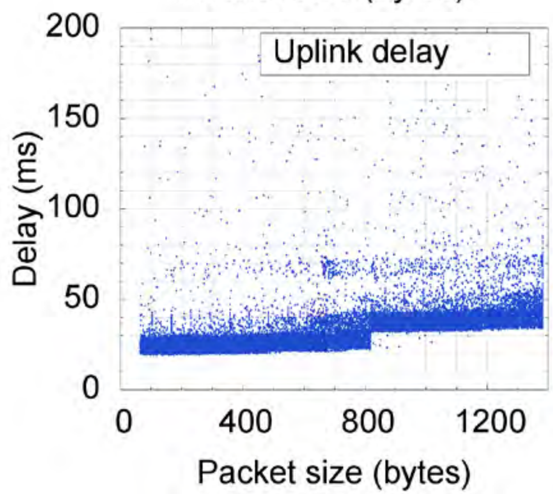
(a) Send time (client) **(b) Receive time (server)**

J.Fabini and M.Abmayer**: "Delay Measurement Methodology Revisited: Time-slotted Randomness Cancellation",** *IEEE Transactions on Instrumentation and Measurements*, 2013, doi:10.1109/TIM.2013.2263914

Capacity changes with load

- **Network „optimization“**
  - **On-demand capacity allocation**
    - Triggers operational regimes
    - Capacity changes within milliseconds
    - Current performance = f(history, load)
      Sporadic sensor reportings?
    - „The more you ask for, the more you get
      - Higher load ***decreases*** packet delay
      - Challenges fundamental algorithms (e.g., TCP)
  - Flow aggregation
    - Per-user-, per-link-, or per-cell



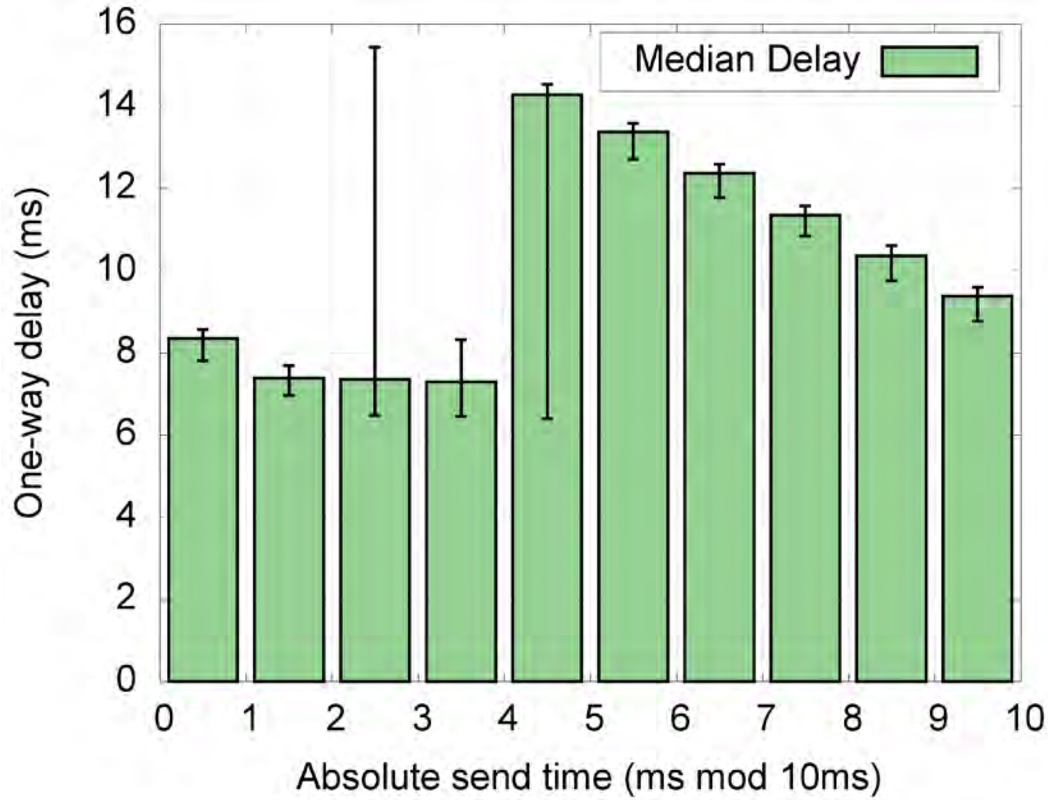


How Identify Timing-Middleboxes?

- **Key Concept**: Differentiate between **systematic** and **transient timing impairments.**
- Host vs. network
  - Isolate systematic uncertainty factors and their timing
  - Improve systems and measurement methodologies
    - Quality of active delay measurement samples
    - Repeatability of measurements, predictability of behavior
    - Validity of measurements beyond specific packet and session
  - Timing
  - **Challenge:** Uncertainty factors aggregate along network path
    - Example: time-slotted link -> reactive link -> time-slotted link
    - Difficult to isolate origin (Possible solutions: hop-by-hop measurements, randomness re-generation, …)

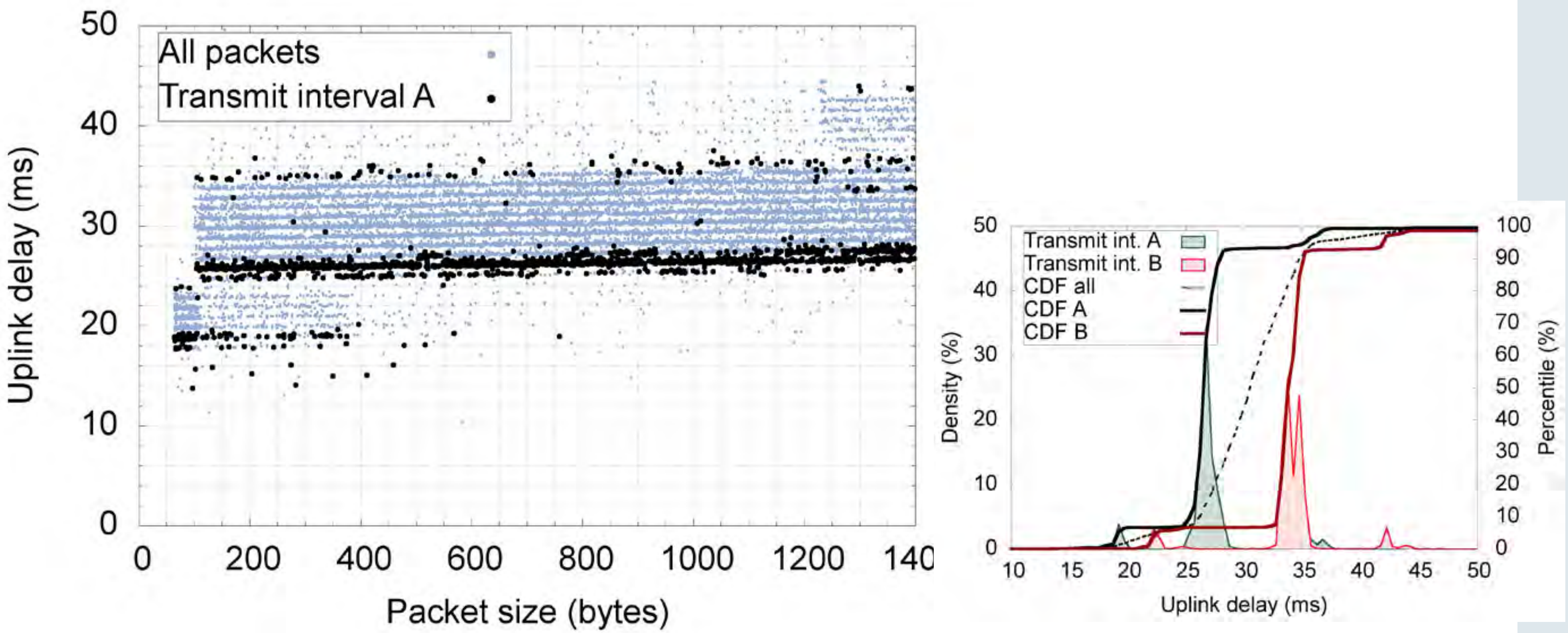
Example: Systematic Impairment

- End-to-end delay depends on absolute send time
- Session-specific: inference on session state



Side-Note: Fit Protocols to Networks?

- Example: E2E delay of periodic streams (LTE UL)



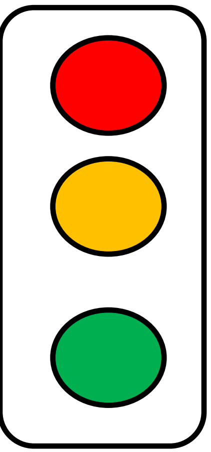
J.Fabini and T.Zseby: **„The The Right Time: Reducing Effective End-to-End Delay in Time-Slotted Packet-Switched Networks“,** ***IEEE/ACM Transactions on Networking*** **(2015) doi:10.1109/TNET.2015.2451708**

Conclusion

- Middleboxes: Systems and Networks
  - Prerequisite: Session state
- Main metric: **transparency to end systems**
  - **Time Domain**: Impairments on OSI Layer1&2 detectable by hop-by-hop measurements of timing
  - **Value Domain**: Impairments on OSI Layer >=3 detectable by intermediate or end systems
- Challenge: Measurement methodology
  - Traffic patterns, aggregated link behavior, interferences, …
  - Detection of systematic behavior can reveal transient impairments!

Outlook

- **Observatory could categorize paths & systems: Middlebox categories**



  - **Impairments in value domain: „True“ middlebox**
    - **C**hanges fields, values, protocol flow at IP layer and above
  - **Impairments in time domain**
    - **Transparent** wrt values, stores session-state
    - Tempting middlebox „candidate“ (may act in the value domain)
  - No impairments detected

- **Essential: Make measurement parameters, assumptions, and restrictions part of data set!**
  - Example: start-time influence onto end-to-end delay…
  - **The right metadata-format is a huge (main?) challenge!**

Bibliography

Delay Measurement Methodology and Measurement Accuracy:

[1] J.Fabini and M.Abmayer: "Delay Measurement Methodology Revisited: Time-slotted Randomness Cancellation", *IEEE Transactions on Instrumentation and Measurements*, 10/2013, doi:10.1109/TIM.2013.2263914

[2] J.Fabini, T.Zseby, "M2M communication delay challenges: Application and measurement perspectives," in IEEE *Instrumentation and Measurement Technology Conference (I2MTC), 2015,* doi: 10.1109/I2MTC.2015.7151564

Measurement methodology standardization:

[3] J.Fabini and A.Morton: IETF RFC 7312 "Advanced Stream and Sampling Framework for the IP Performance Metrics Framework (IPPM)", Internet Engineering Task Force, 08/2014

Tools:

[4] J.Fabini and M.Hirschbichler: „Representative Delay Measurements (RDM): Facing the Challenge of Modern Networks", Proceedings of the 8th International Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS '14), doi:10.4108/icst.Valuetools.2014.258181

Delay optimization:

[5] J.Fabini and T.Zseby: „The The Right Time: Reducing Effective End-to-End Delay in Time-Slotted Packet-Switched Networks", *IEEE/ACM Transactions on Networking* (2015) doi:10.1109/TNET.2015.2451708

Thank you for your attention!

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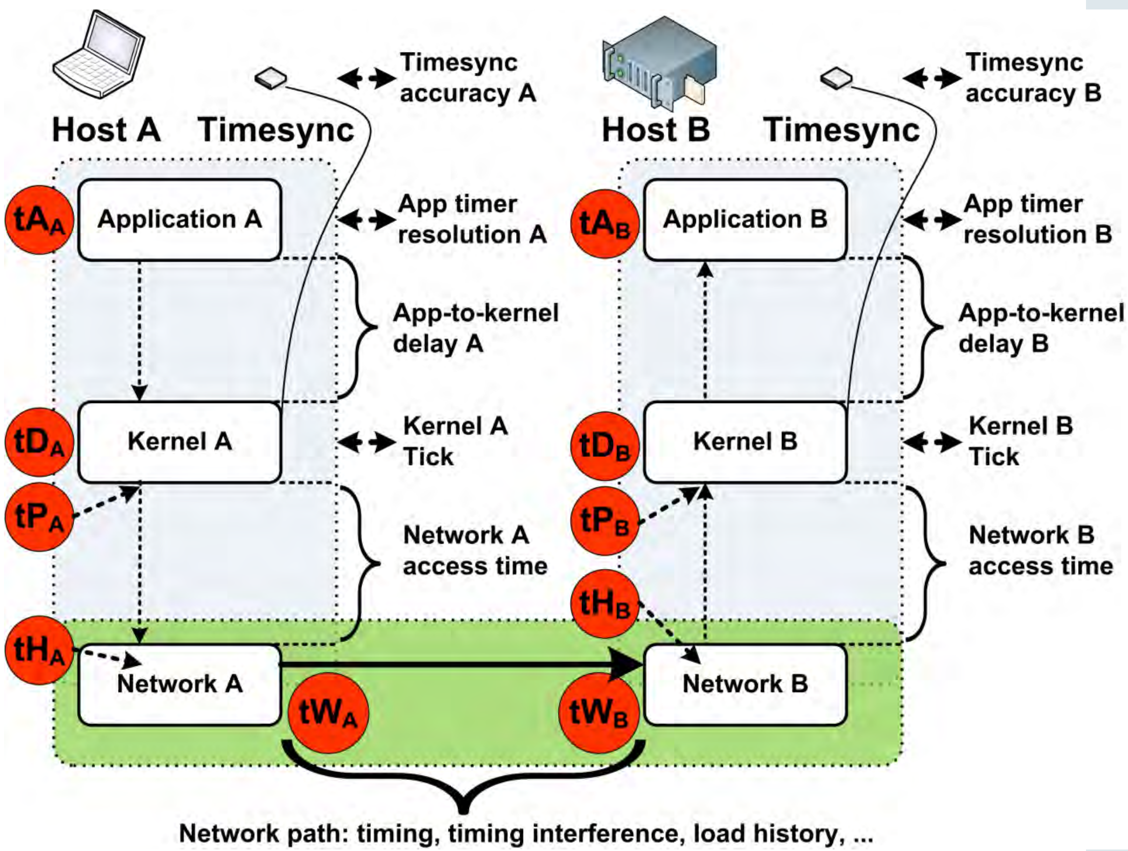
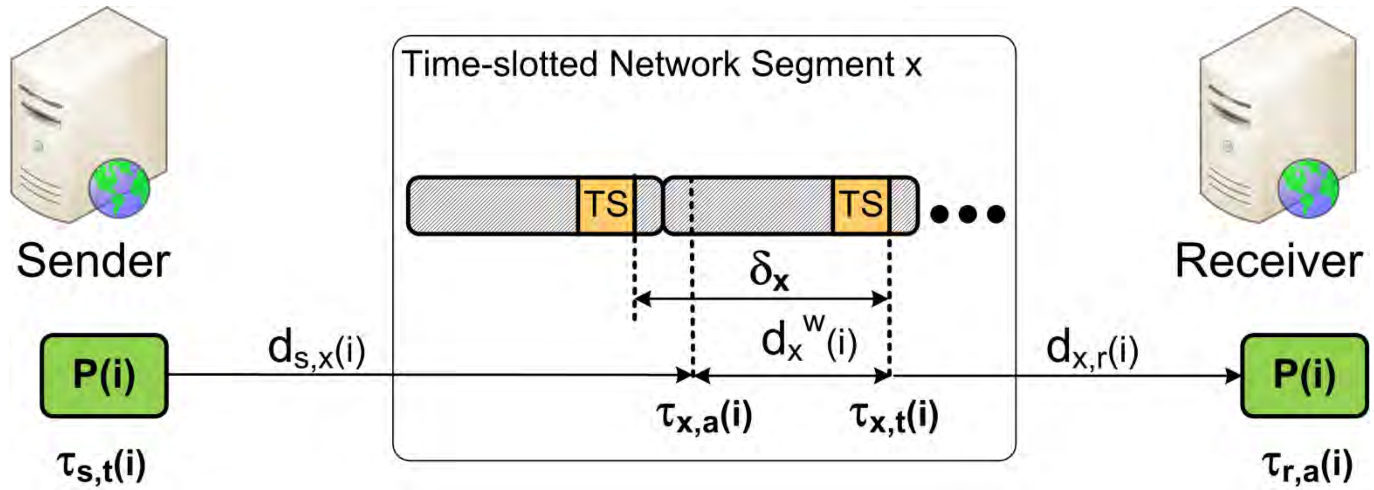
Uncertainty Factors in Communications

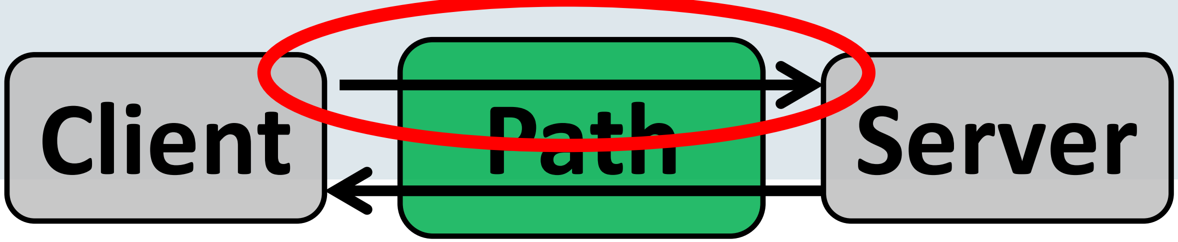
- **Host**
  - Timestamps
    - Resolution
    - Host vs. wire time
    - Standard definitions
  - Clock synchronization
  - App-to-network delay
- **Network**
  - Time-slotting
  - Reactive networks
  - Optimizers
  - Security mechanisms



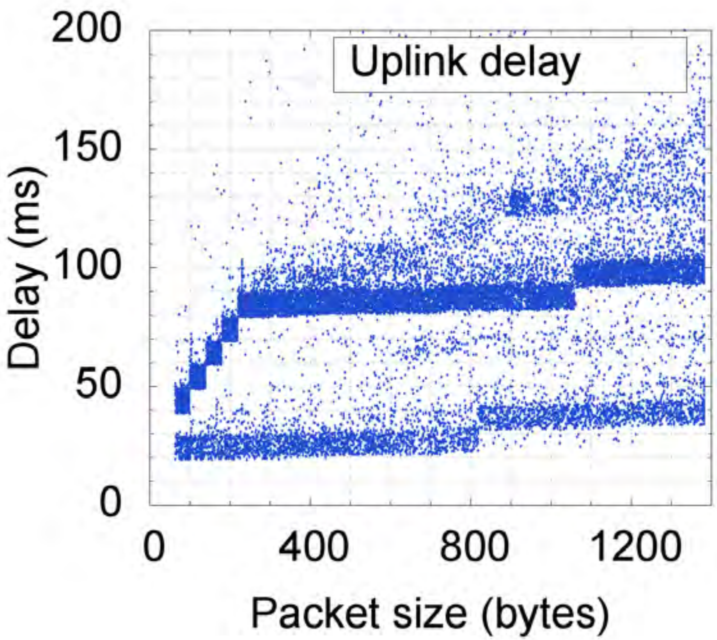
Backup Slide:
Path Bias onto Packet Timing (ctd)



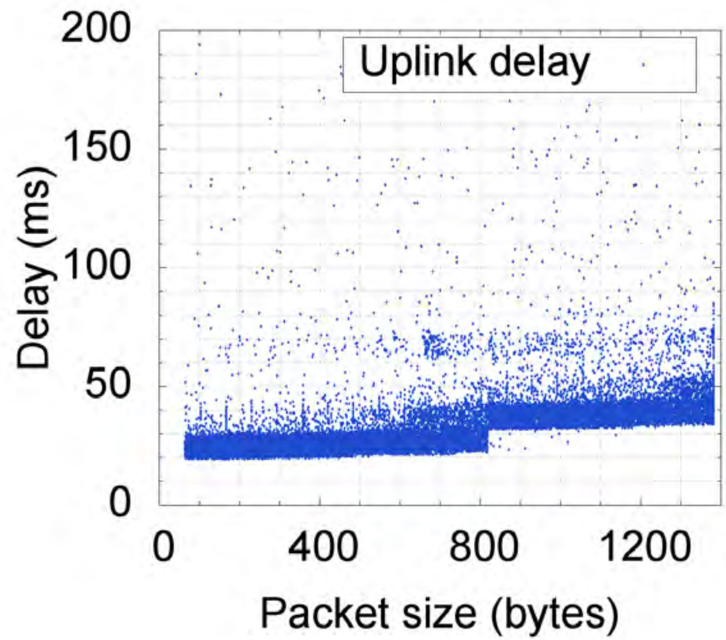
- Random sampling **cancelled** after first time-slotted link
- Packet synchronous with each other and with global time (mod. network period)



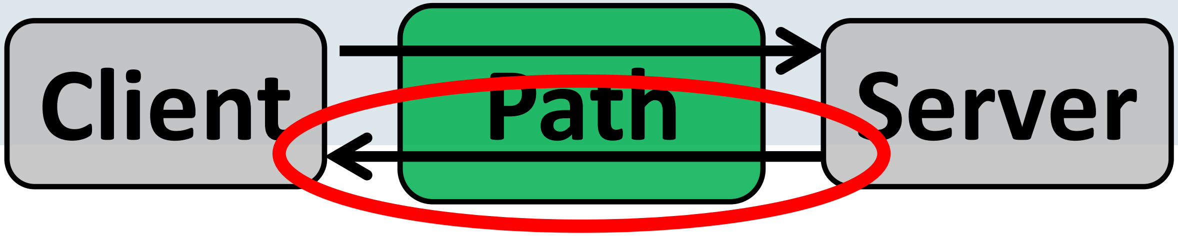
Backup: HSPA Uplink (high rate)



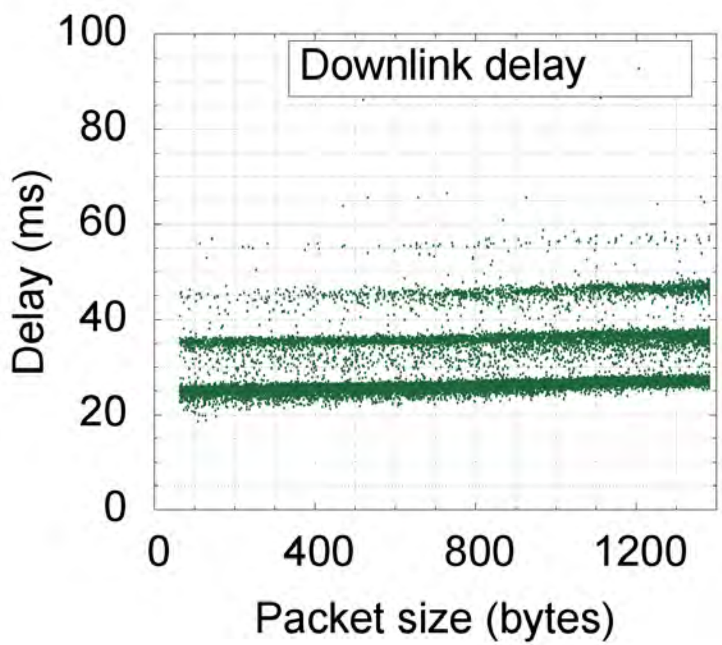
(a) RFC 2330 compliant low bit rate scenario



(b) RFC 2330 compliant higher bit rate scenario



Backup: HSPA DL (**reverse** link)



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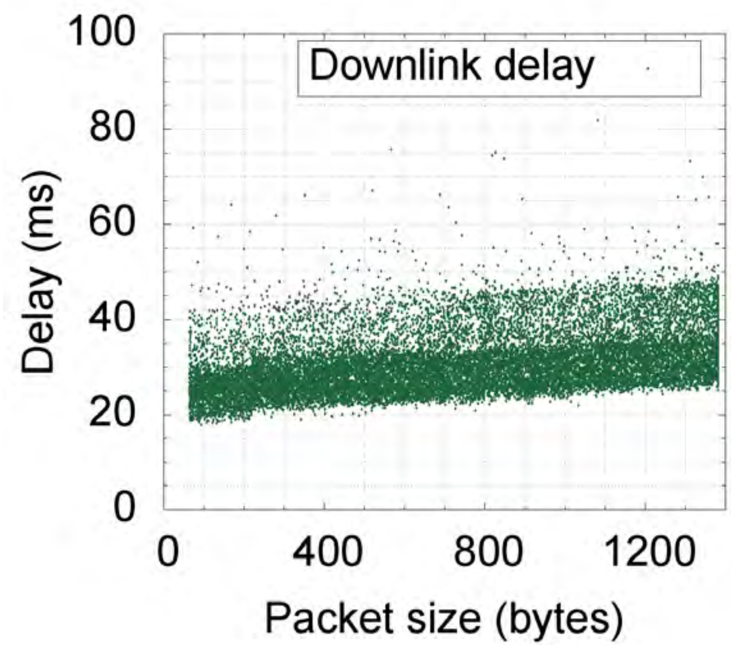
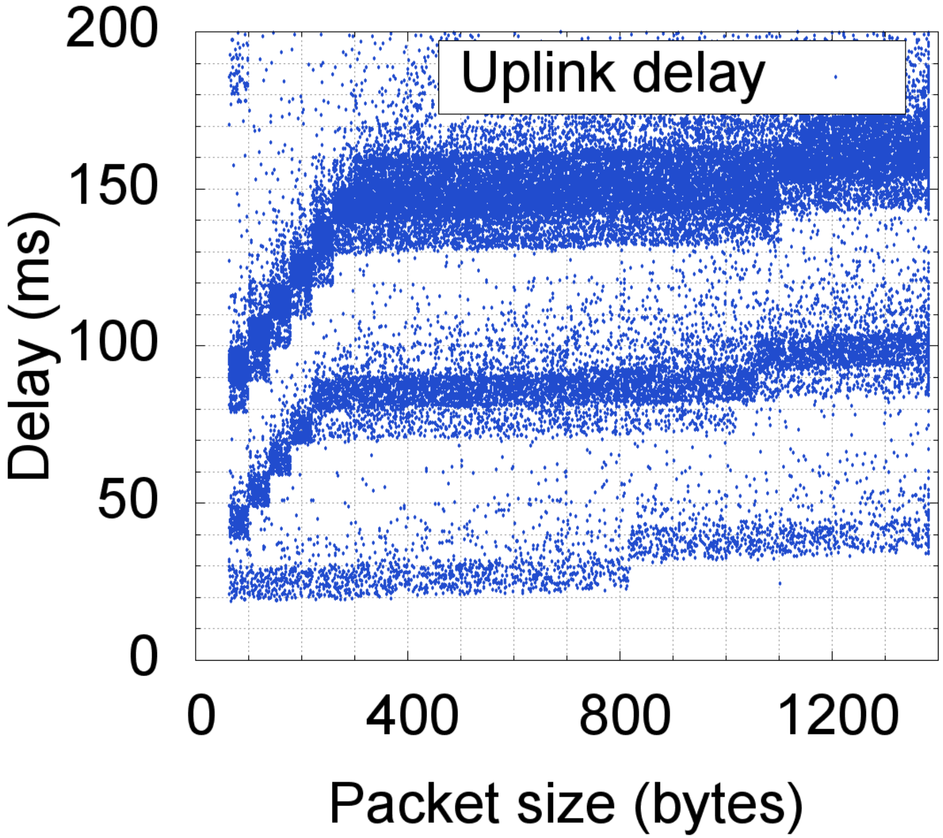
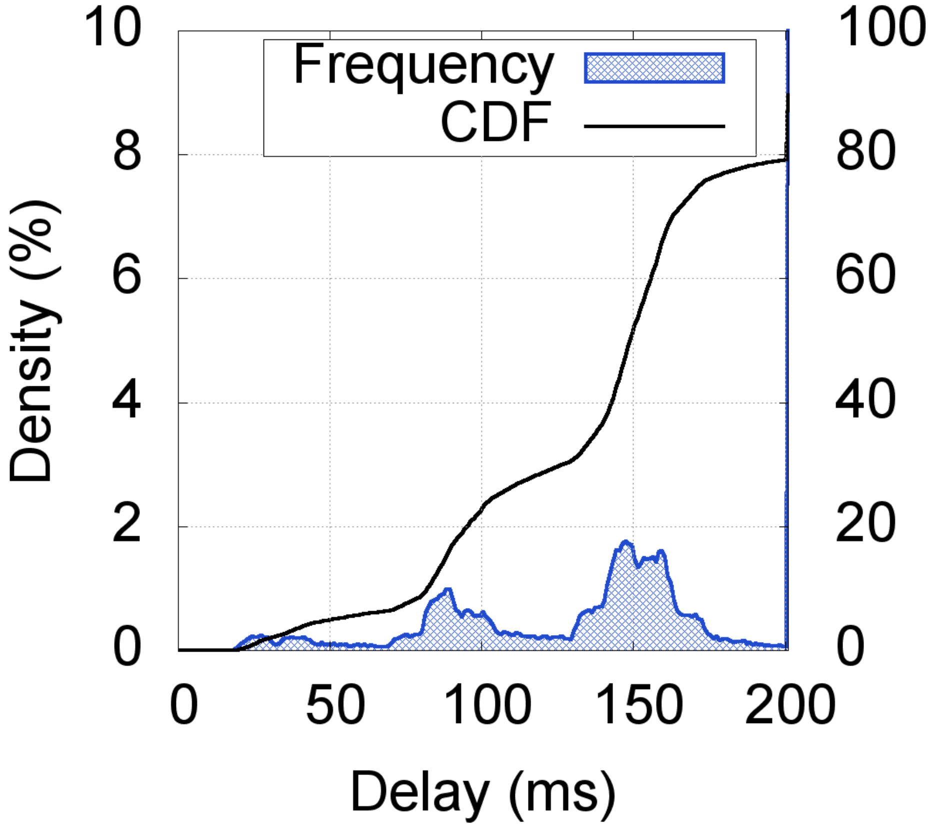


(b) Server-regenerated randomness

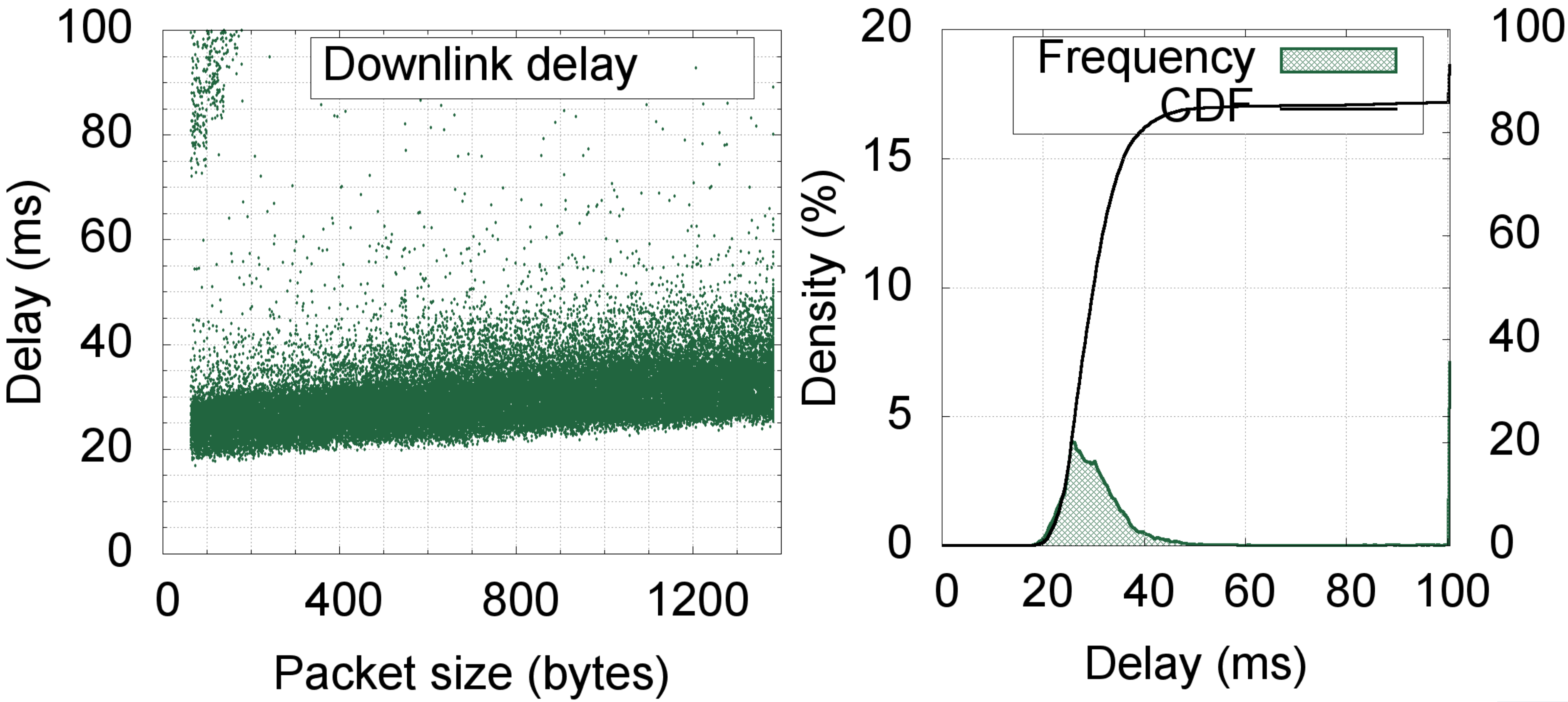
HSPA: Randomized Uplink Delay





Details: random 50K packets, 64-1400 bytes, i.p.delay 100-5000 ms (total 36 hrs)

HSPA: Randomized Downlink Delay



Details: random 50K packets, 64-1400 bytes, i.p.delay 100-5000 ms (total 36 hrs)