Dynamic Regulation of Mobile 3G/HSPA Uplink Buffer with Receiver-Side Flow Control

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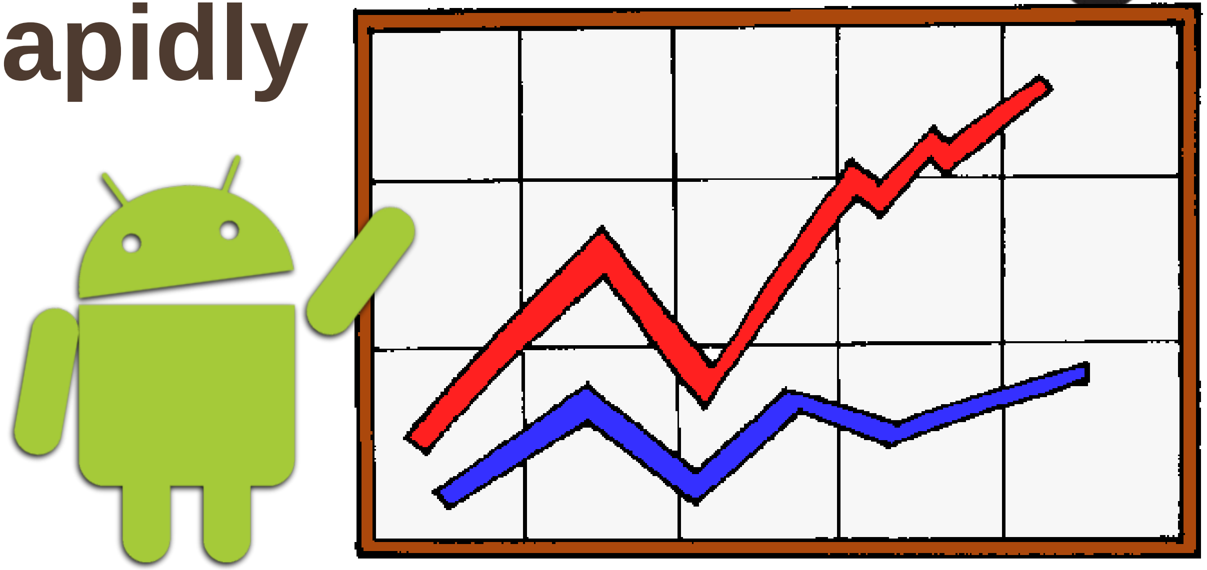
Smartphones are everywhere

- US smartphone penetration exceeded 50% in Q2, 2012
- Mobile data traffic growing rapidly as well



Source: http://www.chetansharma.com/USmarketupdateQ22012.htm

Not just for surfing the web…

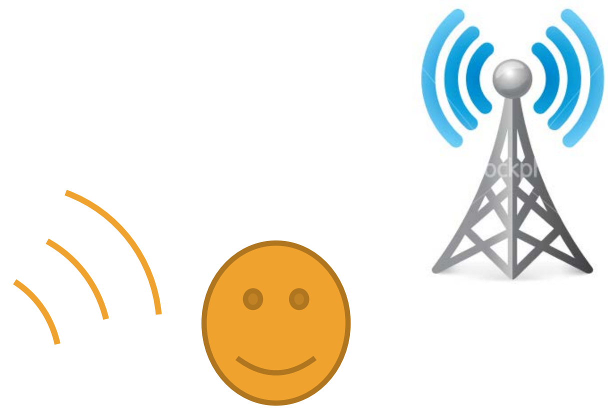
- **Users uploading significant amounts of data in the form of photos and videos**

e.g. AT&T observed 40% more data uploaded than downloaded during a football match

(7 Feb 2012)

- **Uploads often conducted in the background**

What are the users doing?



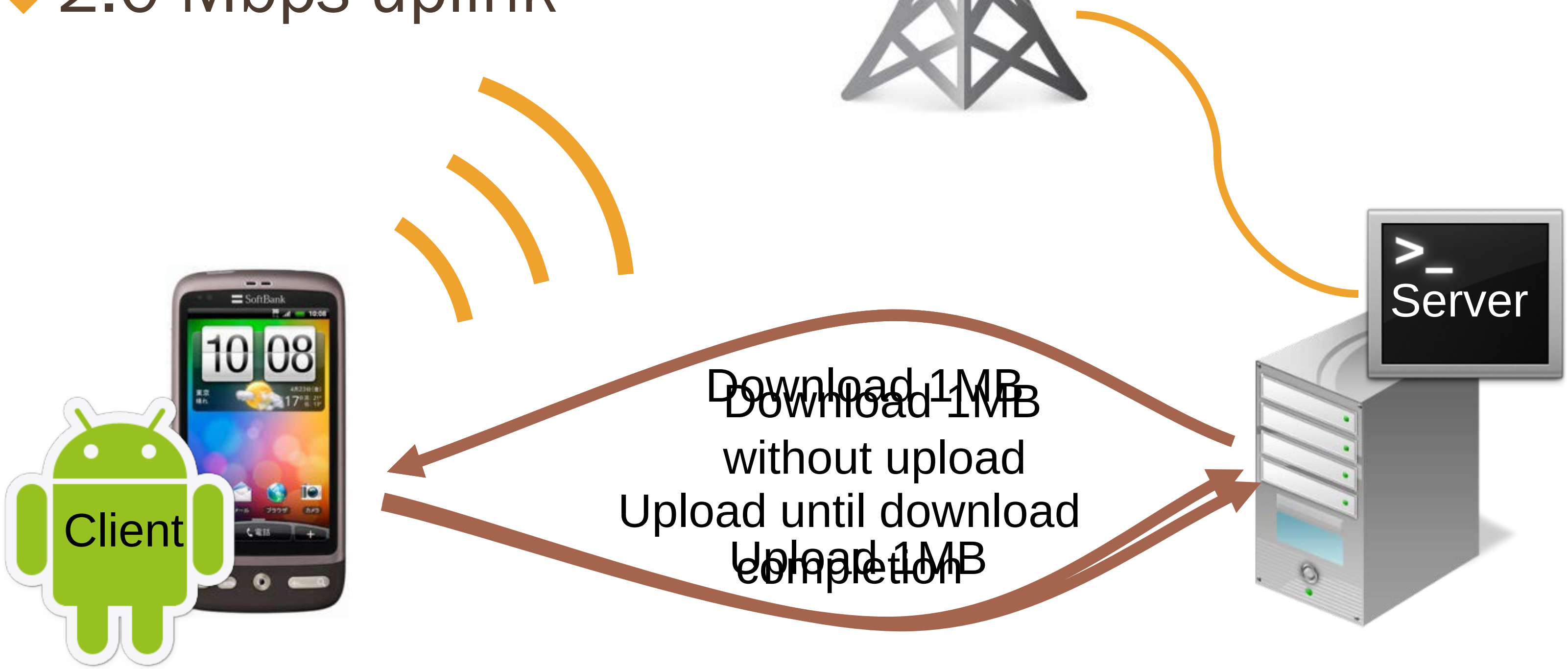
What happened?

The Problem

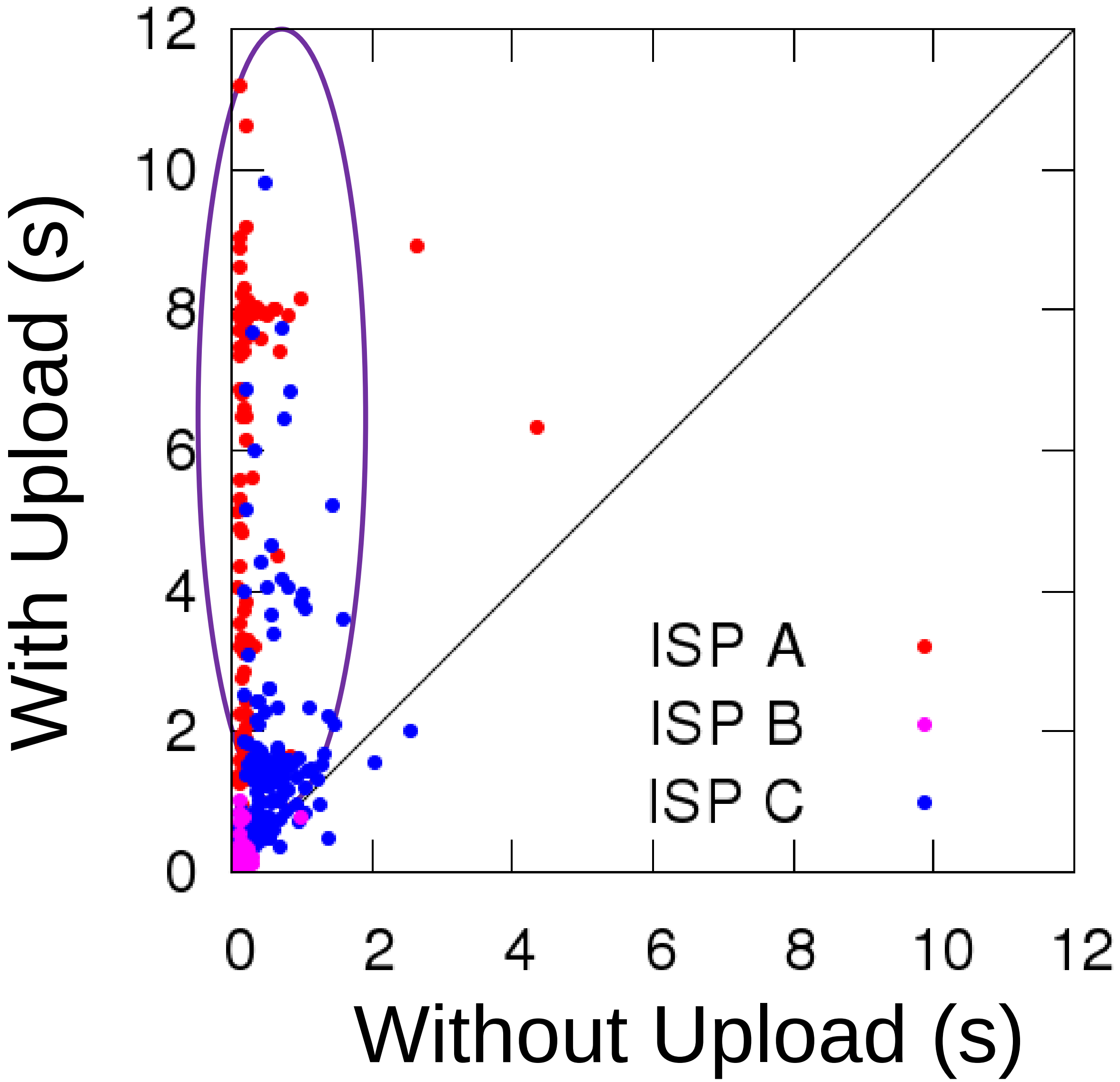
Background uploads can degrade downloads significantly!

Experiment Setup

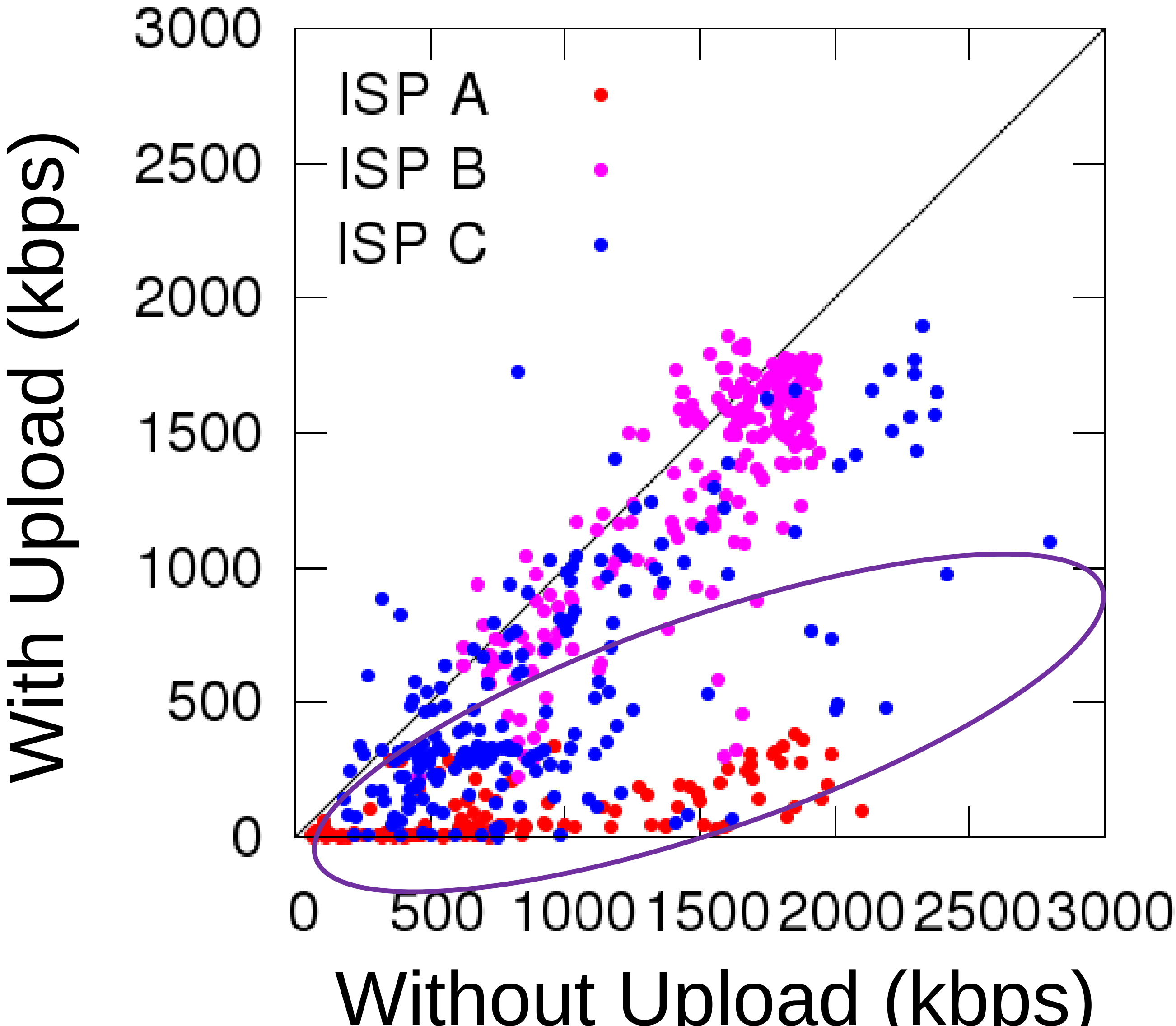
- Android Phones
- 3 Local Telcos
  - 7.2 Mbps downlink
  - 2.0 Mbps uplink



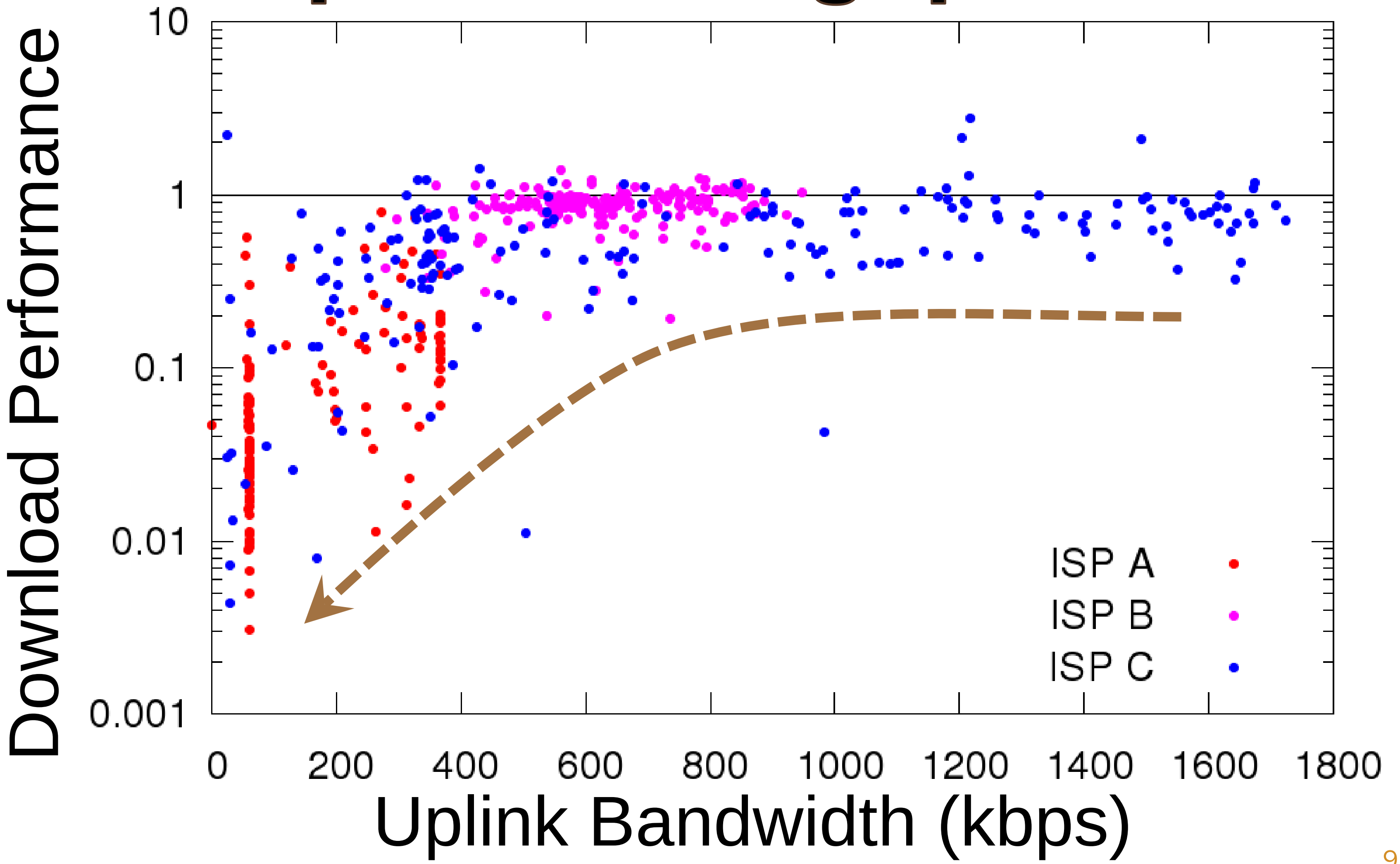
Download Roundtrip Time



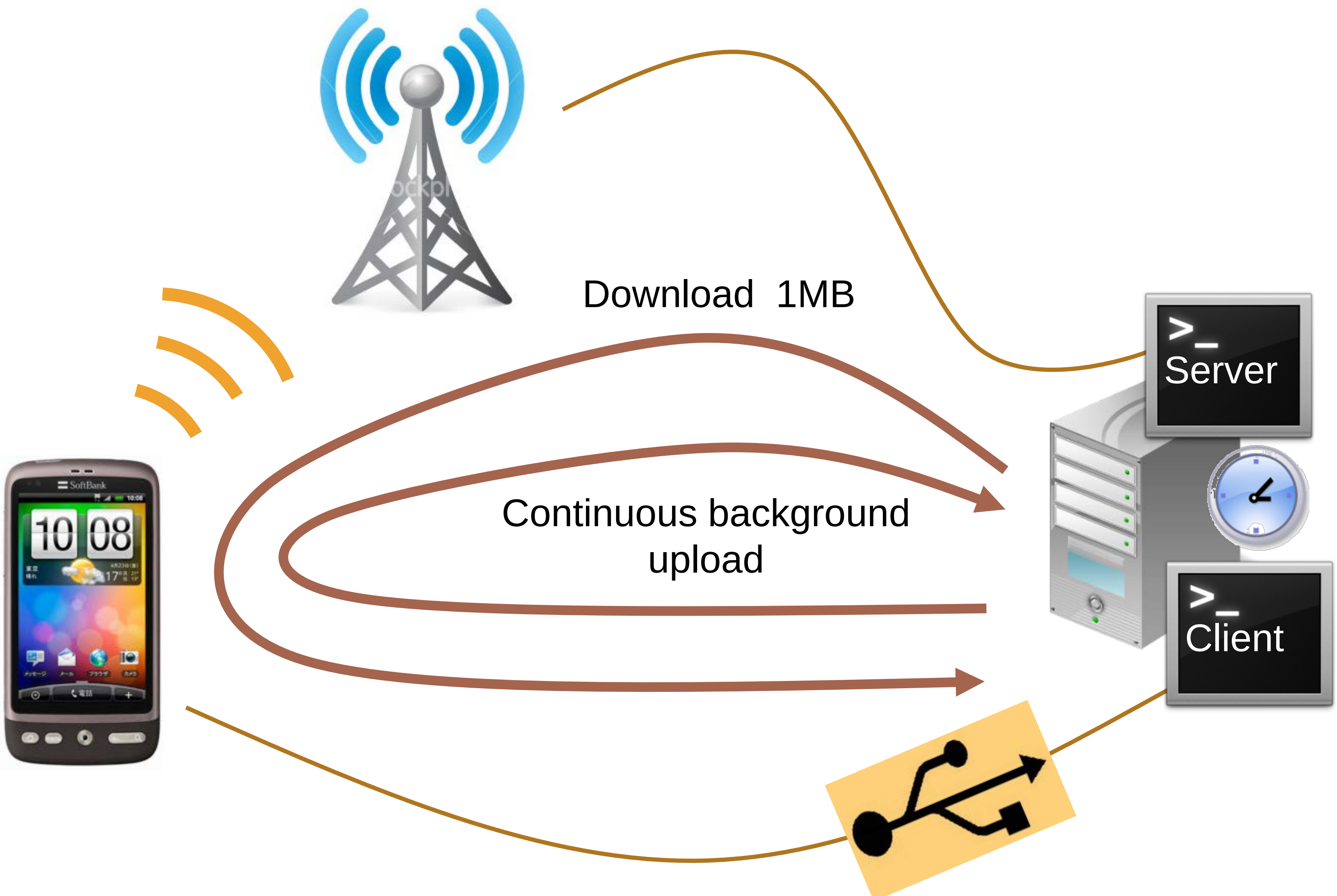
Download Throughput



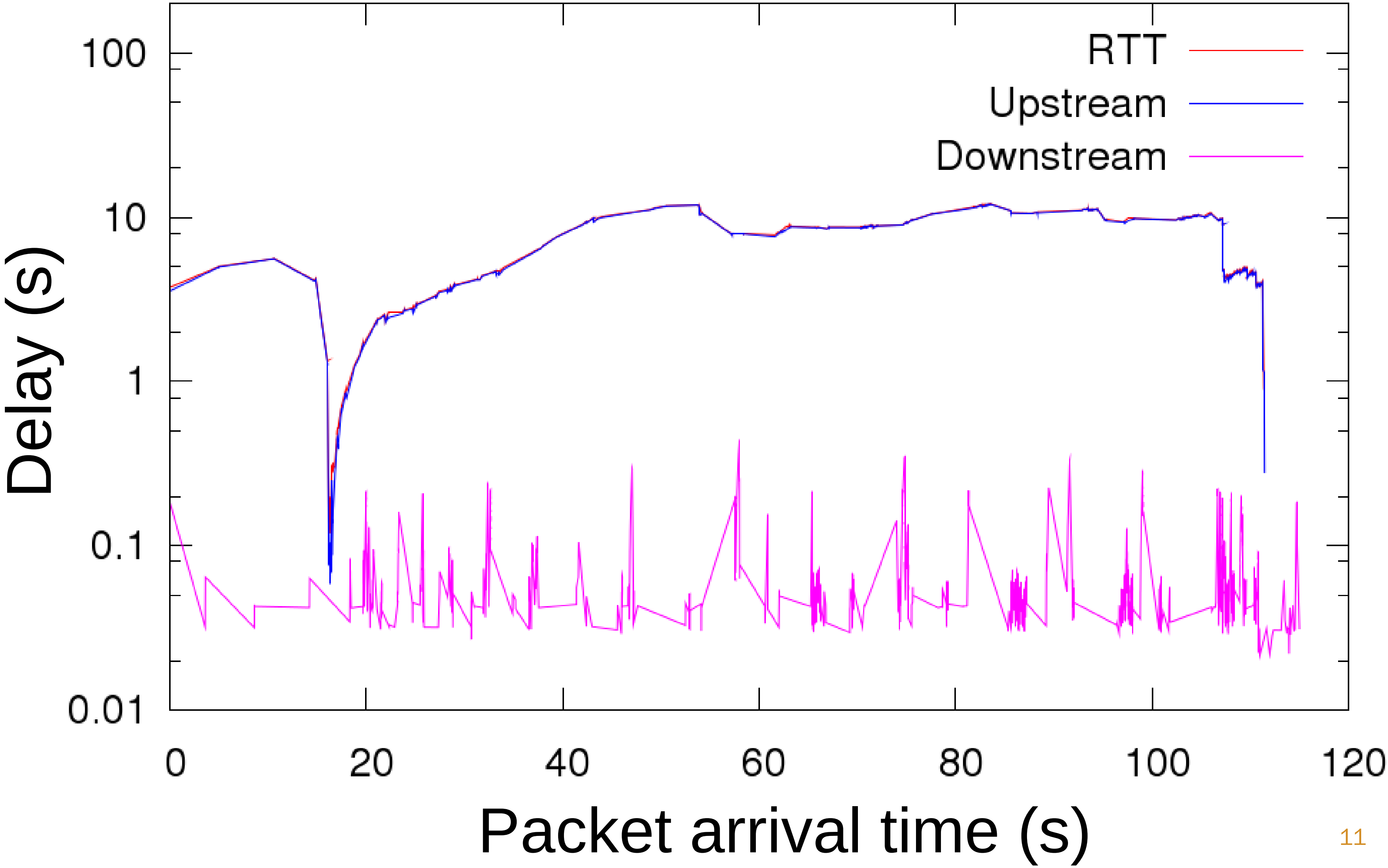
Problem is exacerbated by low uplink throughput



Experiment Setup (Loopback)



RTT dominated by uplink delay

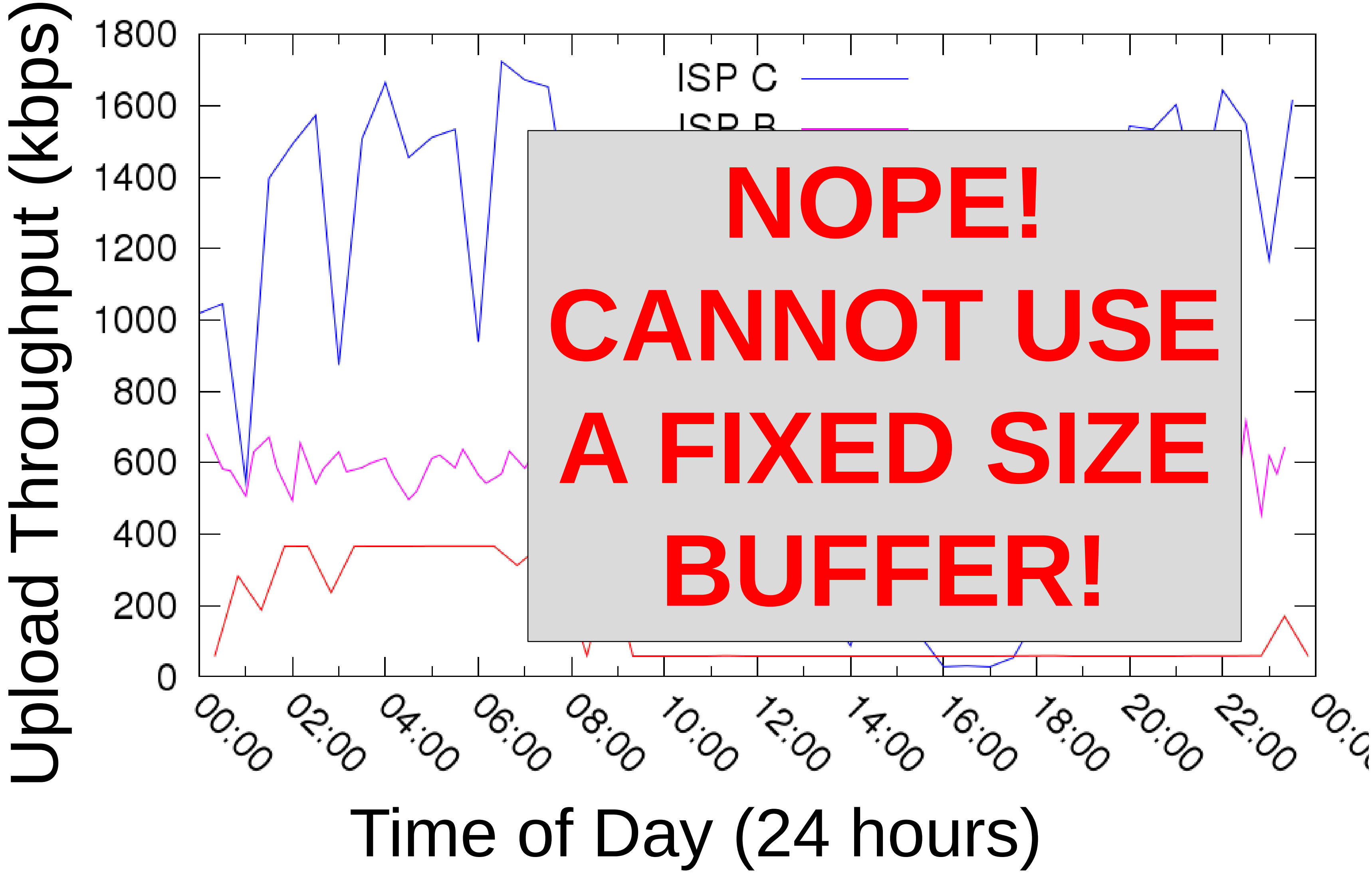


Understanding the Problem

- **NOT caused by ACK Compression**
- **Data Pendulum Problem** *[Heusse et al. 2011]*
  - Sized properly, buffers take turns to fill up
  - Sized improperly, low-speed link with large buffer becomes the sole bottleneck
- **Uplink is the bottleneck in a 3G/HSPA mobile network**

Can we just size the uplink buffer correctly?

Understanding the Problem



Previous Solutions

- **Optimizing how the ACKs are sent** *[Balakrishnan et al. 1999/2002]*
- **Using different queues for data and ACK packets** *[Podlesny et al. 2012]*
- **TCP Vegas** *[Brakmo et al. 1995]*

All *Sender-Side* Solutions

Why not Sender-Side Solutions?

- **Not General**
  - Only works for the devices already deployed with the solution
  - Devices may use network interfaces other than 3G/HSPA (e.g. Wi-Fi)
- **"Implement complexity at the server, not the client"**
  - It may take years to update client-side software *[Adya et al. 2011]*

Our Solution

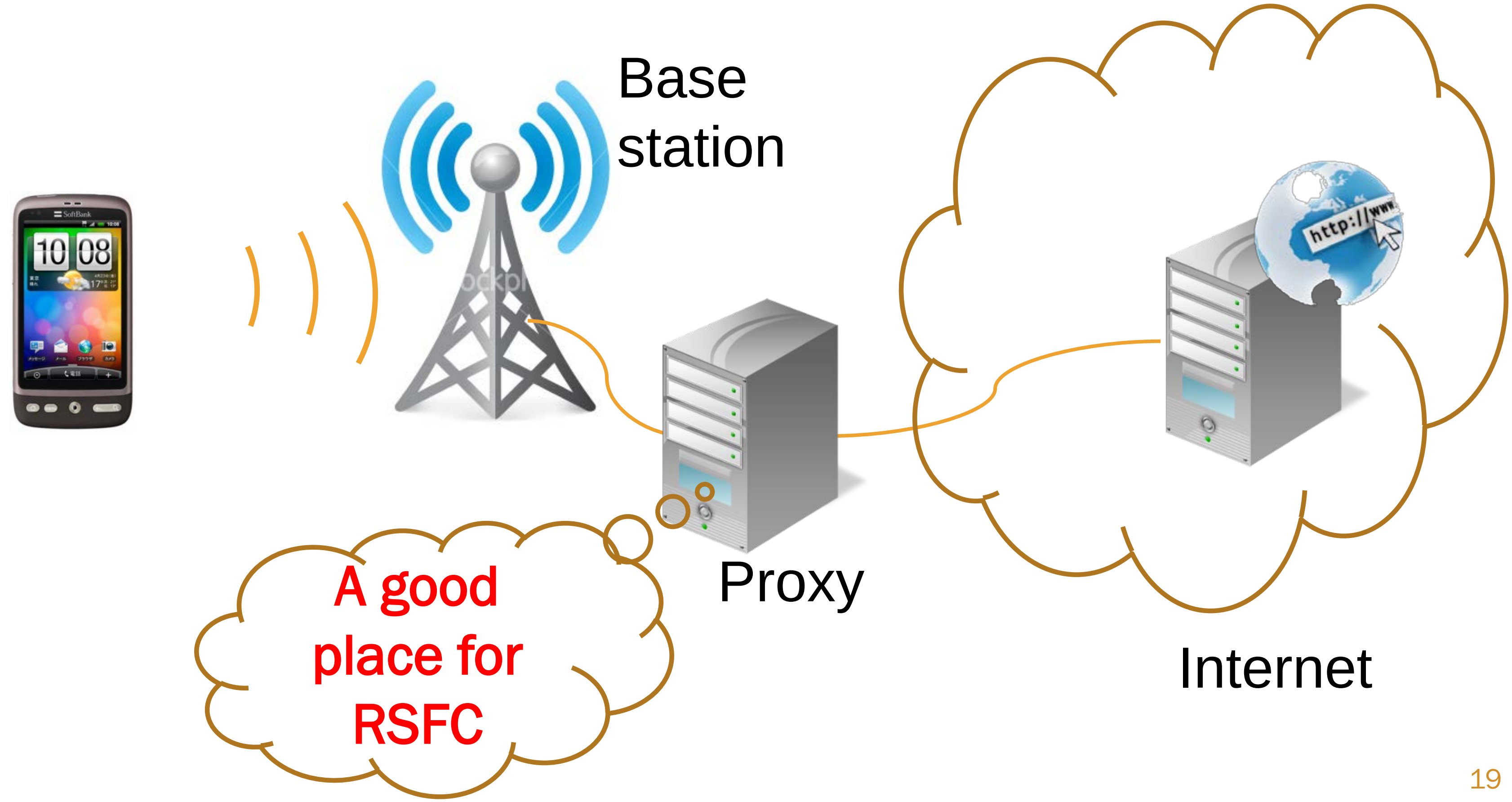
Receiver-Side Flow Control (RSFC)

Our Approach

- Can implement at ISP network proxies
- Works transparently for any device using the 3G/HSPA mobile network
- Changes immediately deployable

Practical Deployment

Easily deployed at ISP proxy



Receiver-Side Solutions

- **Freeze-TCP** *[Goff et al. 2000]*
- **Reducing delay for interactive applications while maintaining throughput for bulk transfers** *[Spring et al. 2000]*
- **Improving fairness** *[Kalampoukas et al. 2002, Andrew et al. 2008]*

Used for Other Purposes

Key Idea

Reduce # of packets in the uplink buffer by adjusting the TCP receiver window (`rwnd`)

What is the right `rwnd`?

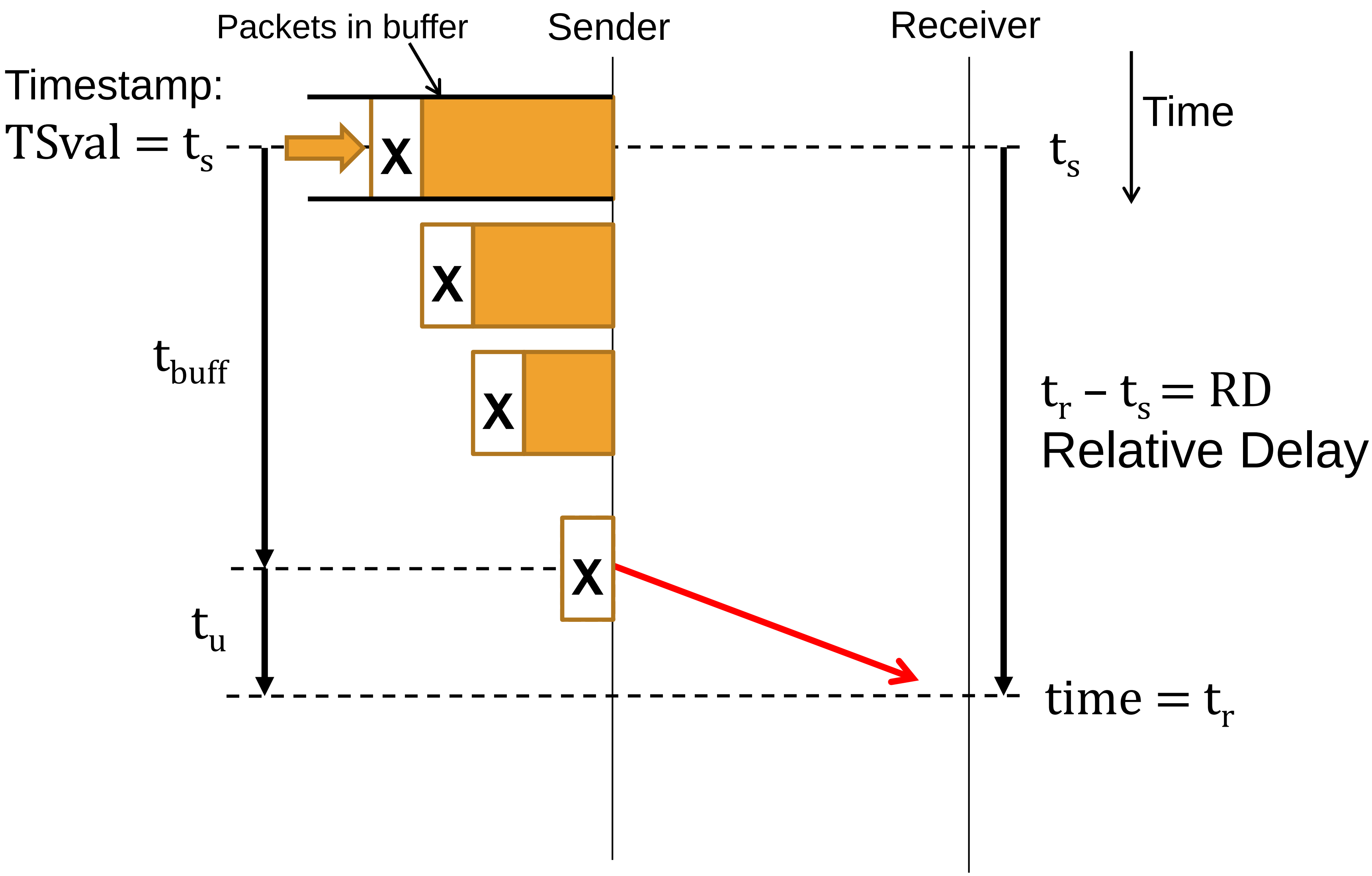
rwnd Value

- **Set to bandwidth-delay product (BDP)?**
- **Not so simple…**
  - How do we estimate BDP?
  - Network fluctuations

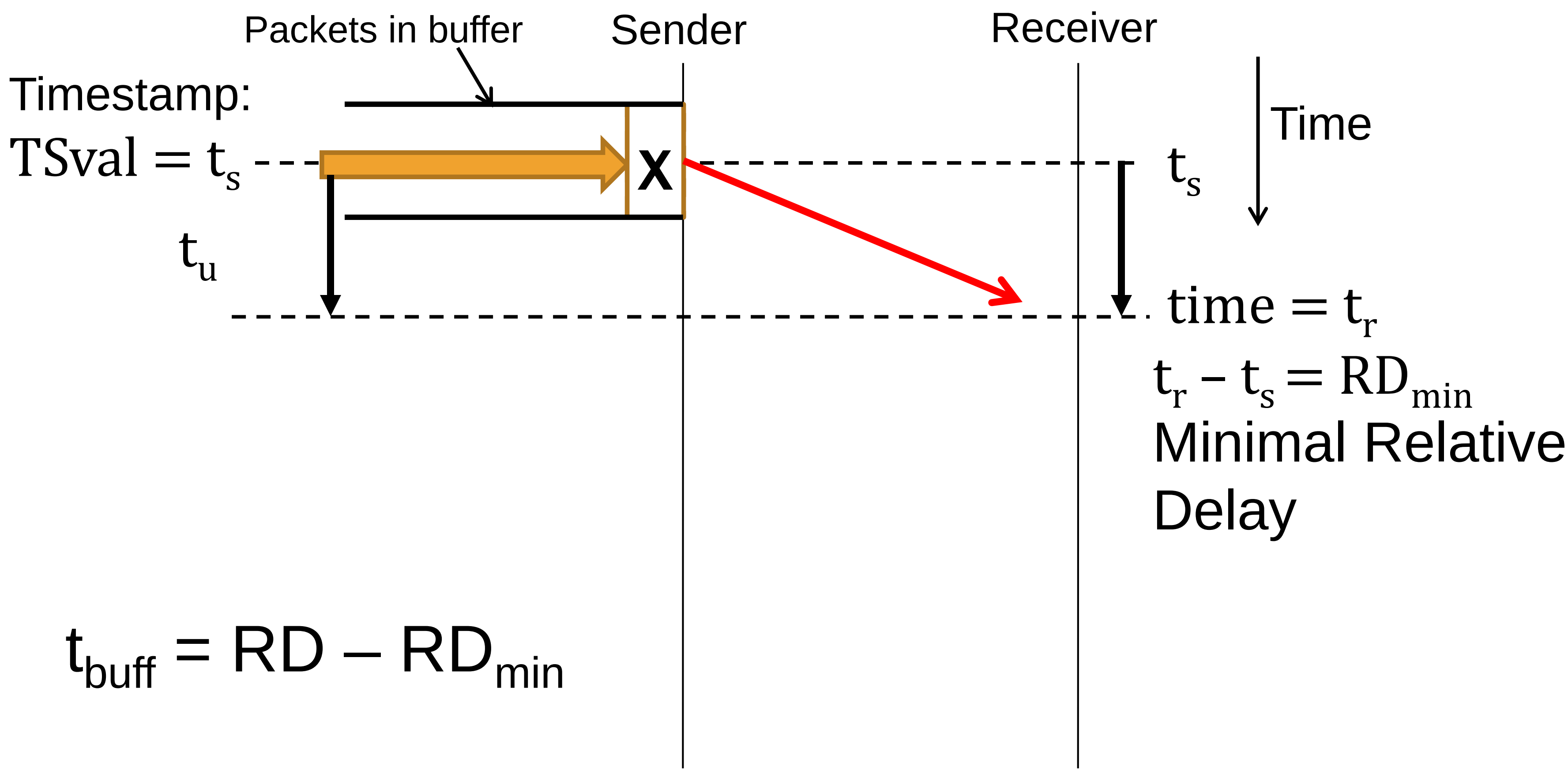
Approach: Negative Feedback

- Estimate time packet spends in buffer t_{buff} using TCP Timestamp
- Set a threshold T
  - $t_{buff} > T$, clamp rwnd
  - $t_{buff} < T$, increase rwnd

Estimating t_{buff}



Estimating t_{buff}



$$t_{buff} = RD - RD_{min}$$

No need to synchronize sender and receiver!

Estimating BDP

- Measure receive rate ρ at receiver
- Minimal RTT (RTT_{min})
- Ideal window is the bandwidth-delay product:
  - $rwnd = \rho \times RTT_{min}$

Summary

- $t_{buff} > T$, $rwnd = \rho \times RTT_{min}$ (fast state)
- $t_{buff} < T$, rwnd++ (slow state)
- In our implementation
  - T is set to RTT_{min}

Handling changes in the network

- Changes in bandwidth
- Decrease in the delay
- Increase in the delay
  - Slight increase:
    detect increased receive rate ρ
  - Large increase: **monitor** state

See details in paper!

Evaluation

- Reduces RTT
- Improves download throughput
- Reduces webpage loading time
- Fair and efficient
- Adapts to changes in network conditions
- Compatible with sender-side algorithms

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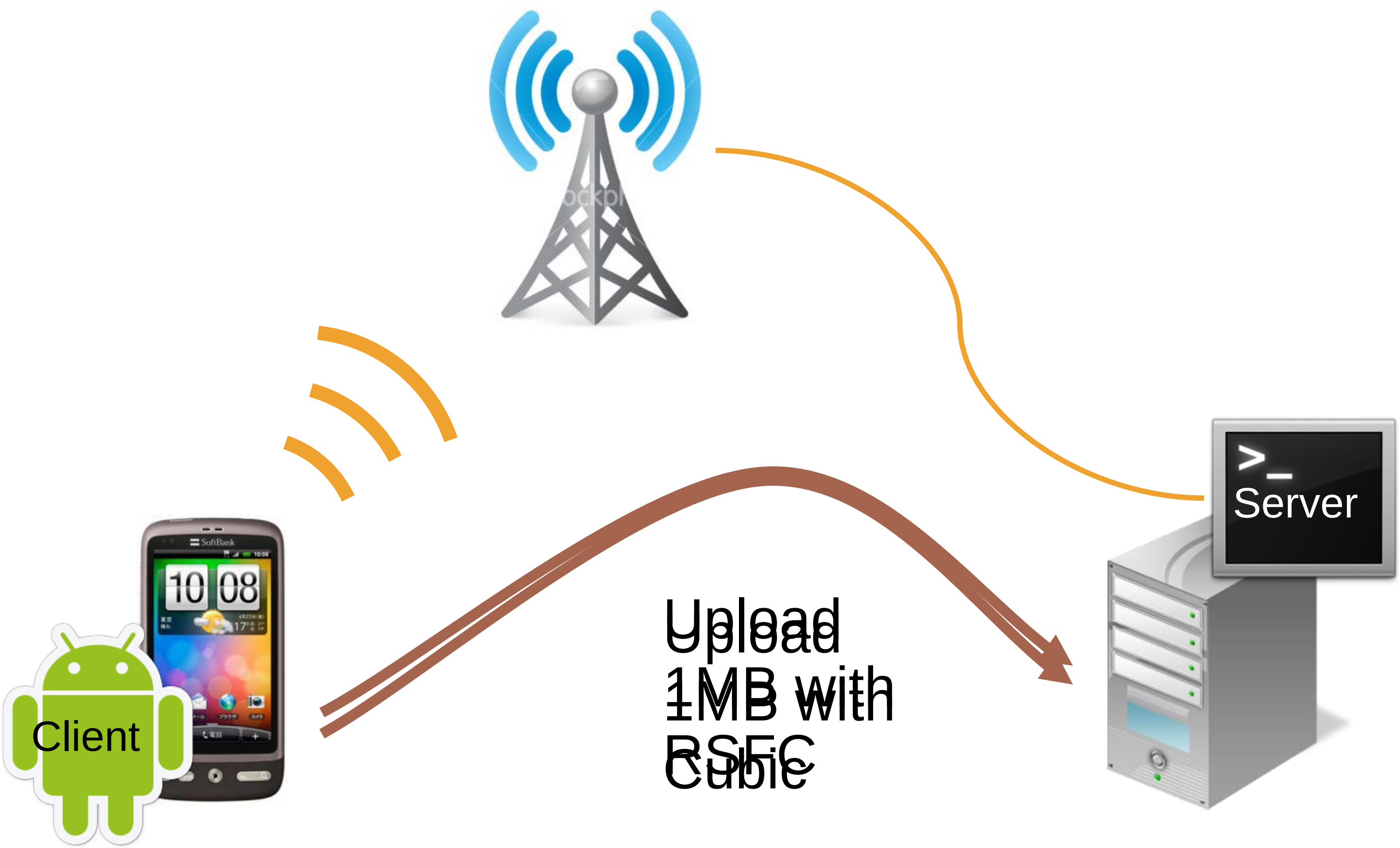
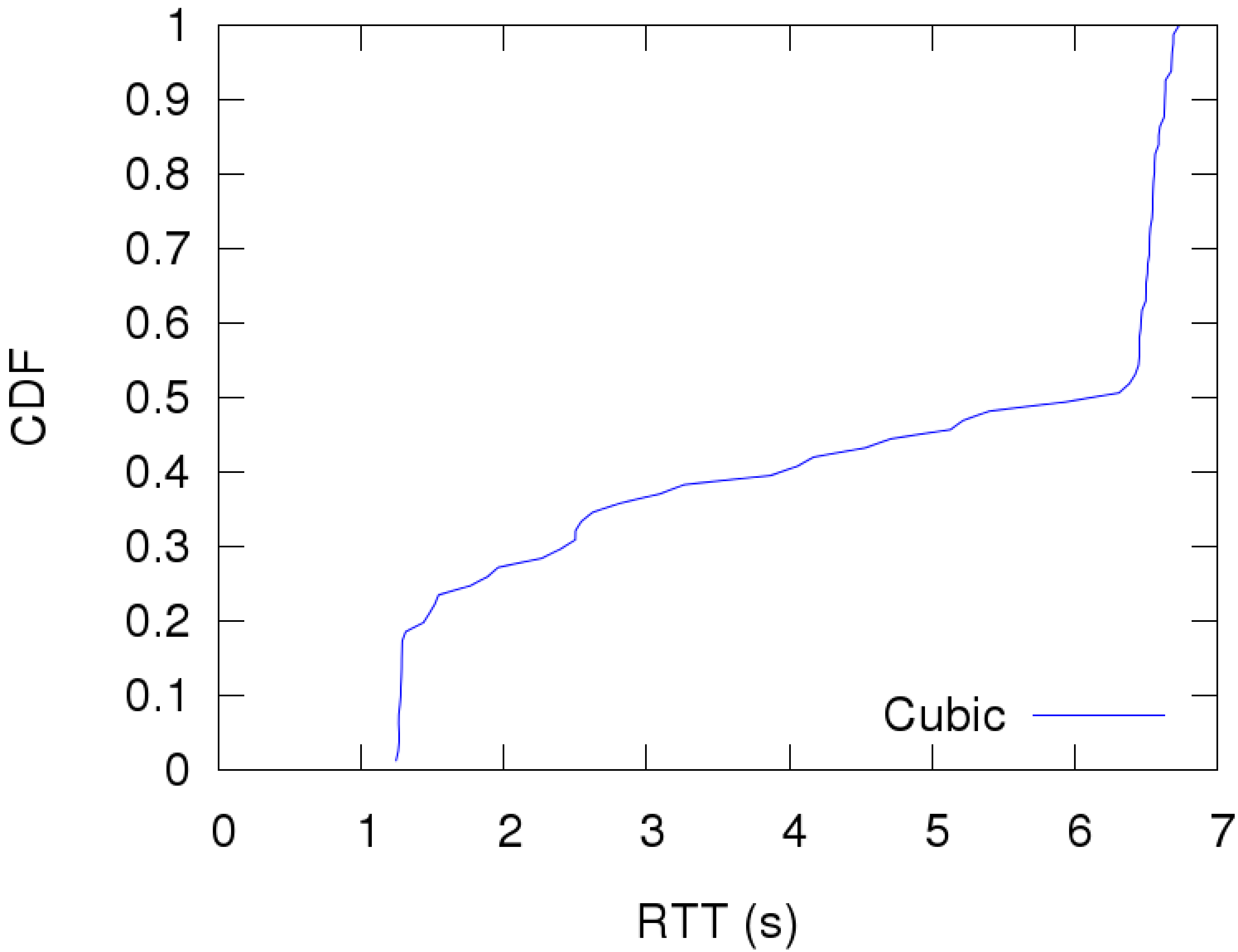
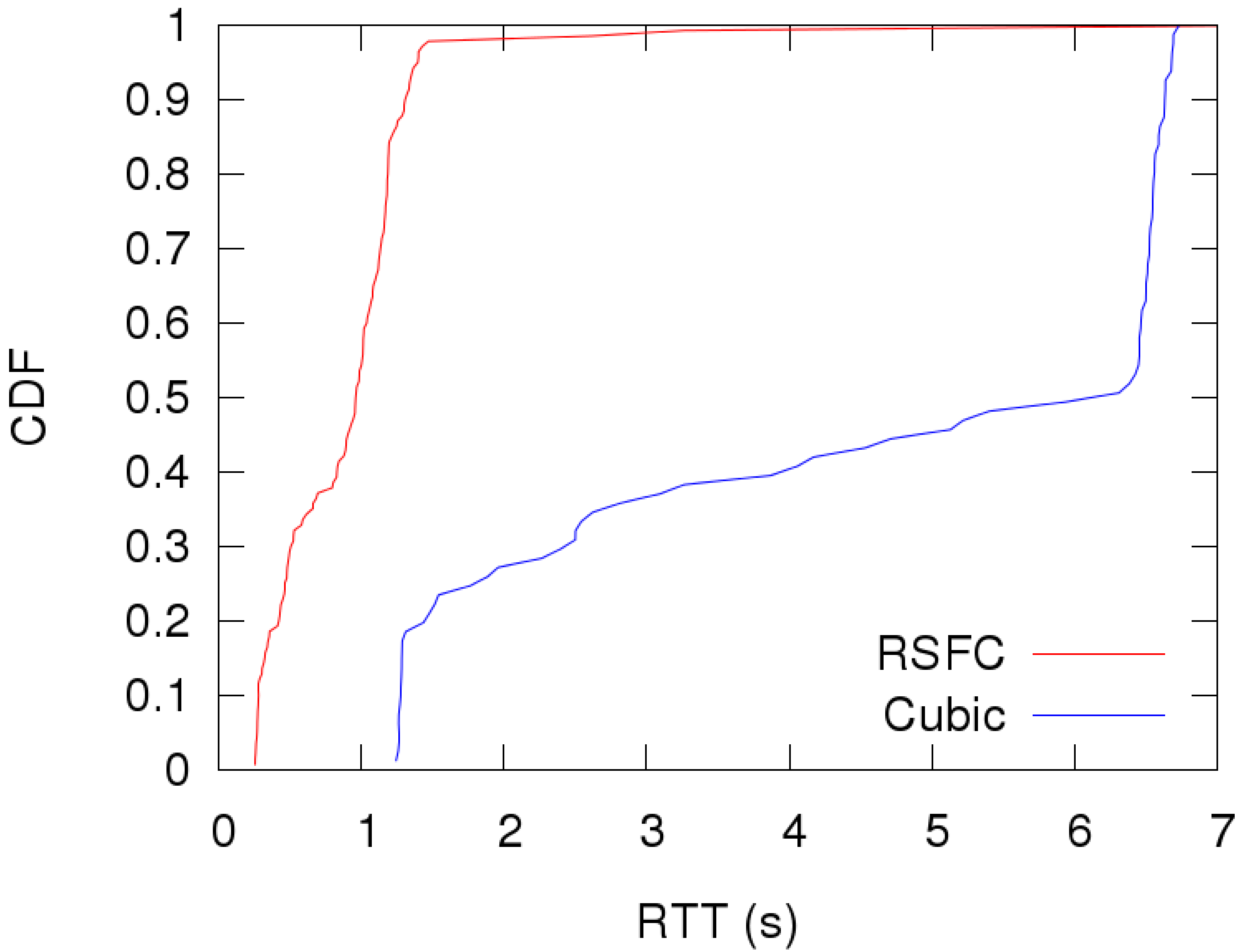
Reduce RTT



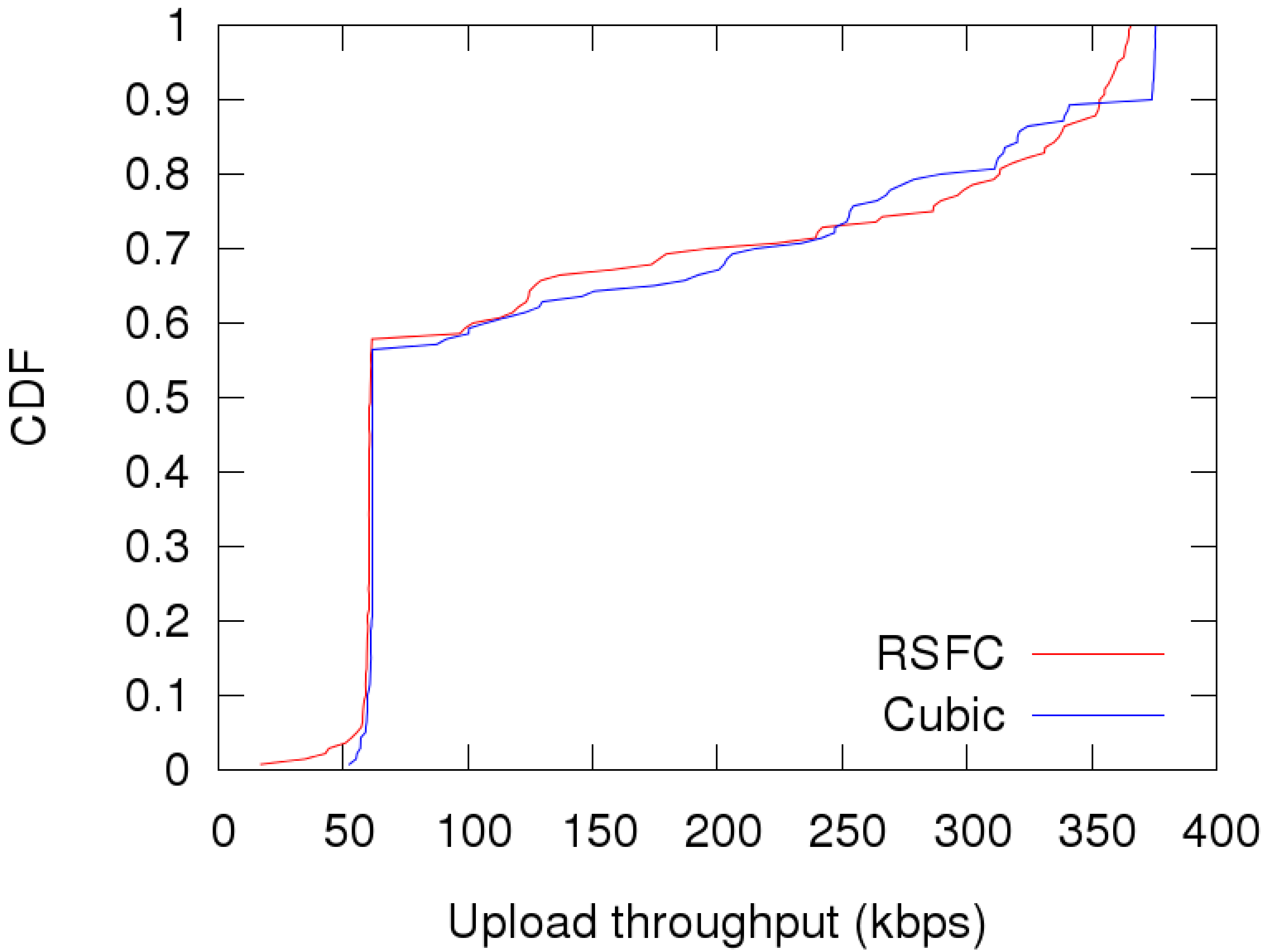
Reduction in RTT



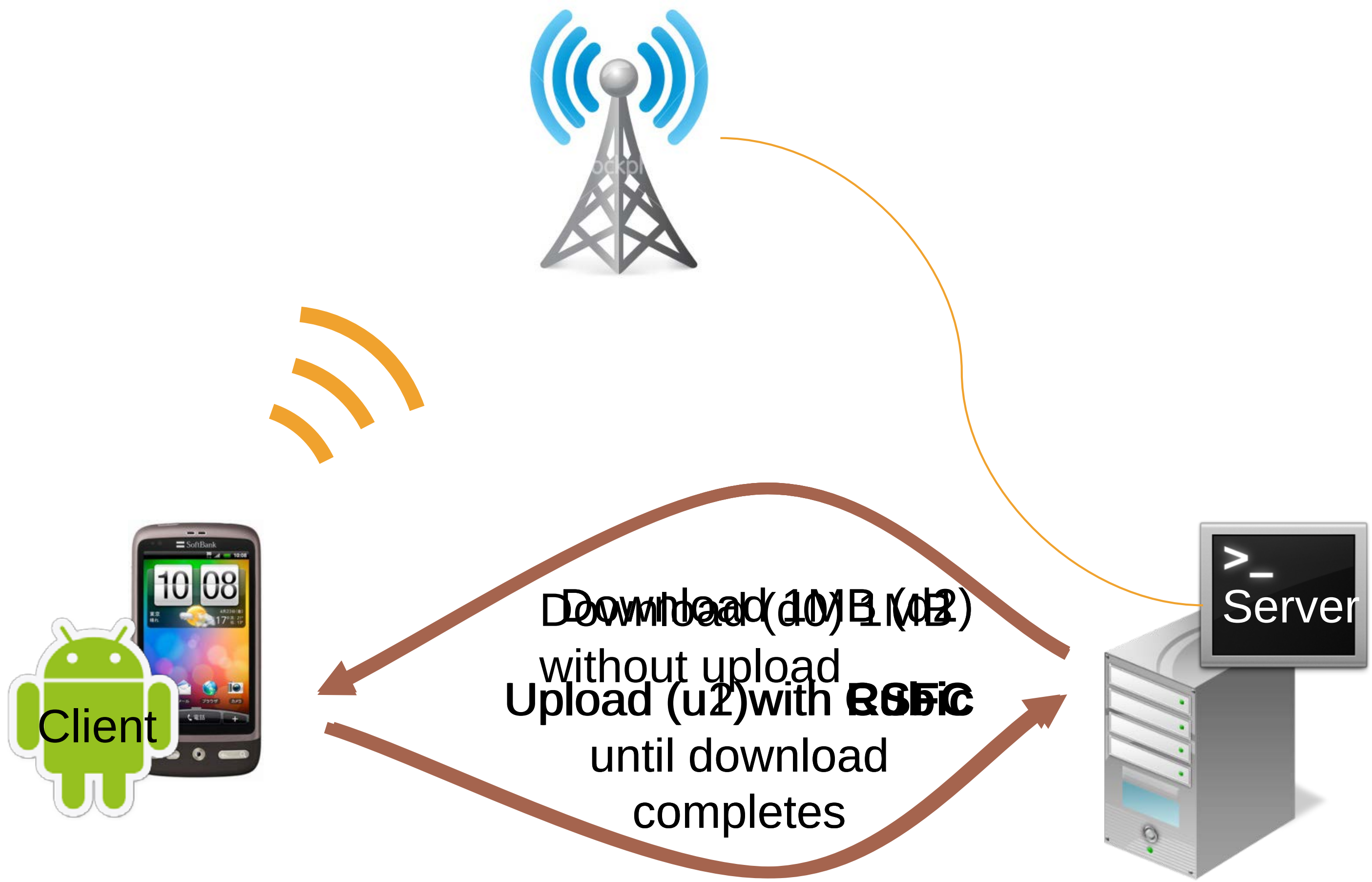
Reduction in RTT



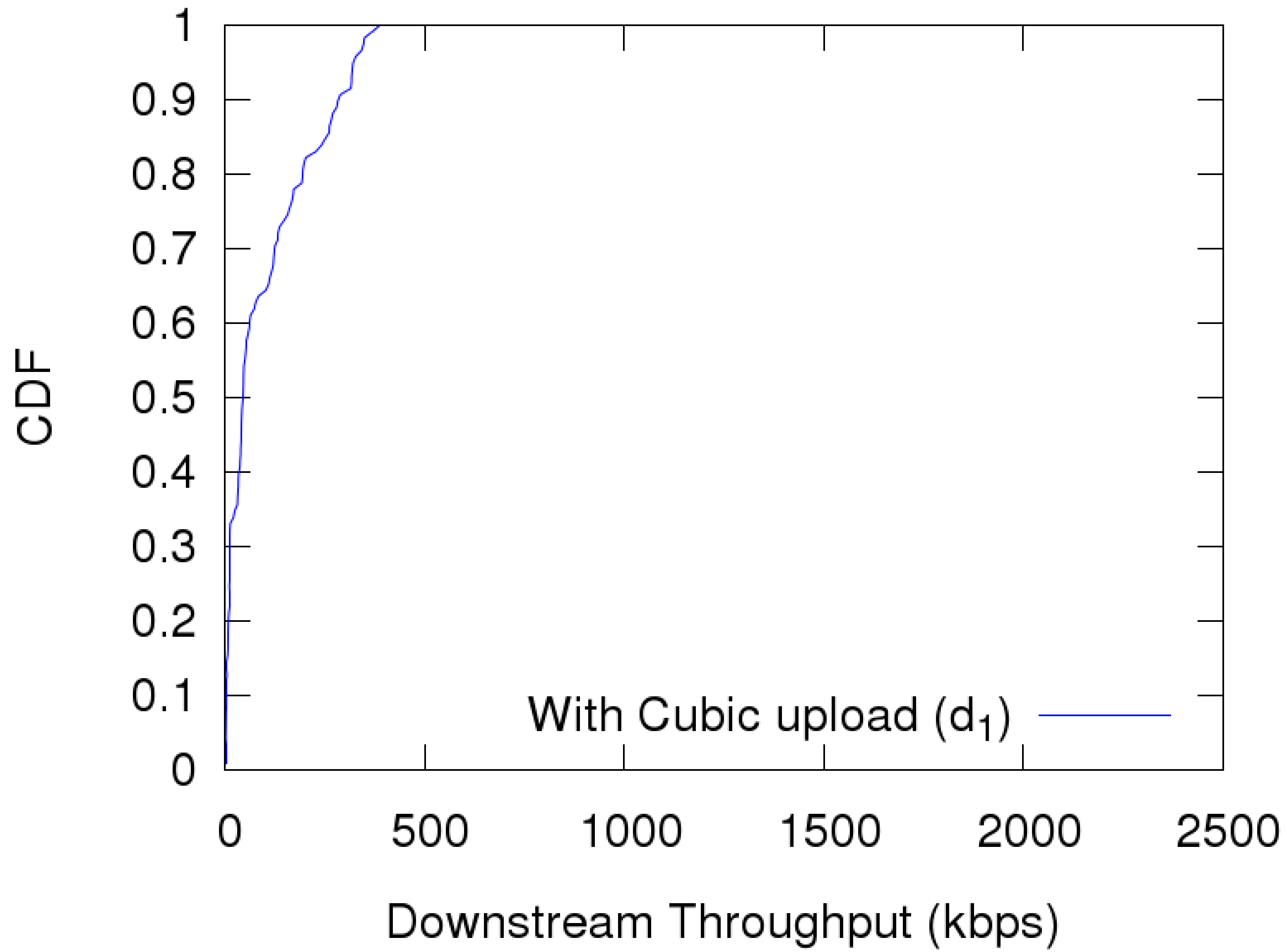
No Reduction in Throughput



Improve Download Throughput



Better Downstream Performance



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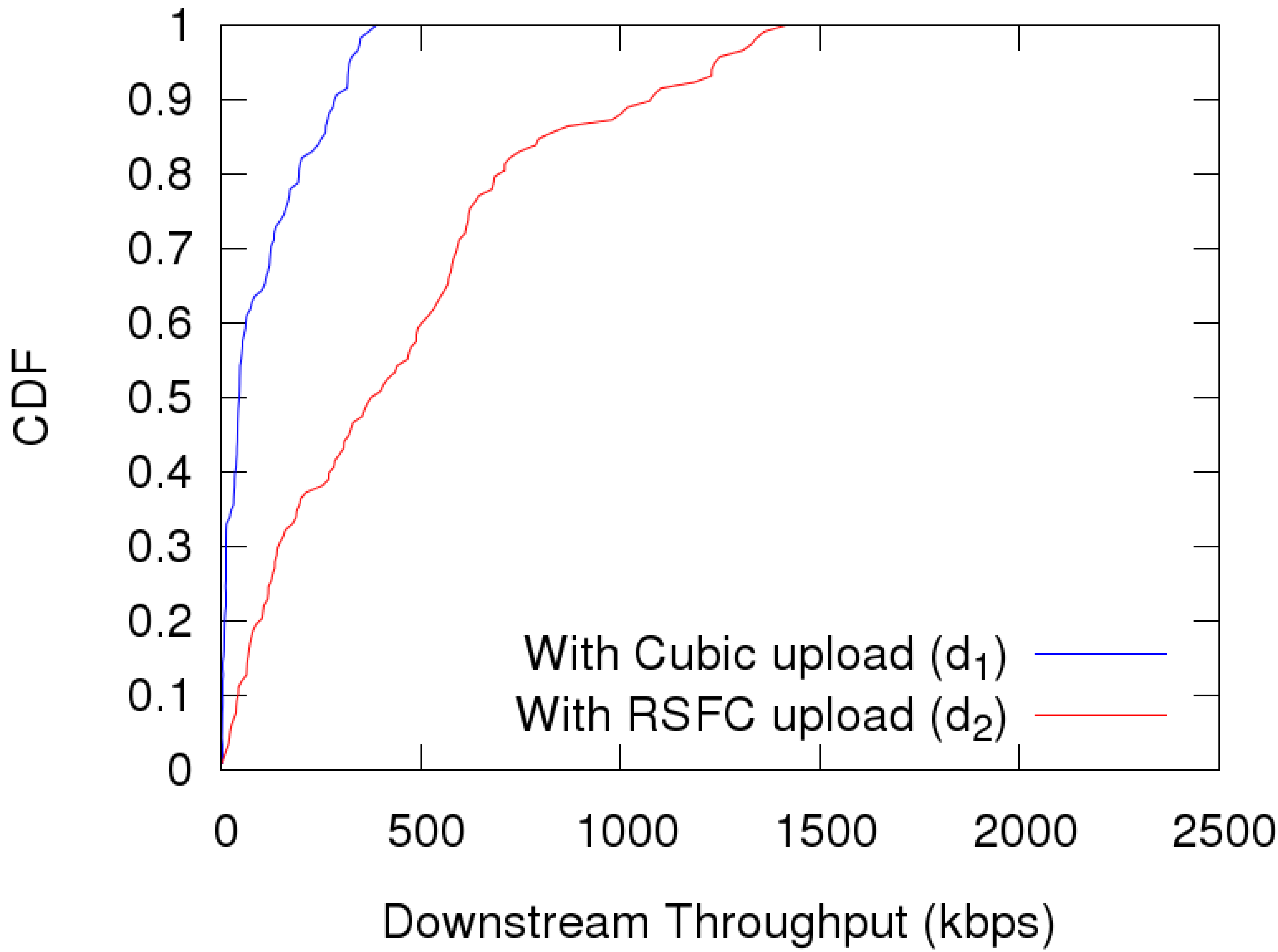

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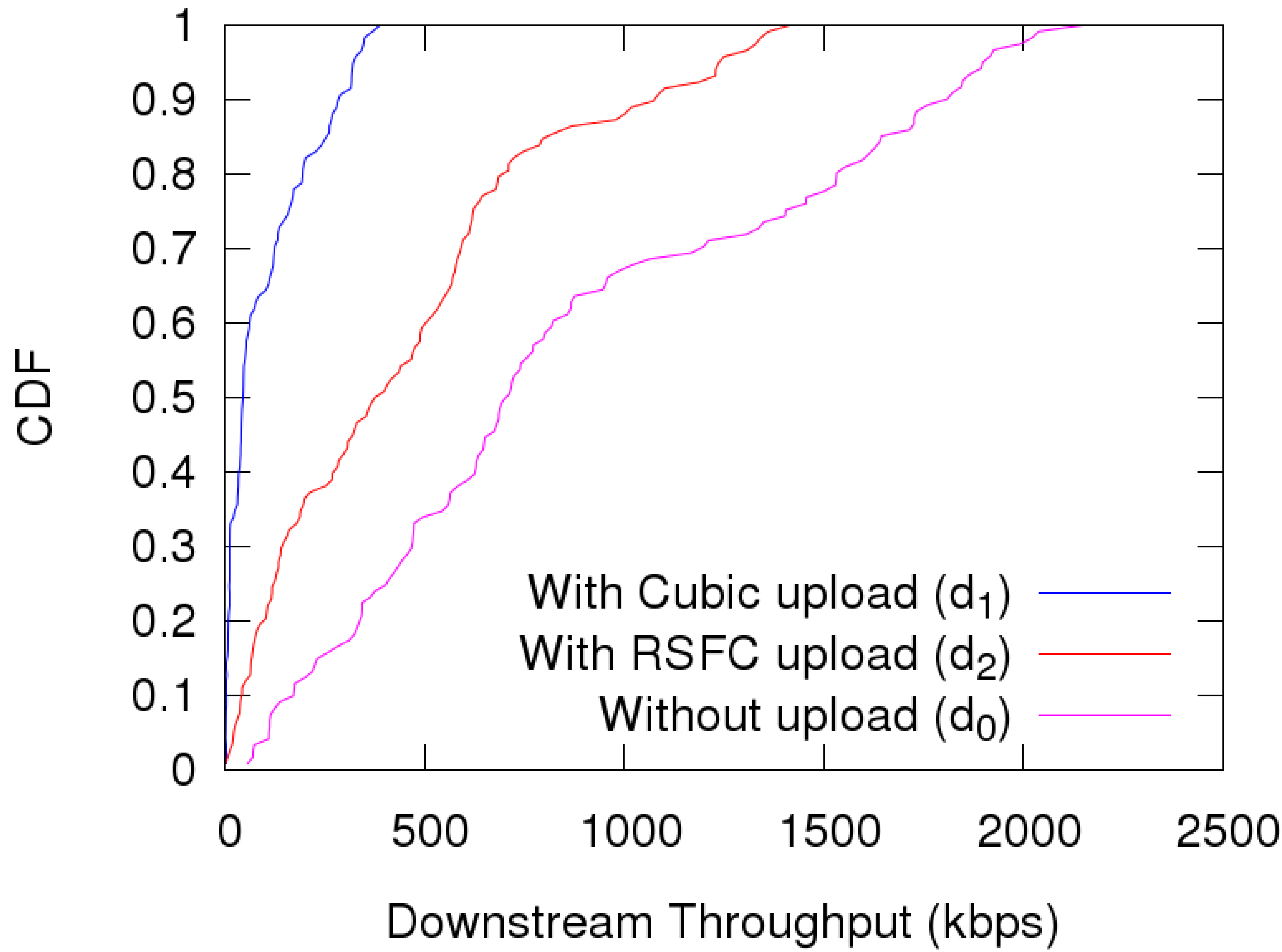
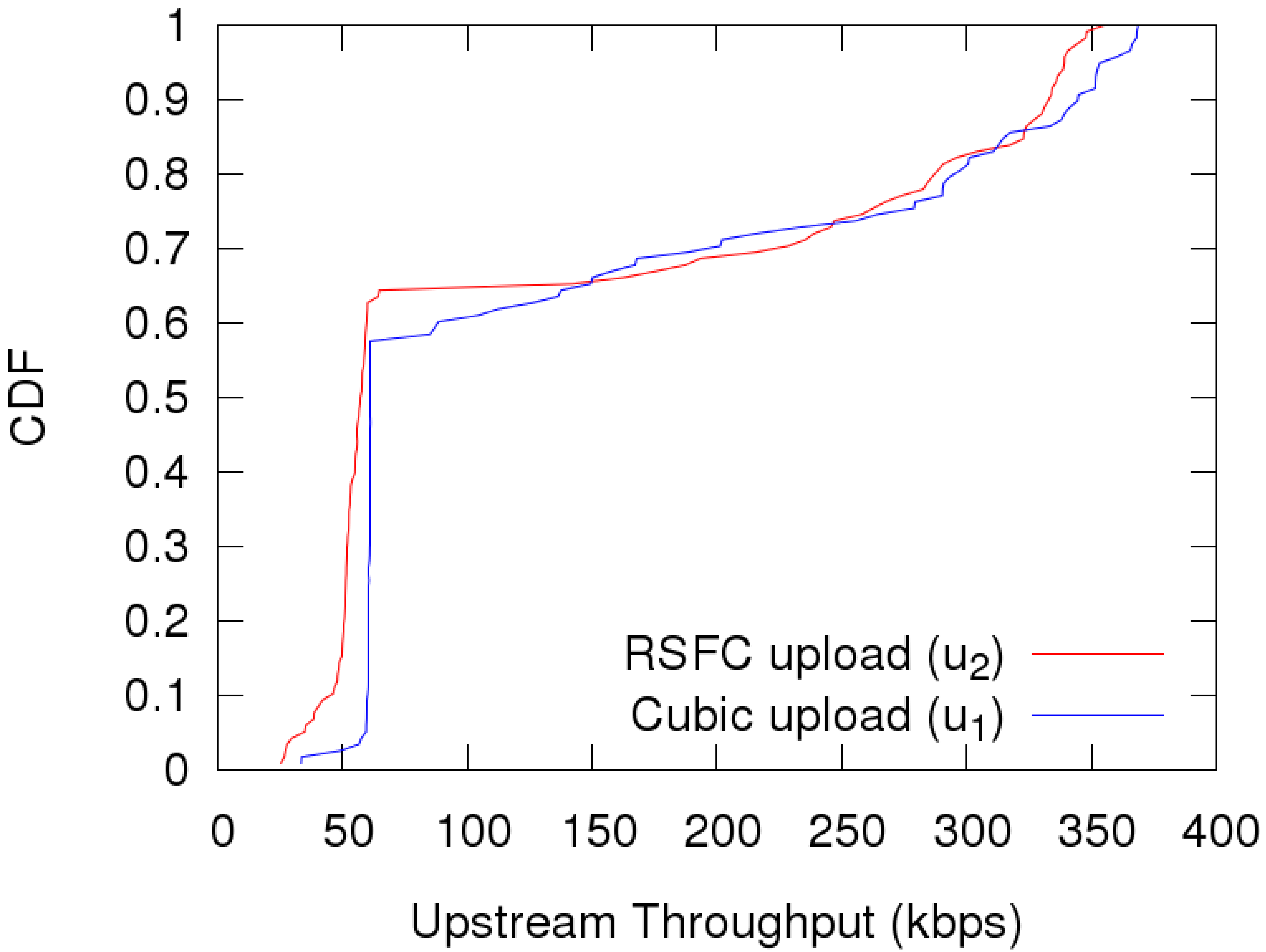
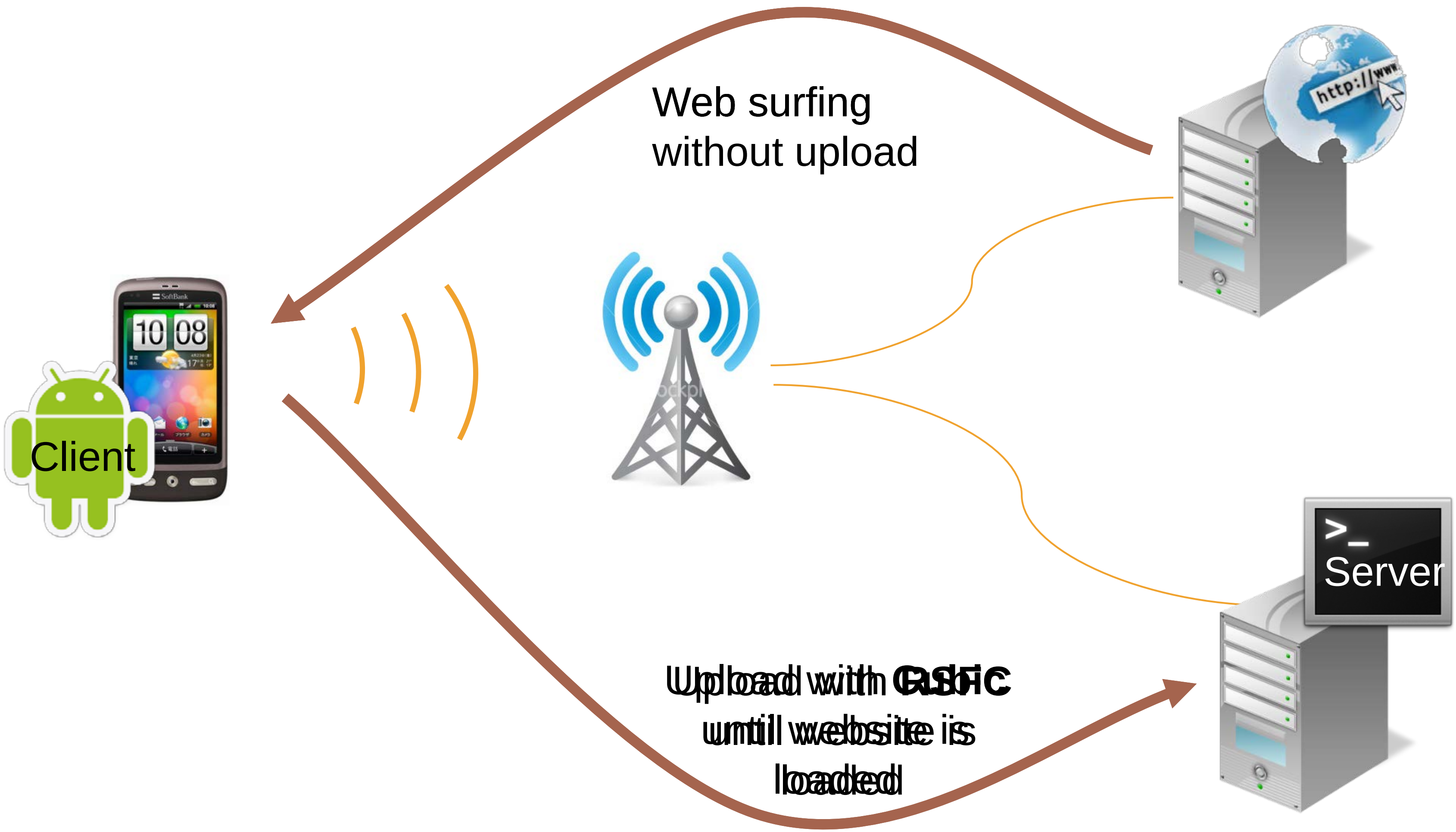


Little Impact on Upstream

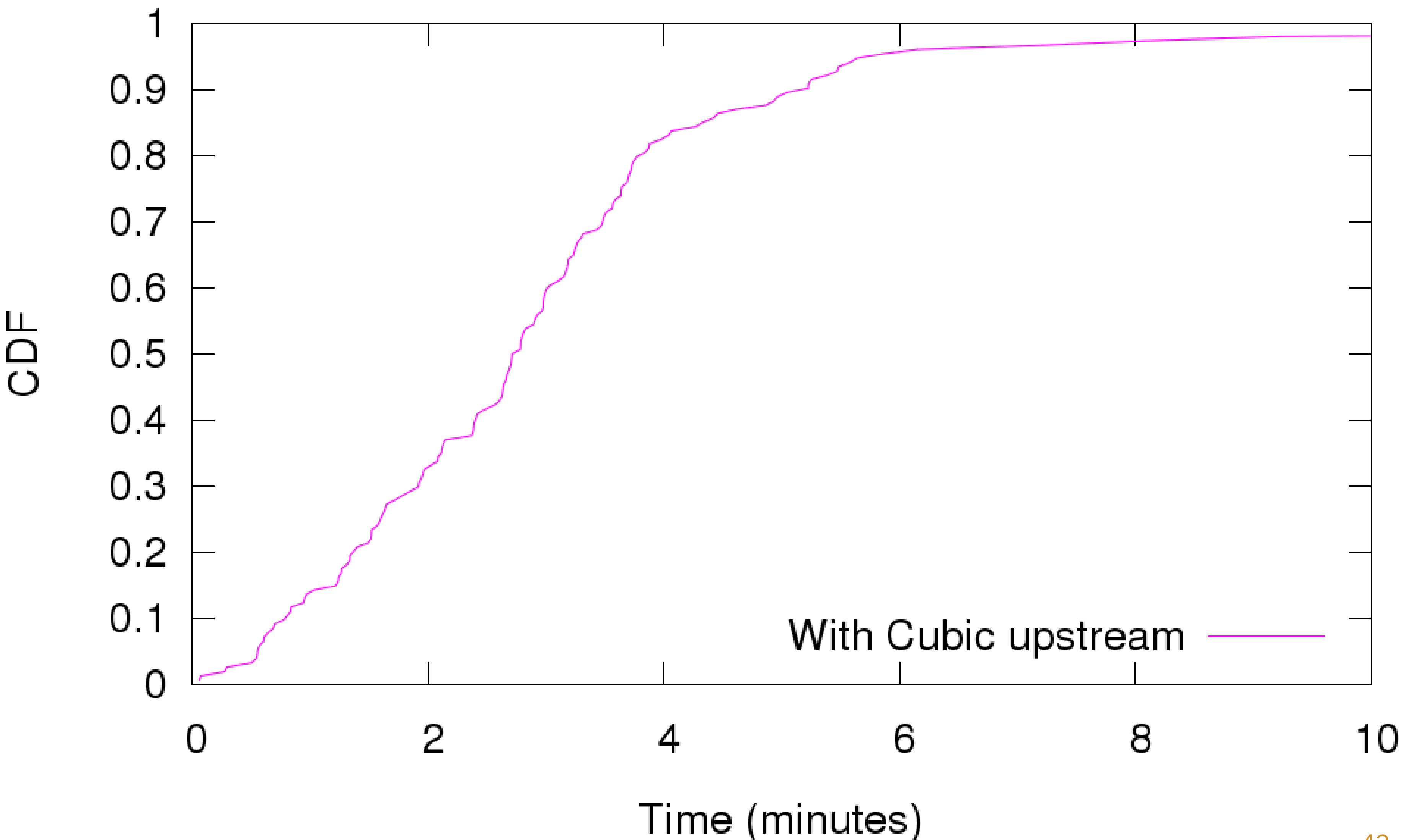


Improve Web Surfing

- Alexa top 100 sites



Webpages Load Faster



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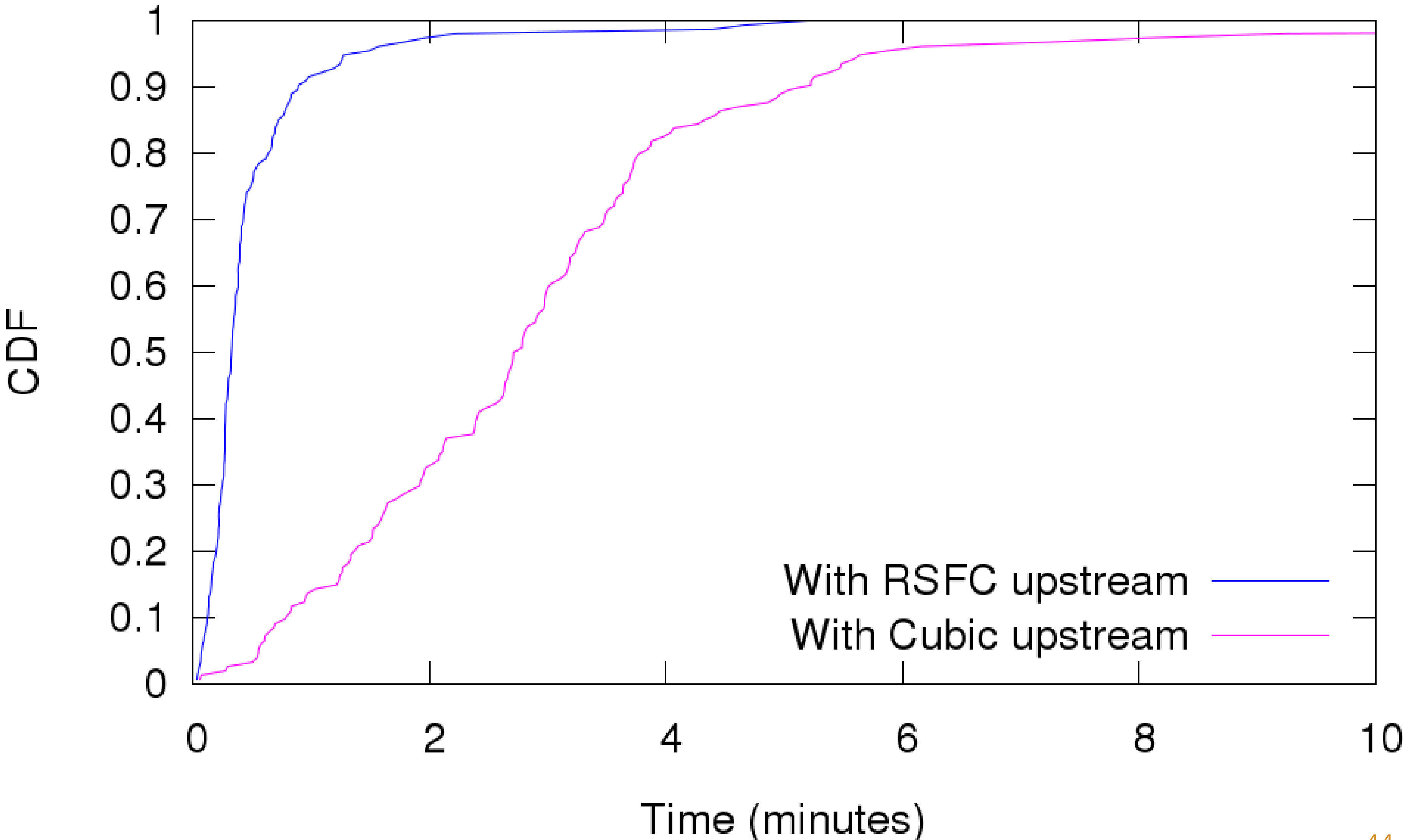

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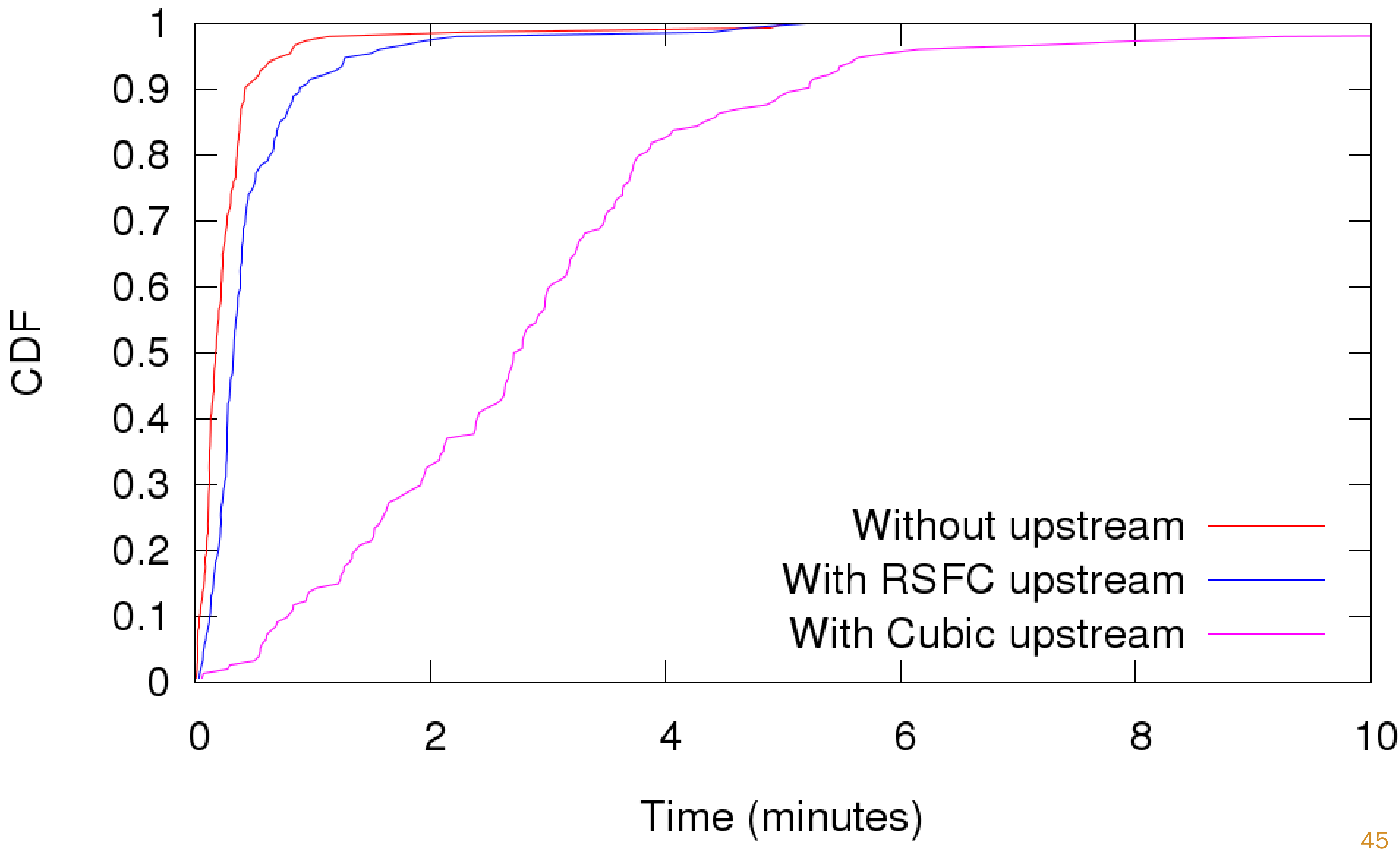


Conclusion

- Saturated uplink can cause serious performance degradation
- Receiver-Side Flow Control
  - ✓ Reduces queuing delay significantly
  - ✓ Improves downstream performance
  - ✓ Reduces loading time of webpages
  - ✓ Compatible with existing TCP variants
  - ✓ Easily deployed at ISP proxies

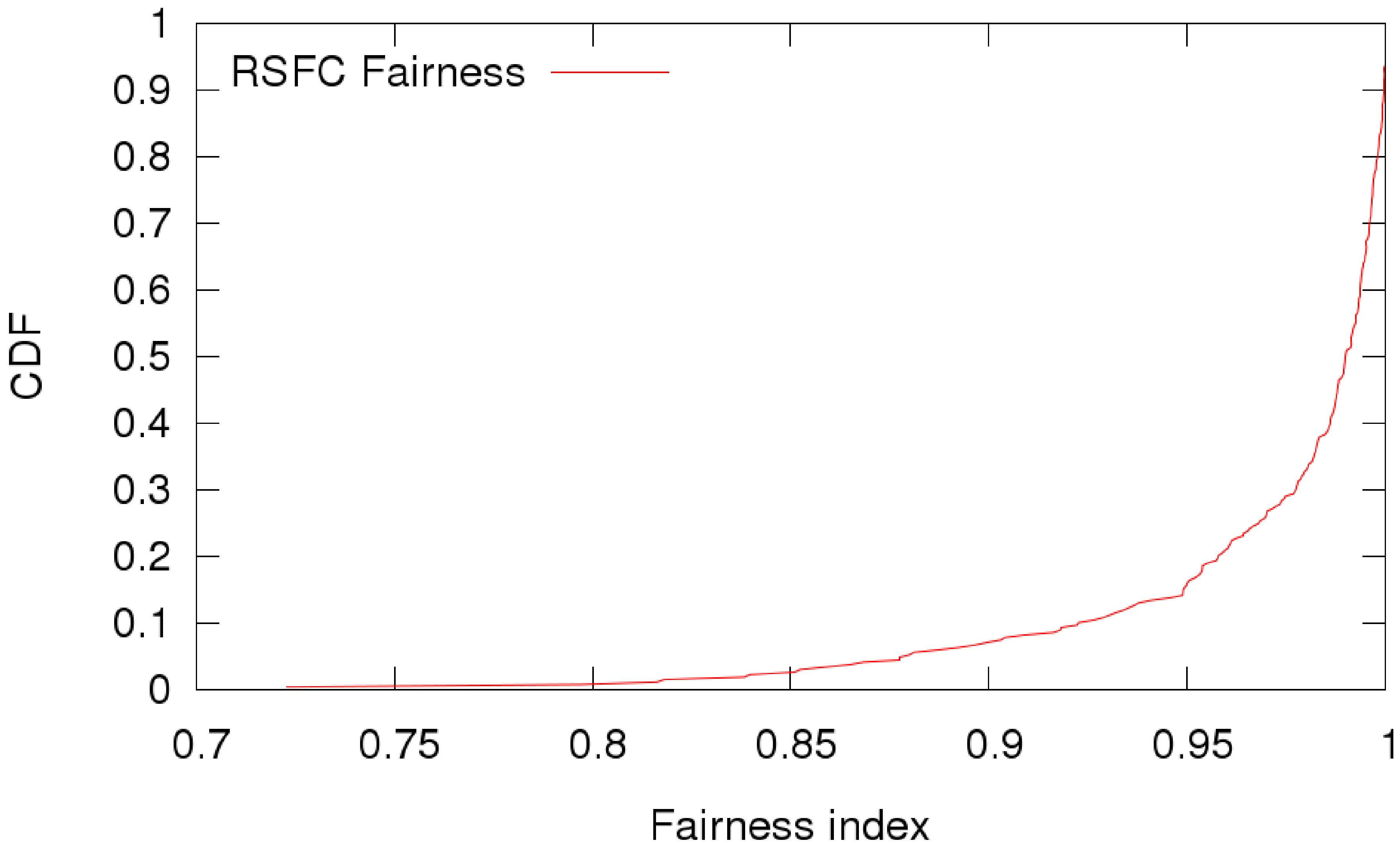
THANK YOU

Fairness of Competing RSFC Uploads

- Run two RSFC uploads concurrently
- Calculate Jain fairness index:

$$(R_1 + R_2)^2 / (2(R_1^2 + R_2^2))$$

Fairness of Competing RSFC Uploads

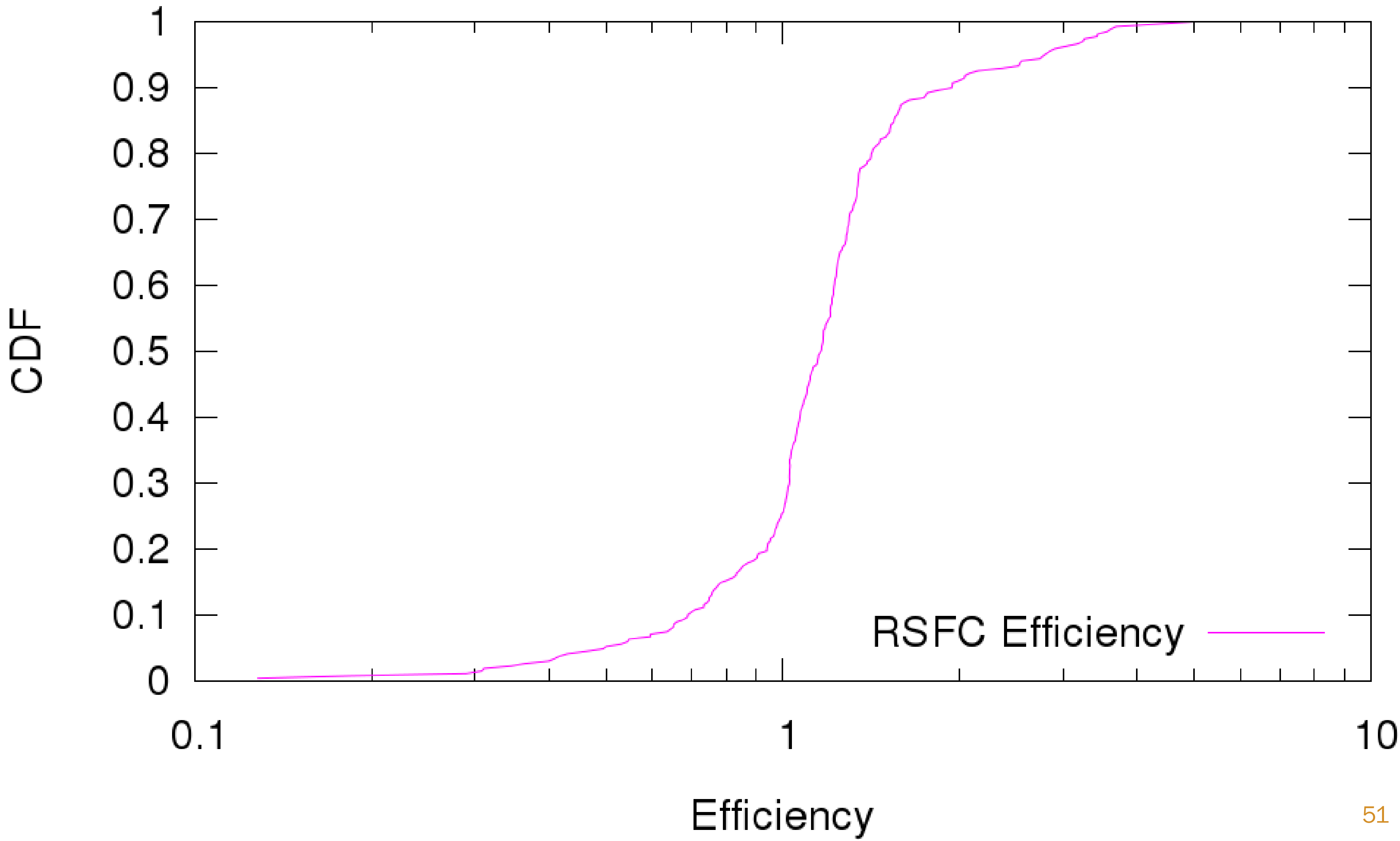


Efficiency of Competing RSFC Uploads

- Run two RSFC uploads concurrently
- Compare the aggregate throughput to a single TCP:

$$(R_1 + R_2) / R_{tcp}$$

Efficiency of Competing RSFC Uploads



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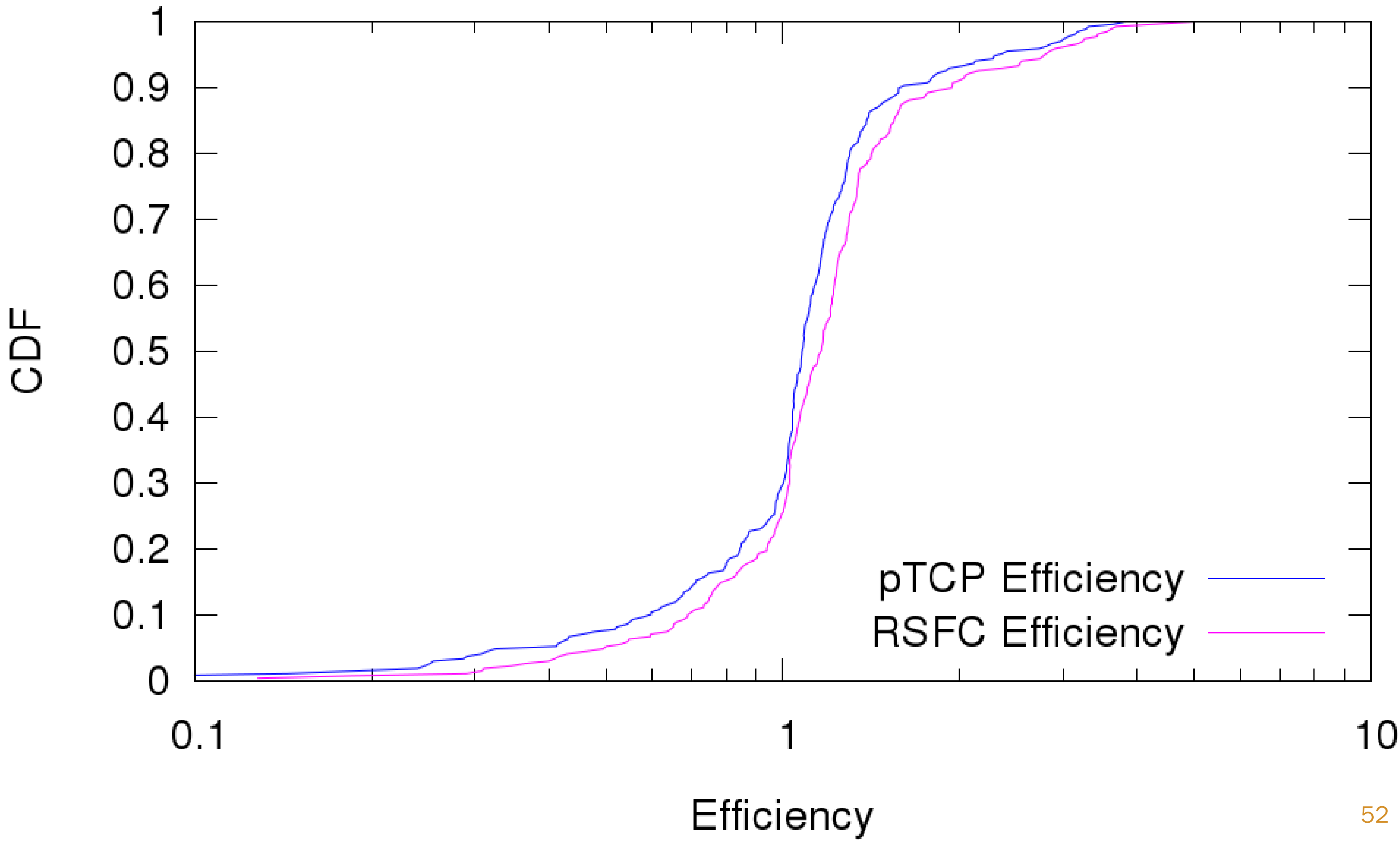
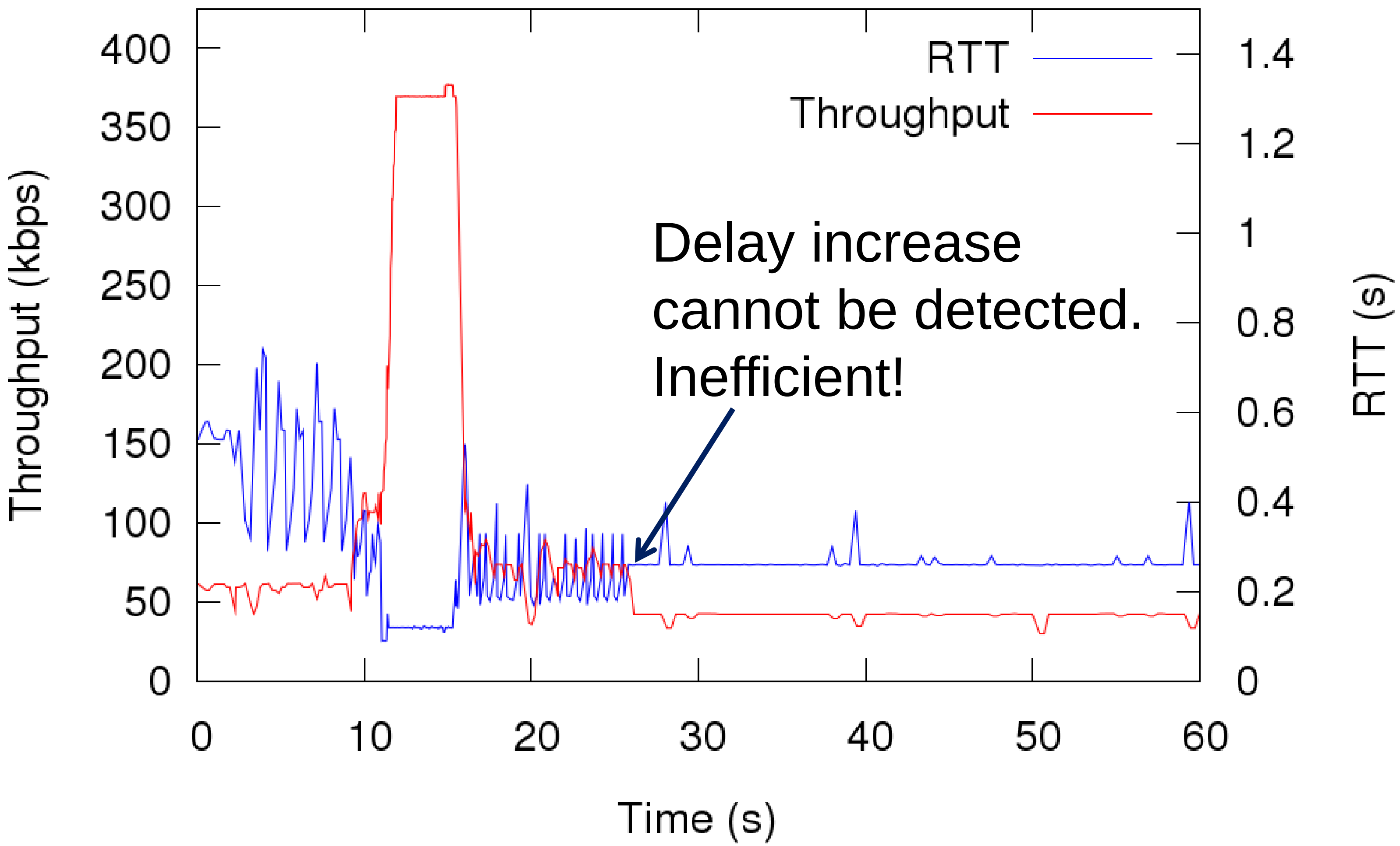


Adapting to Changing Network Conditions

- **Compare with one RSFC version without:**
  - Checking ρ
  - Monitor state

Adapting to Changing Network Conditions

Without the two methods



Adapting to Changing Network Conditions

With the two methods