Enabling users to control their Internet

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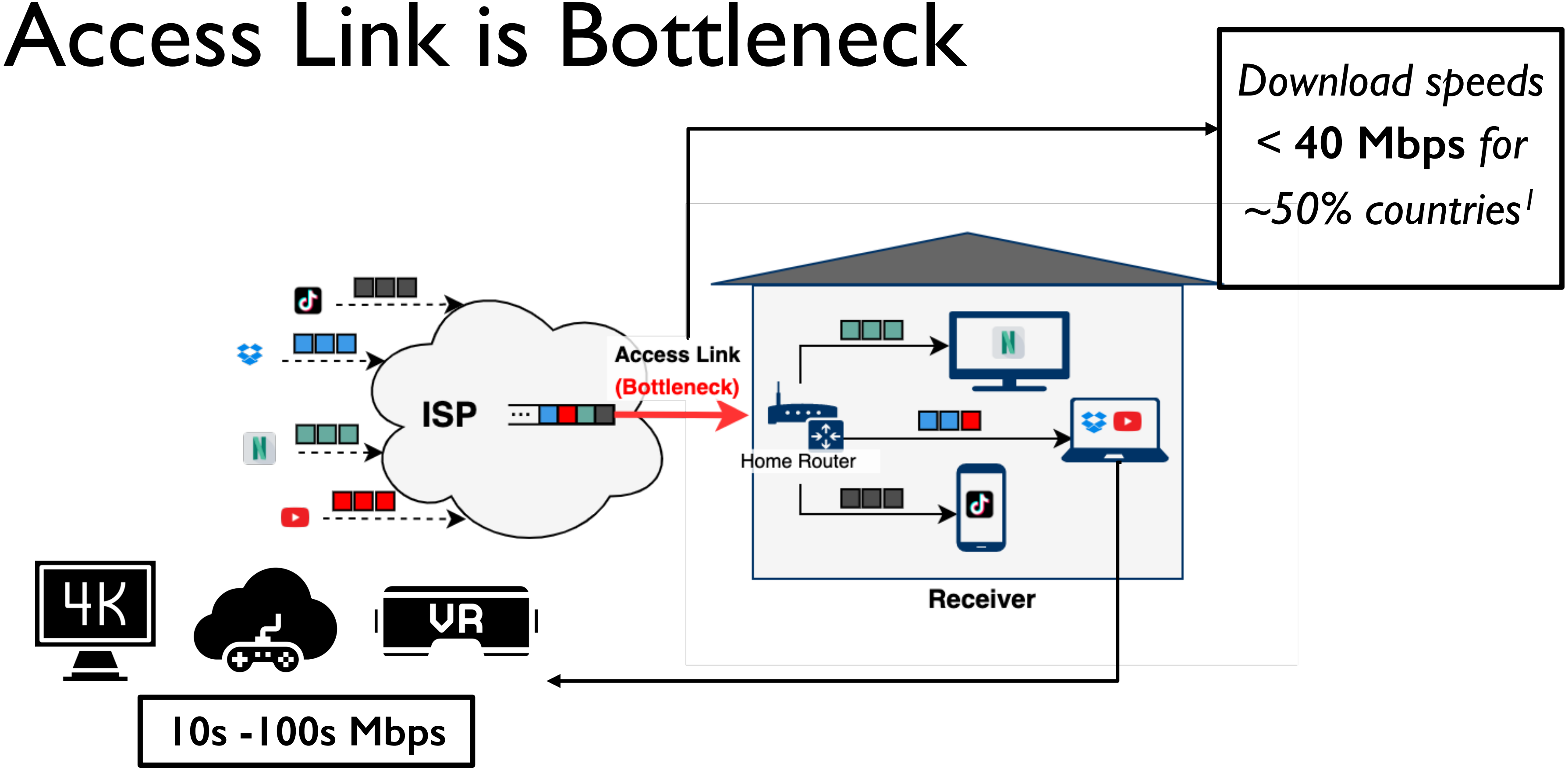
Access Link is Bottleneck

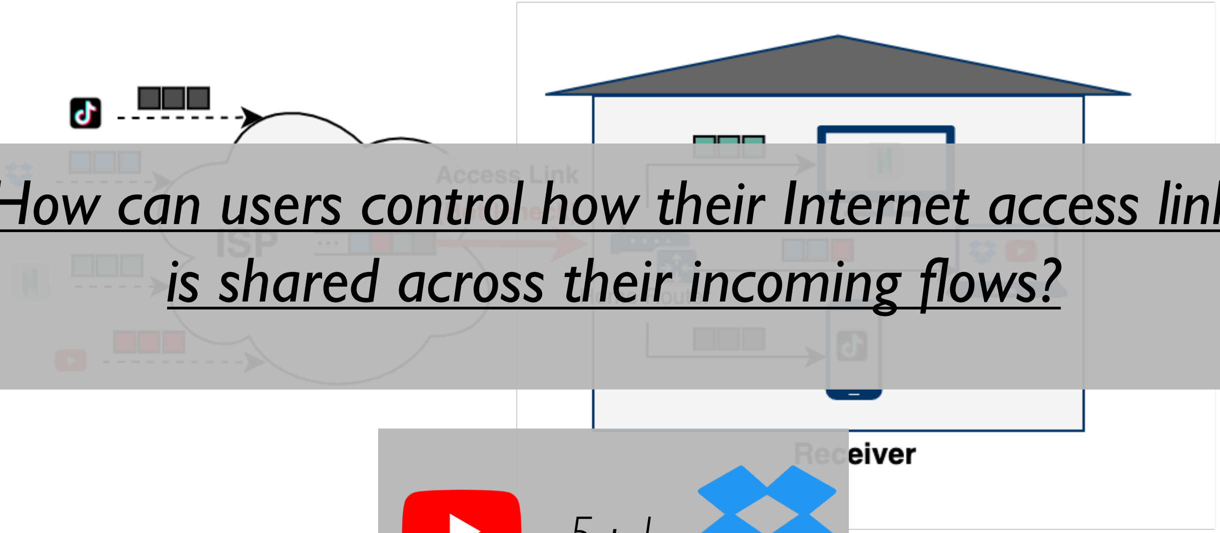


Download speeds **< 40 Mbps** *for ~50% countries*[1]

10s - 100s Mbps

[1] Global Speedtest Index Data, accessed April 2023

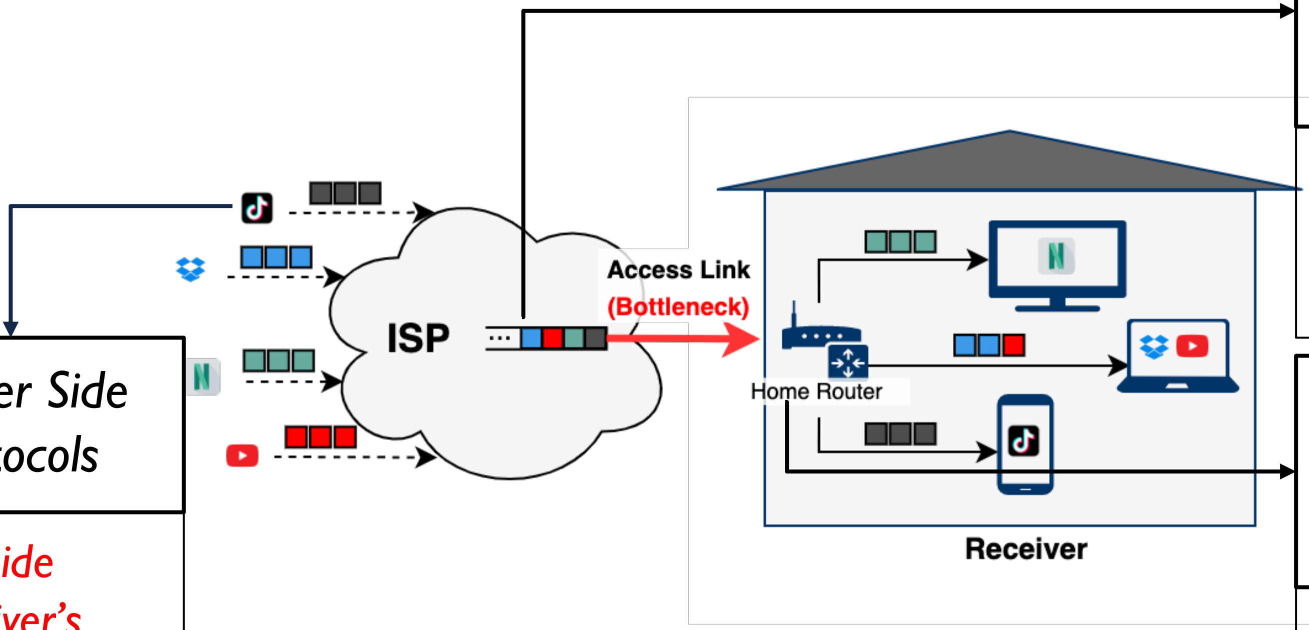
Controlling the Access Link



How can users control how their Internet access link is shared across their incoming flows?

5 : 1

Controlling the Access Link



Sender Side Protocols

- *Outside receiver's control*

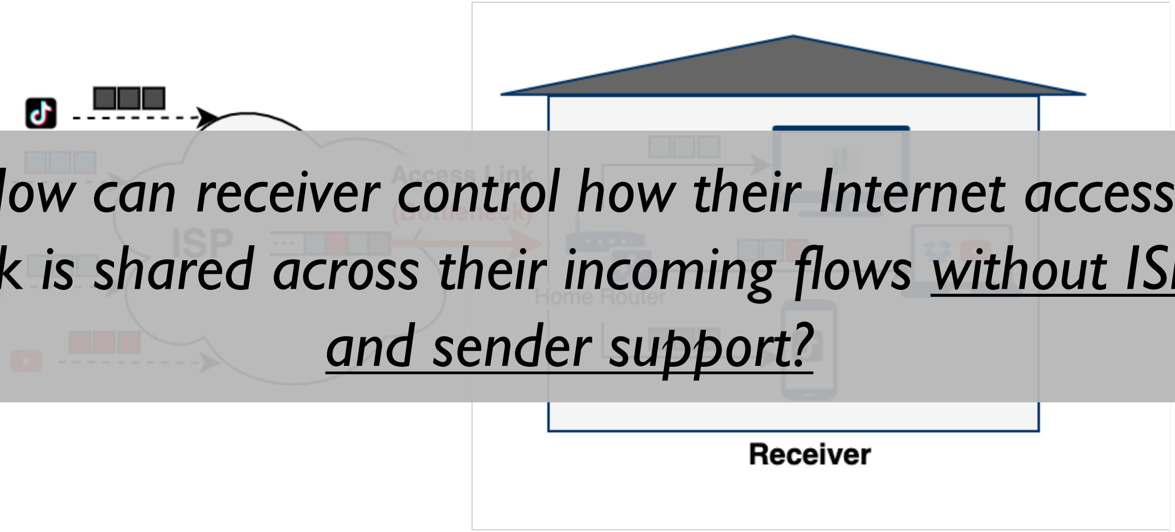
WFQ or Prioritization at ISP

- *Ideal*
- *Outside receiver's control*

WFQ or Prioritization at Home Router

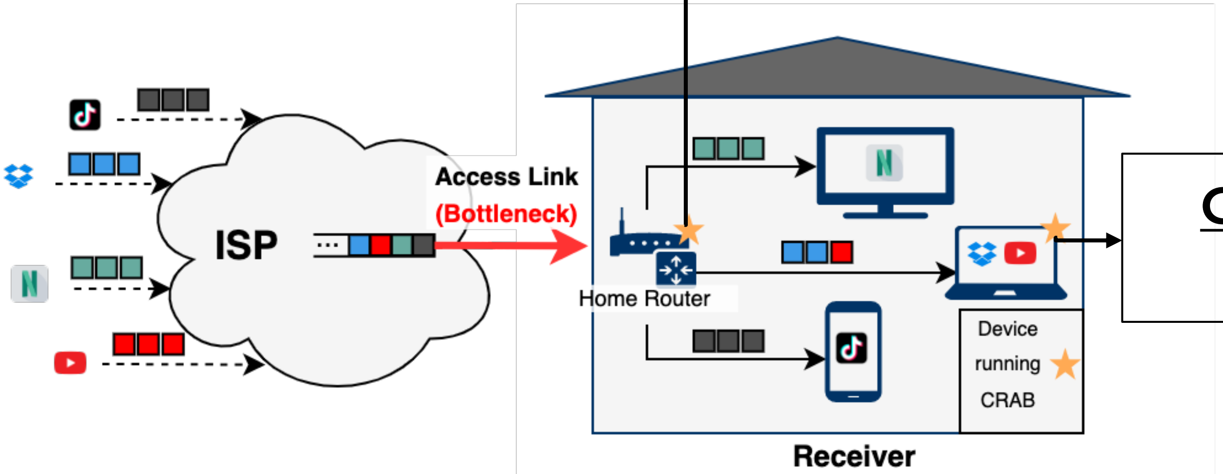
- *Does not help when access link is bottleneck*

Controlling the Access Link



How can receiver control how their Internet access link is shared across their incoming flows without ISP and sender support?

Our System: CRAB*



CRAB@Home Router

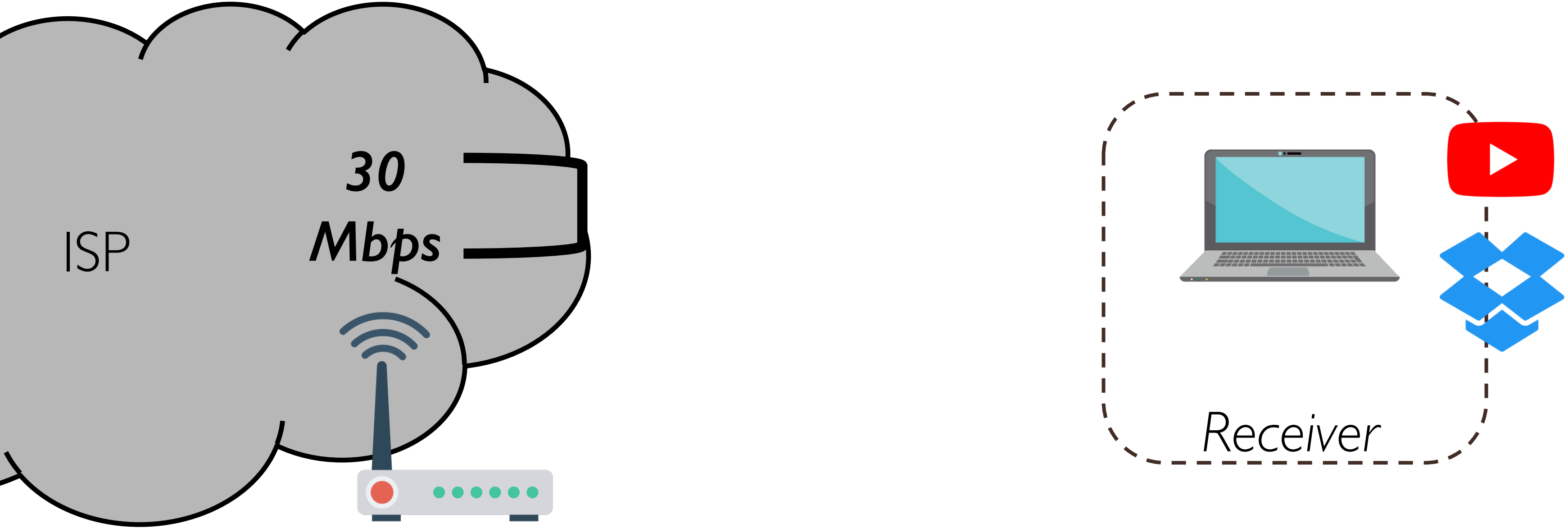
CRAB@End Device

Enables users to control how their Internet access link is shared across their incoming flows without any support from the ISP or senders.

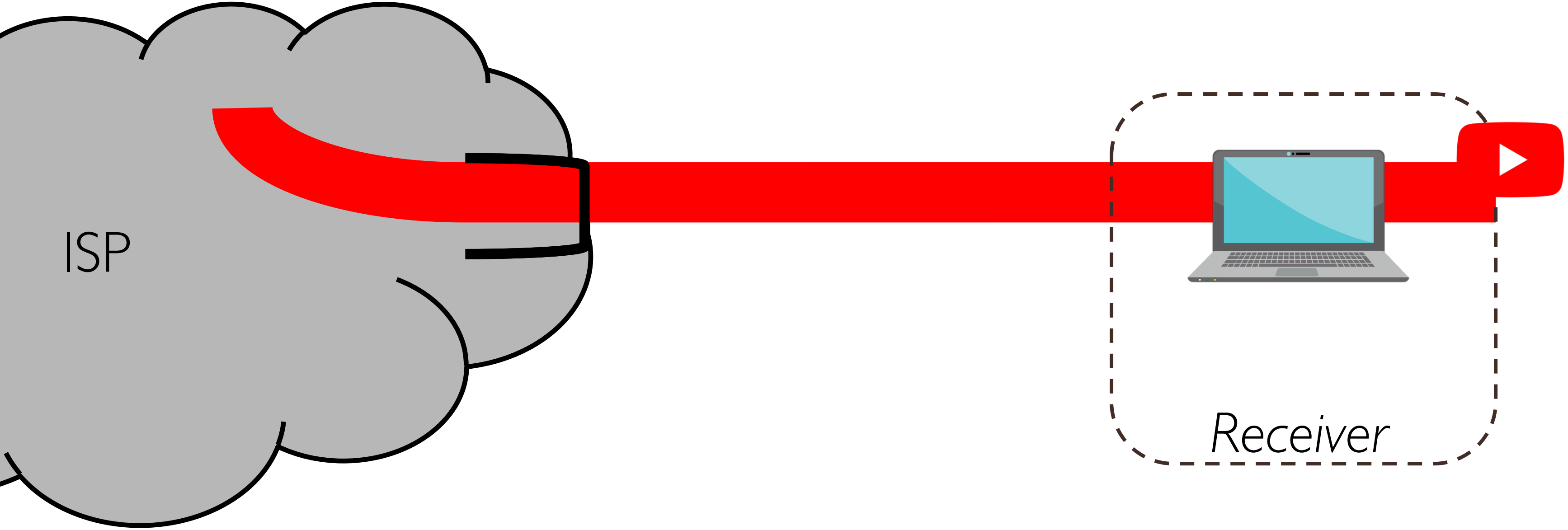
*Customizable Receiver-driven Allocation of Bandwidth

Case Study Setup

- *4K video streaming (YouTube) vs bulk download*
- *Emulated ISP controlled link with 30 Mbps bottleneck bandwidth*



4K Video Alone



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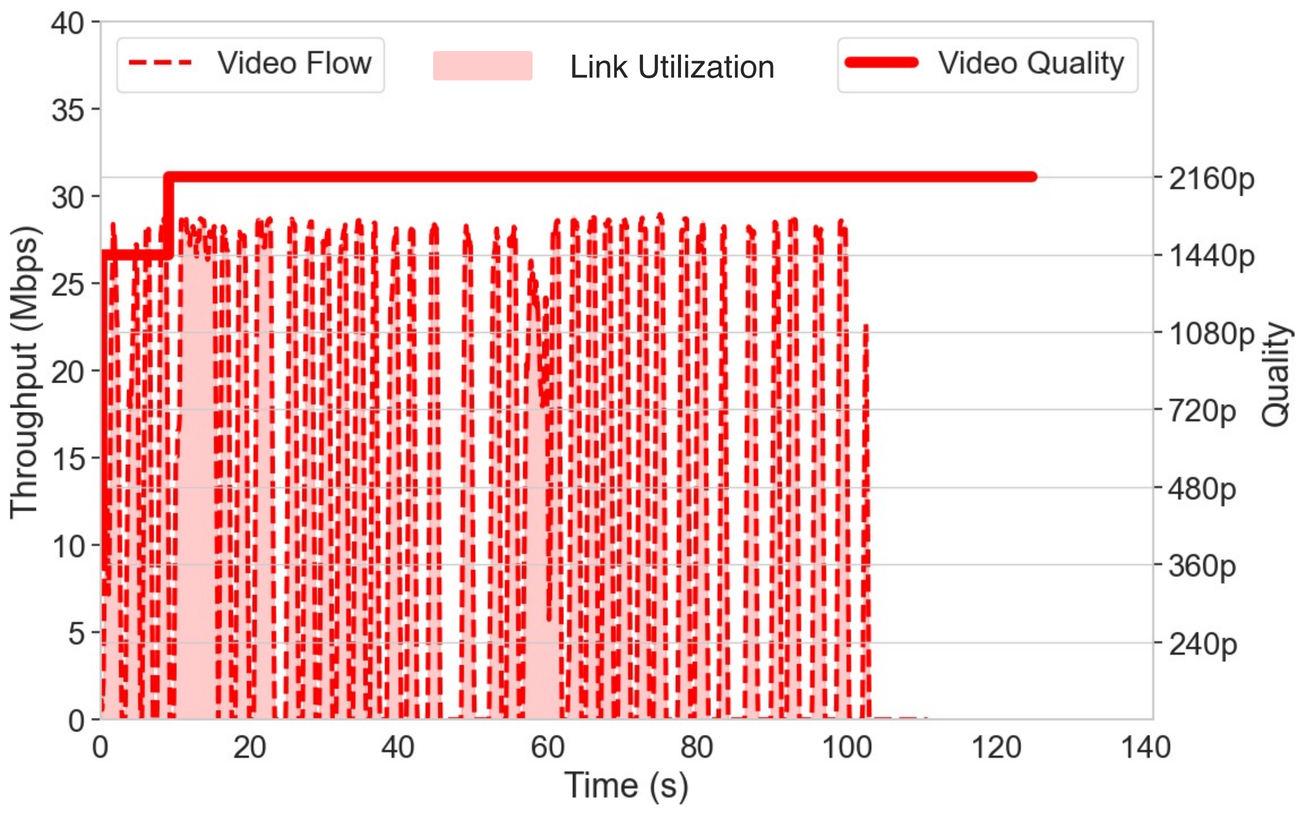

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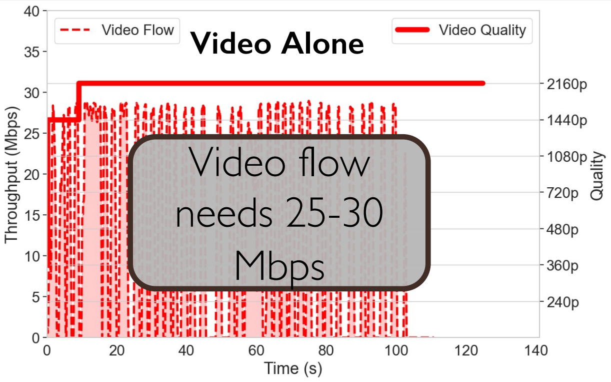
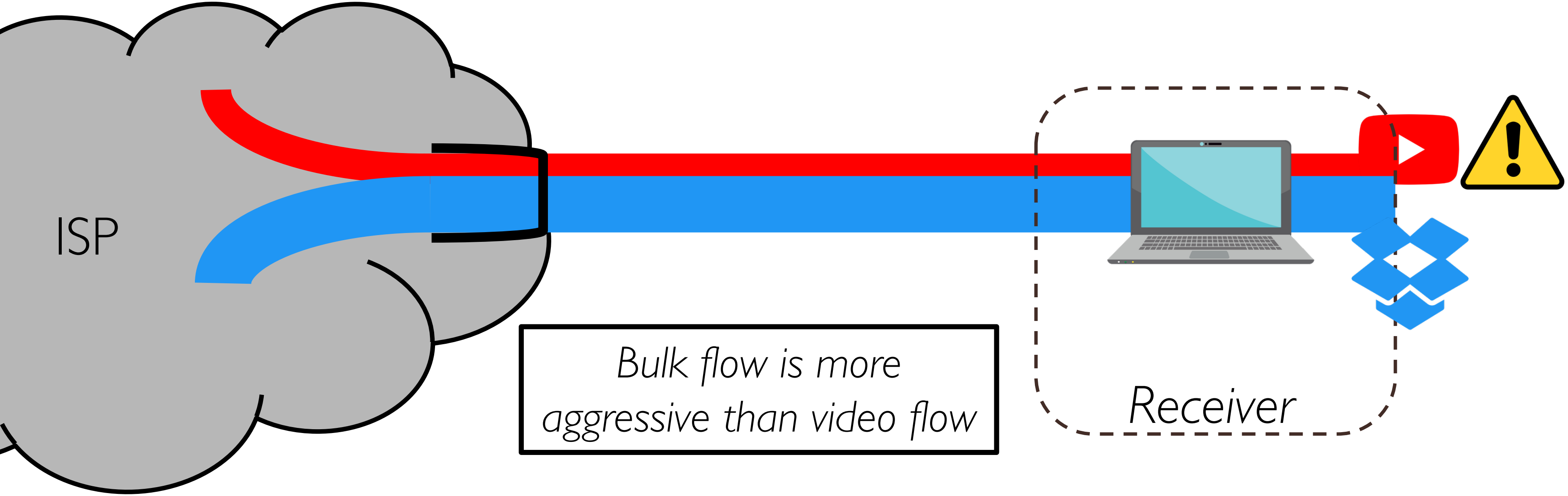


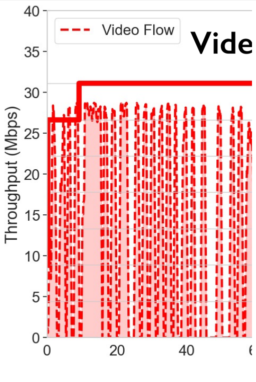
Video flow needs 25-30 Mbps

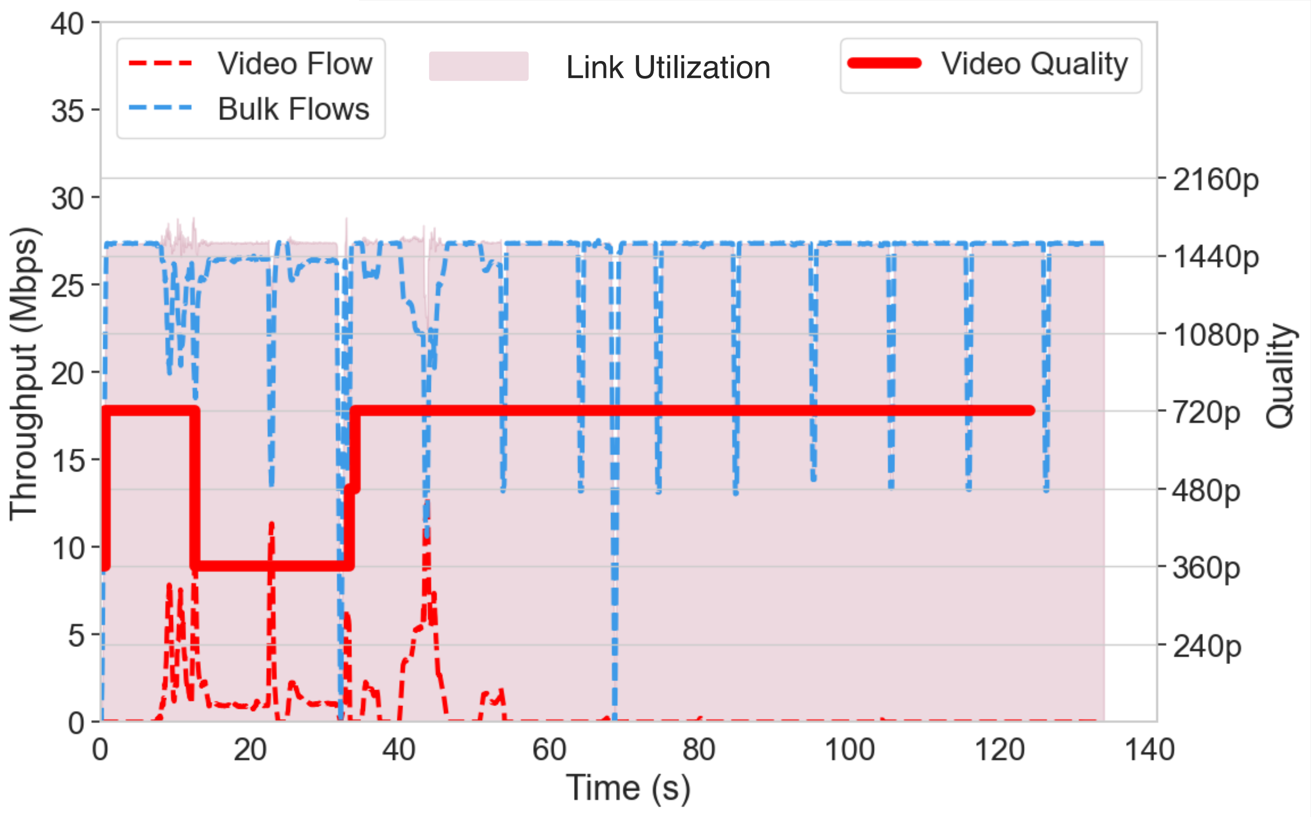
4K Video with Bulk Download



Bulk flow is more aggressive than video flow

4K Video with Bulk Download





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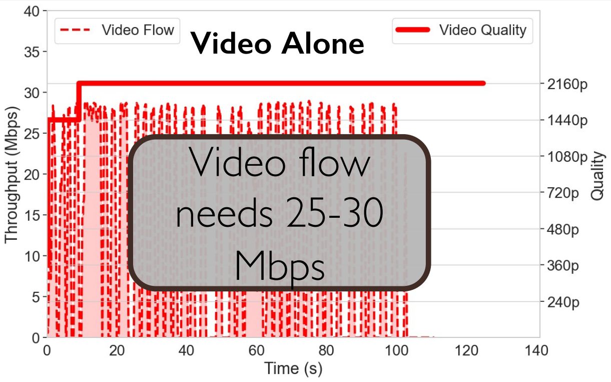

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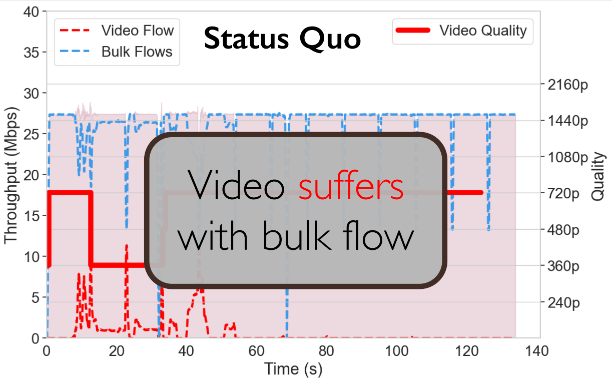
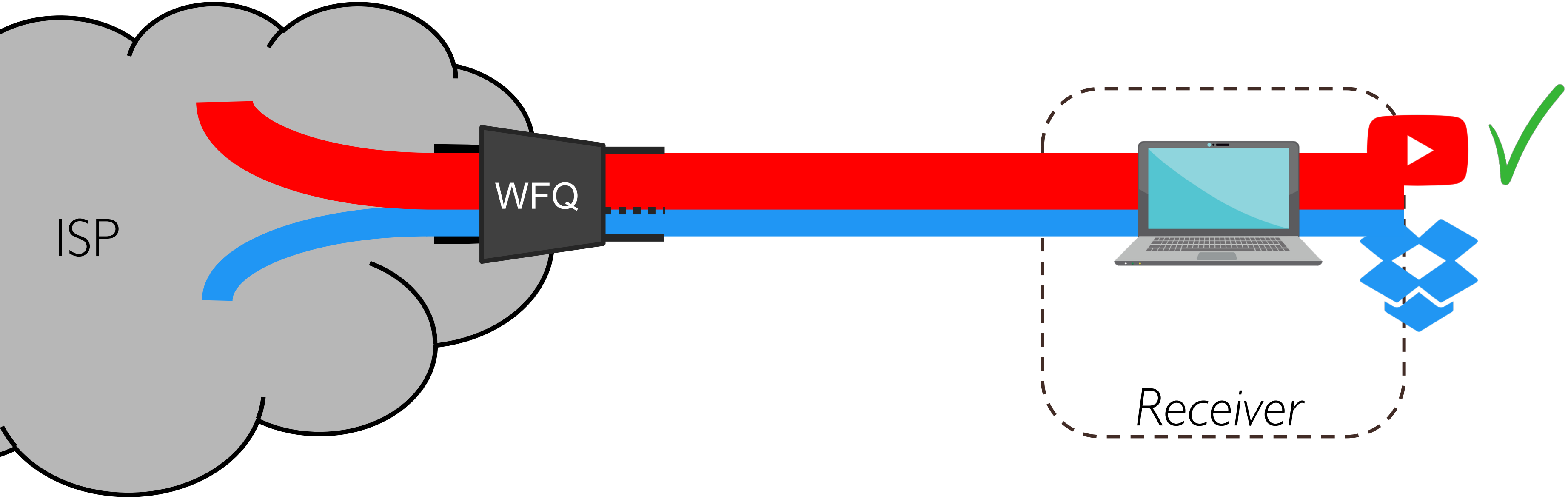


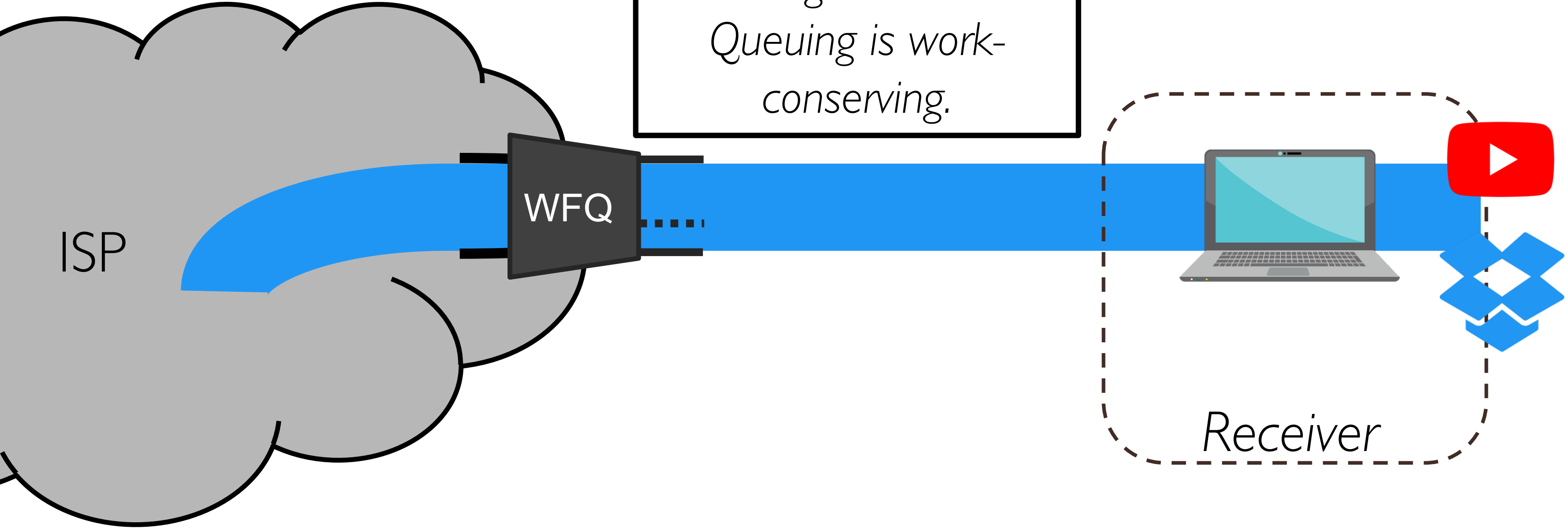
Video suffers with bulk flow

Weighted Fair Queuing @ISP



Weighted Fair Queuing @ISP

Weighted Fair Queuing is work-conserving.



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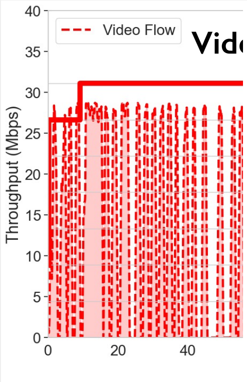
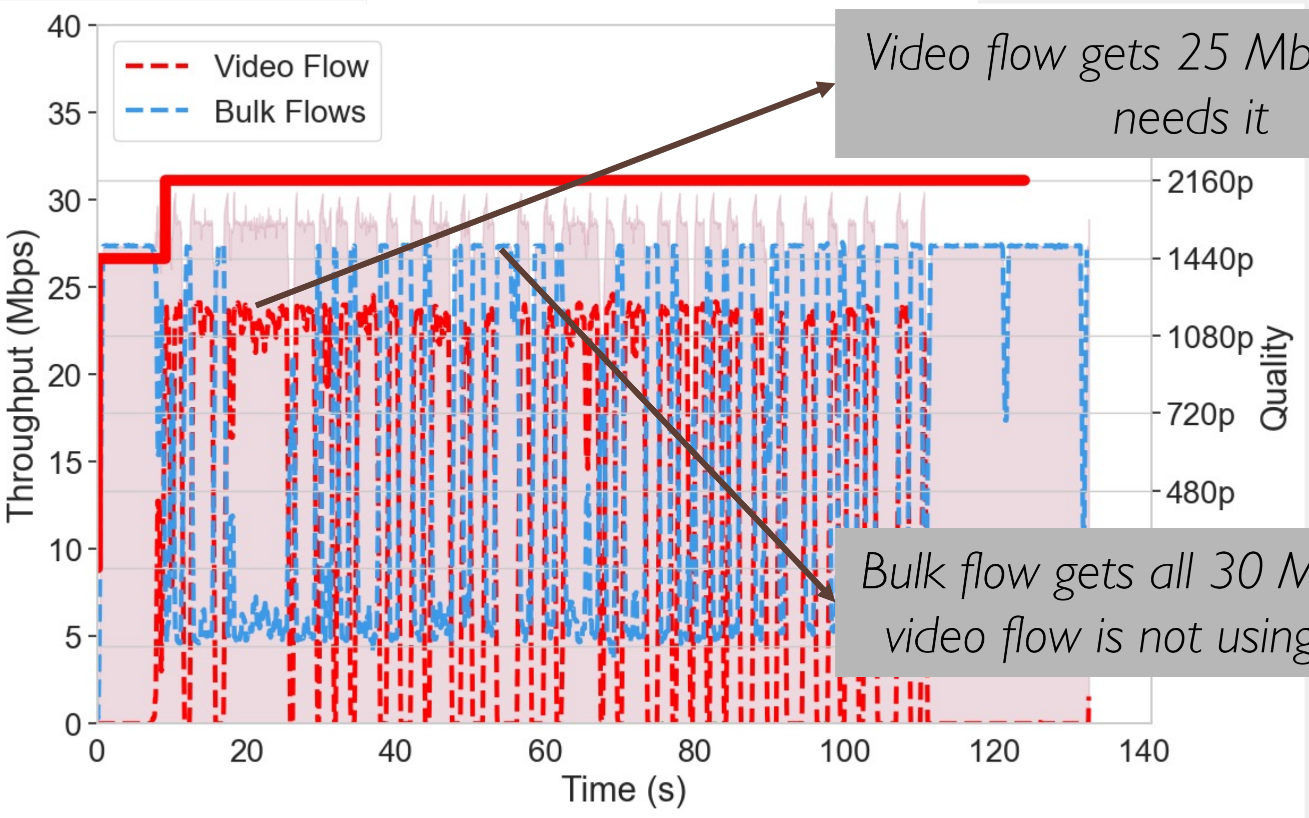
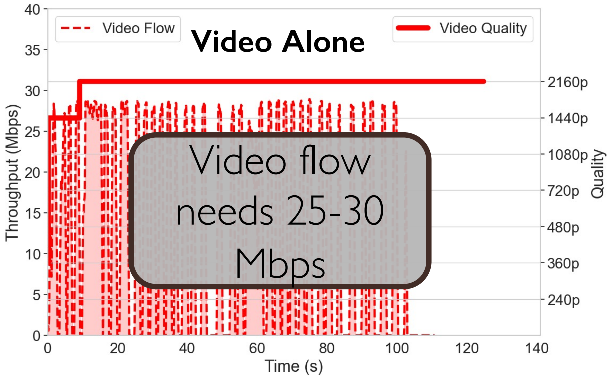




Video flow gets 25 Mbps when it needs it

Bulk flow gets all 30 Mbps, when video flow is not using its share

Weighted Fair Queuing @ISP



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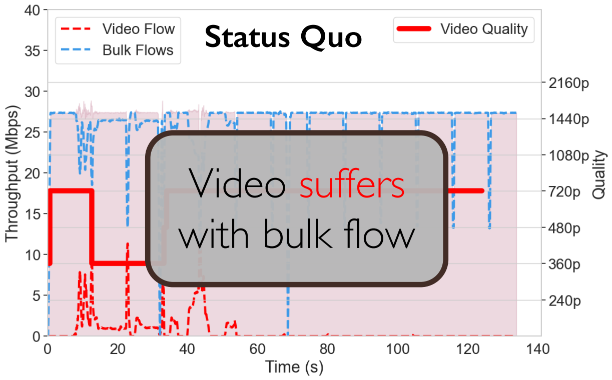

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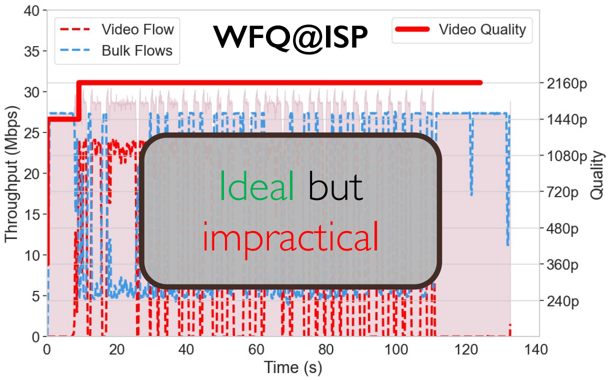
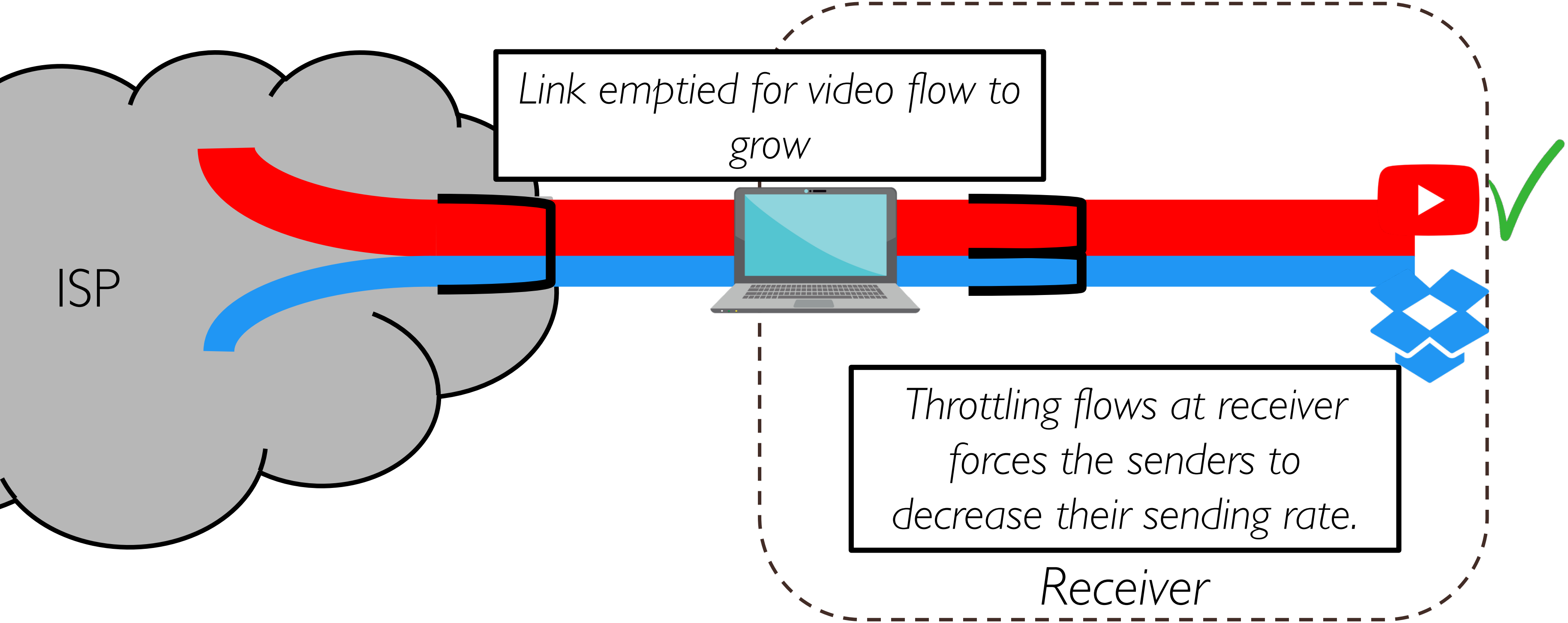


Ideal but impractical

What can we do at Receiver?

- Estimate link bandwidth*
- Compute the weighted fair share rate of each flow and throttle them to that rate.

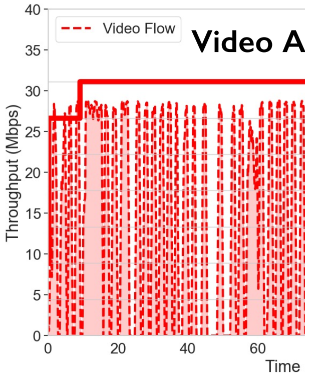
Throttling at the Receiver

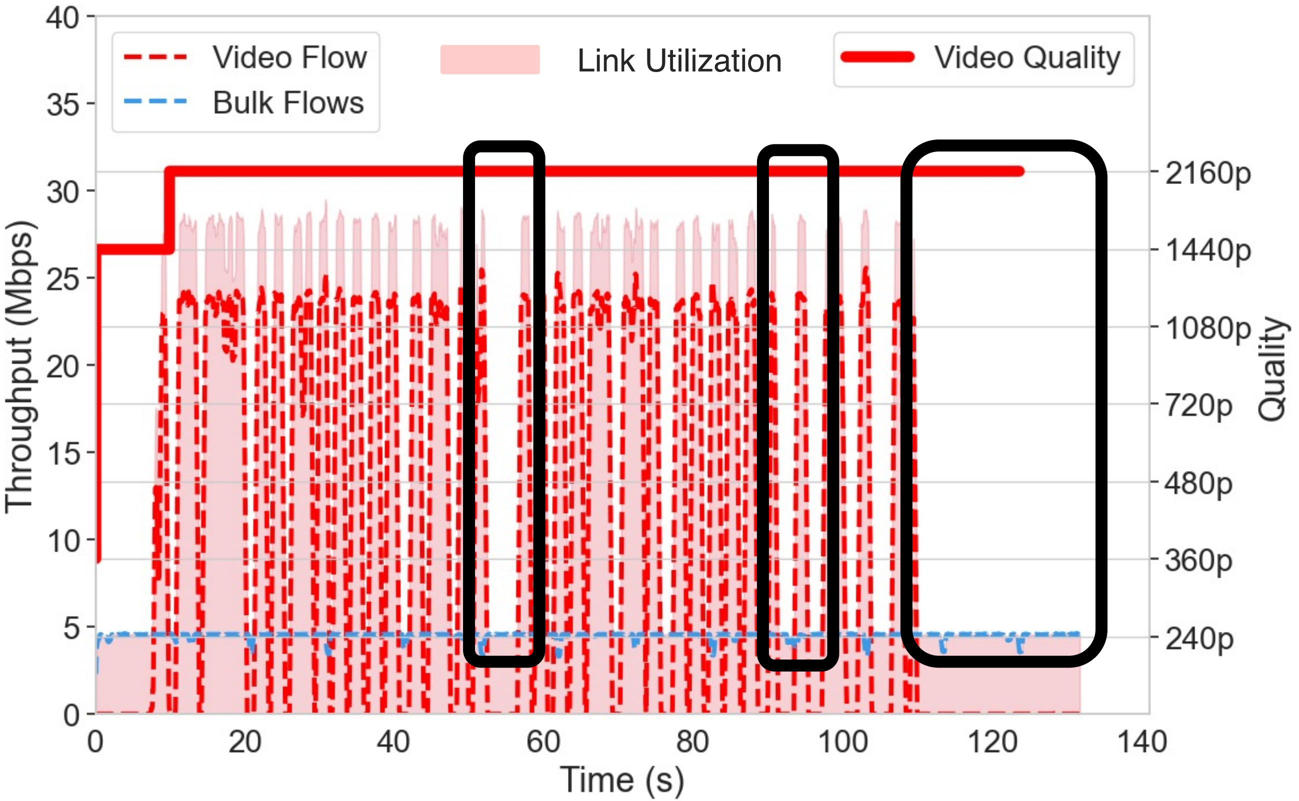


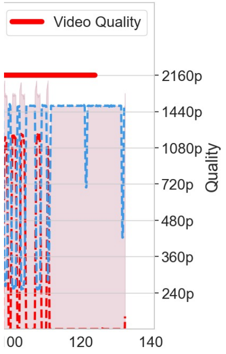
Link emptied for video flow to grow

Throttling flows at receiver forces the senders to decrease their sending rate.

Throttling at the Receiver







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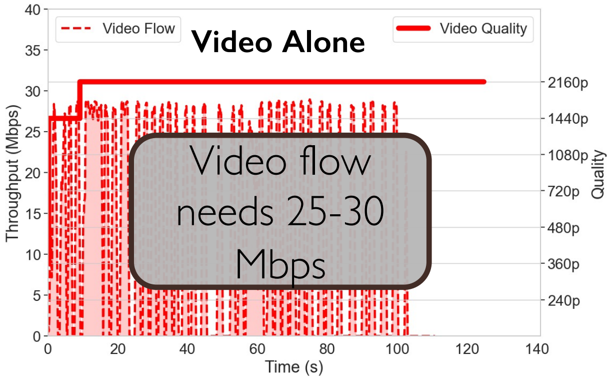
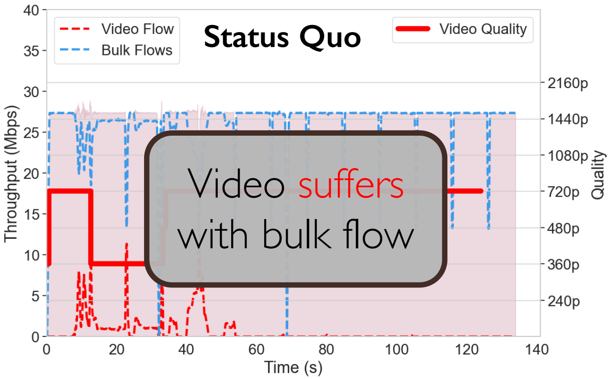


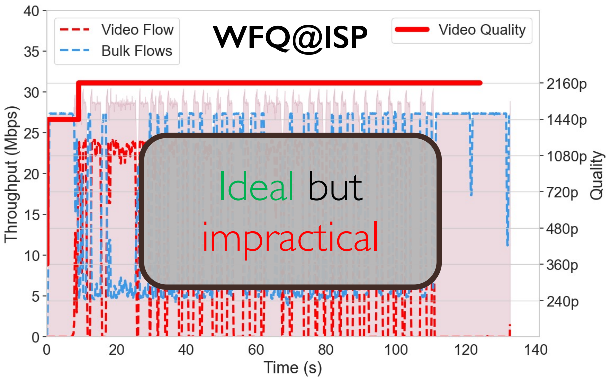
Video Alone

Video flow needs 25-30 Mbps



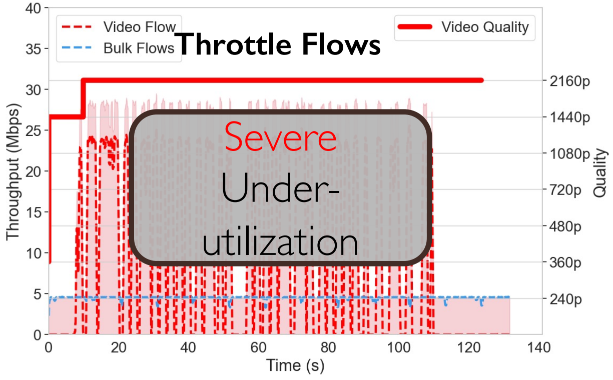
Status Quo

Video suffers with bulk flow



WFQ@ISP

Ideal but impractical



Throttle Flows

Severe Under-utilization

What can we do at Receiver?

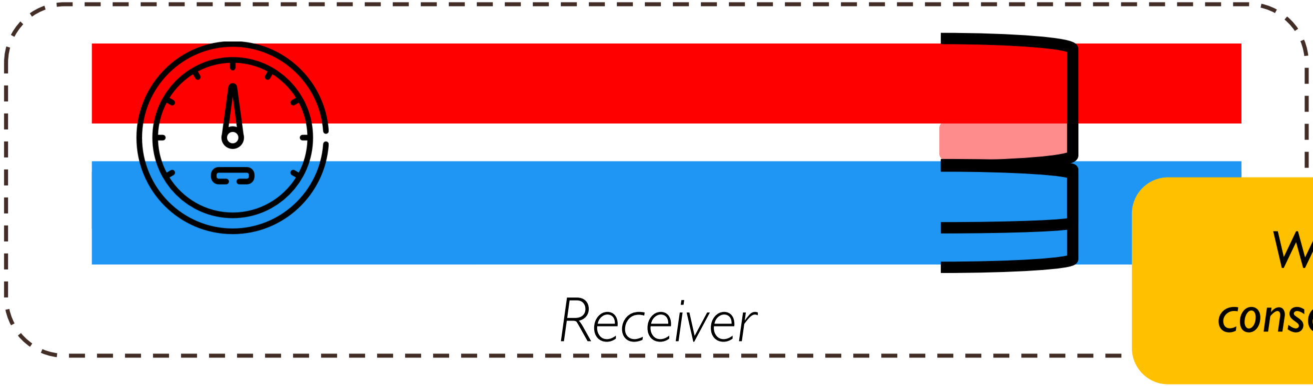
- Estimate link bandwidth*
- Compute the max-min weighted fair share rate of each flow and throttle them to that rate.
- Reallocate unused capacity to other flows.

Avoiding Bandwidth Wastage

Attempt 1: Reallocate any unused bandwidth to other flows instantaneously

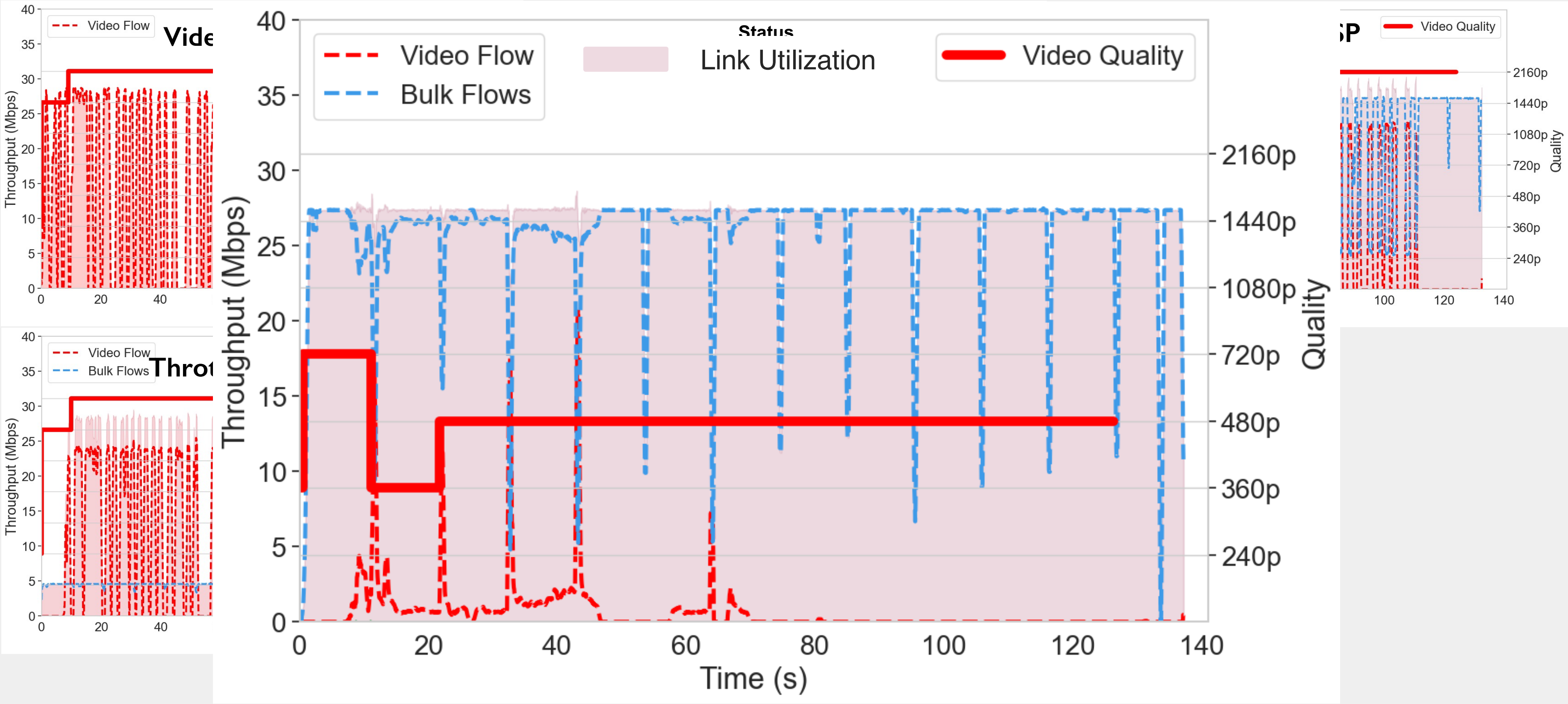
Infer flow demands by ***instantaneous*** *arrival rate*

Adjust the throttling rate after reallocating unused bandwidth

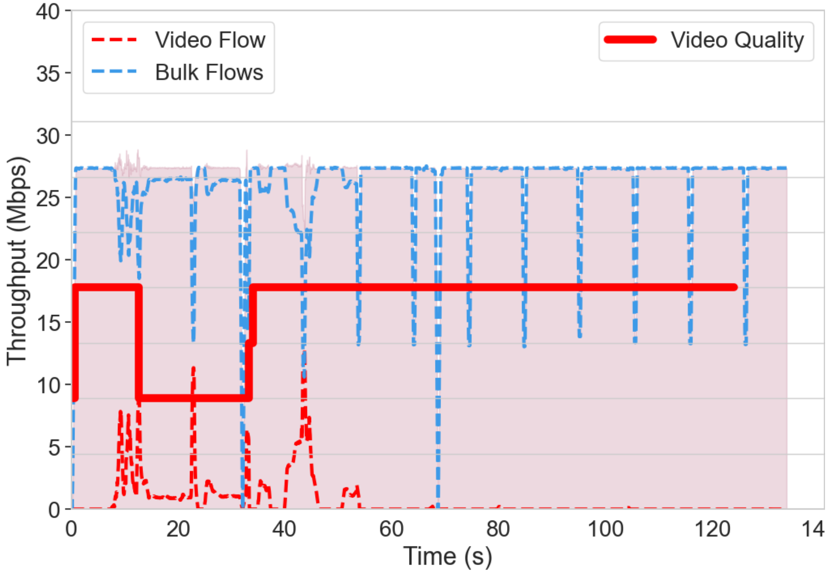


Work conserving!

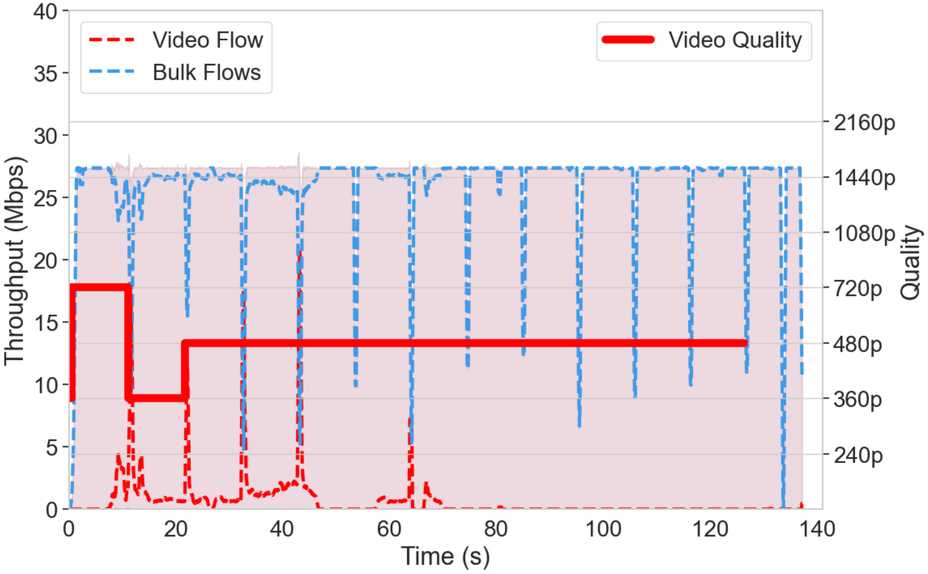
Instantaneous Reallocation



Instantaneous Reallocation

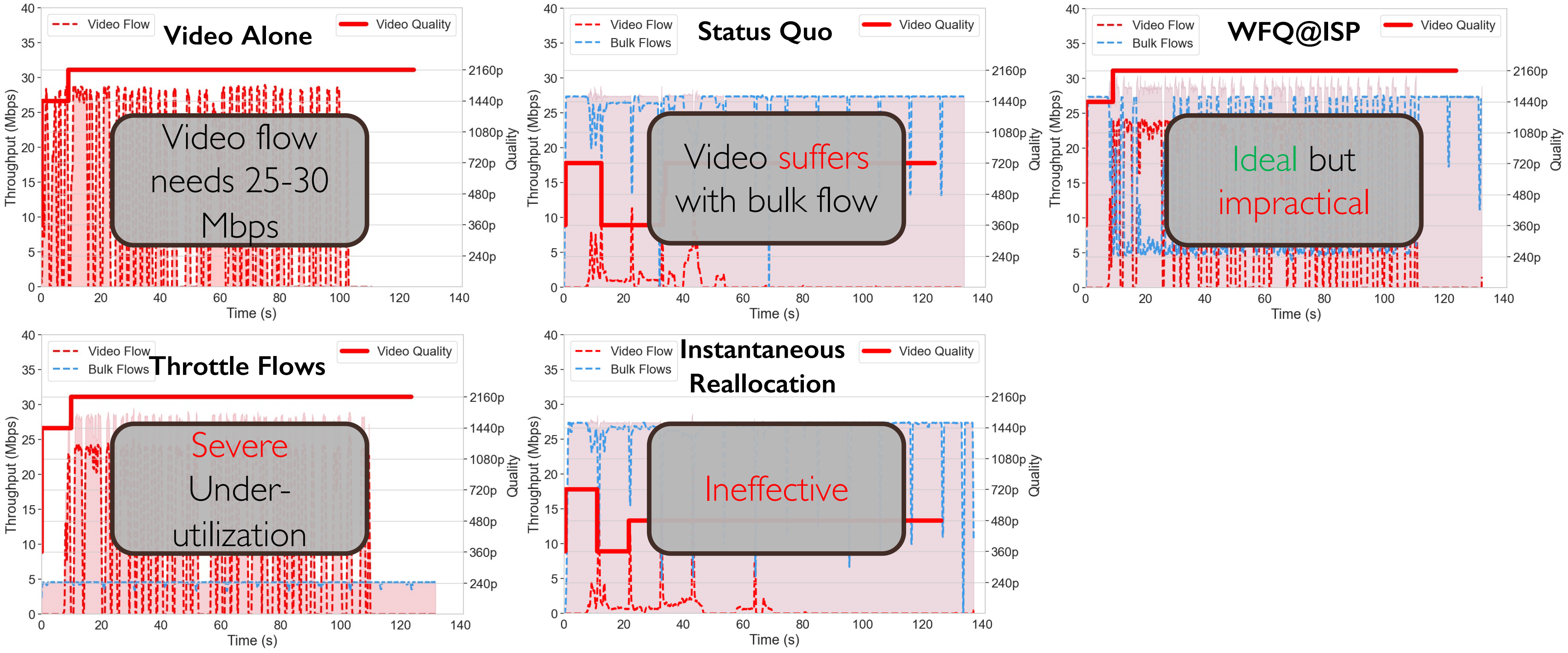


Status quo
(Do nothing!)



Instantaneous
reallocation

Instantaneous Reallocation



Video flow needs 25-30 Mbps

Video suffers with bulk flow

Ideal but impractical

Severe Under-utilization

Ineffective

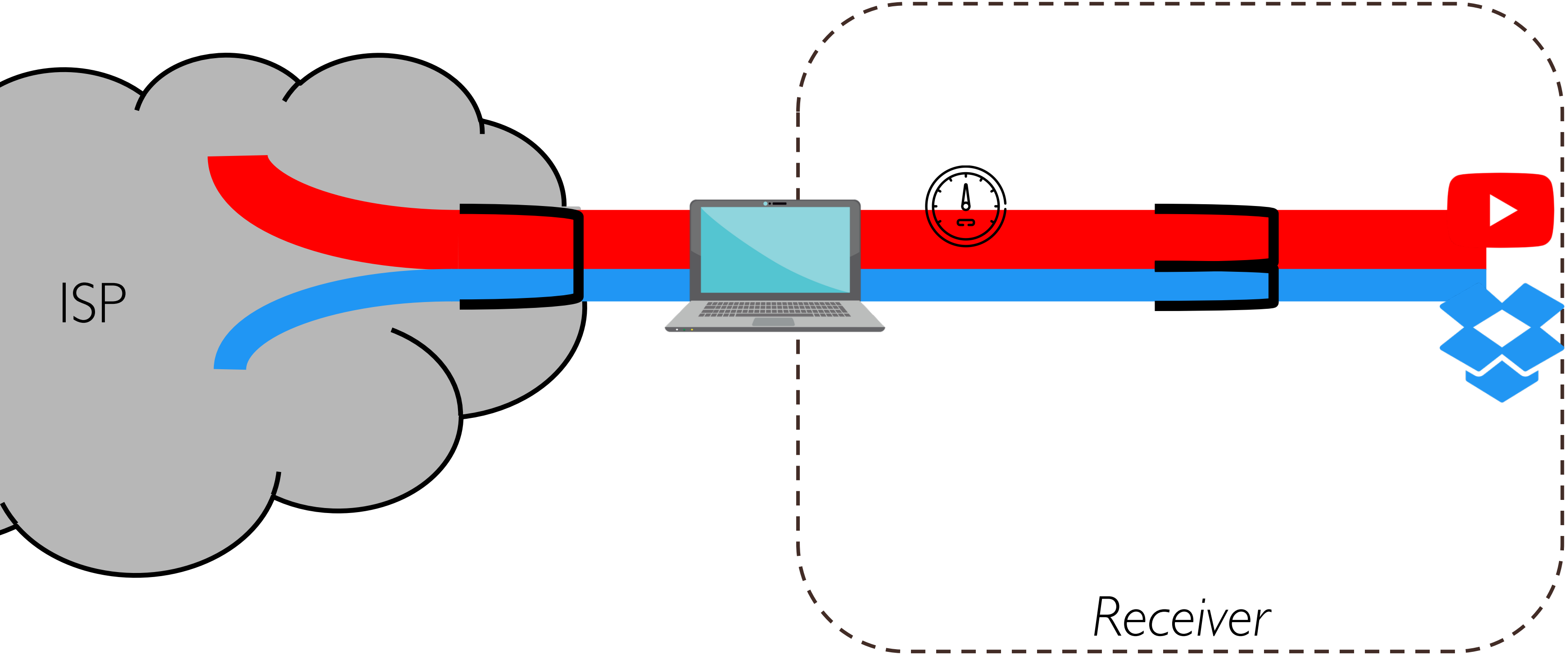
What can we do at Receiver?

- Estimate link bandwidth*
- Compute the max-min weighted fair share rate of each flow and throttle them to that rate.
- Reallocate unused capacity to other flows.
  - *Instantaneous reallocation*
    - *Work-conserving!*
    - *Flow demands based on instantaneous rate are spurious .*
      - *Influenced by link shares experienced at the bottleneck.*
    - *Work conservation means flows not throttled!*
      - *No effect on sending rate.*

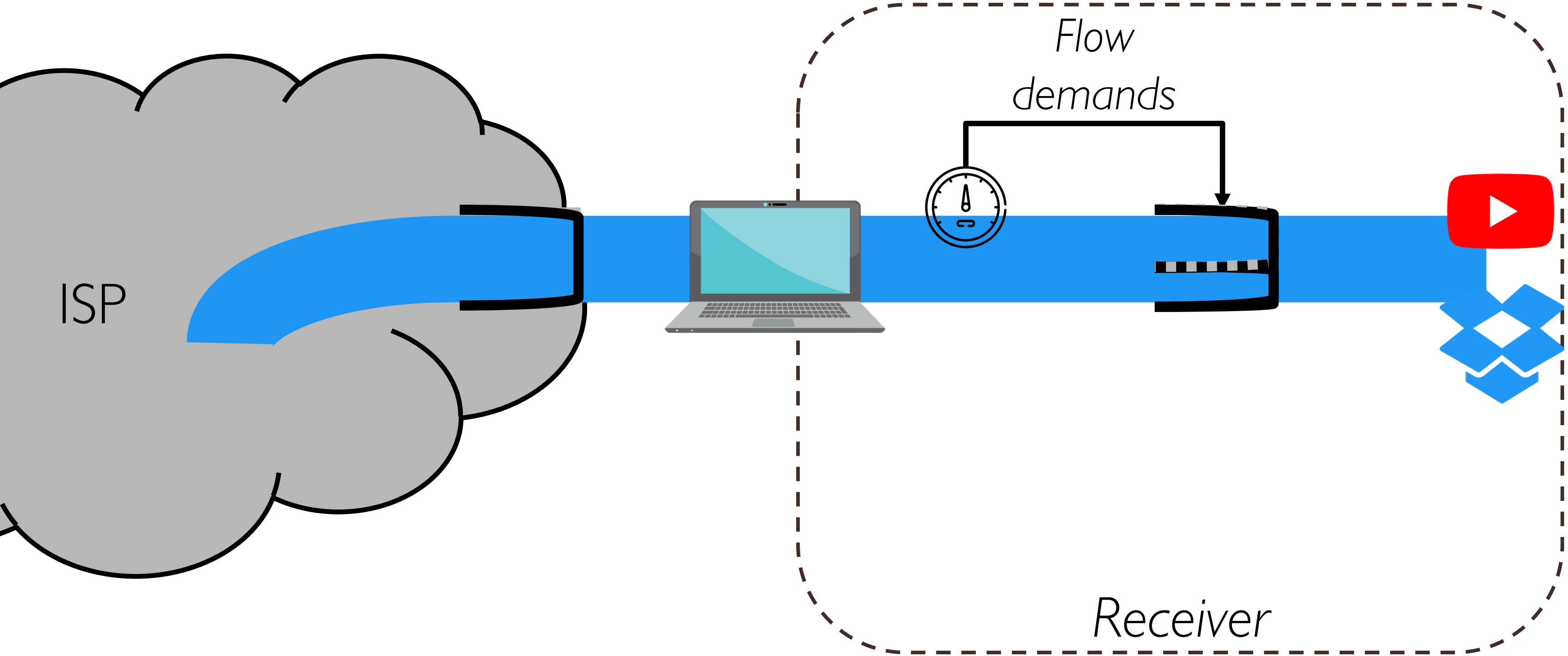
What can we do at Receiver?

- Estimate link bandwidth*
- Compute the max-min weighted fair share rate of each flow and throttle them to that rate.
- Reallocate unused capacity to other flows.
    - ~~*Instantaneous reallocation*~~
    - *React over RTT timescale!*

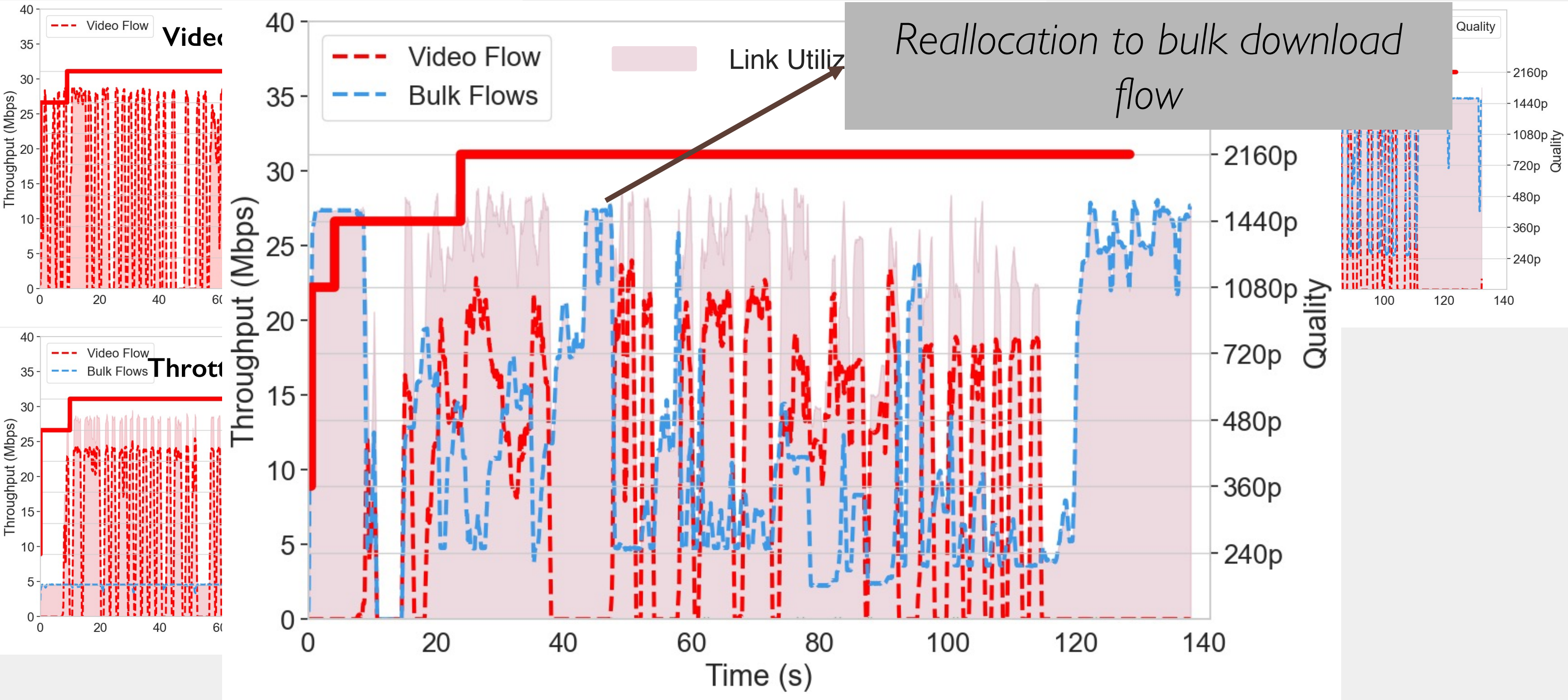
React over RTT Scale



React over RTT Scale

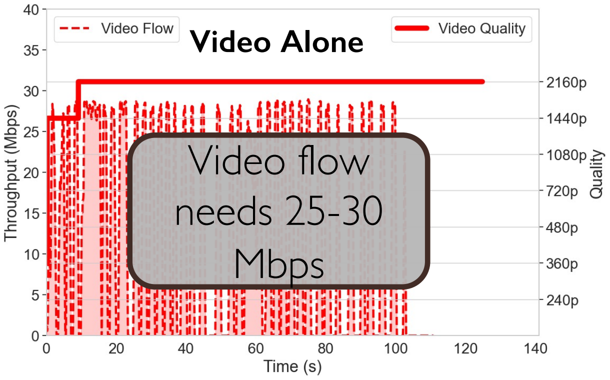


CRAB Approximates WFQ



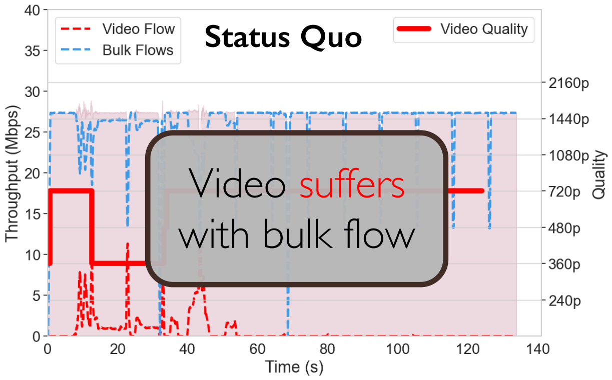
Reallocation to bulk download flow

CRAB Approximates WFQ



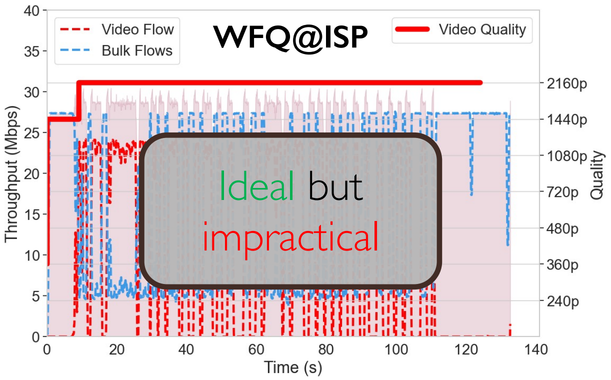
Video Alone

Video flow needs 25-30 Mbps



Status Quo

Video suffers with bulk flow



WFQ@ISP

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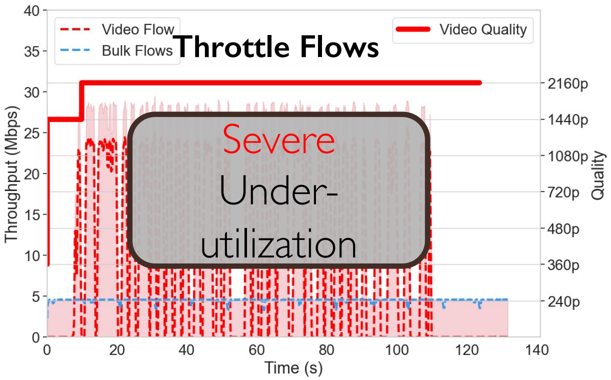
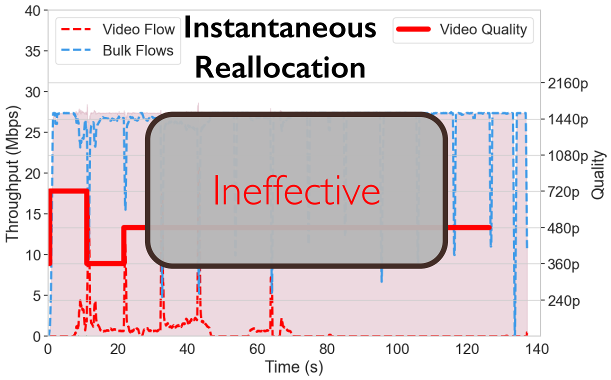


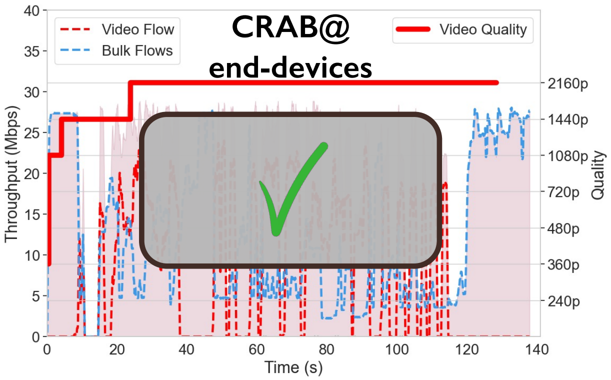
Throttle Flows

Severe Under-utilization



Instantaneous Reallocation

Ineffective



CRAB@ end-devices

What can we do at Receiver?

- **Estimate link bandwidth***
- Compute the max-min weighted fair share rate of each flow and throttle them to that rate.
- Reallocate unused capacity to other flows.
  - *React over RTT timescale!*
- *Quick reclamation when flow demand increases back.*

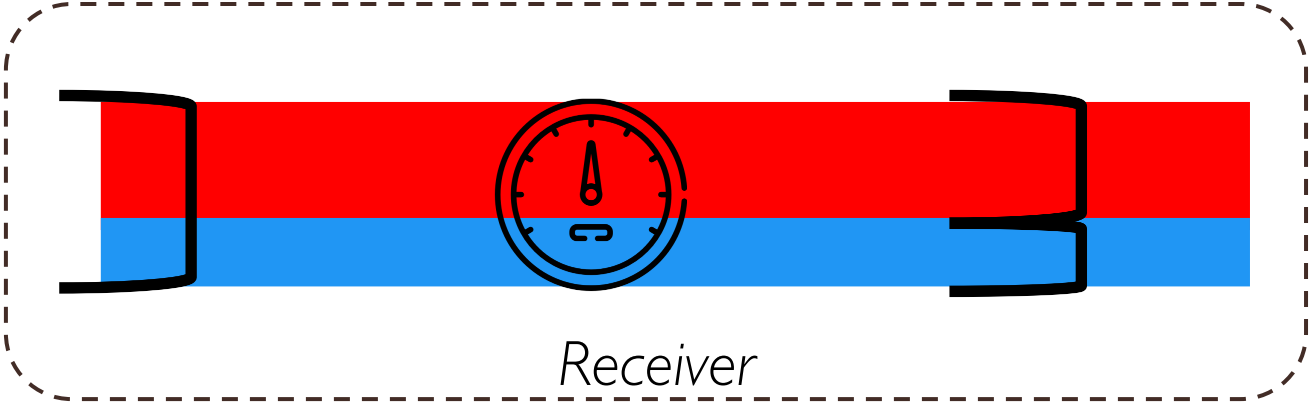
What can we do at Receiver?

- **Estimate link bandwidth by monitoring incoming flows.**
- Compute the max-min weighted fair share rate of each flow and throttle them to that rate.
- Reallocate unused capacity to other flows.
  - *React over RTT timescale!*
- *Quick reclamation when flow demand increases back.*

Bandwidth Estimation

Challenges

- ***Passively*** *detecting increases in link bandwidth*
    - *How do we know link bandwidth has increased when we have throttled flows ourselves?*



Bandwidth Estimation

Challenges

- ***Passively*** *detecting increases in link bandwidth*
    - *Increase bandwidth share of a flow by fractional amount and detect changes in per-flow throughput in next few RTTs.*

Bandwidth Estimation

Challenges

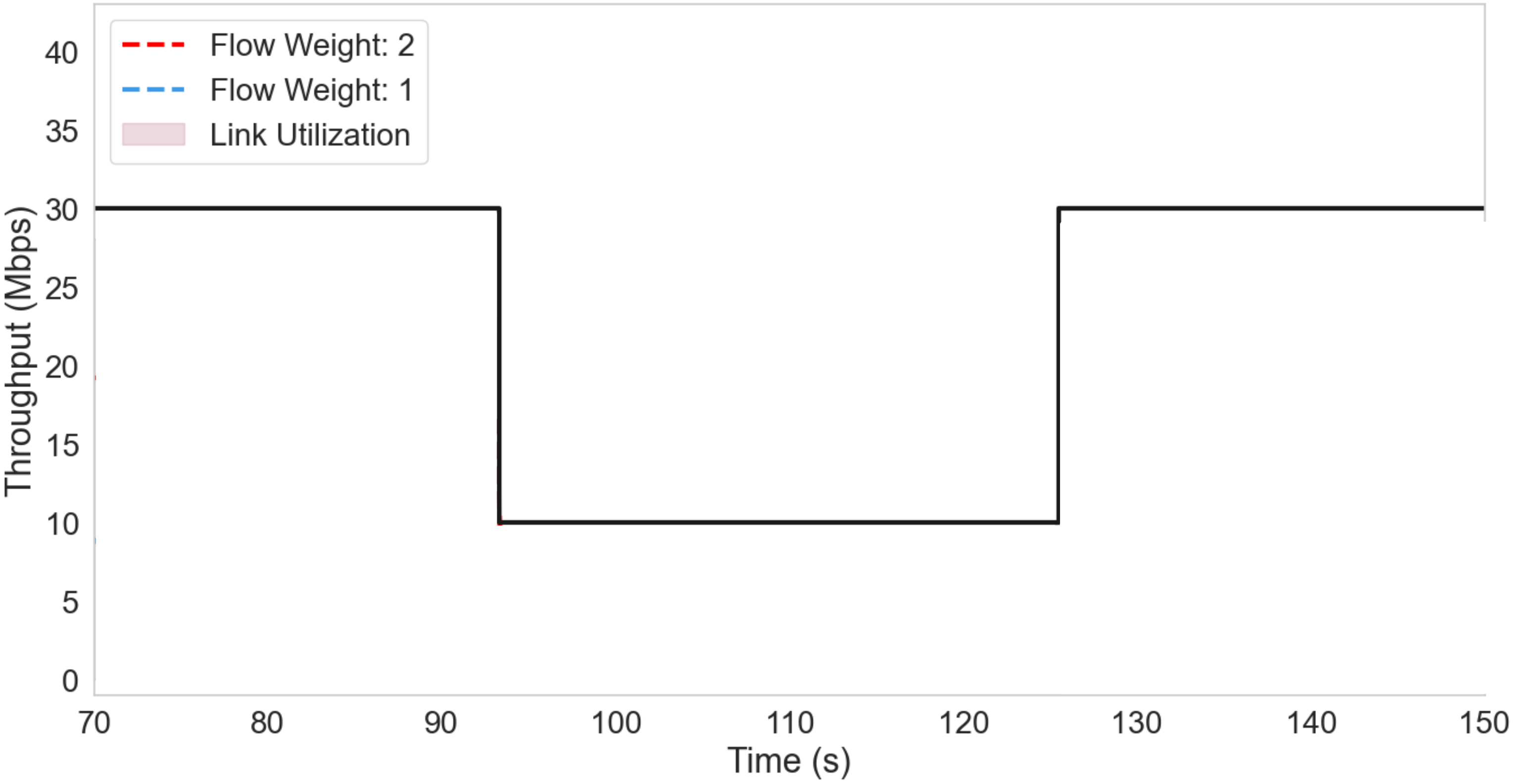
- ***Passively*** *detecting increases in link bandwidth*
    - *Increase bandwidth share of a flow by fractional amount and detect changes in per-flow throughput in next few RTTs*
        - *Which flow to select? A random **saturating** flow*
        - *What amount for fractional increment? Start small, grow exponentially.*

Bandwidth Estimation

Challenges

- ***Passively*** *detecting increases in link bandwidth*
    - *Increase bandwidth share of a flow by fractional amount and detect changes in per-flow throughput in next few RTTs*
        - *Which flow to select? A random* ***saturating*** *flow*
        - *What amount for fractional increment? Start small, grow exponentially*
- *Differentiating between link bandwidth drop versus application usage drop*
    - *Prioritize reallocation over reducing bandwidth estimate.*

Bandwidth Estimation: Microbenchmark



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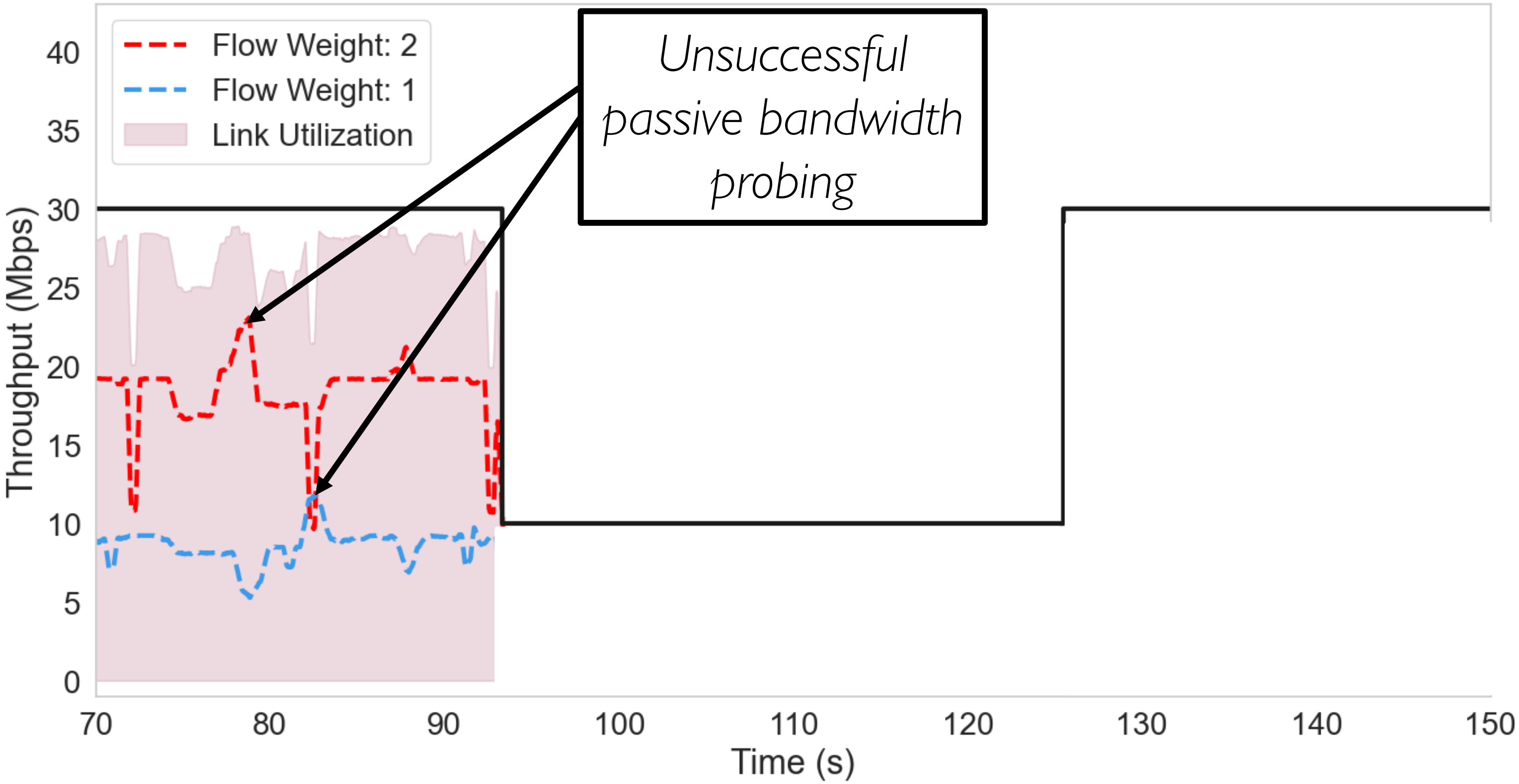
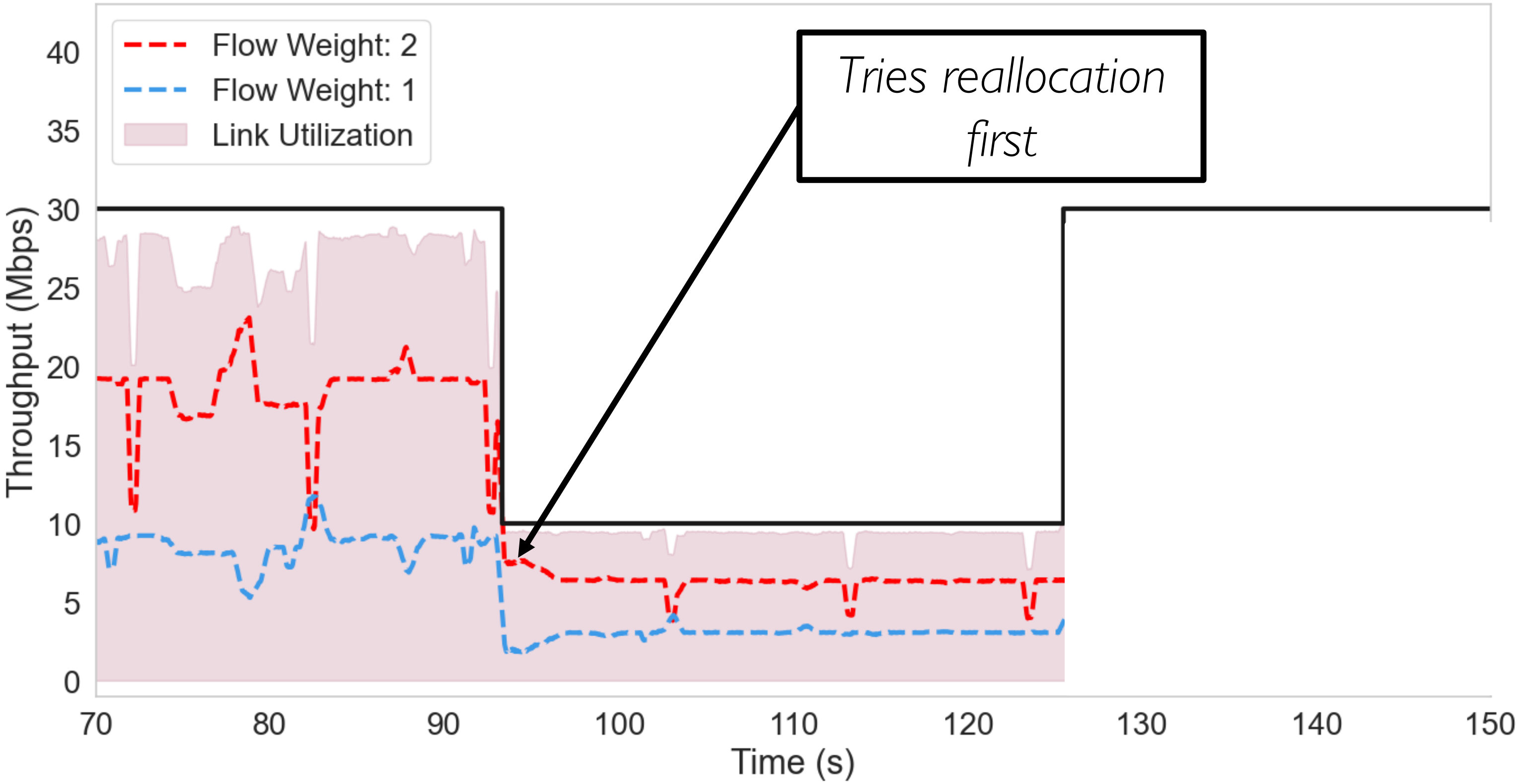


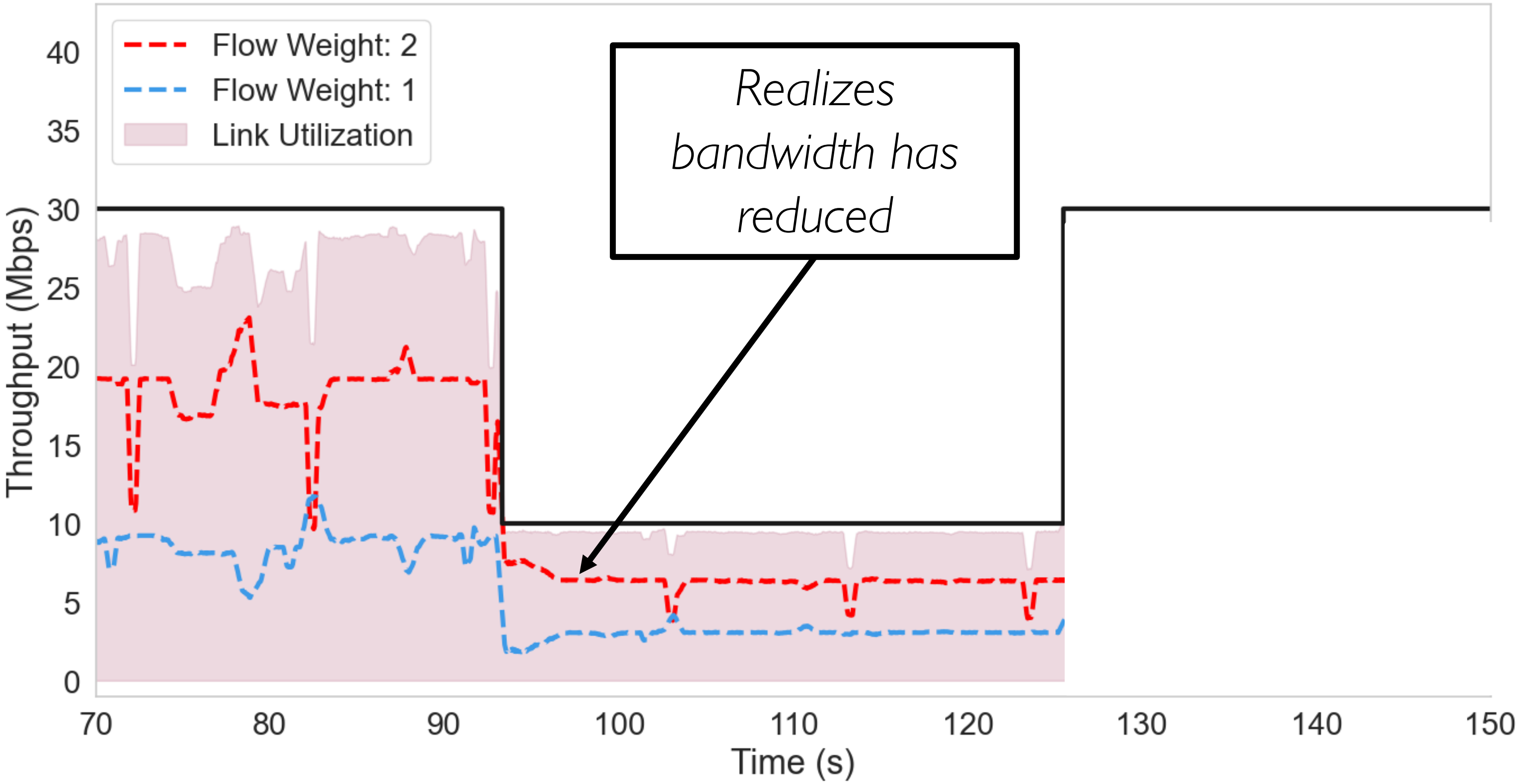
Unsuccessful passive bandwidth probing

Bandwidth Estimation: Microbenchmark



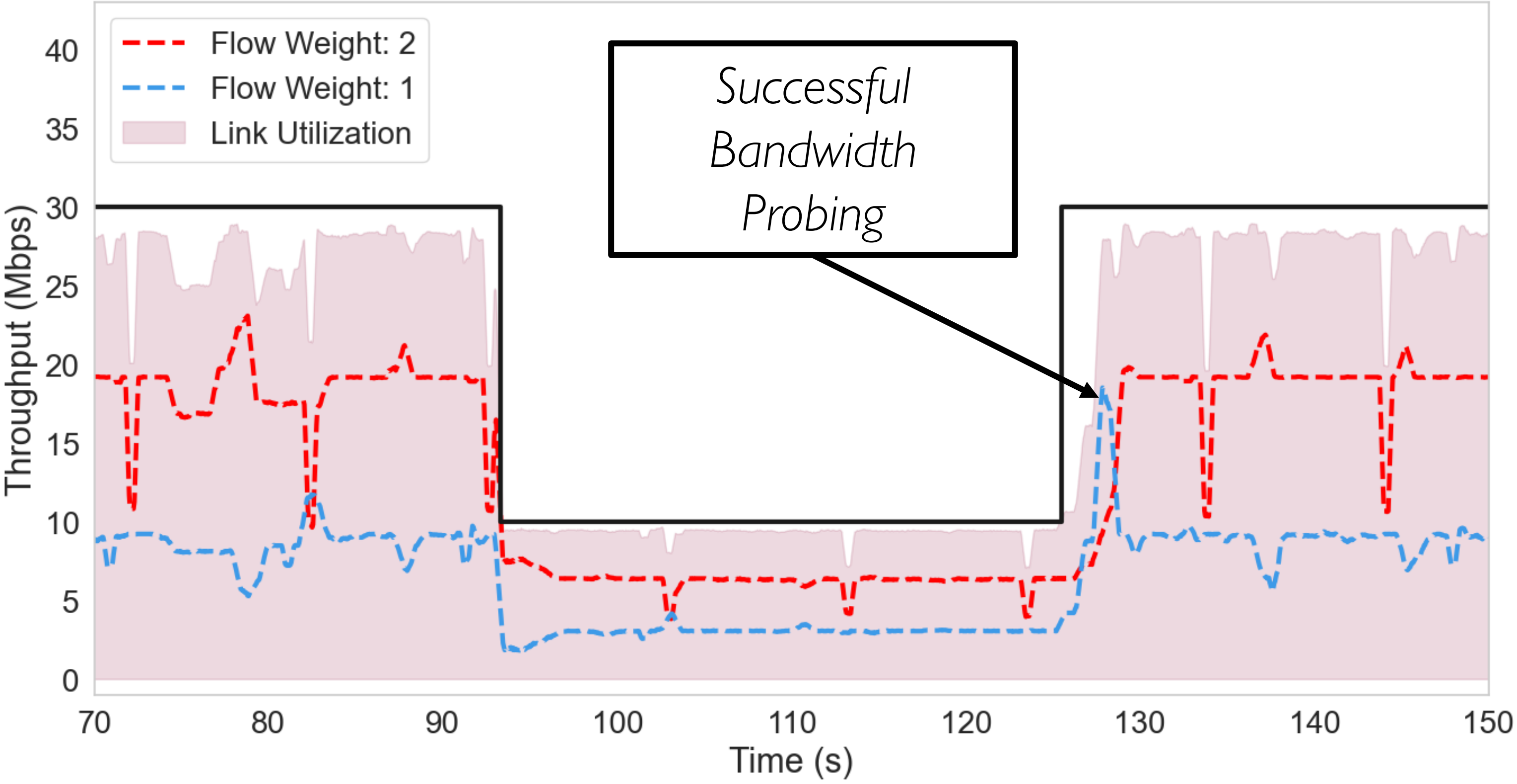
Tries reallocation first

Bandwidth Estimation: Microbenchmark



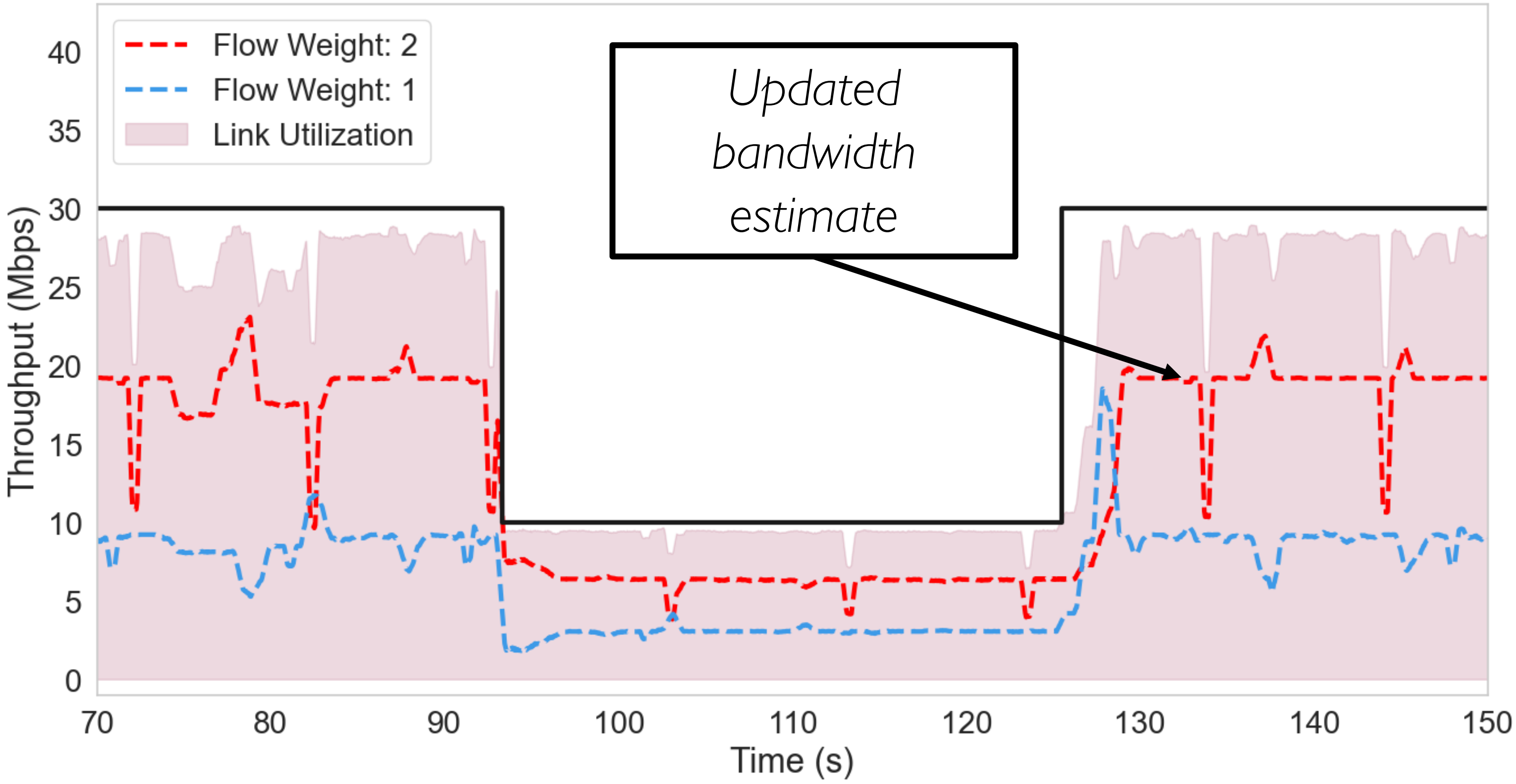
Realizes bandwidth has reduced

Bandwidth Estimation: Microbenchmark



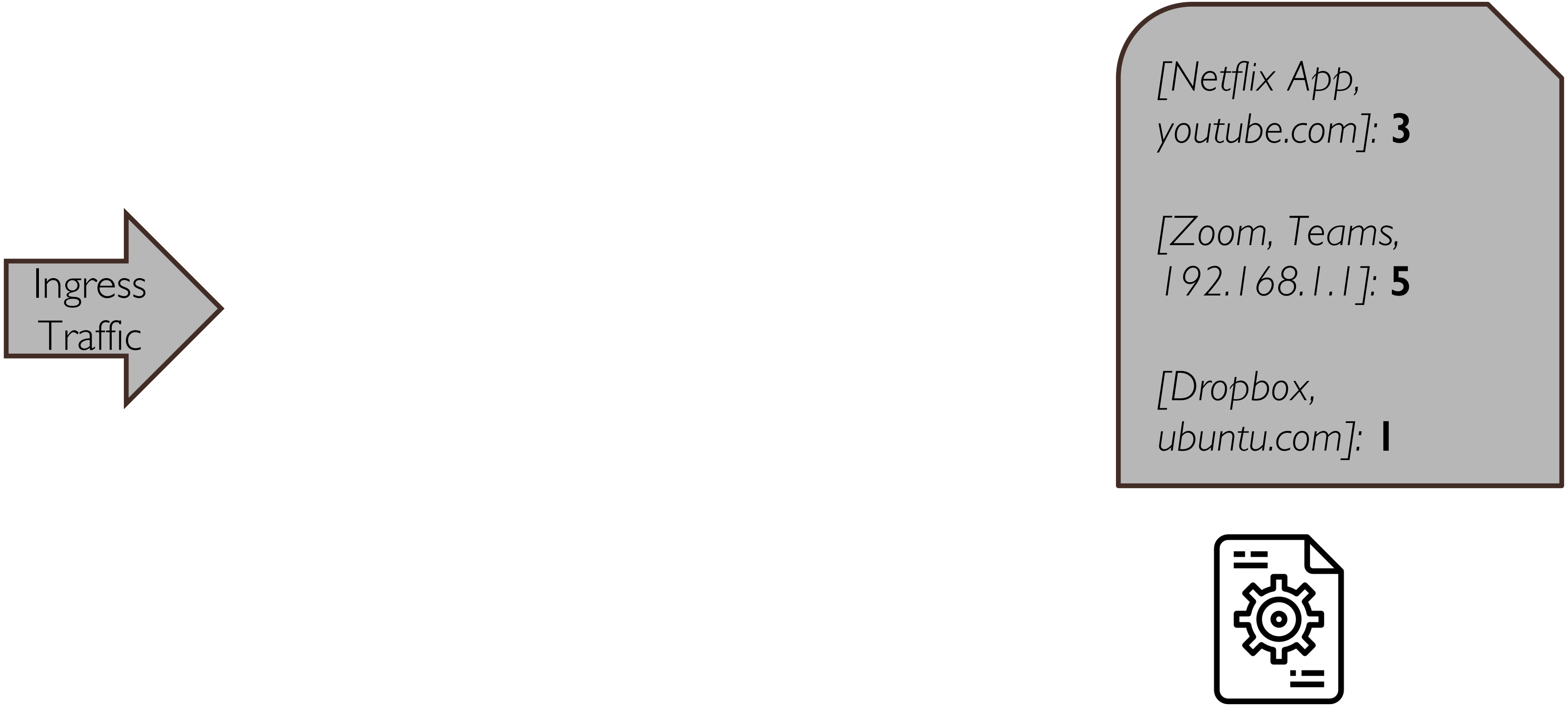
Successful Bandwidth Probing

Bandwidth Estimation: Microbenchmark



Updated bandwidth estimate

Overall CRAB Design



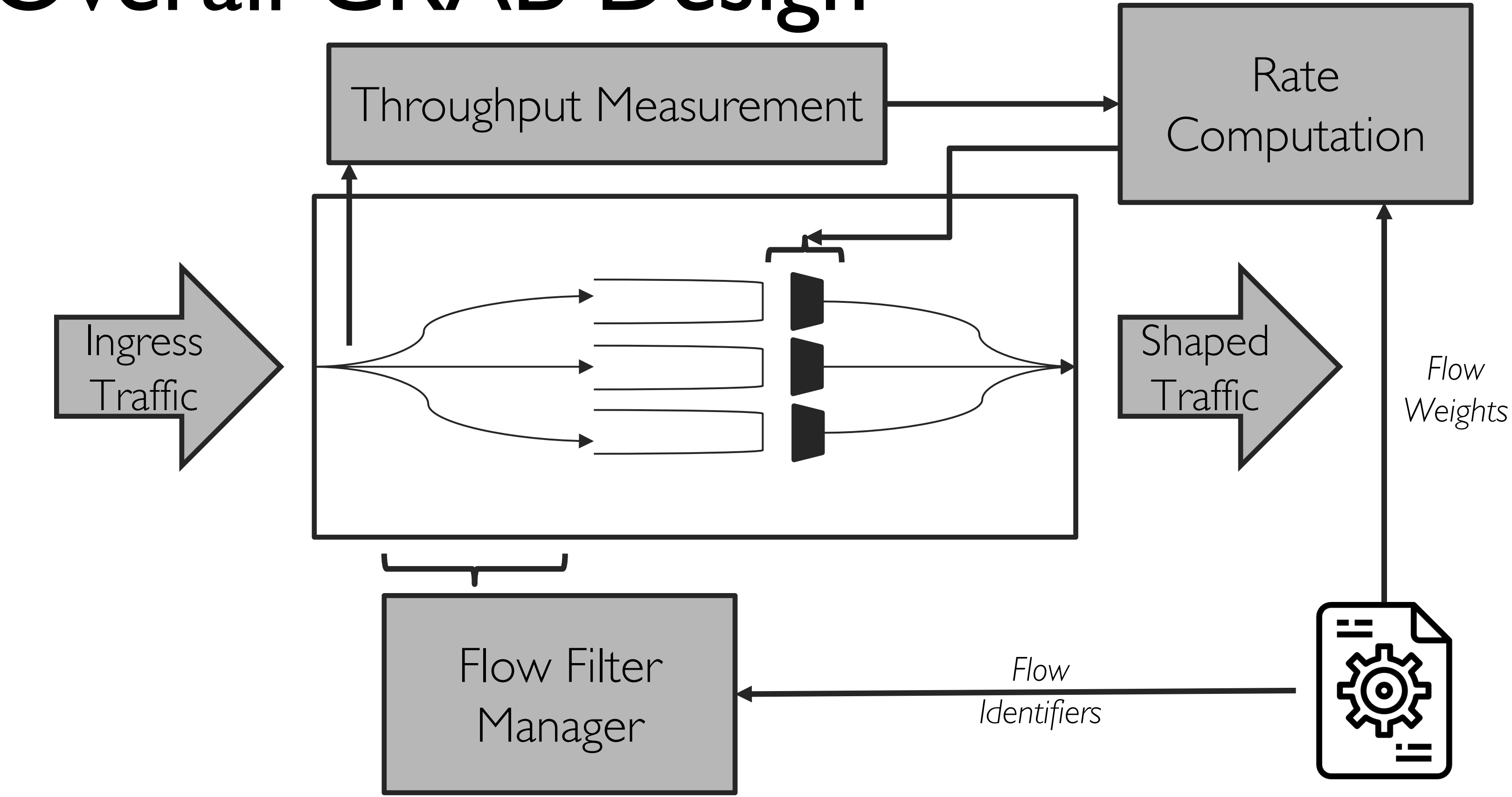
Ingress Traffic

[Netflix App, youtube.com]: **3**

[Zoom, Teams, 192.168.1.1]: **5**

[Dropbox, ubuntu.com]: **1**

Overall CRAB Design



CRAB at the home router

- Shares access link bandwidth between devices
  - Config file contains ***destination IP addresses*** with weights
- No coordination needed with CRAB running at devices!

Evaluation

- Improves video streaming QoE (2-3 x) in presence of bulk flows.
- Improves webpage loads (2x faster) in presence of bulk flows.
- Microbenchmarks:
    - Testing reallocation/reclamation with varying flow demands
    - Testing bandwidth estimation with varying link bandwidth and flow demands
    - Interaction of router and end-host control loops
    - Sensitivity to configuration parameters
    - Scalability to number of flow groups
    - …

Discussion

- Other contexts:
  - Enterprise networks, coffee shops, airports…
- Limitations:
  - Bandwidth estimation difficult on volatile links (e.g. cellular).
  - Does not help very short-lived flows (finishing within a few RTTs).
  - Some transient underutilization is imminent.

Thank you for listening!

Manage your downlink bandwidth without any support from the ISP or the senders with **CRAB**!

Please reach out if you have any questions or feedback:

ammart2@illinois.edu

https://projectcrab.web.Illinois.edu