Adapting TCP for Reconfigurable Datacenter Networks

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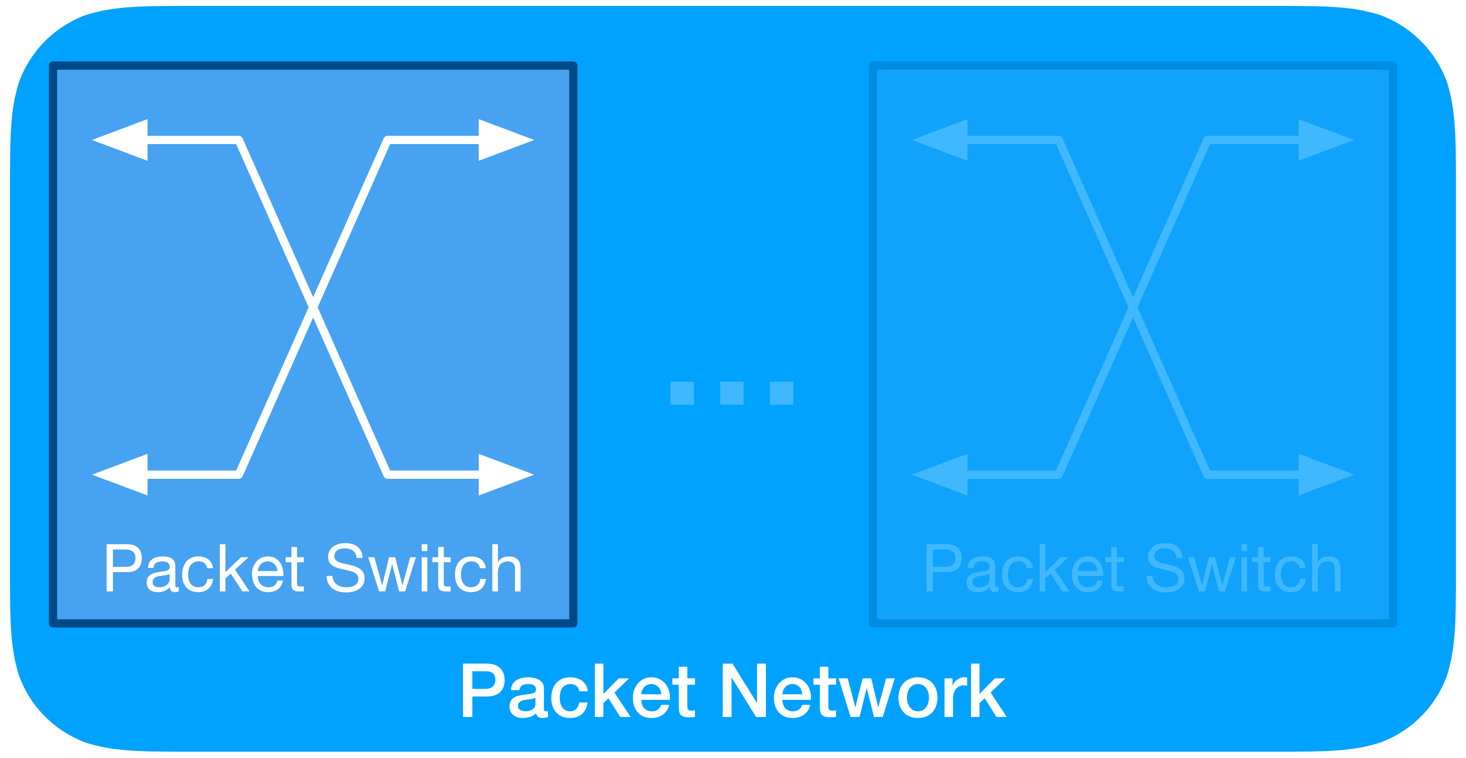
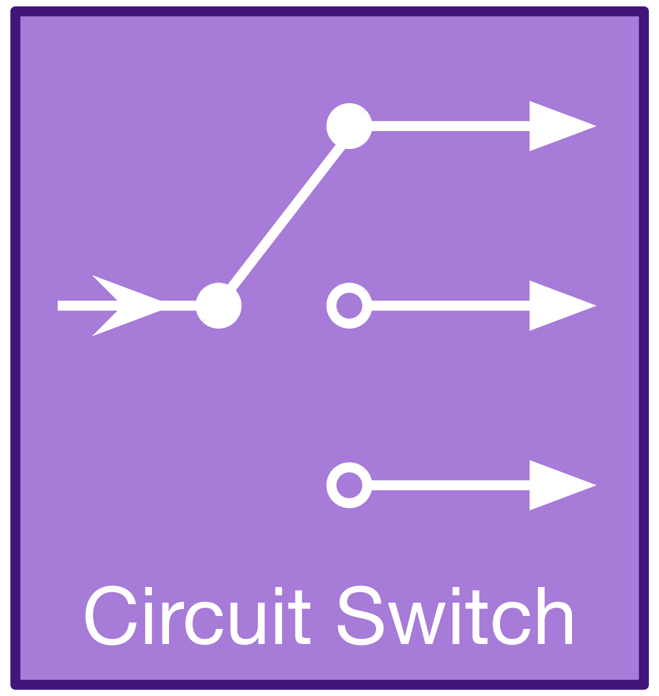
Reconfigurable Datacenter Network (RDCN)

all-to-all connectivity





higher bandwidth,
between certain racks

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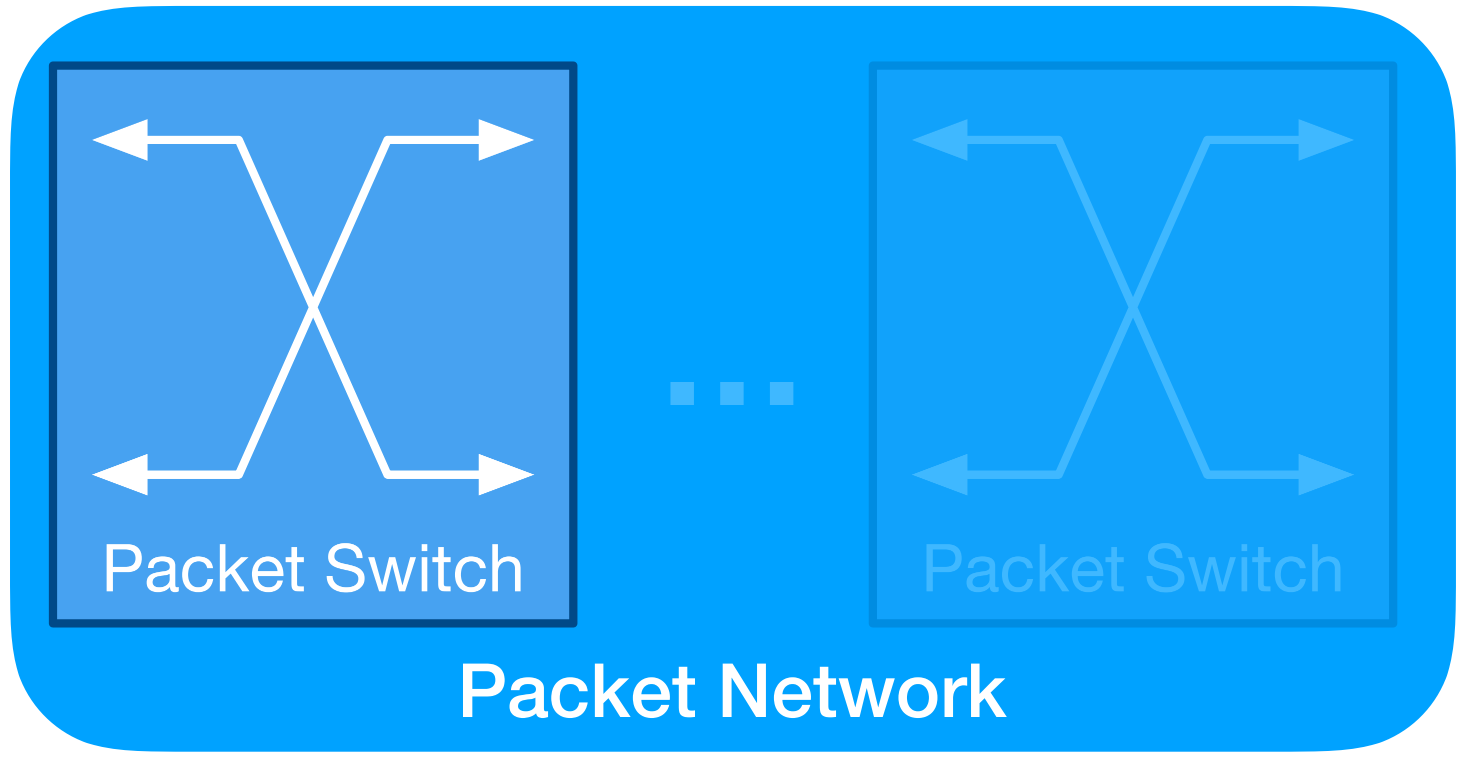
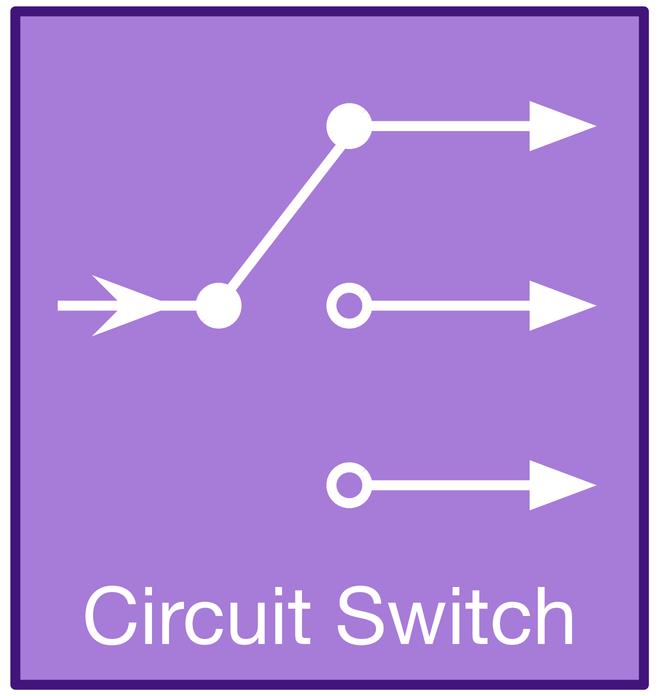
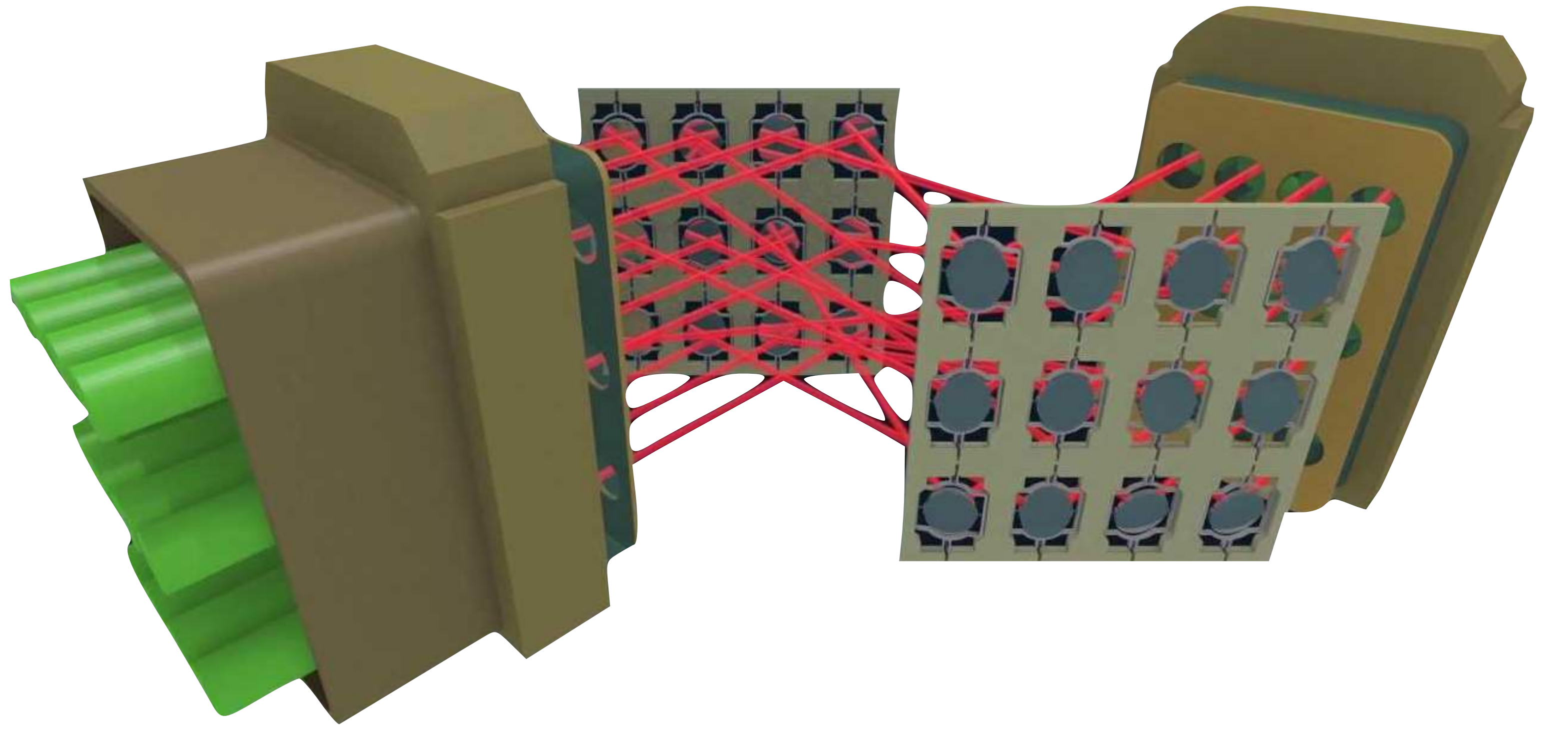




higher bandwidth, between certain racks

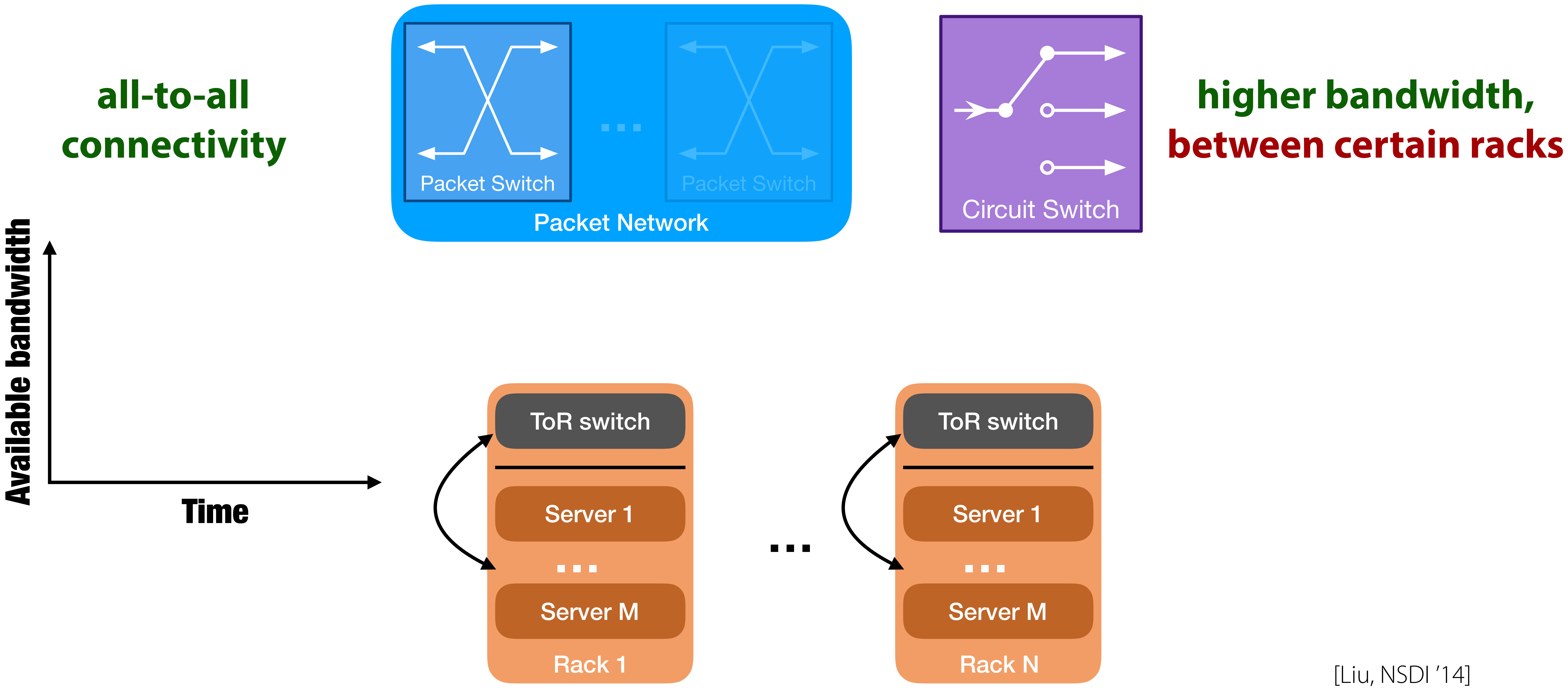
60GHz wireless

free-space optics



optical circuits

Reconfigurable Datacenter Network (RDCN)



[Liu, NSDI '14]

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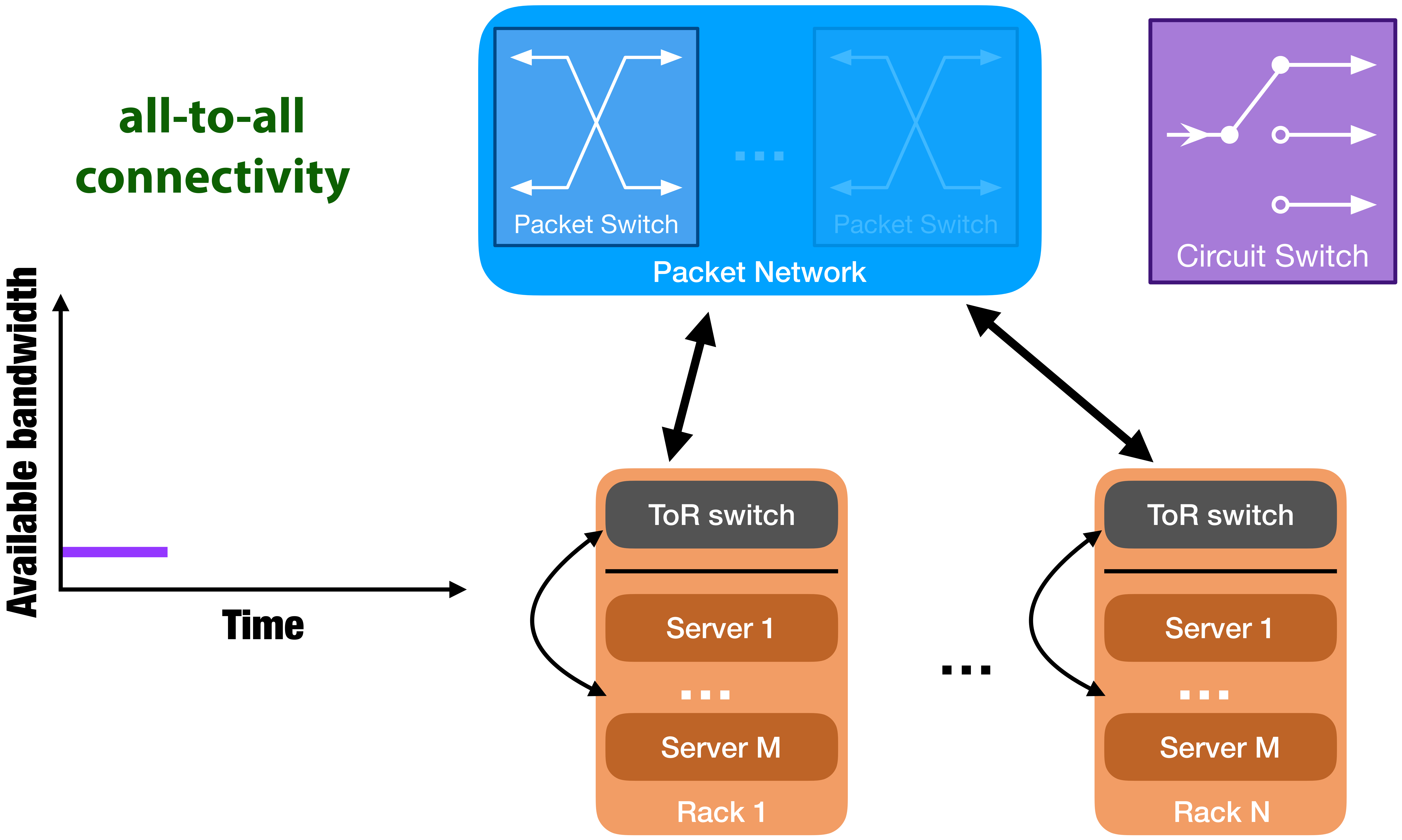

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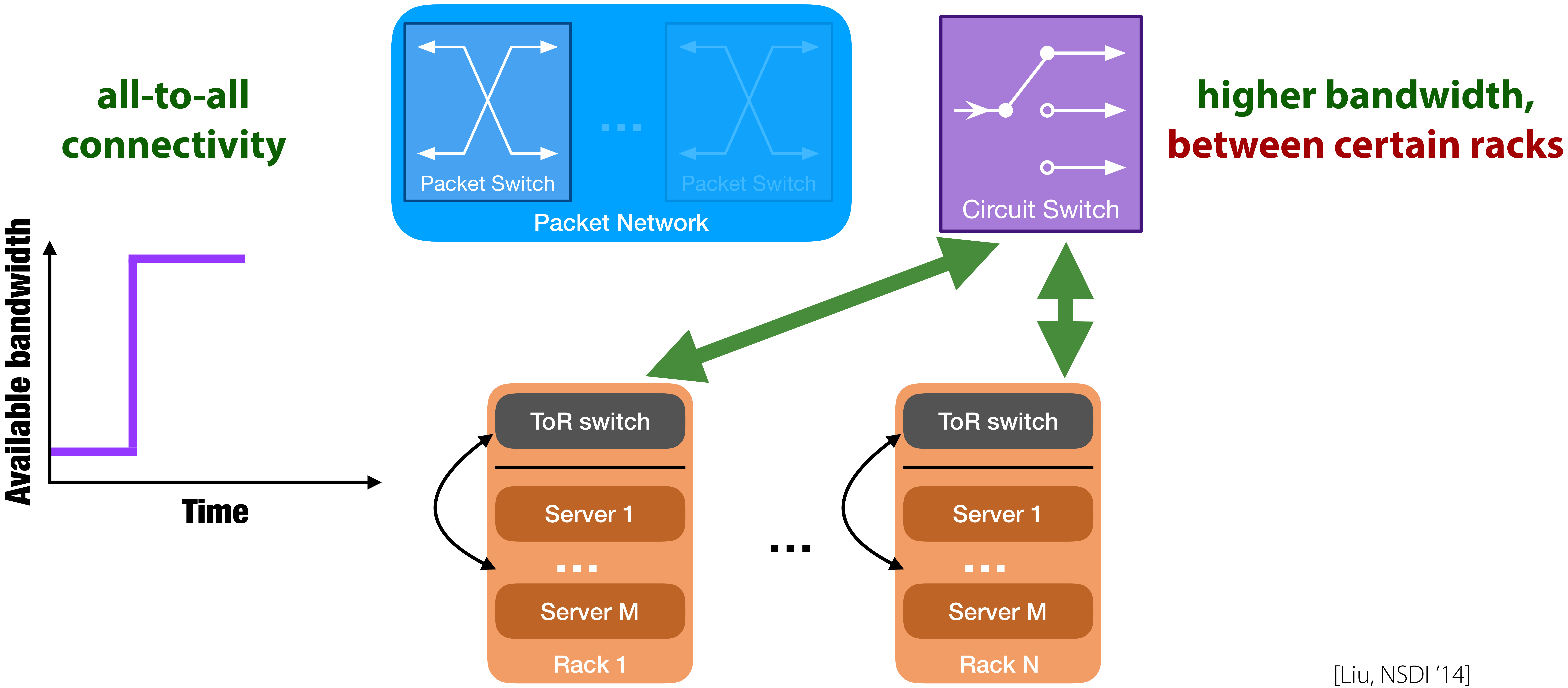

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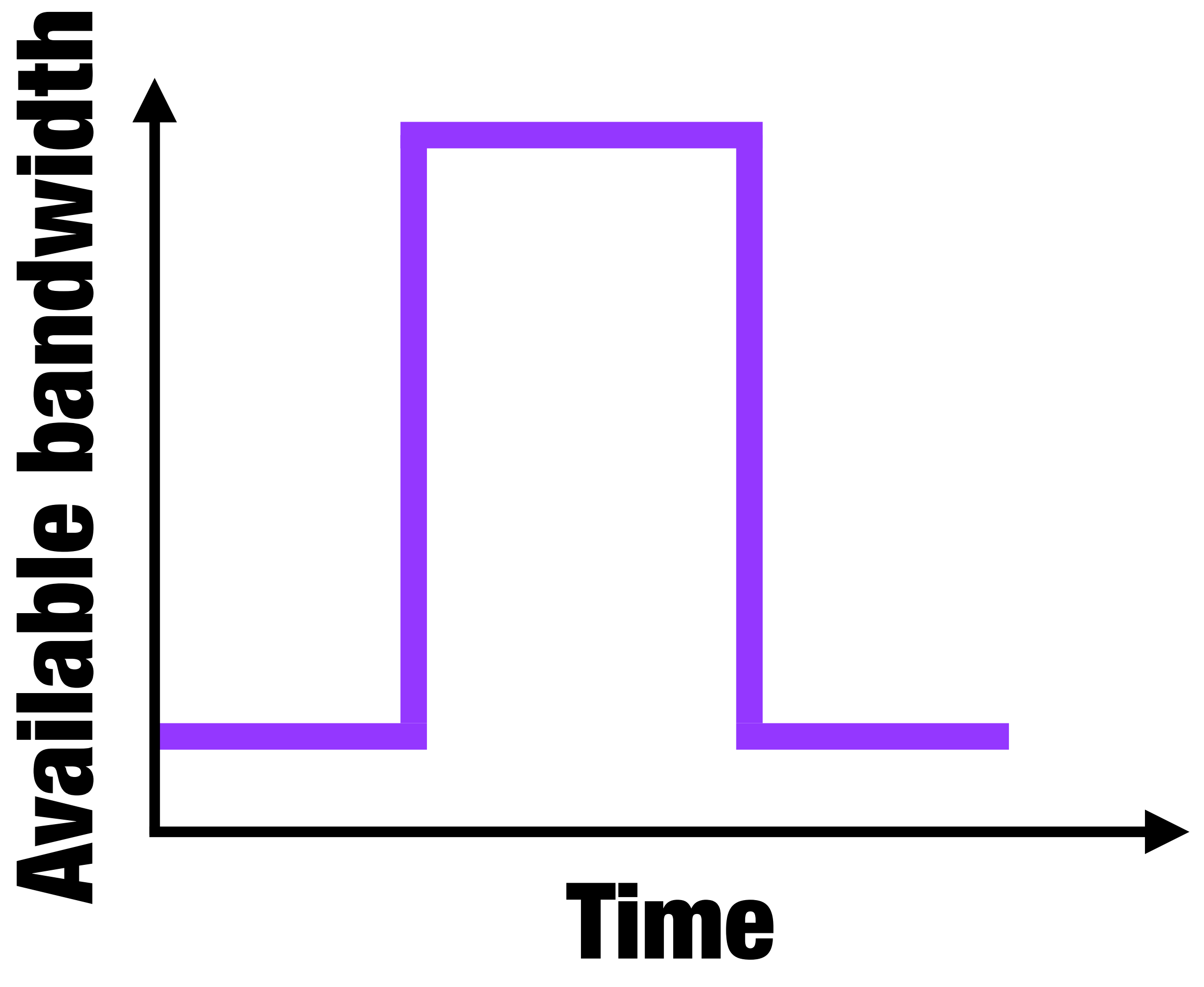

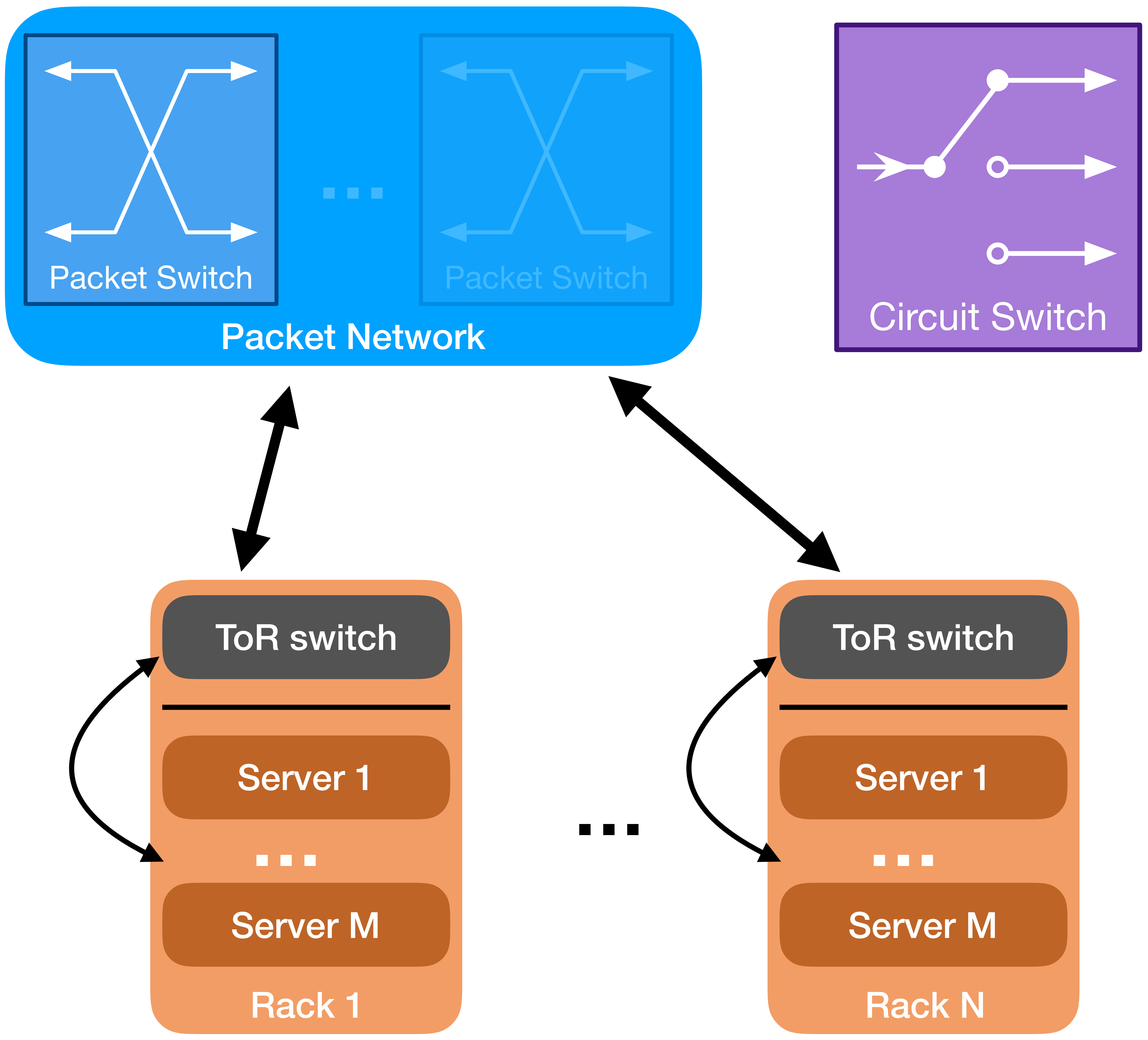

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Reconfigurable Datacenter Network (RDCN)

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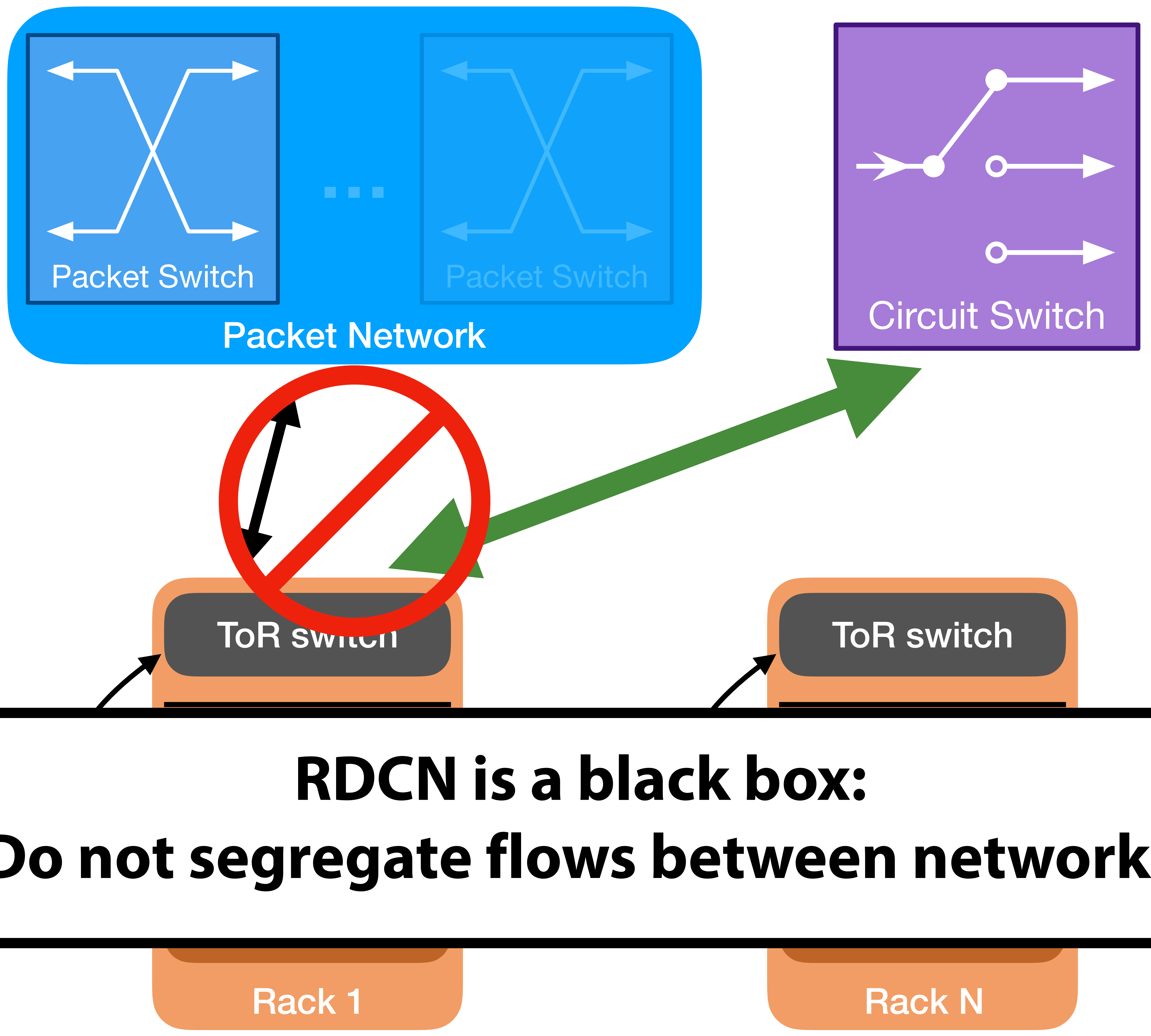


higher bandwidth, between certain racks

RDCN is a black box:
Do not segregate flows between networks

[Liu, NSDI '14]

2010: RDCNs speed up DC workloads

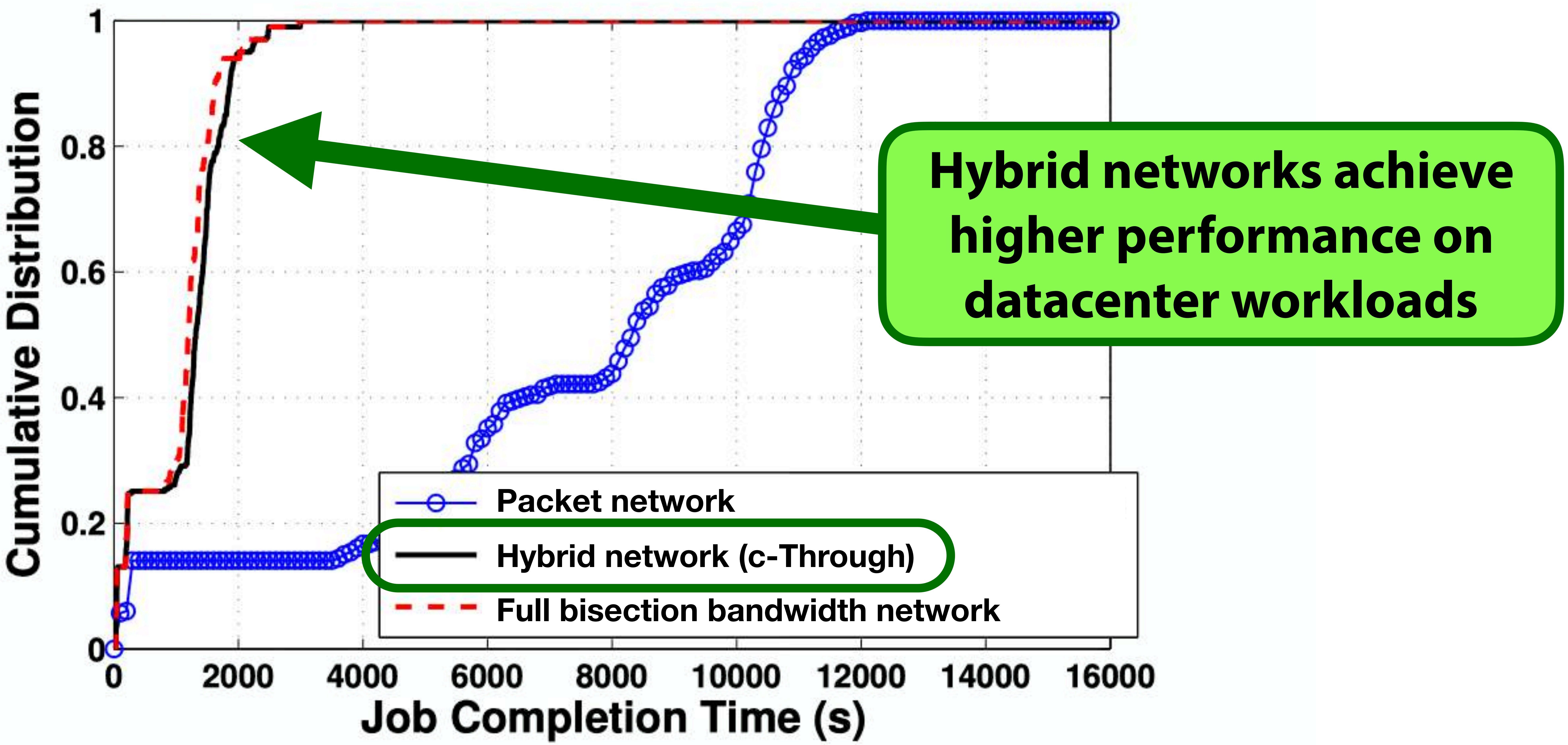
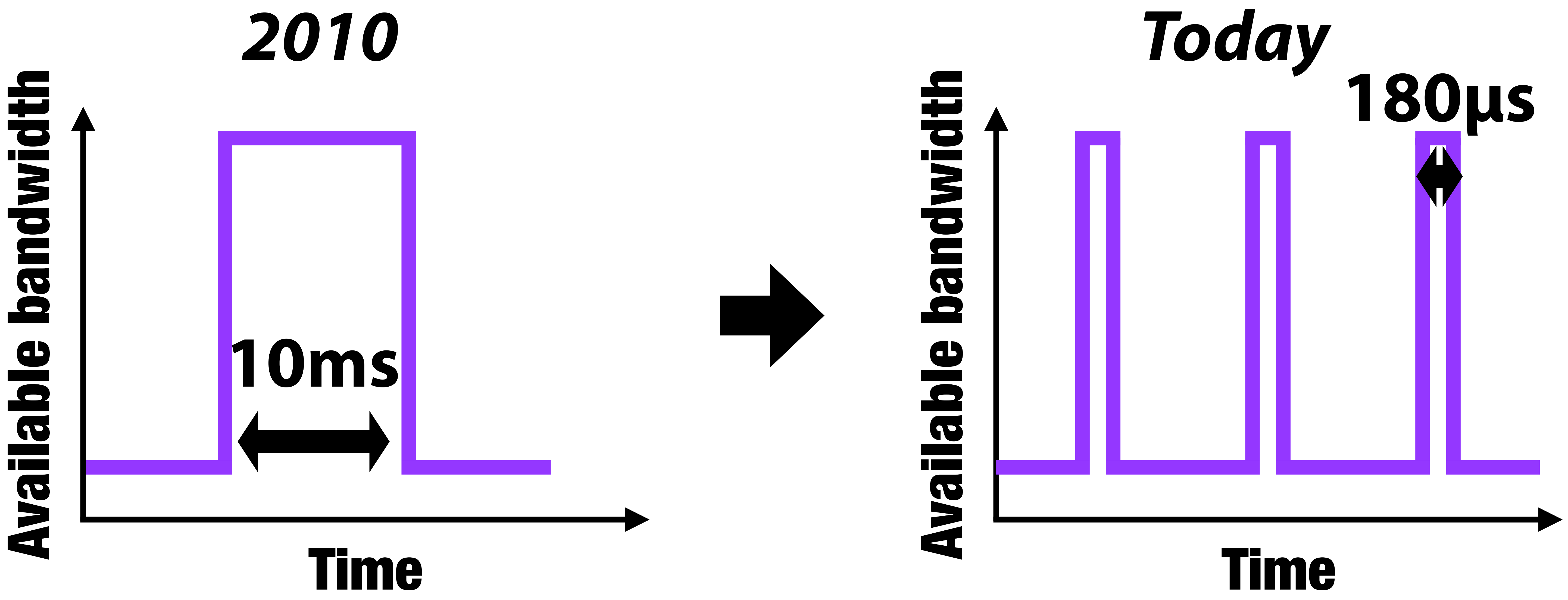


Figure 9: The completion of Hadoop Gridmix tasks

[Wang, SIGCOMM '10]

Today's RDCNs reconfigure 10x as often

Advances in circuit switch technology have led to a 10x reduction in reconfiguration delay ⇒ today, circuits can reconfigure much more frequently

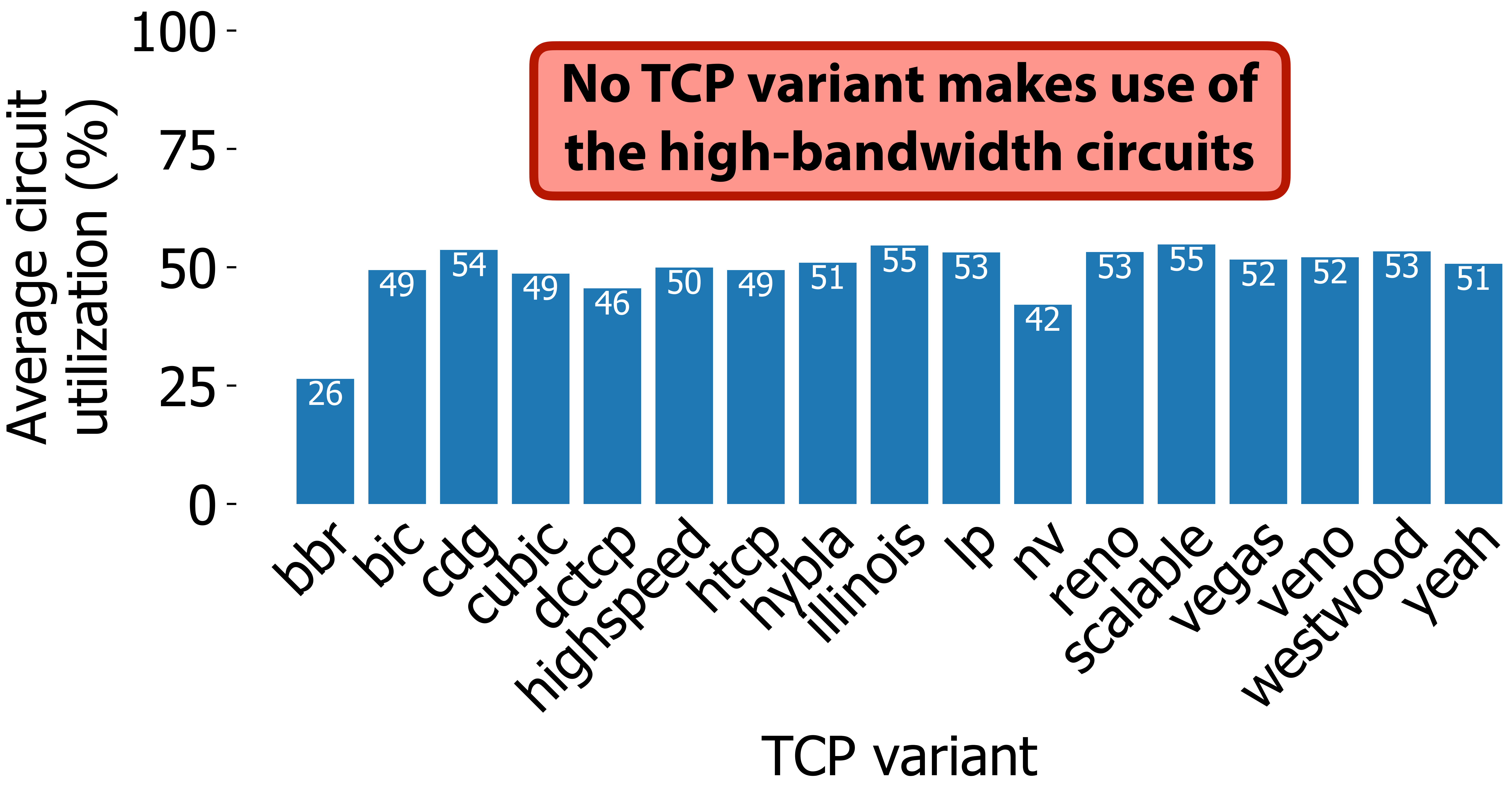


Better for datacenters: More flexibility to support dynamic workloads
Better for hosts: Less data must be available to saturate higher bandwidth NW

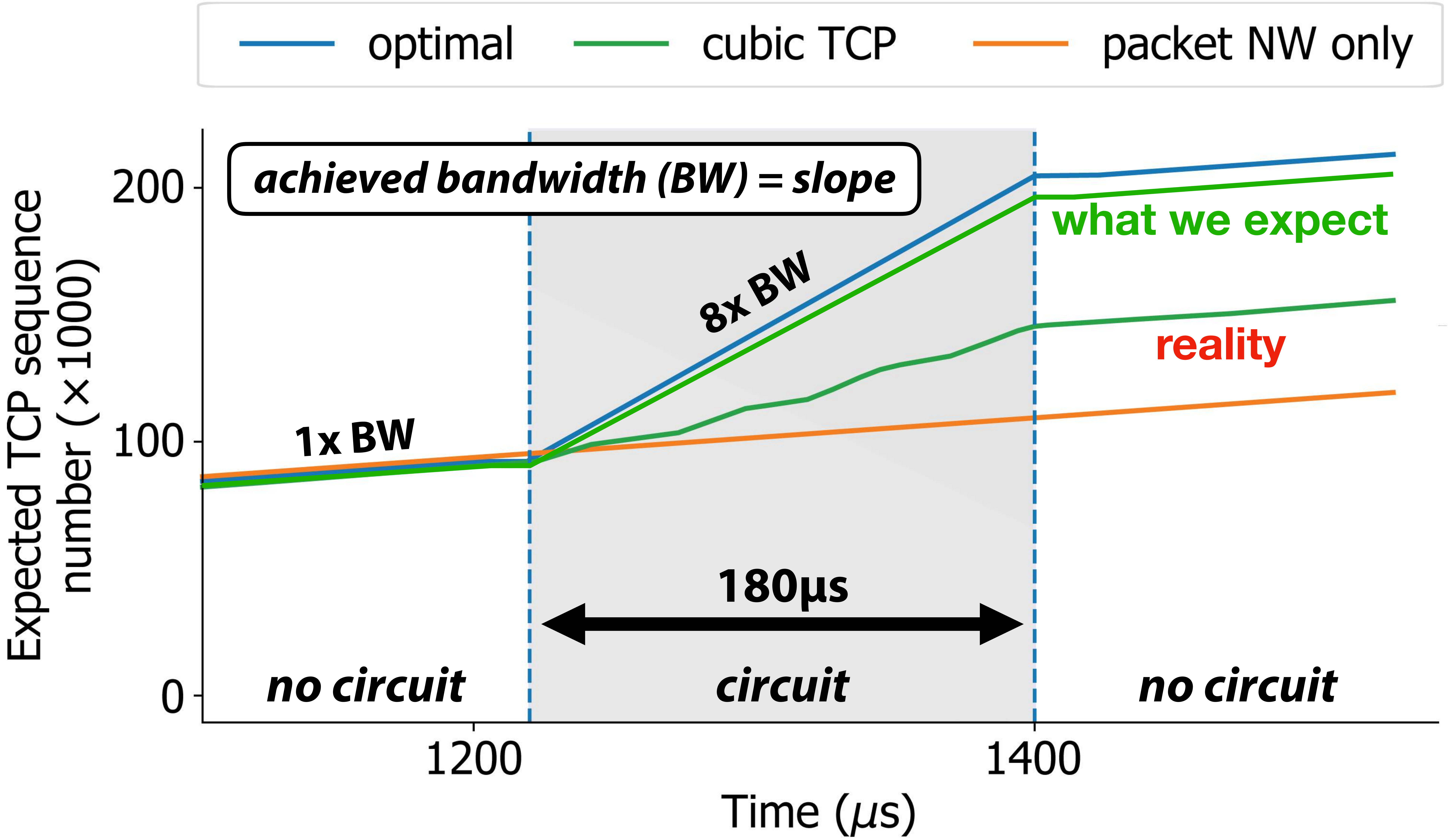
[Porter, SIGCOMM '13]

Short-lived circuits pose a problem for TCP

16 flows from rack 1 to rack 2; packet network: 10 Gb/s; circuit network: 80 Gb/s



TCP cannot ramp up during short circuits



What is the problem?

All TCP variants are designed to adapt to changing network conditions

- E.g., congestion, bottleneck links, RTT

But ***bandwidth fluctuations*** in modern RDCN are an order of magnitude ***more frequent*** (10x shorter circuit duration) and ***more substantial*** (10x higher bandwidth) than TCP is designed to handle

- RDCNs break the implicit assumption of relatively-stable network conditions

This requires an ***order-of-magnitude shift in how fast TCP reacts***

This talk: Our 2-part solution

In-network: Use information about upcoming circuits to transparently "trick" TCP into ramping up more aggressively

- High utilization, at the cost of tail latency

At endhosts: New TCP variant, ***reTCP***, that explicitly reacts to circuit state changes

- Mitigates tail latency penalty

The two techniques can be deployed separately, but work best together

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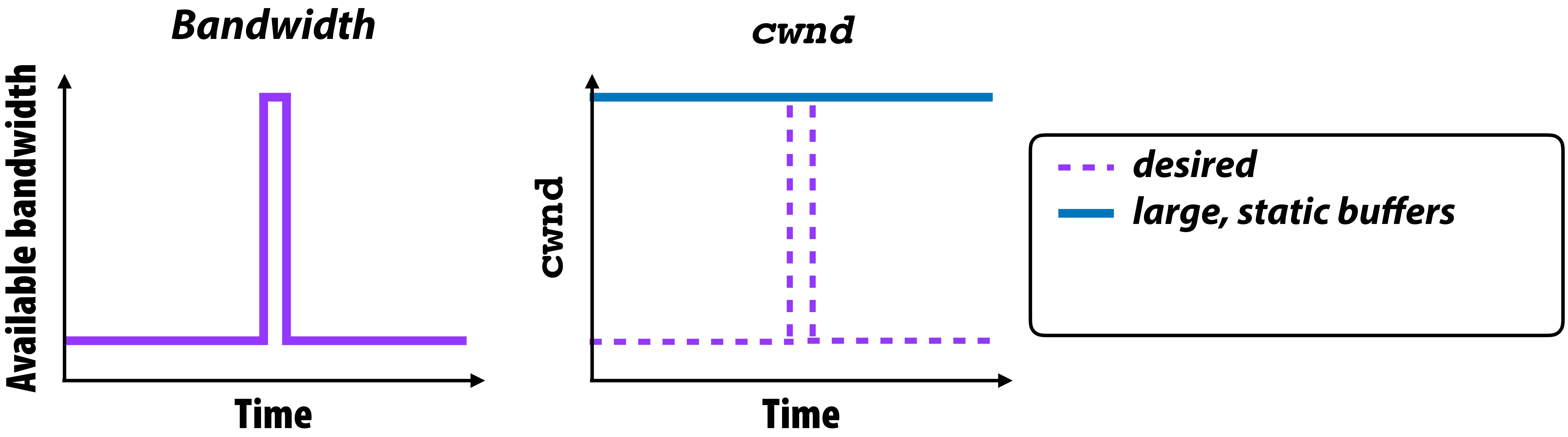
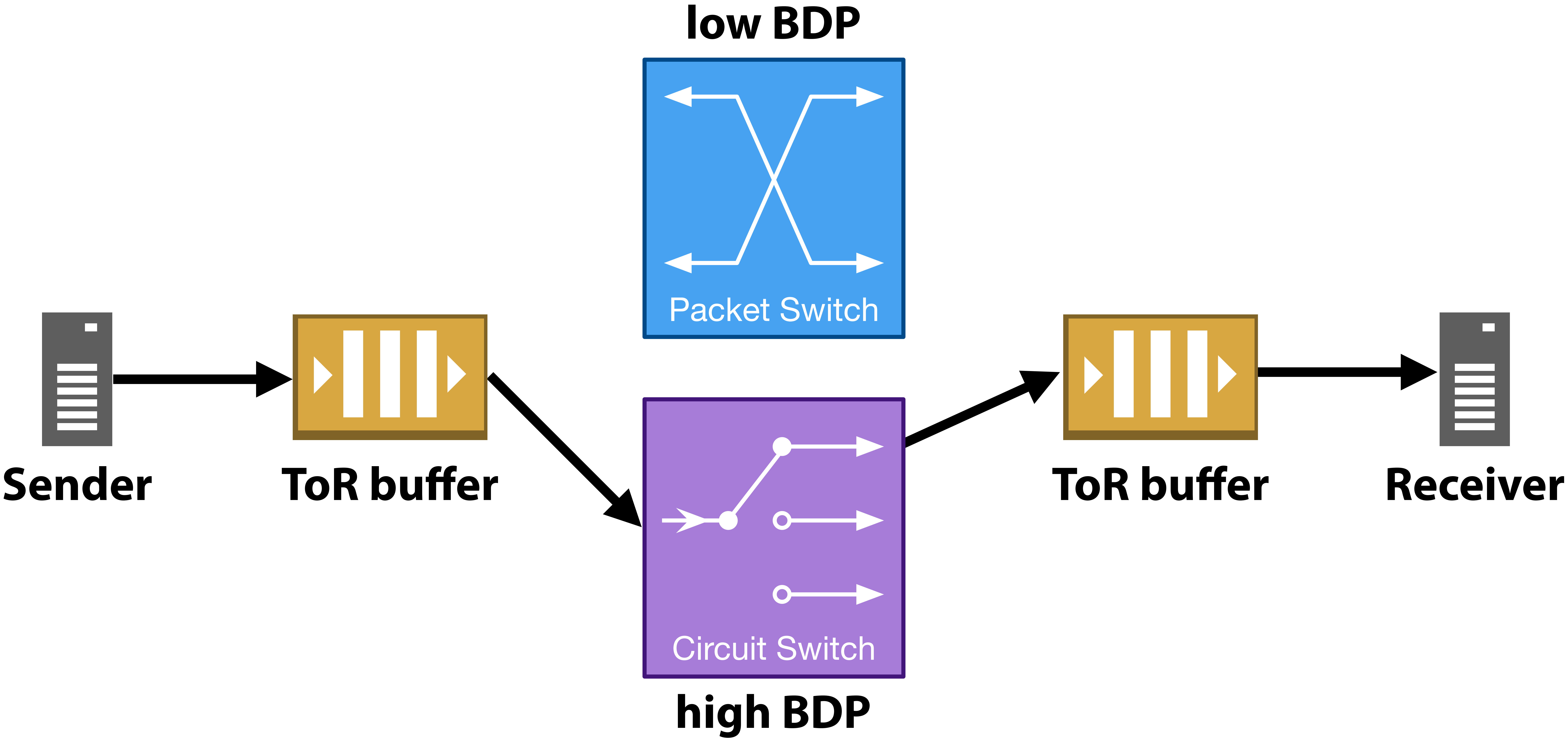
Naïve idea: Enlarge switch buffers

Want we want: TCP's congestion window (**`cwnd`**) to parallel the BW fluctuations

First attempt: Make **`cwnd`** large all the time ***How?*** Use large ToR buffers

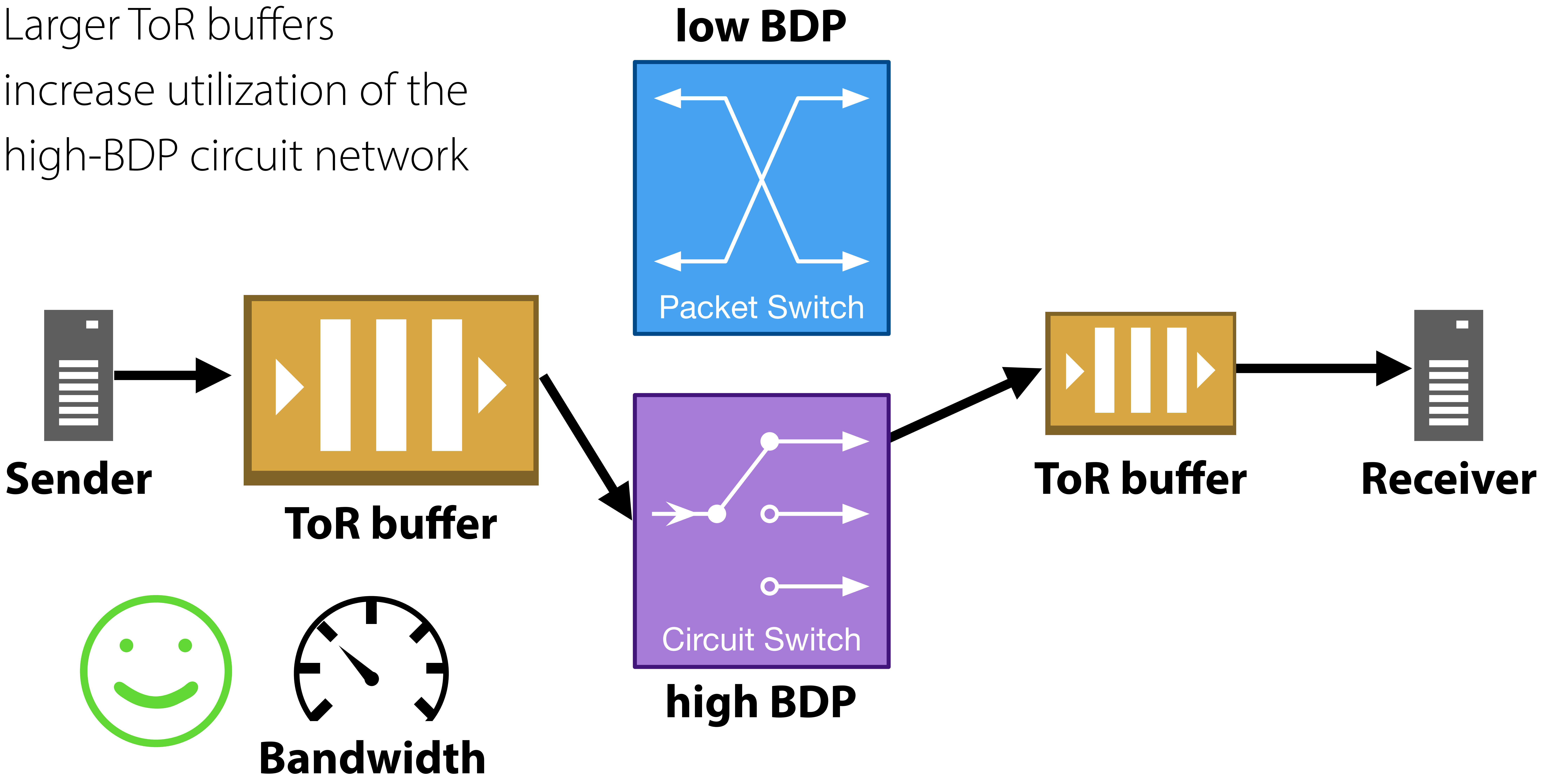


Naïve idea: Enlarge switch buffers



Naïve idea: Enlarge switch buffers

Larger ToR buffers increase utilization of the high-BDP circuit network



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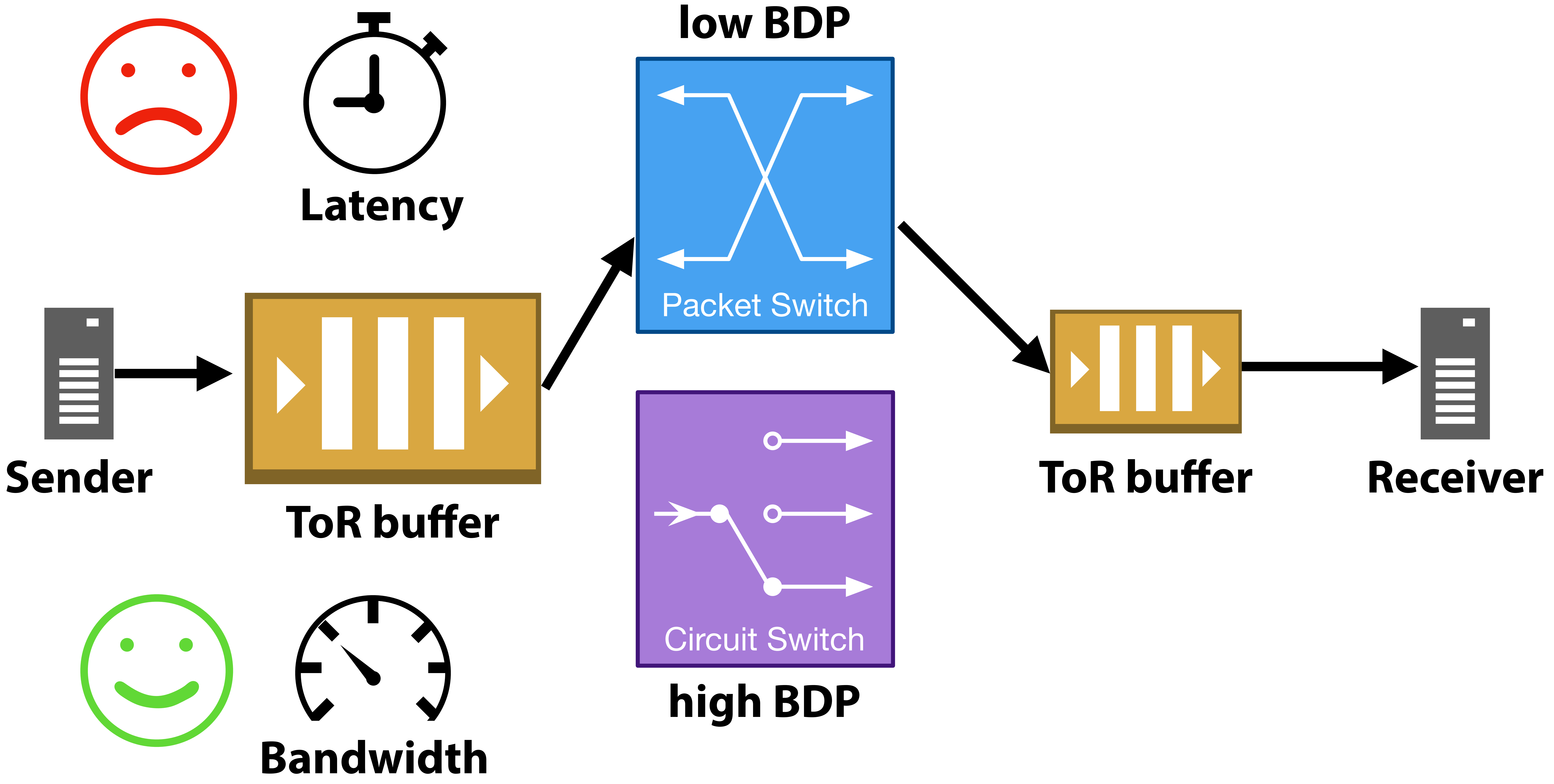
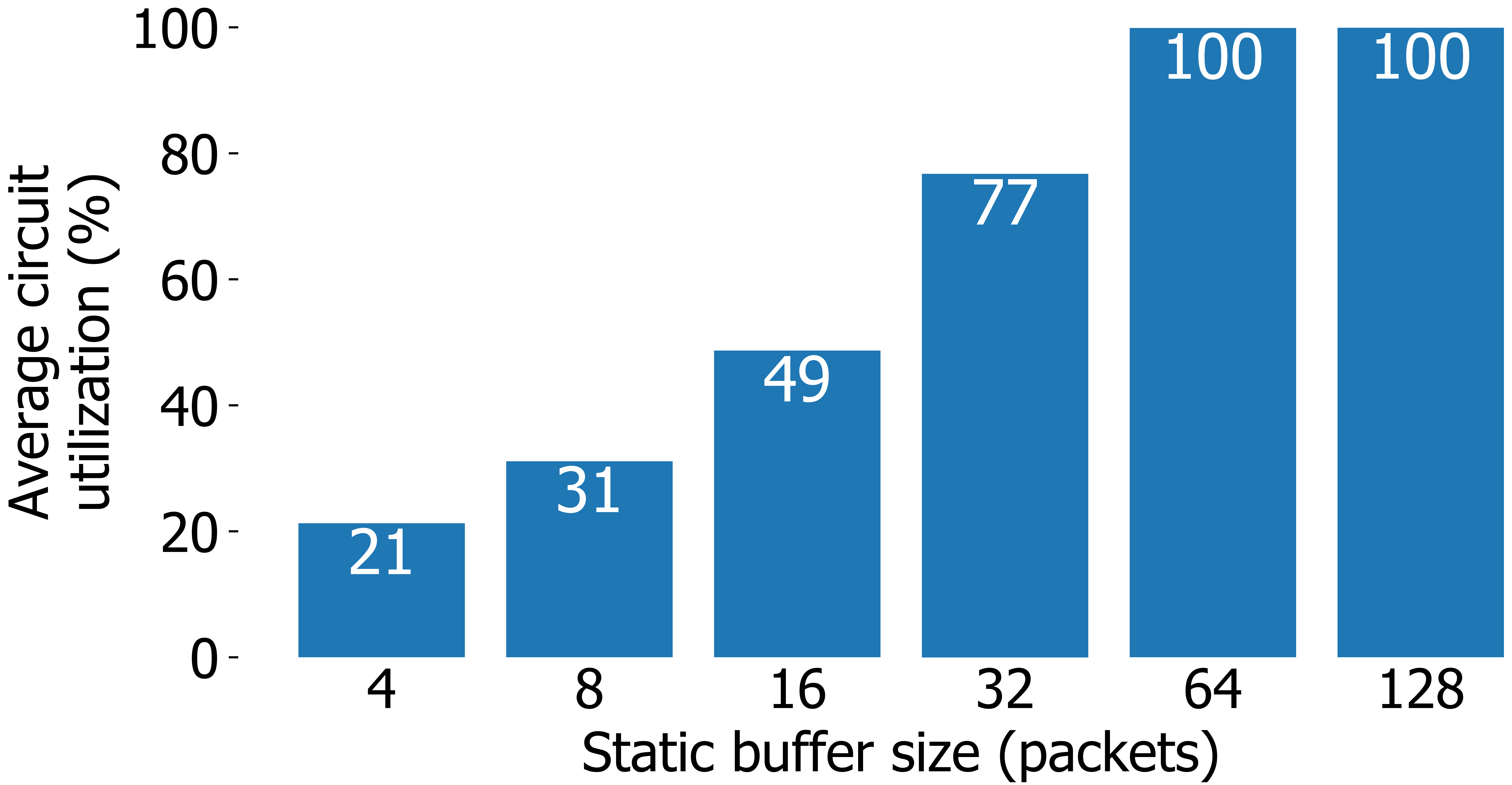
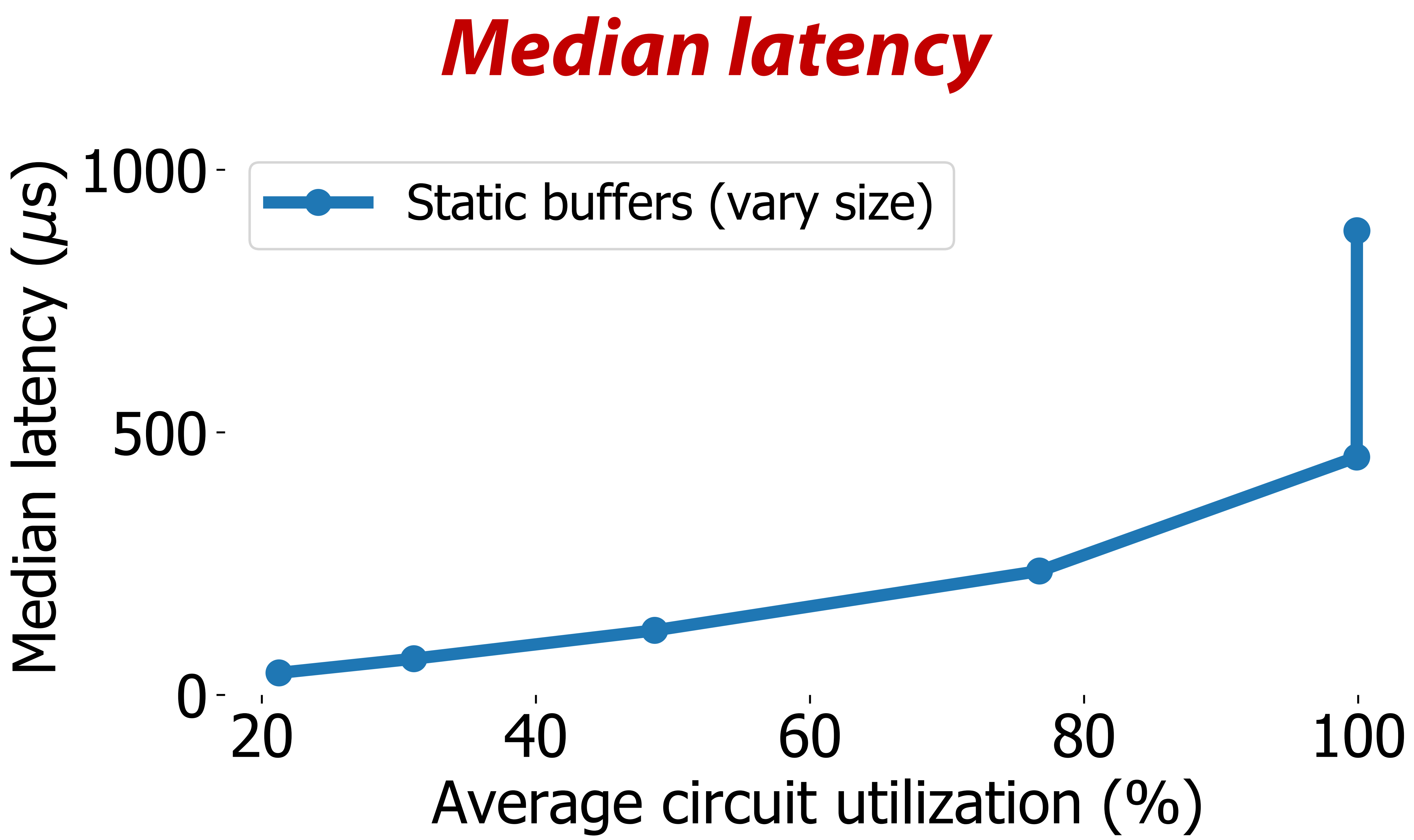


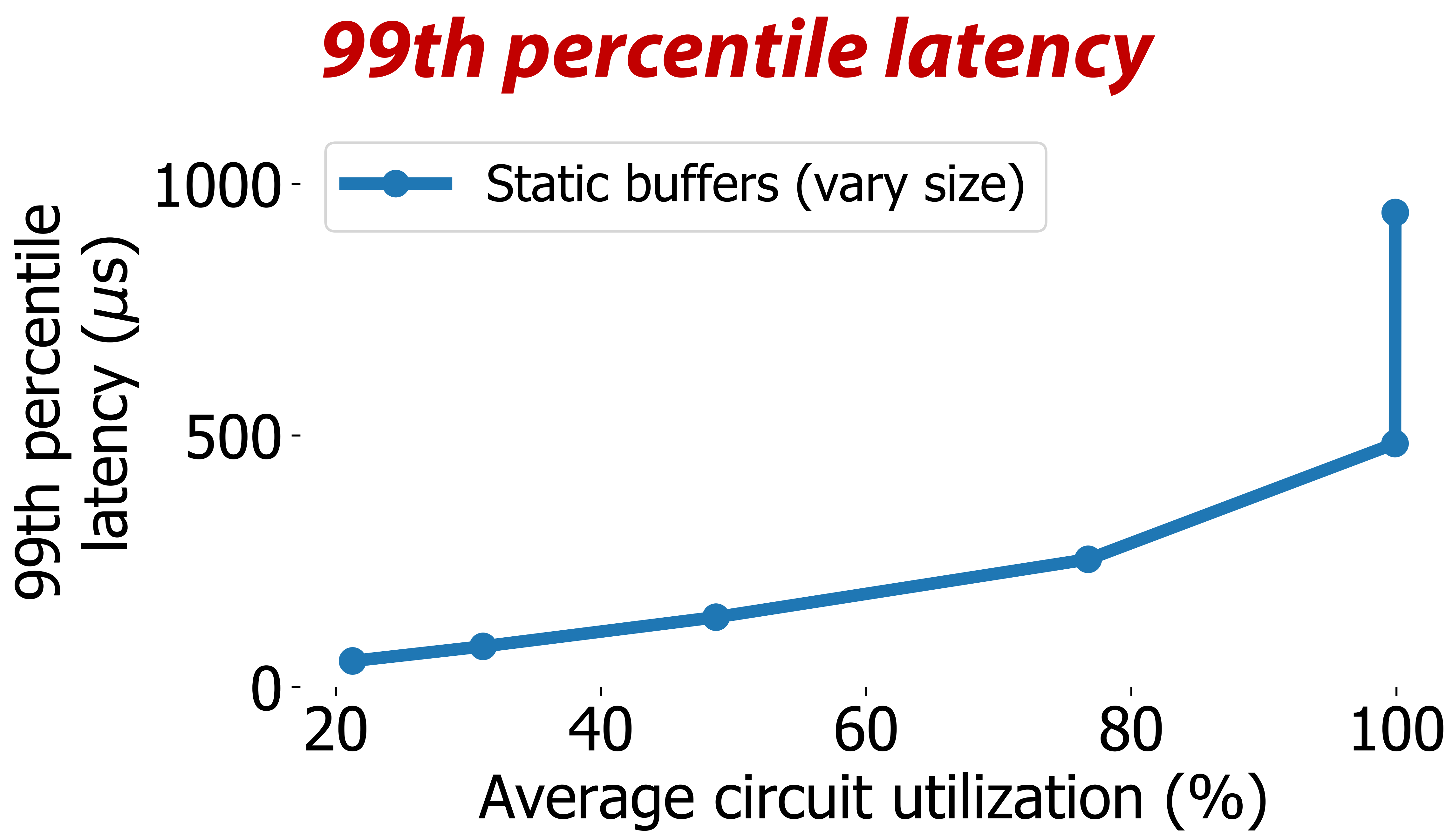
Large queues increase utilization…



16 flows from rack 1 to rack 2; packet network: 10 Gb/s; circuit network: 80 Gb/s

…but result in high latency





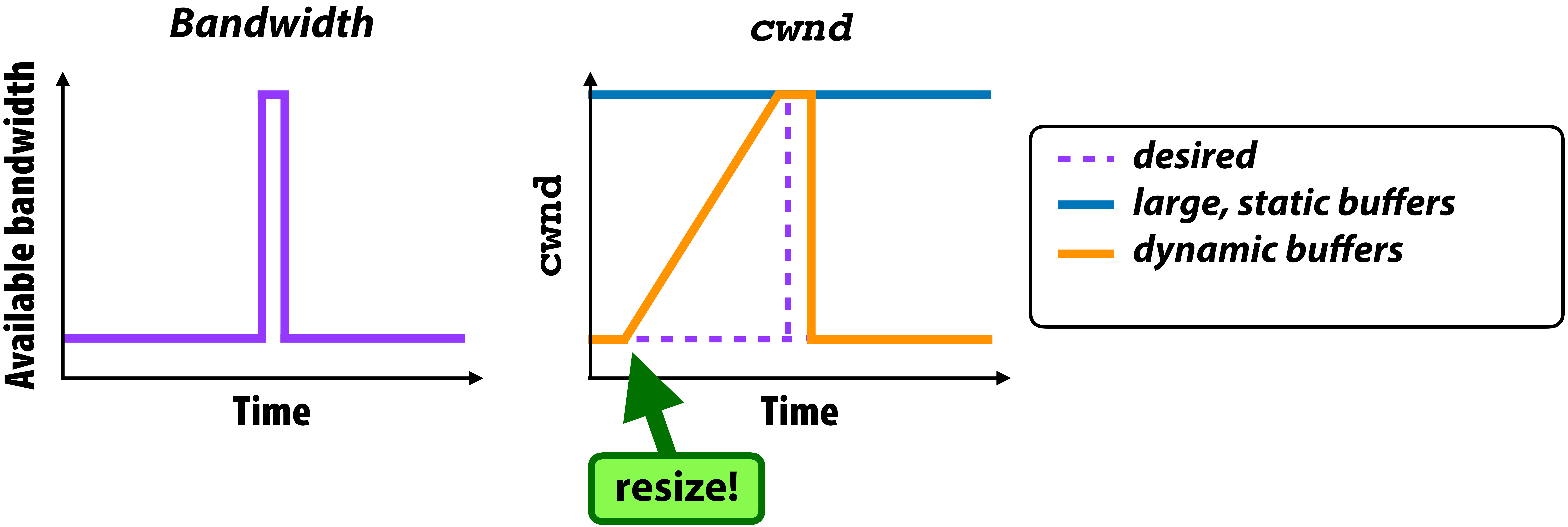
How can we improve this latency?

16 flows from rack 1 to rack 2; packet network: 10 Gb/s; circuit network: 80 Gb/s

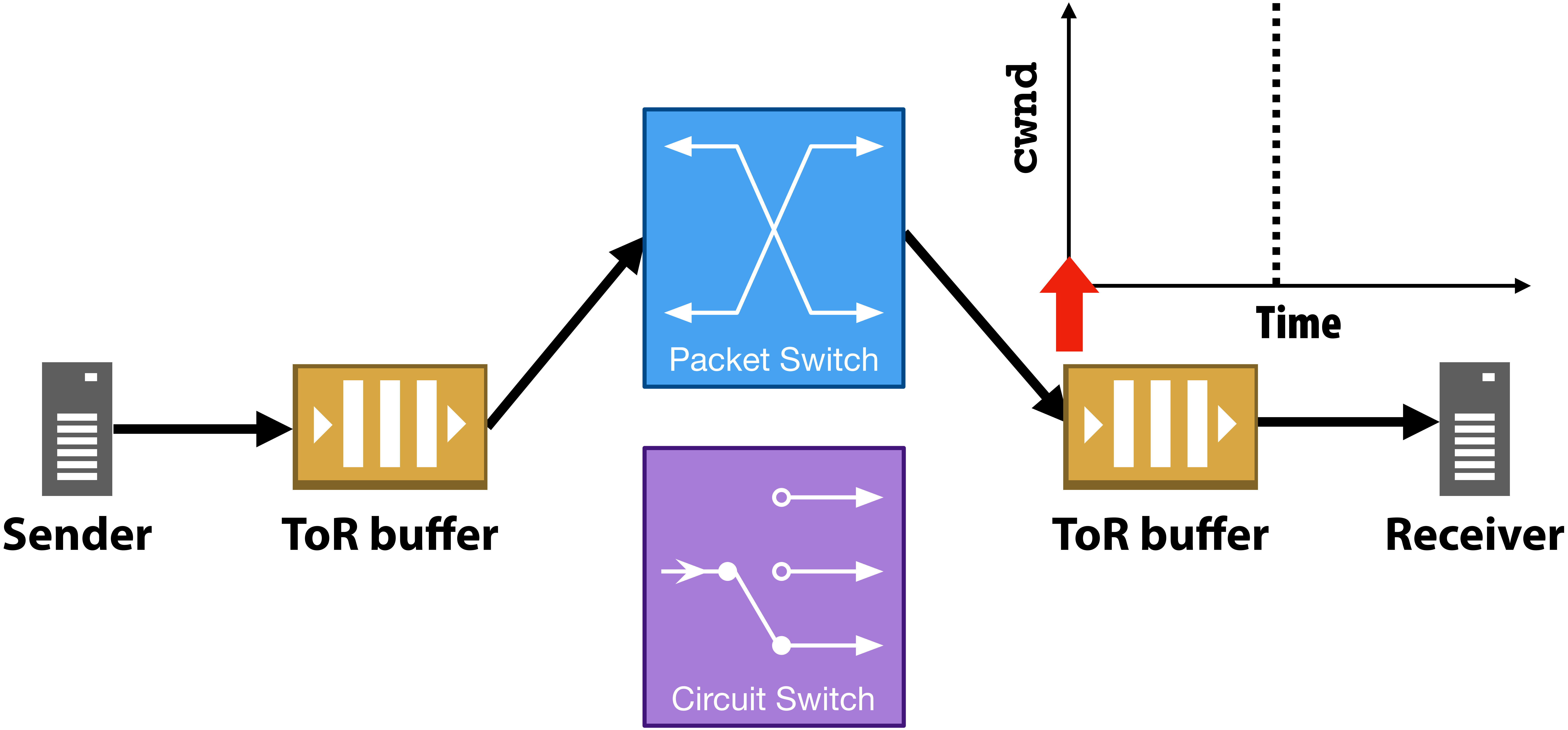
Use large buffers only when circuit is up

Dynamic buffer resizing: Before a circuit begins, transparently enlarge ToR buffers

Full circuit utilization with a latency degradation only during ramp-up period



Resize ToR buffers before circuit begins



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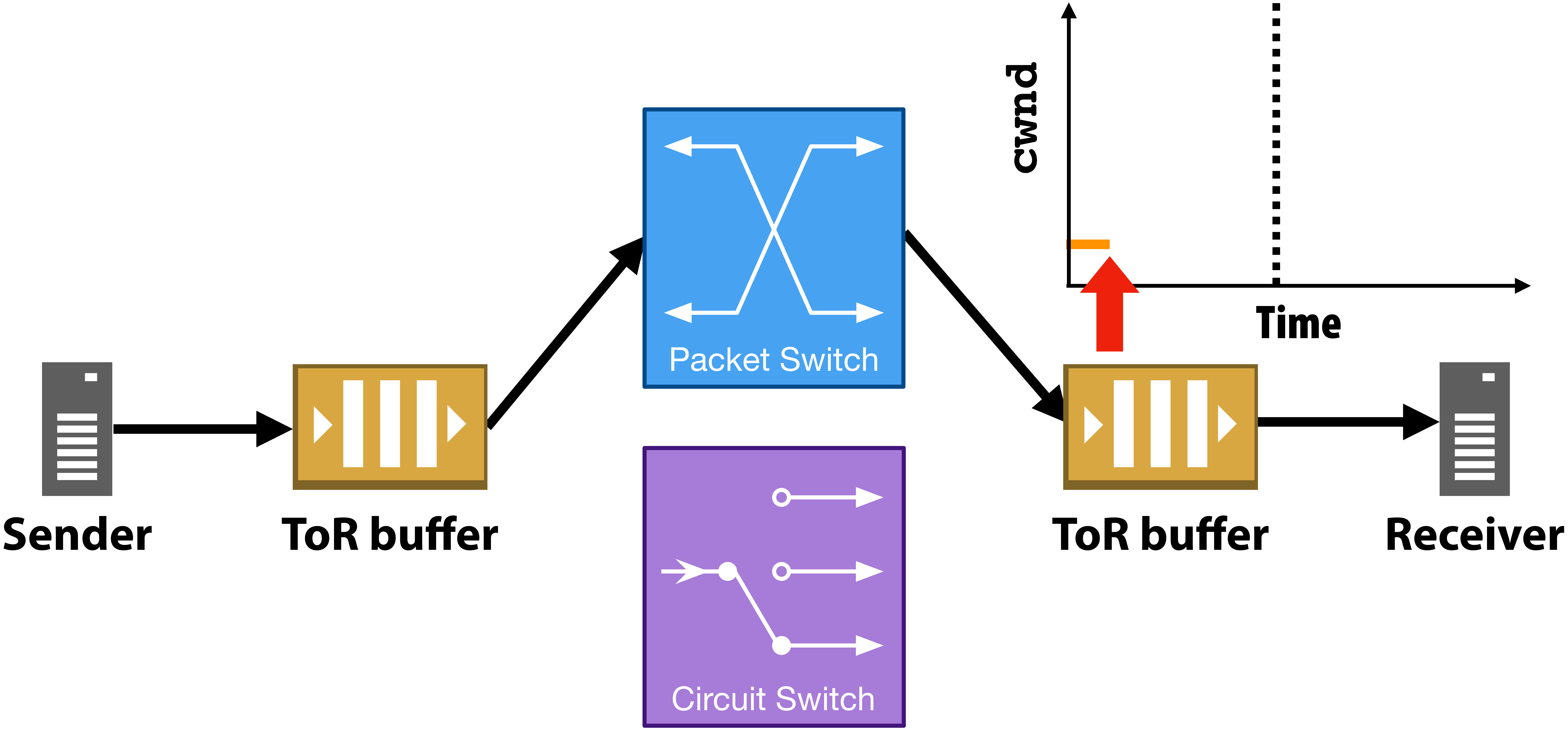

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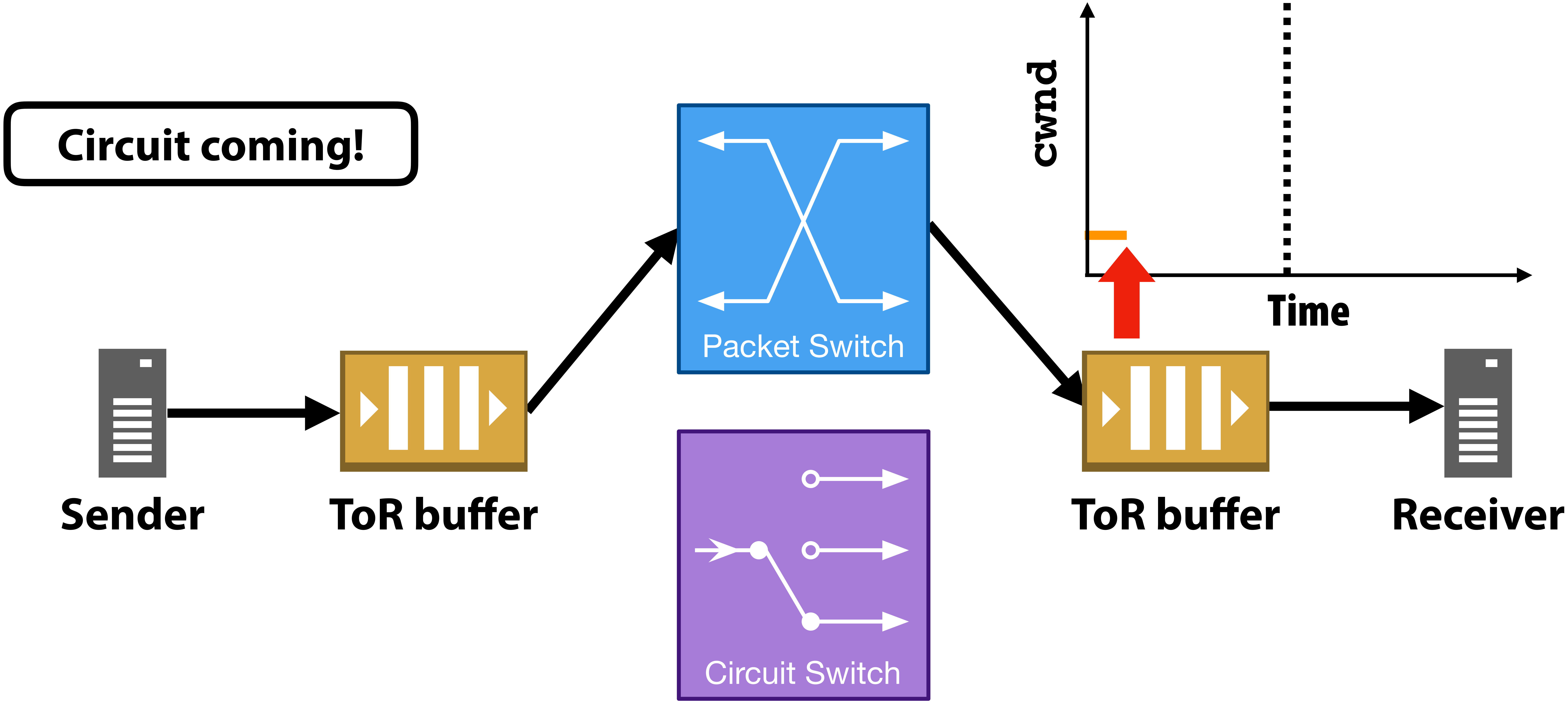

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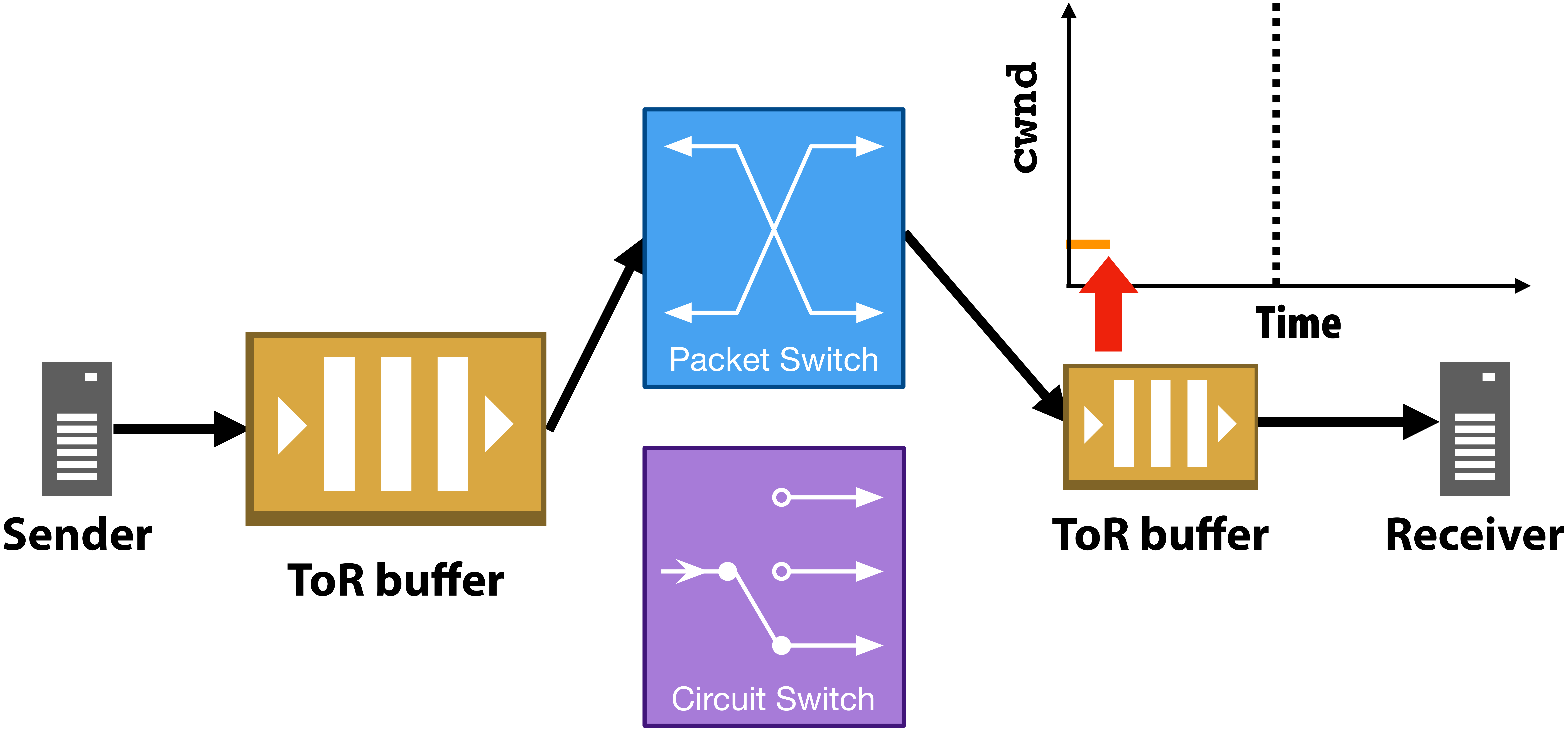

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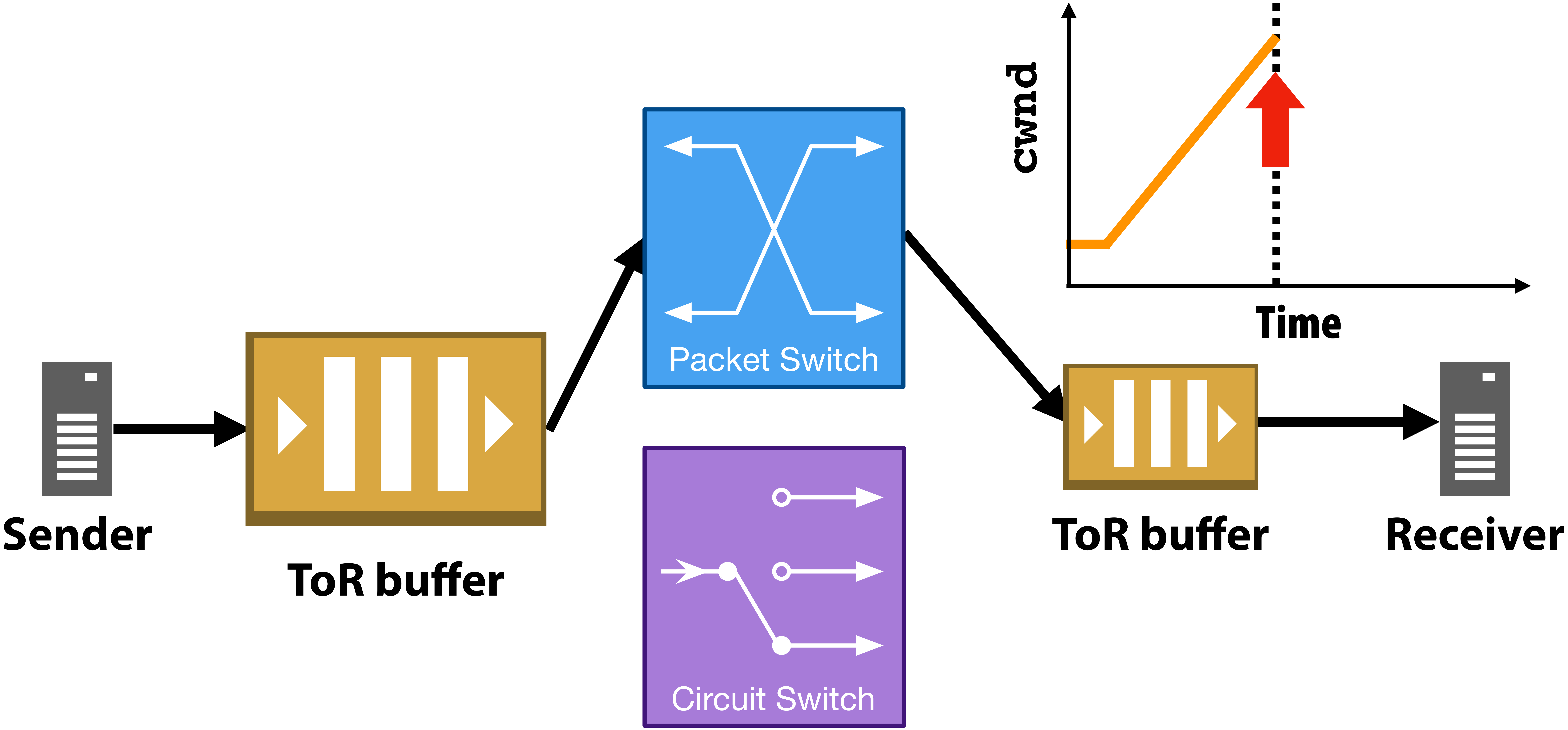

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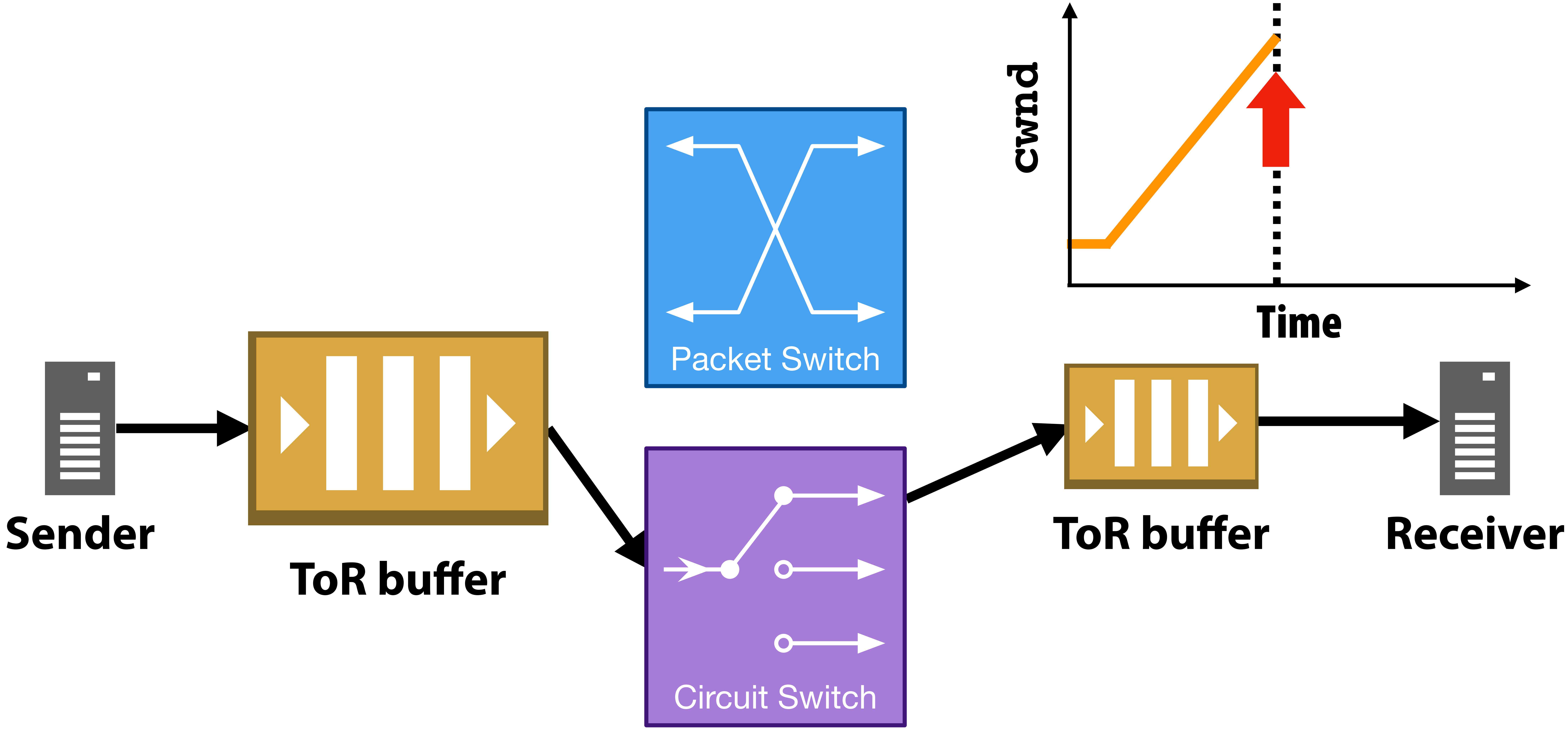

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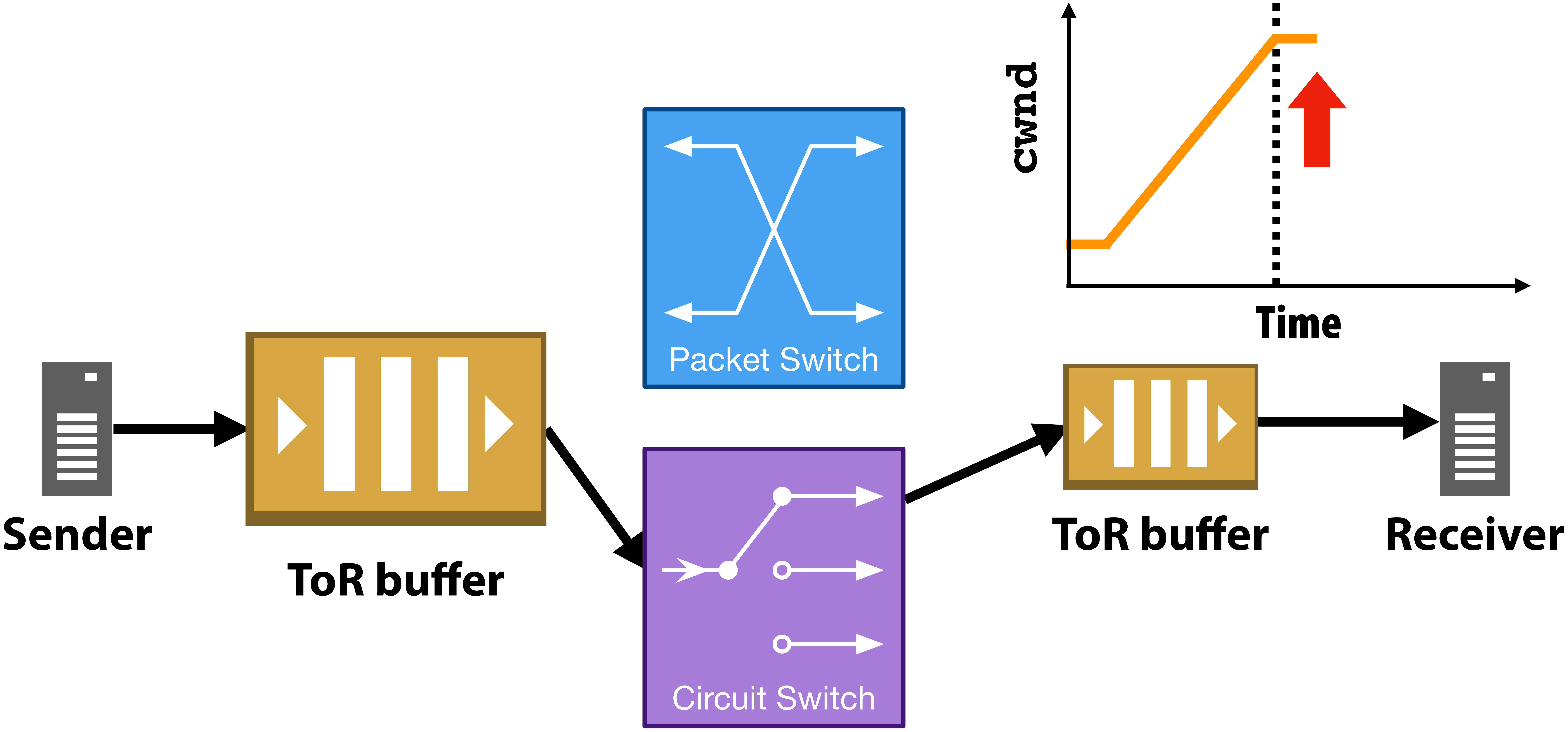

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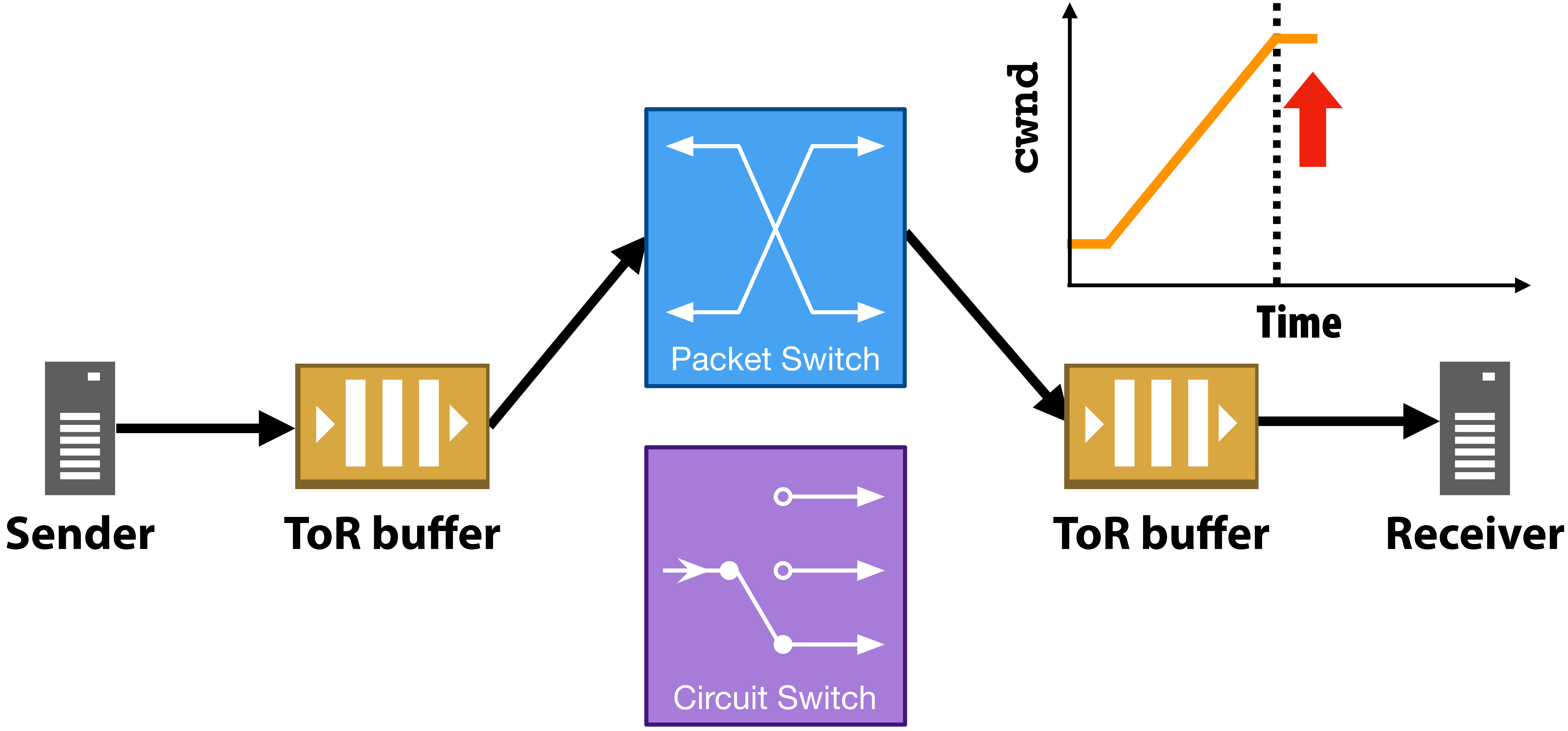

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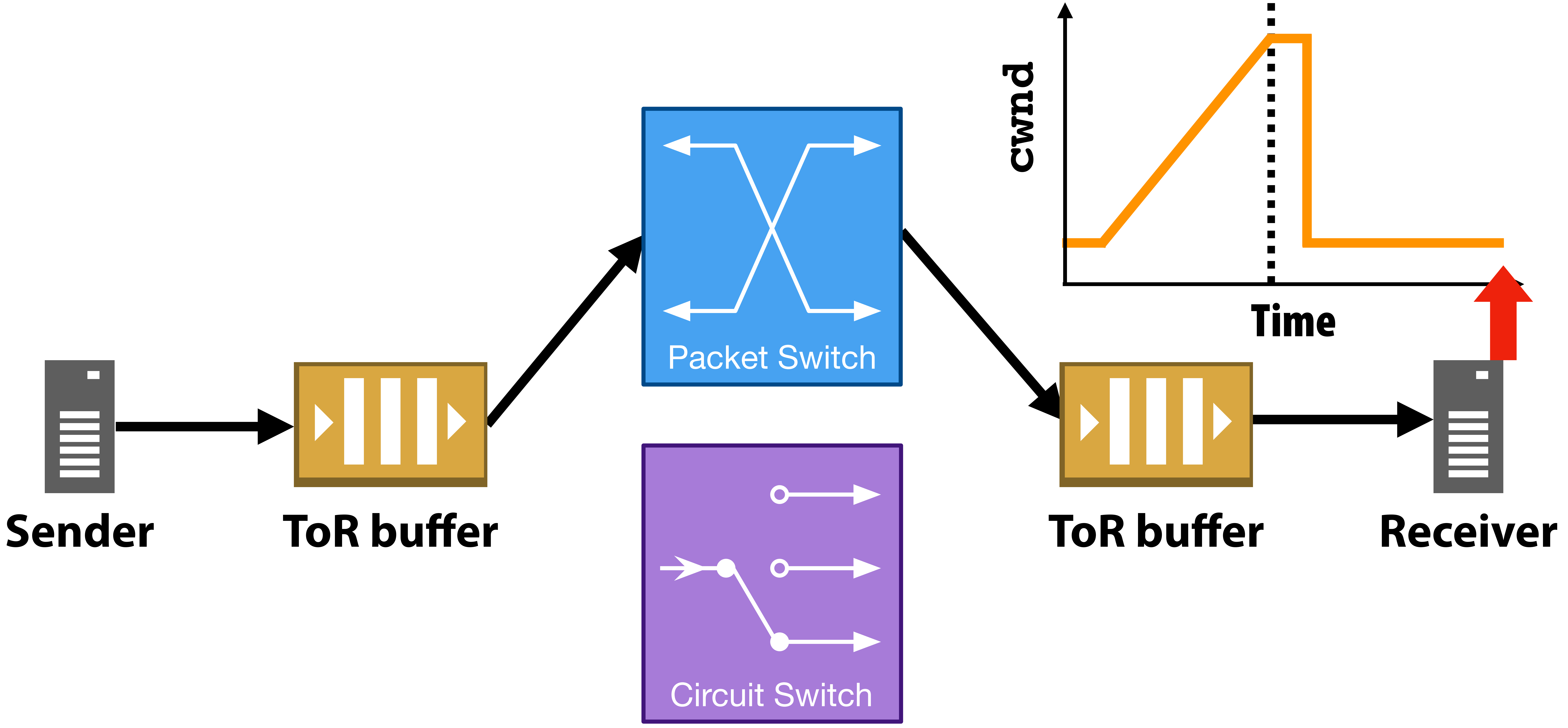


Configuring dynamic buffer resizing

How long in advance should ToR buffers resize (τ)?

- Long enough for TCP to grow `cwnd` to the circuit BDP

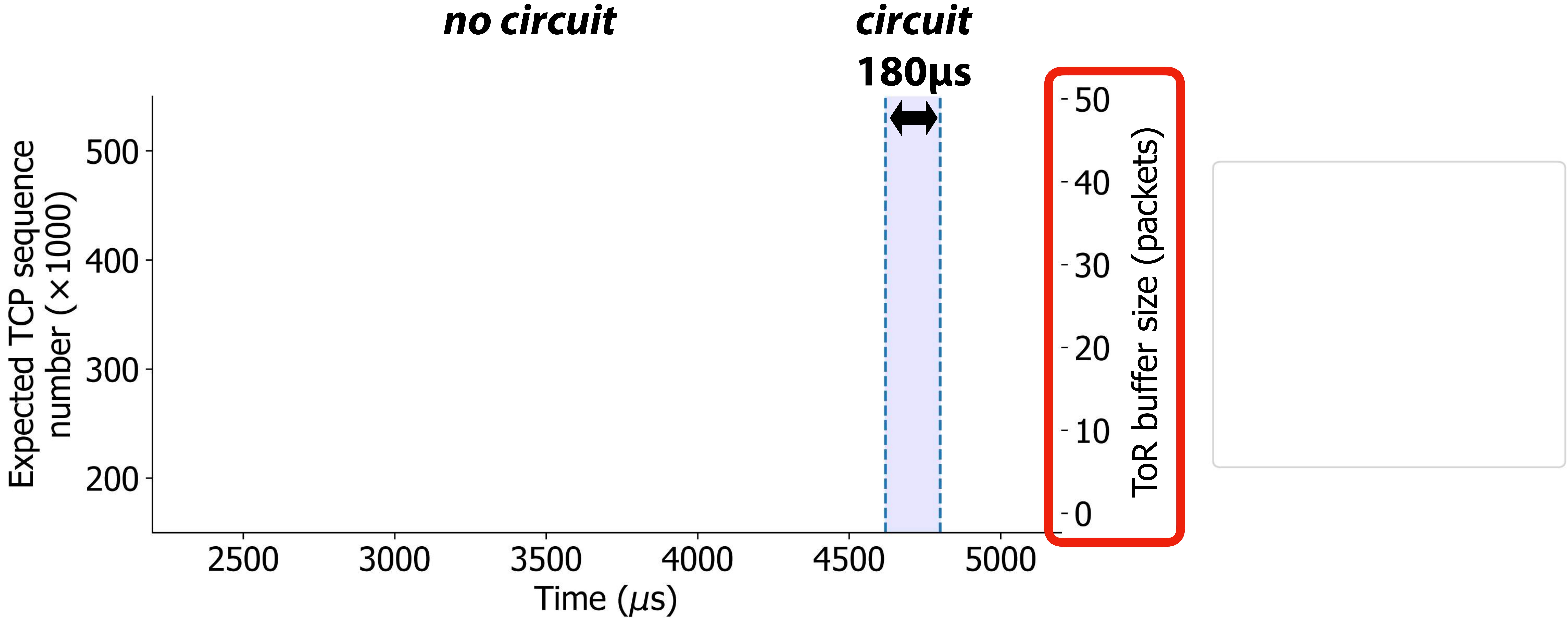
How large should ToR buffers grow to?

- circuit BDP = 80 Gb/s × 40 μs = 45 9000-byte packets

For our configuration, the ToR buffers must hold ~40 packets to achieve 90% utilization, which requires 1800 μs of prebuffering

We resize ToR buffers between sizes of 16 and 50 packets

How long in advance to resize, τ?



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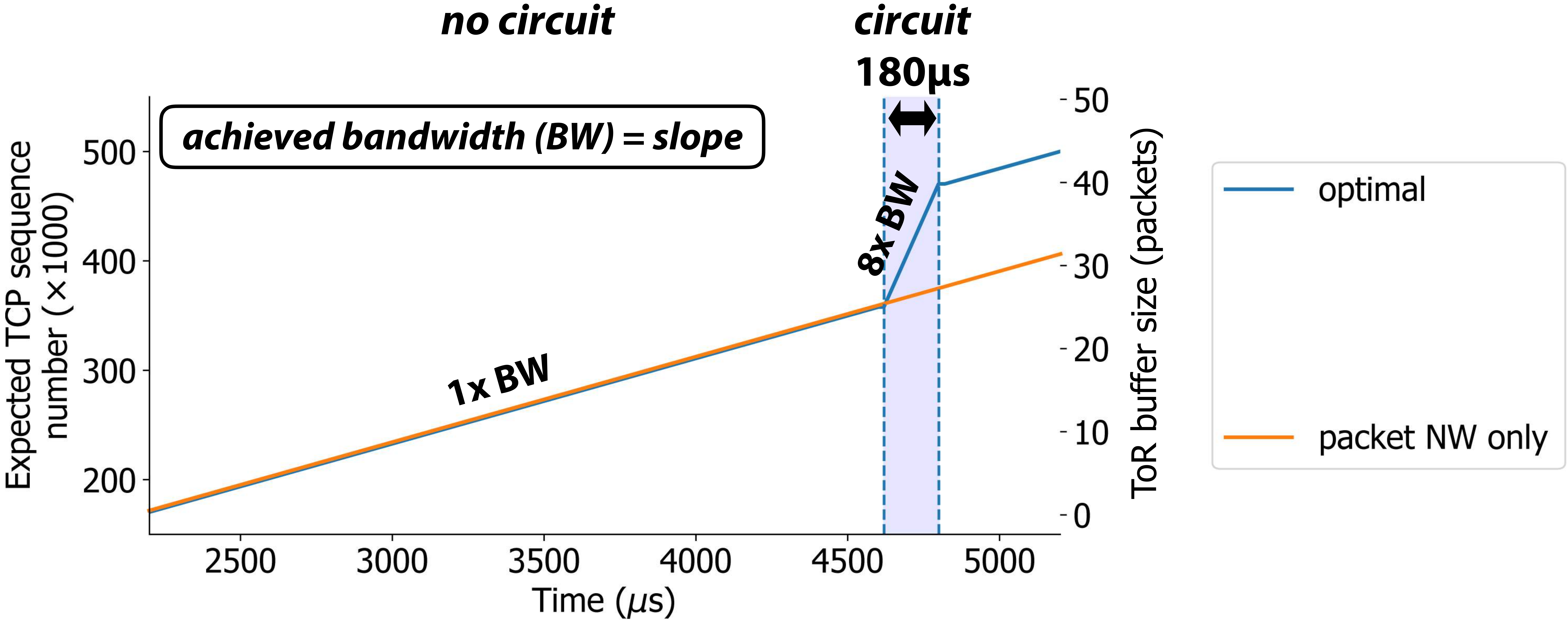

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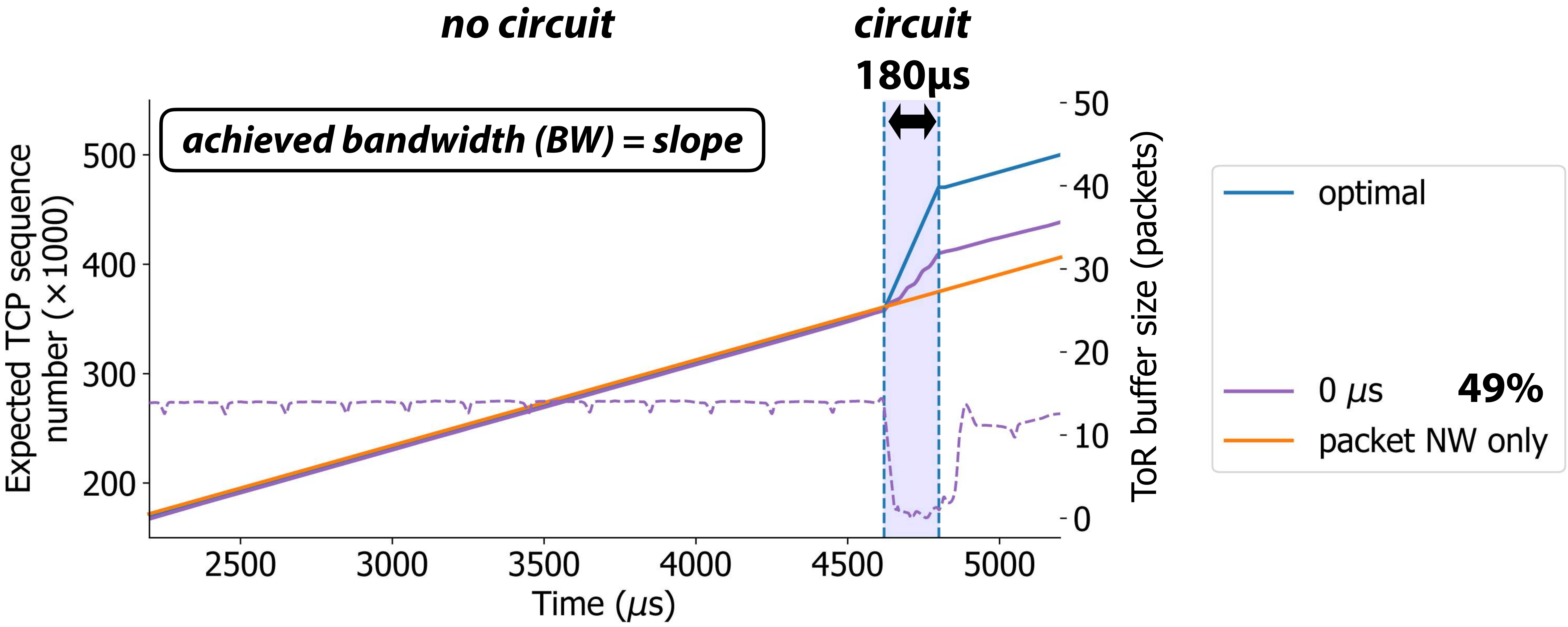

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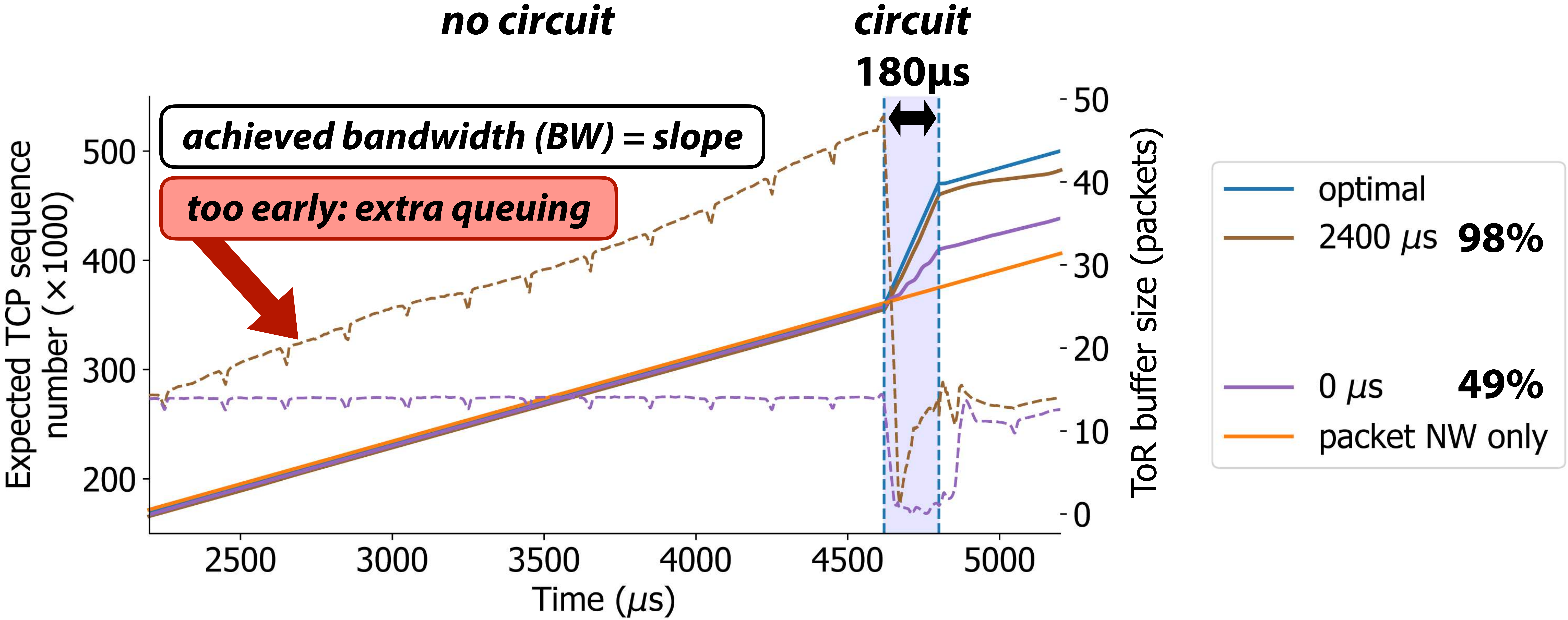

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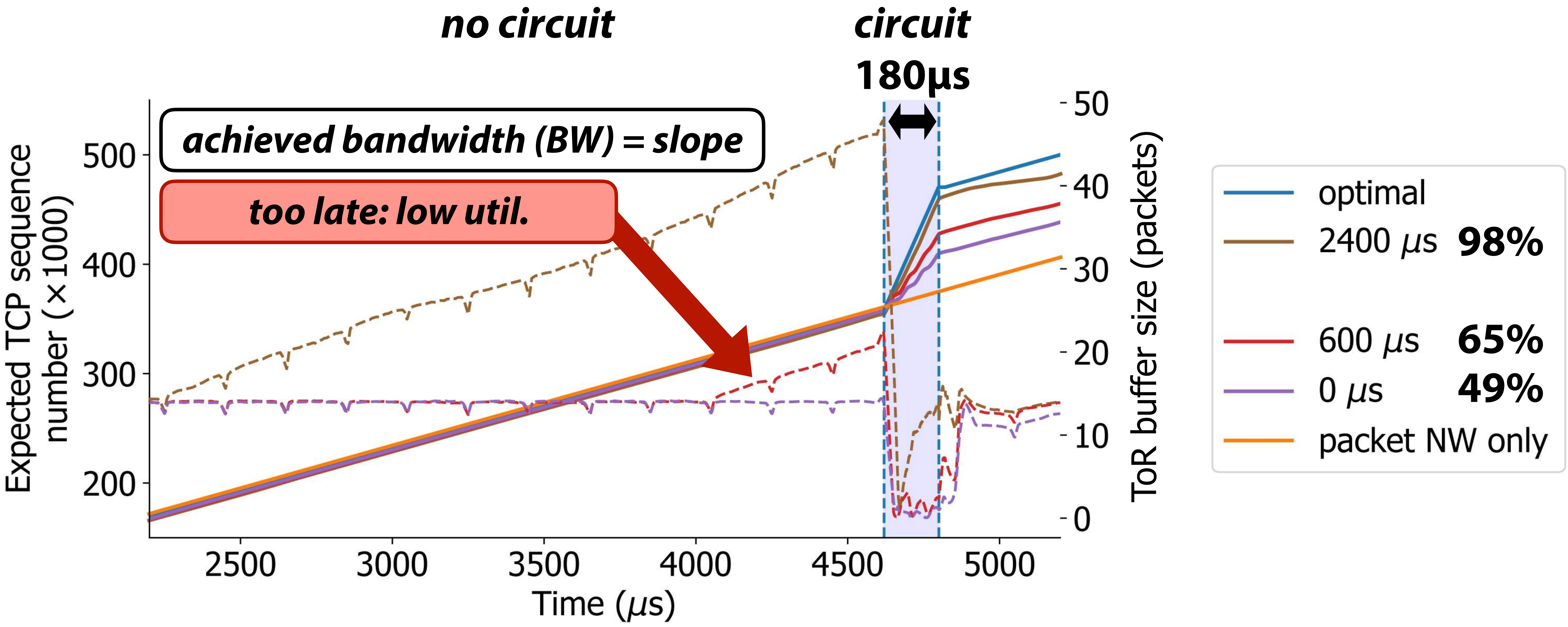

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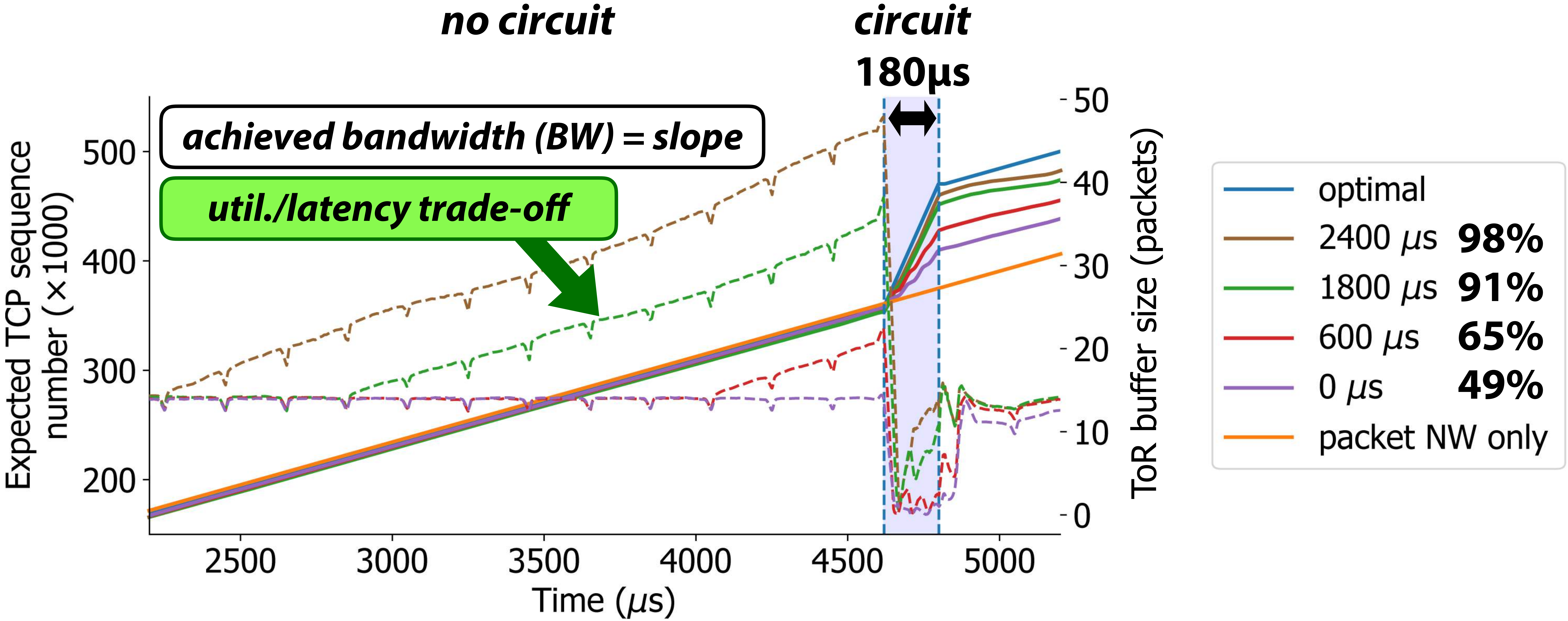

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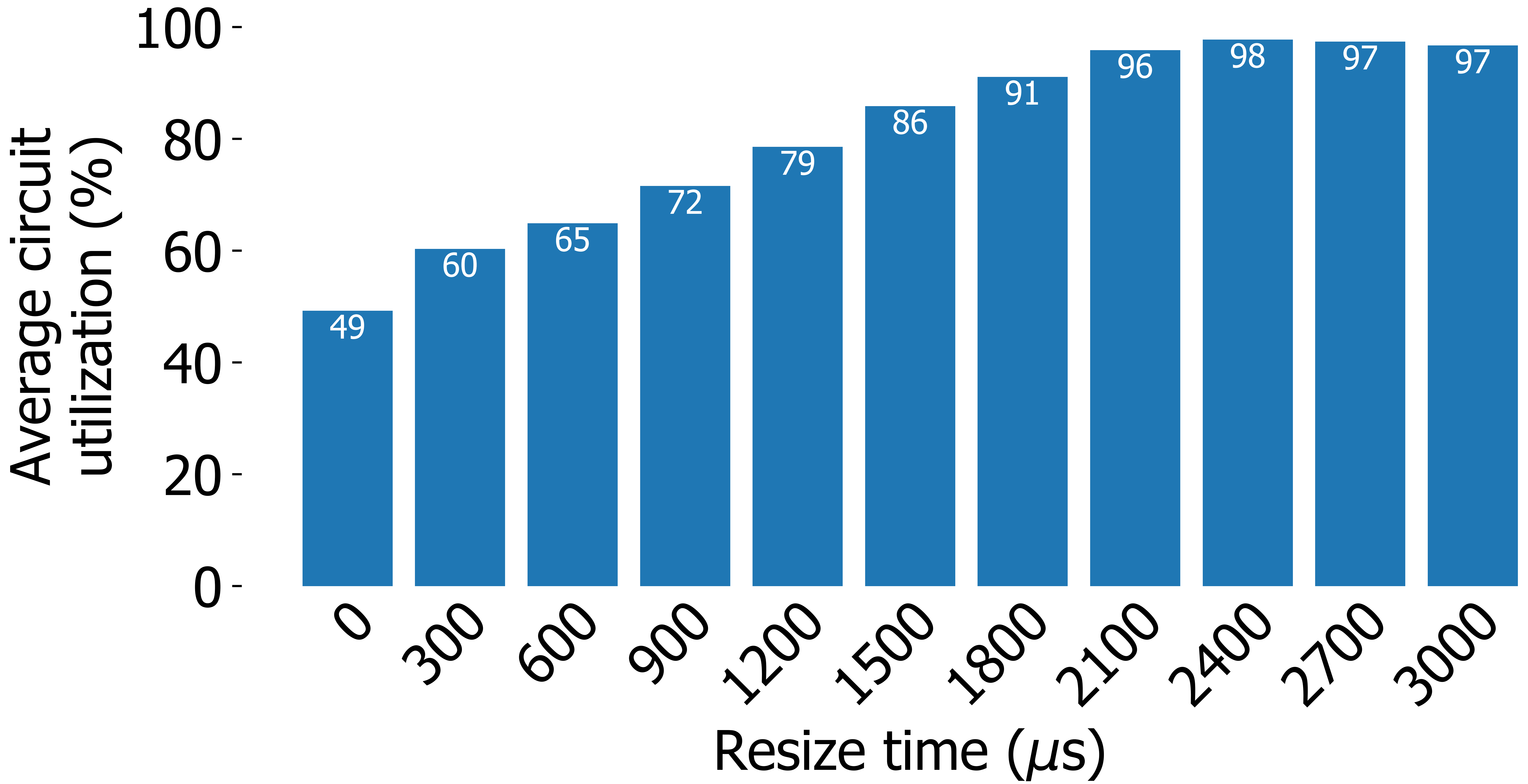
1800µs of prebuffering yields 91% util.



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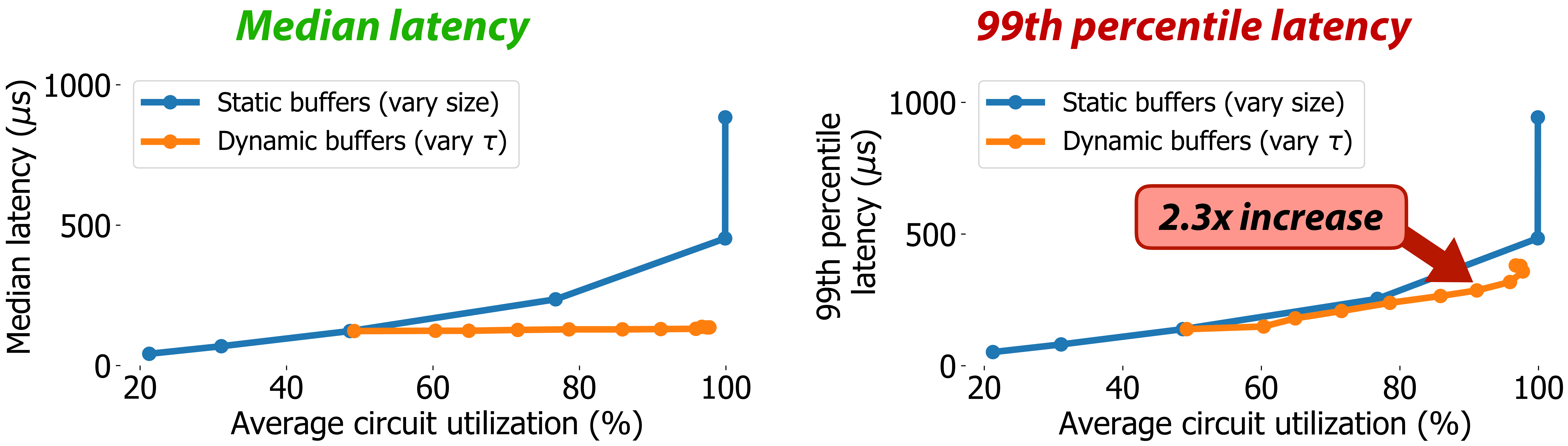
Latency degradation during ramp-up



We cannot use large queues for so long.
Can we get the same high utilization with shorter prebuffering?

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At endhosts: New TCP variant, ***reTCP***, that explicitly reacts to circuit state changes

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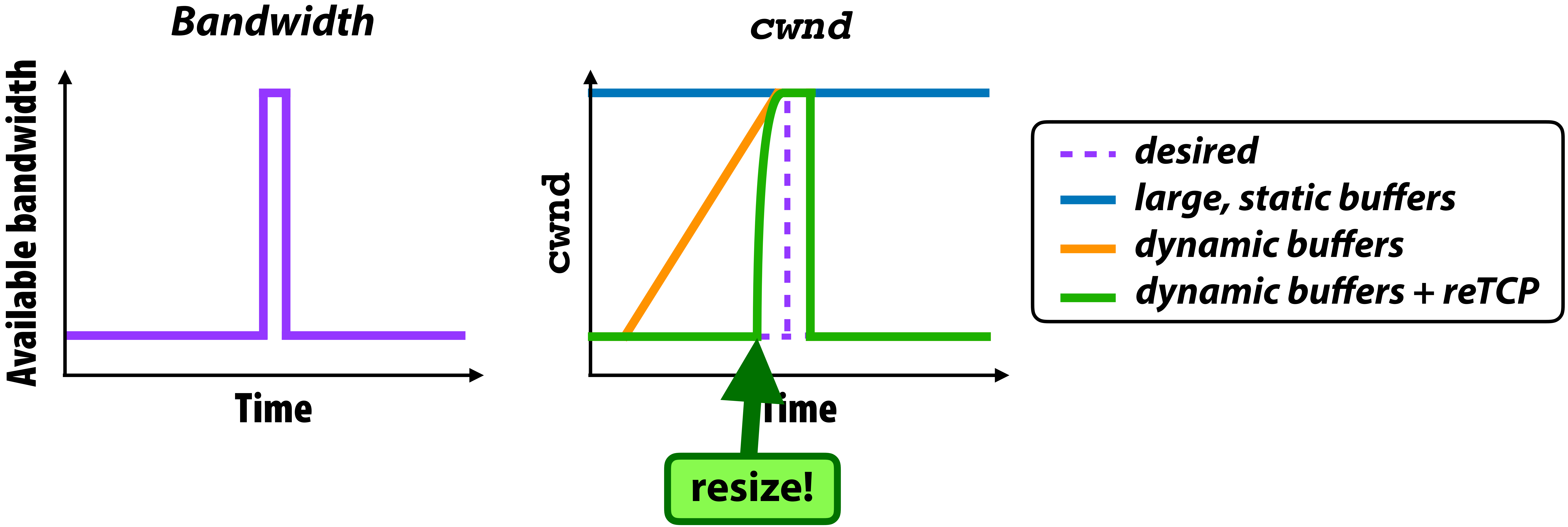
The two techniques can be deployed separately, but work best together

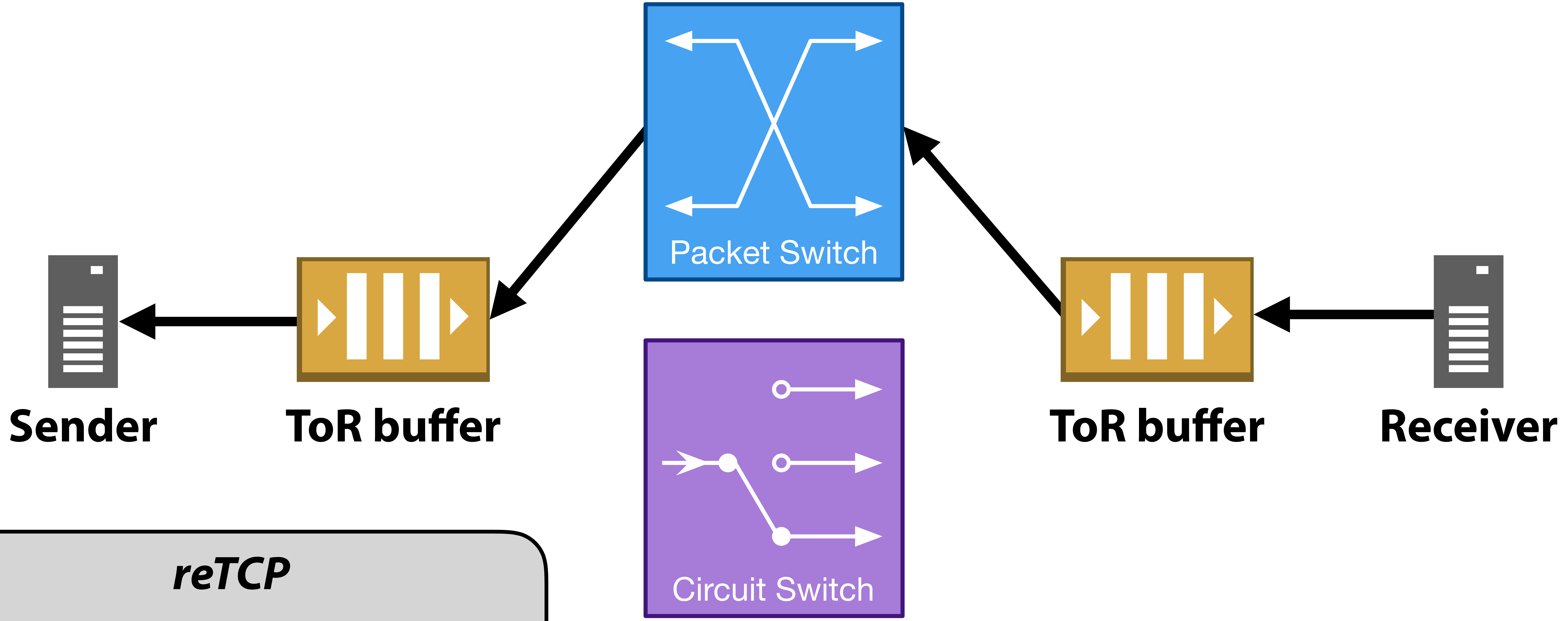
reTCP: Rapidly grow **`cwnd`** before a circuit

1) Communicate circuit state to sender TCP

2) Sender TCP reacts by multiplicatively increasing/decreasing **`cwnd`**



reTCP: Explicit circuit state feedback



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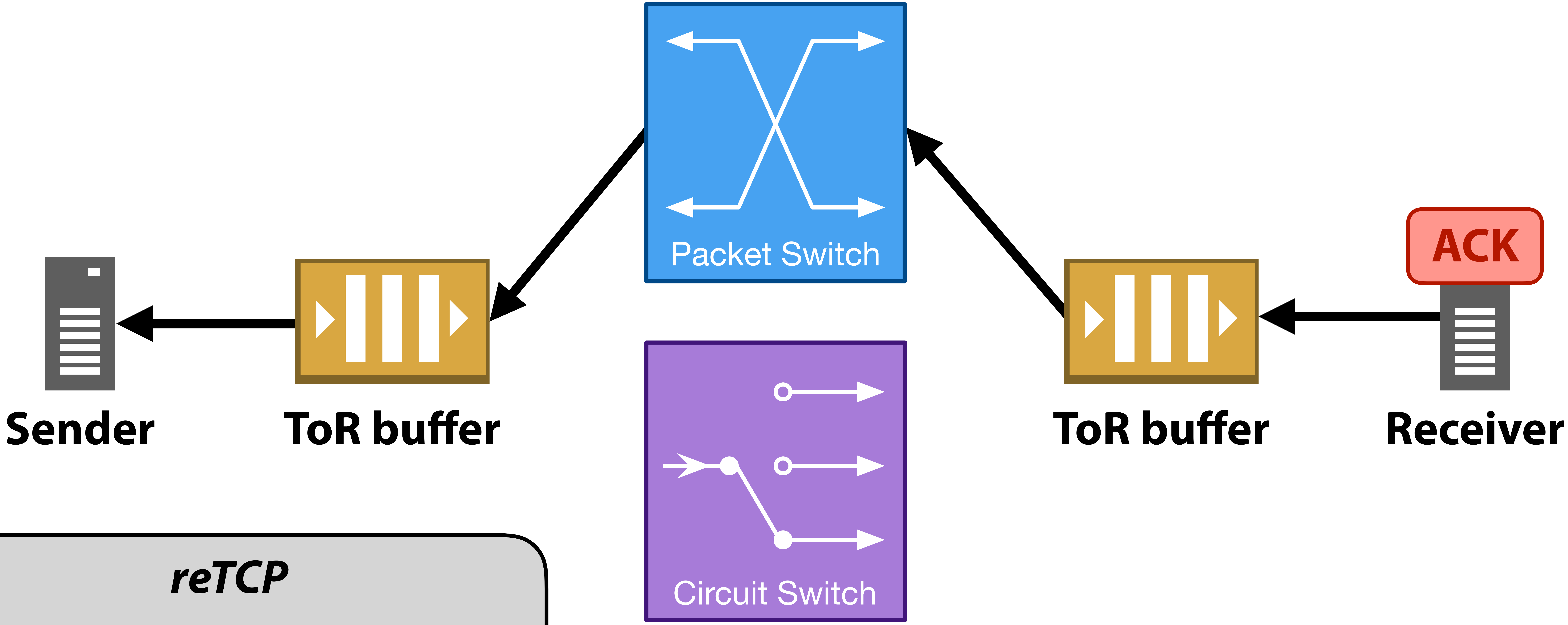

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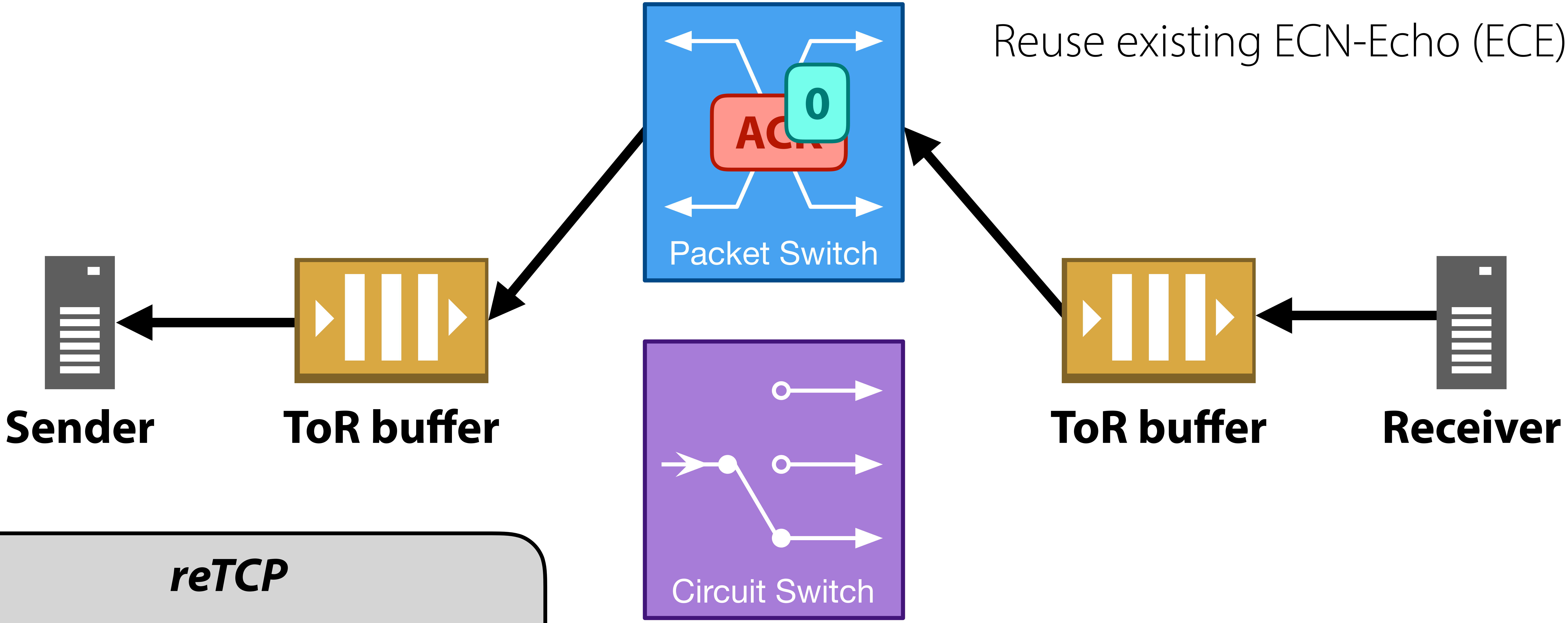
Reuse existing ECN-Echo (ECE) bit



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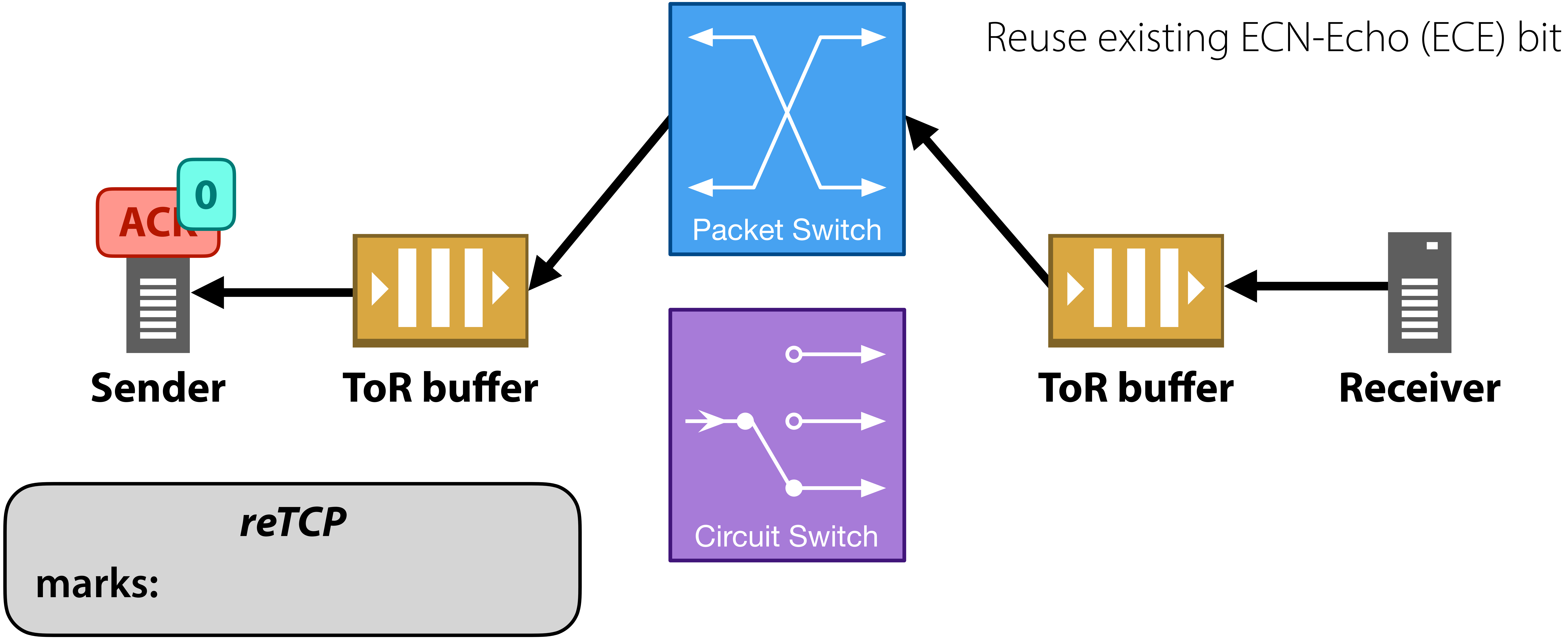

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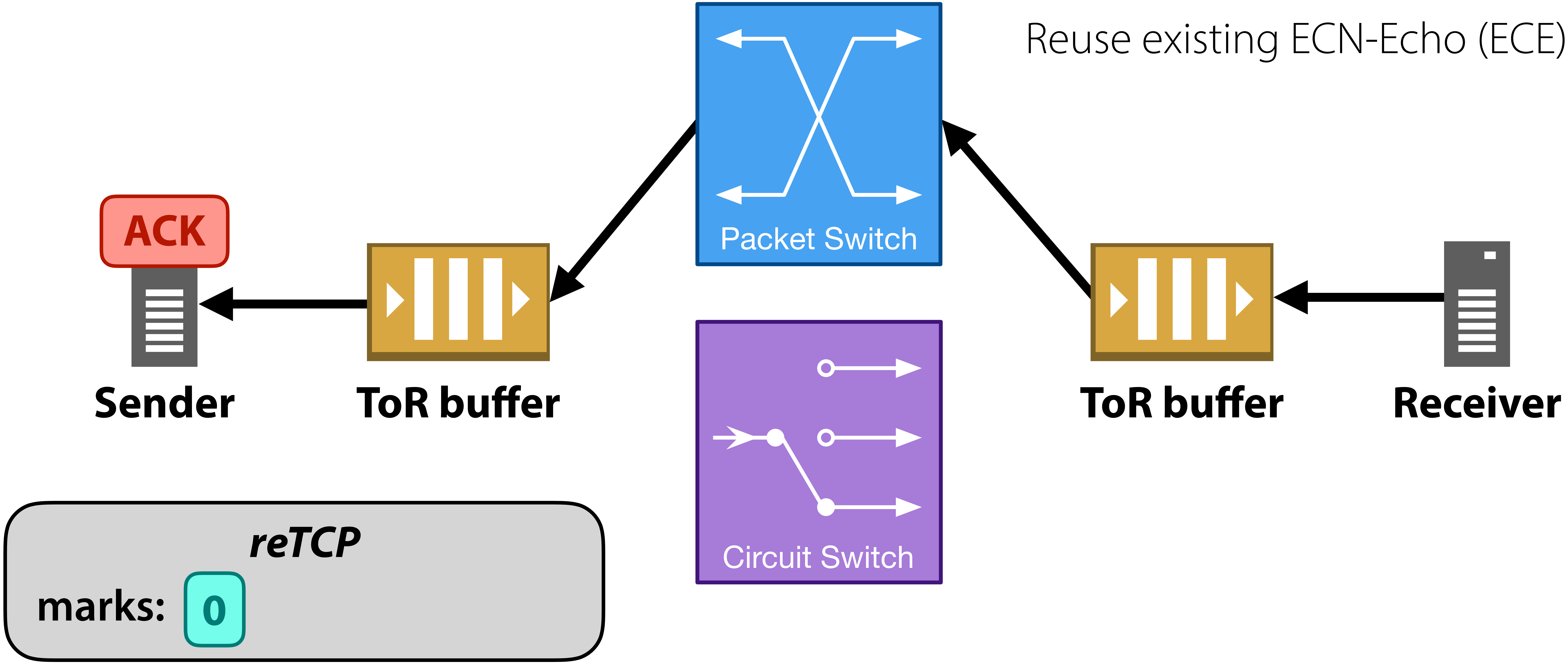

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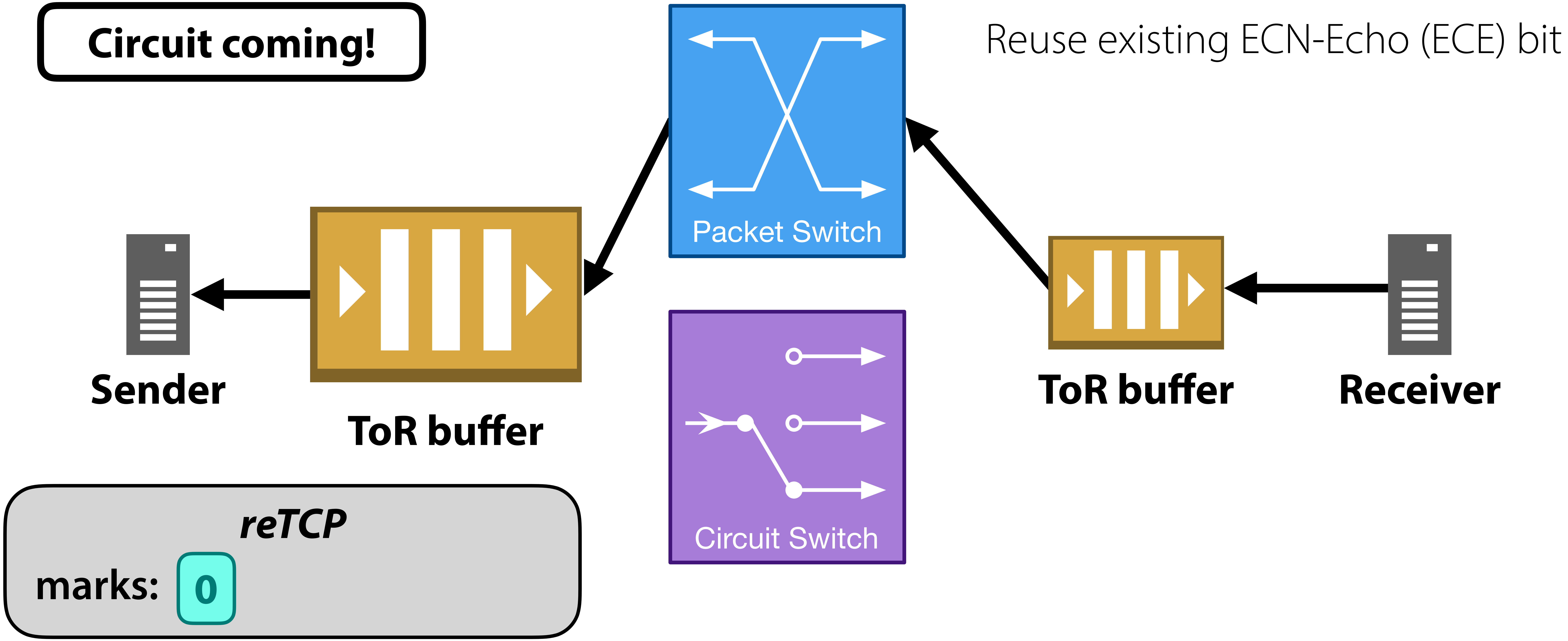

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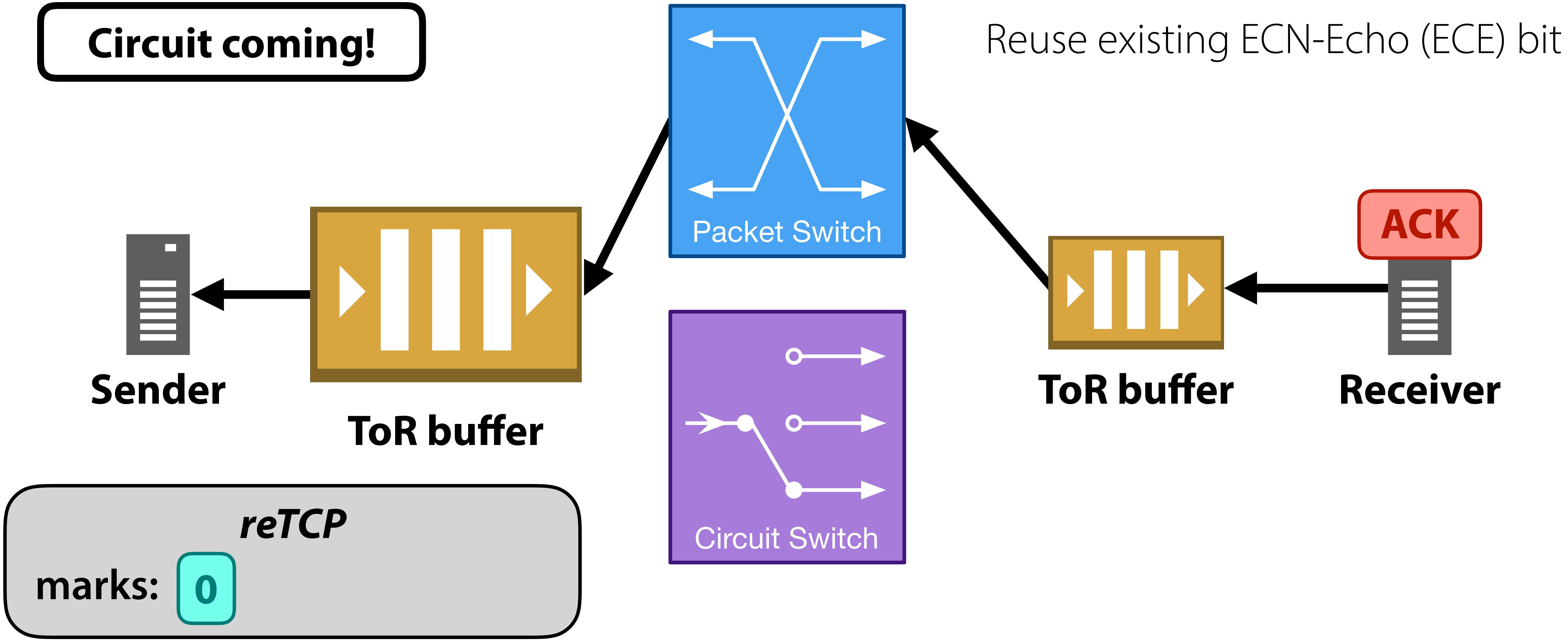

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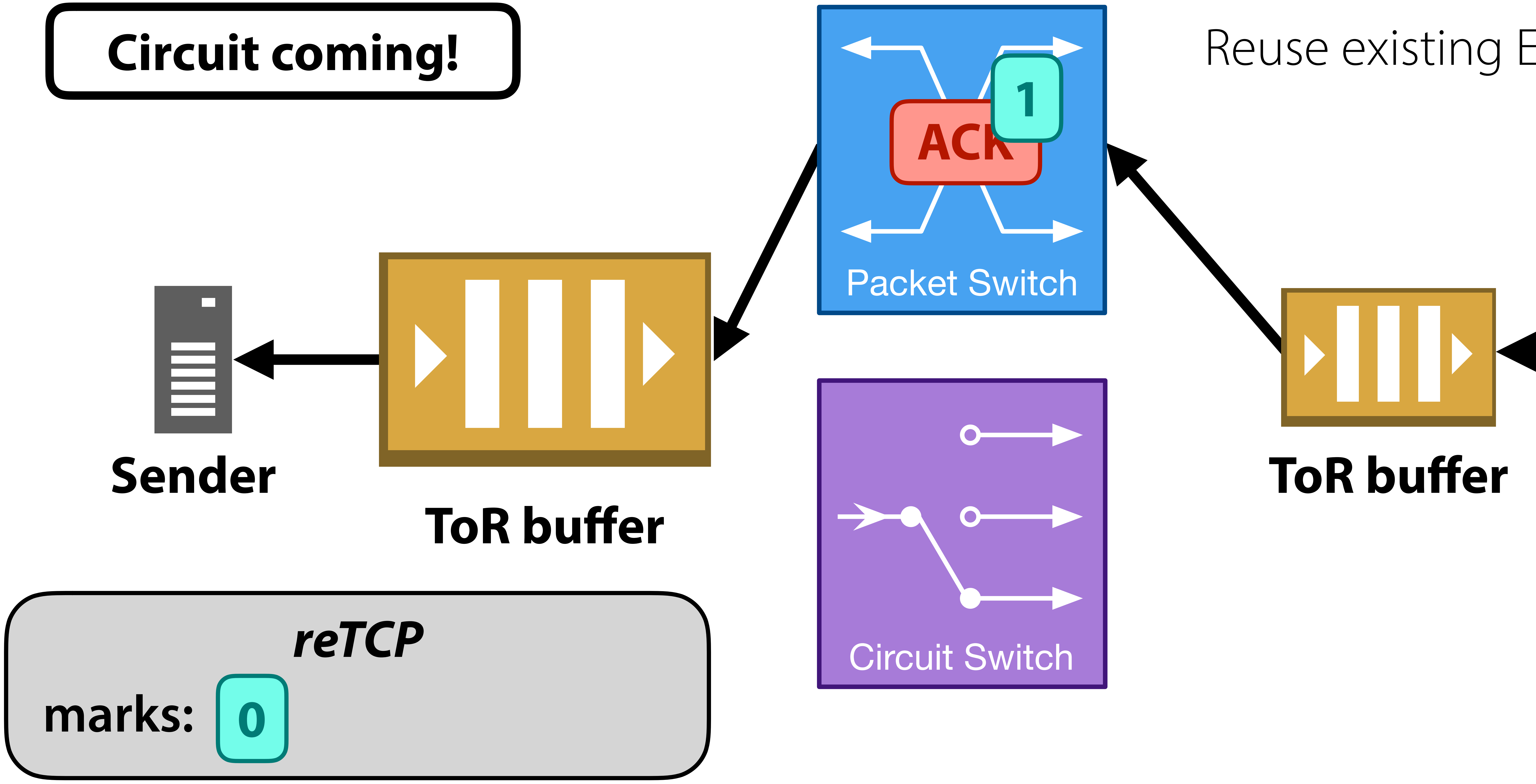

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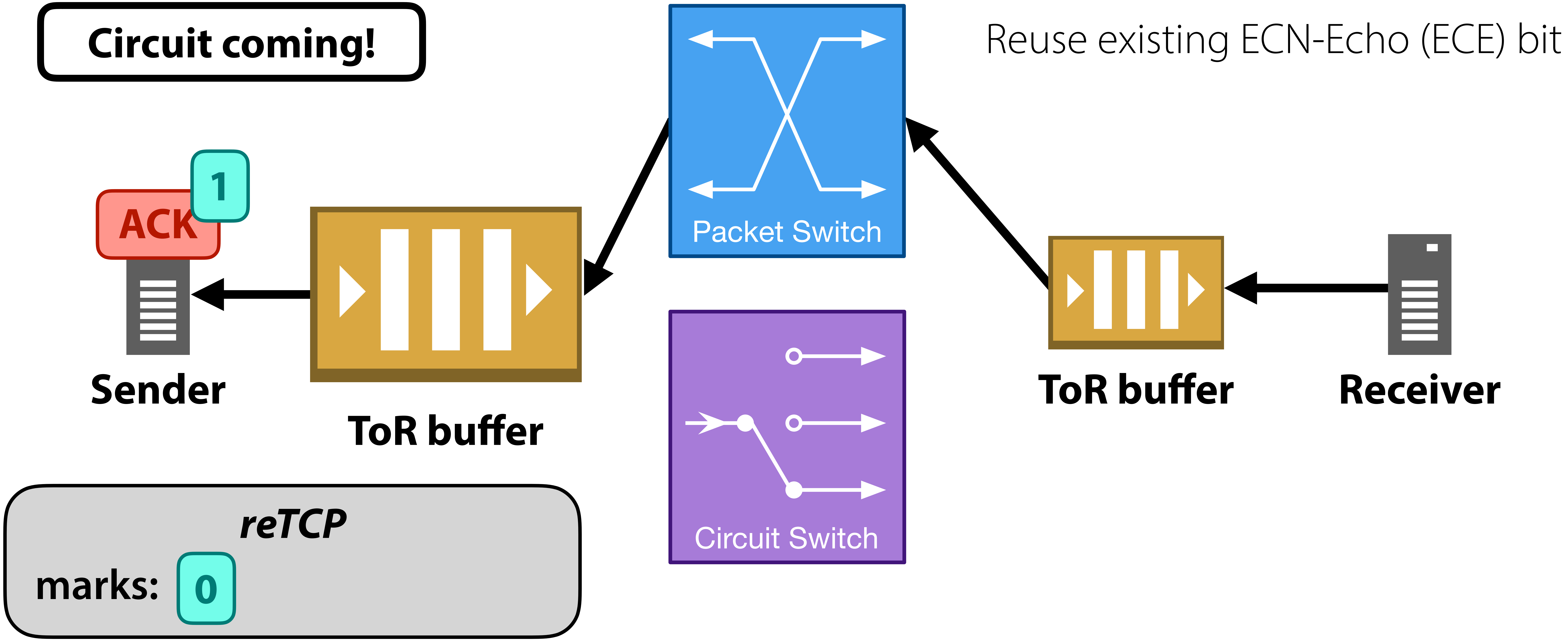

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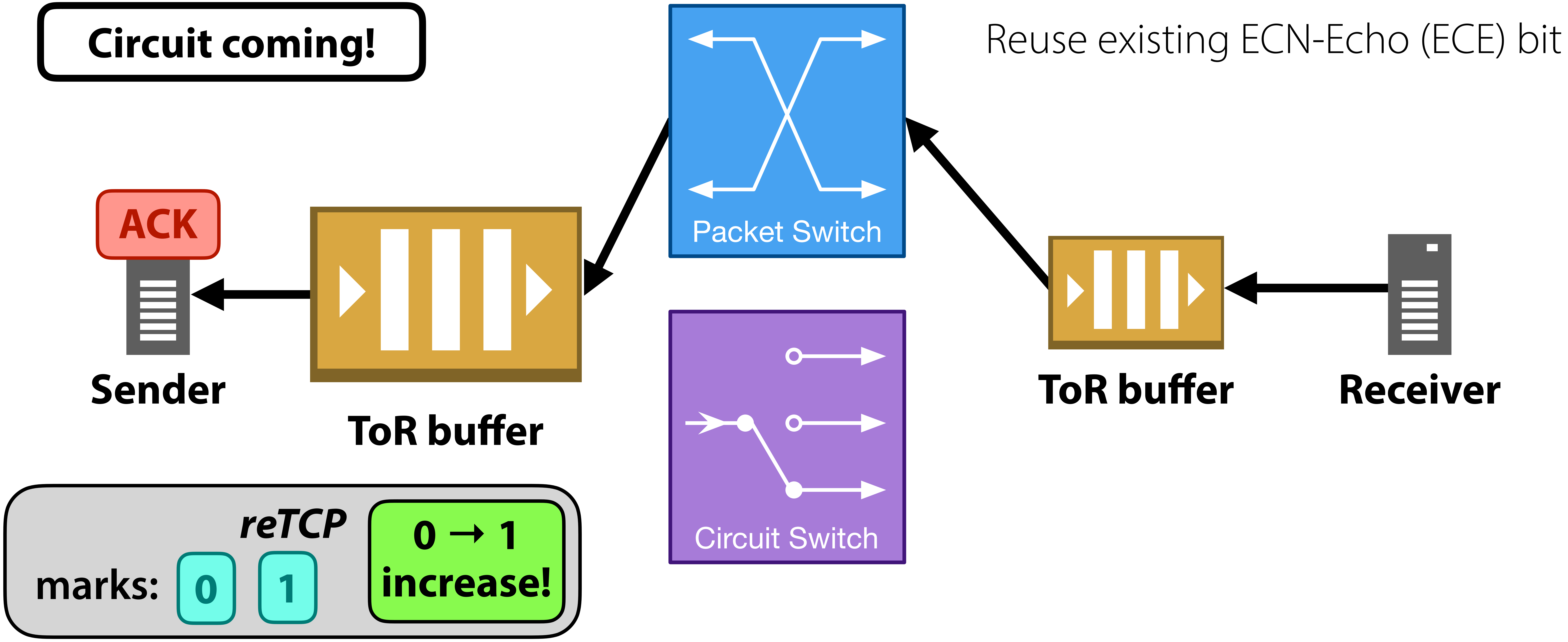

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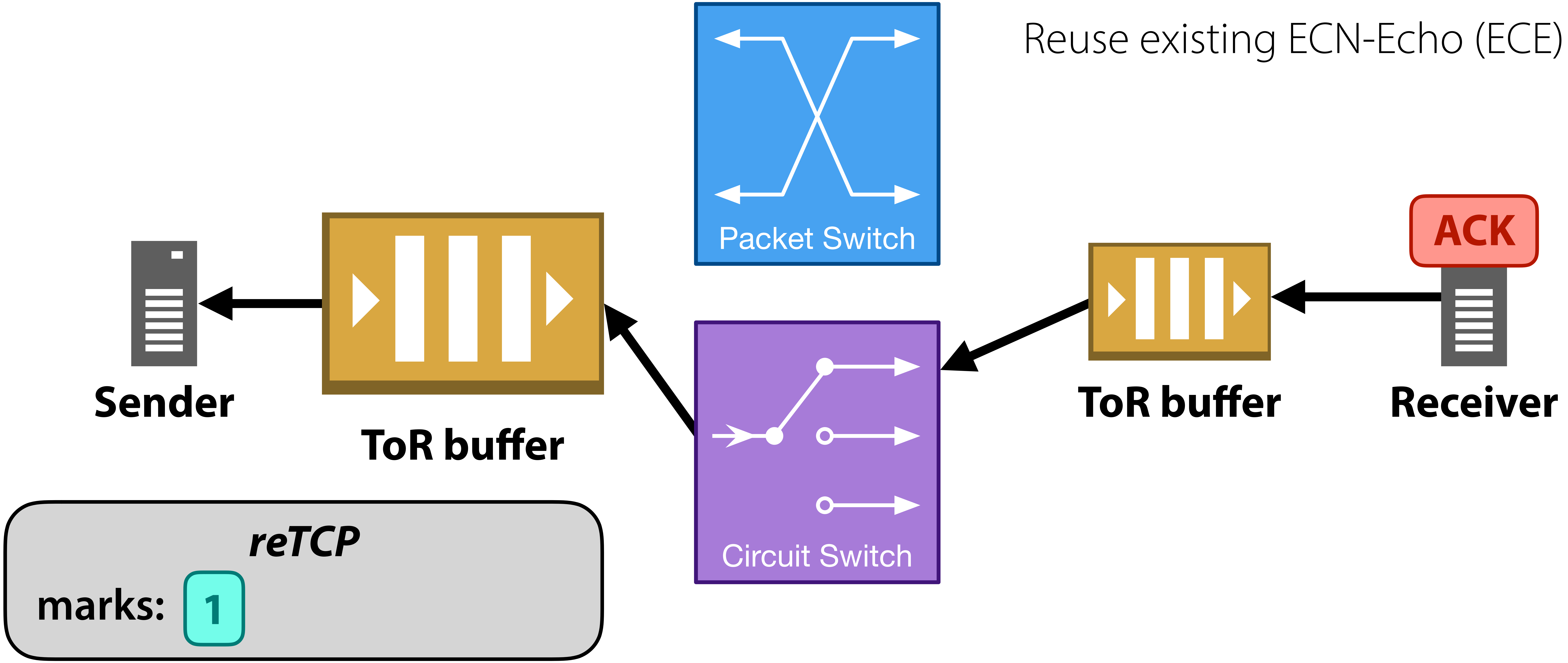

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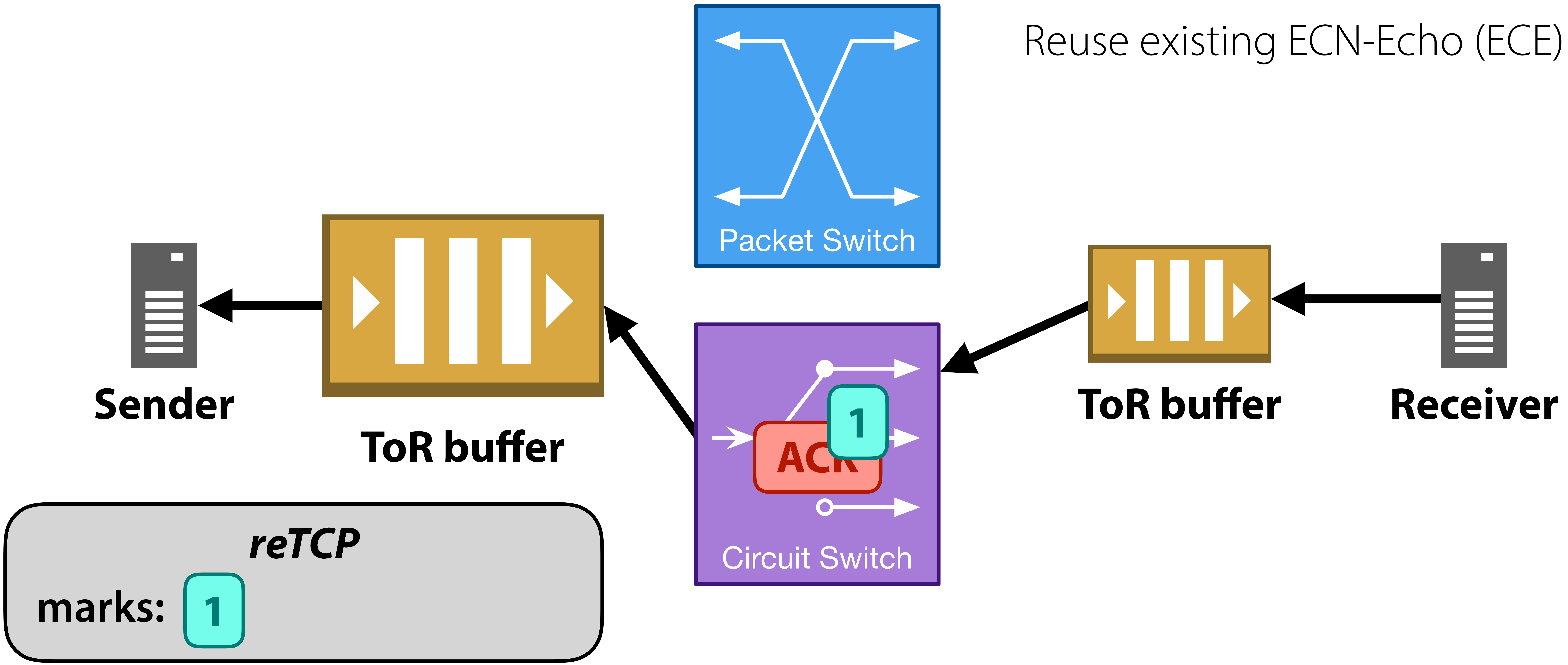

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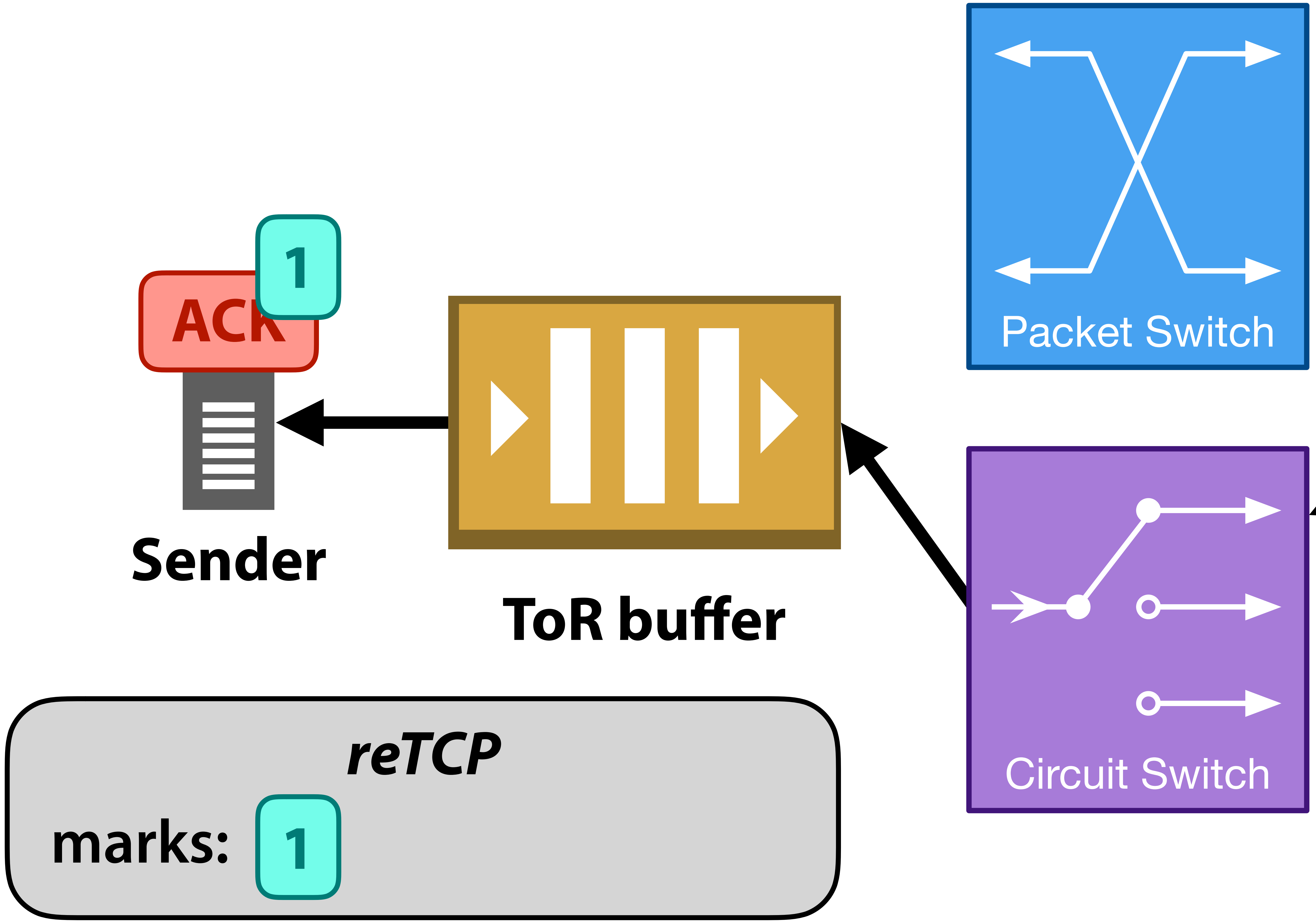

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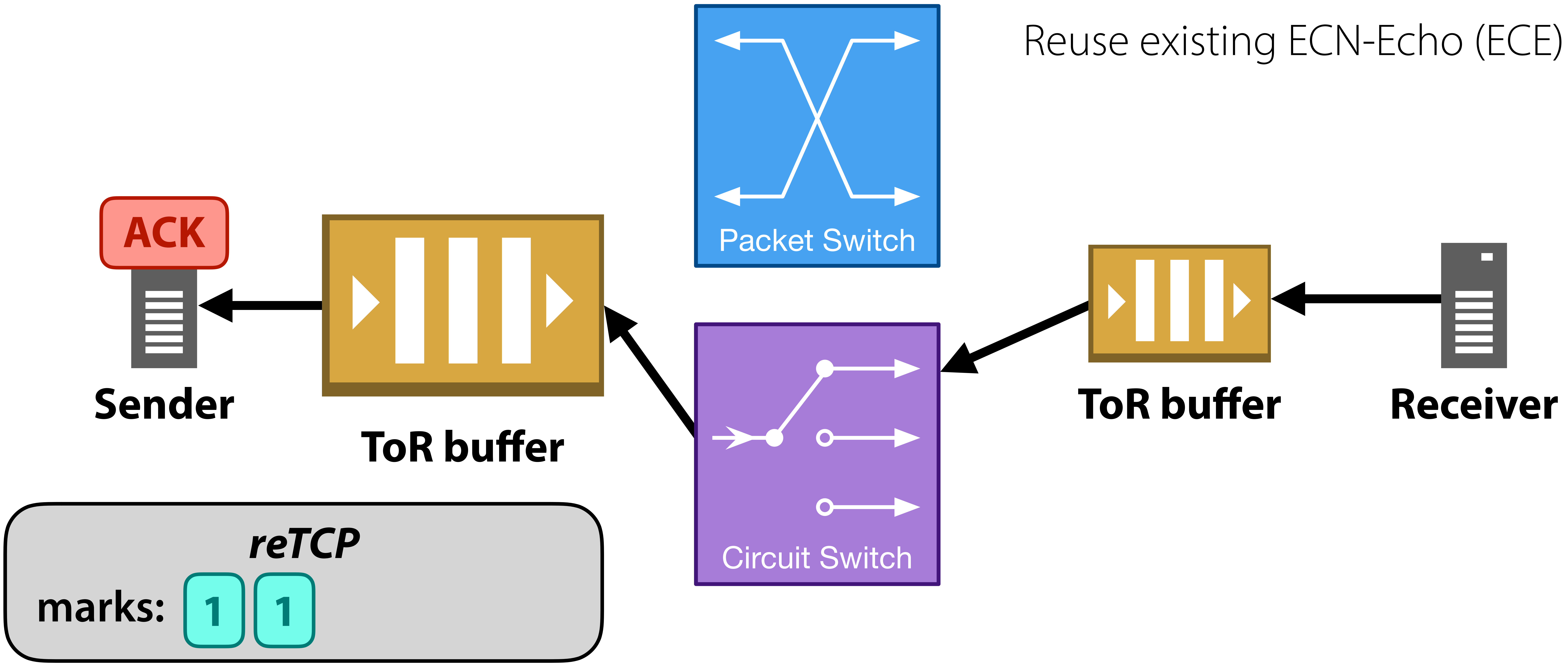

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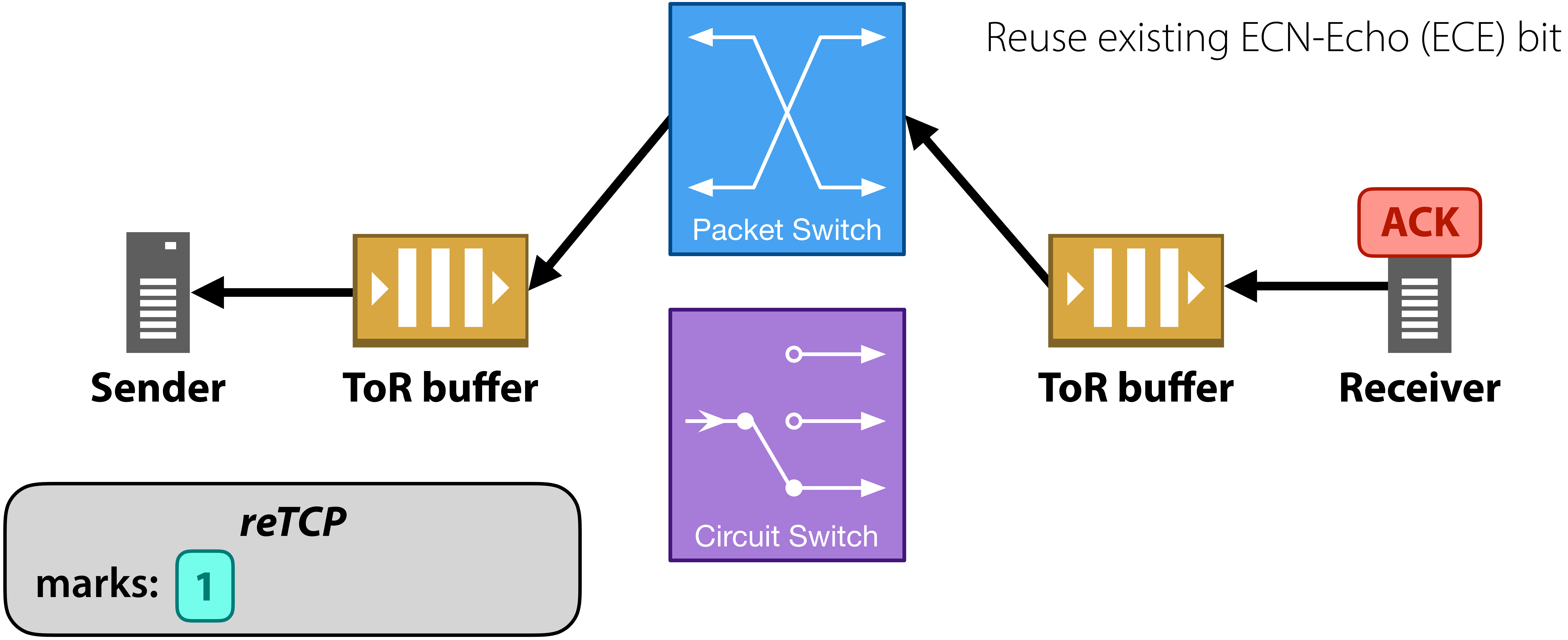

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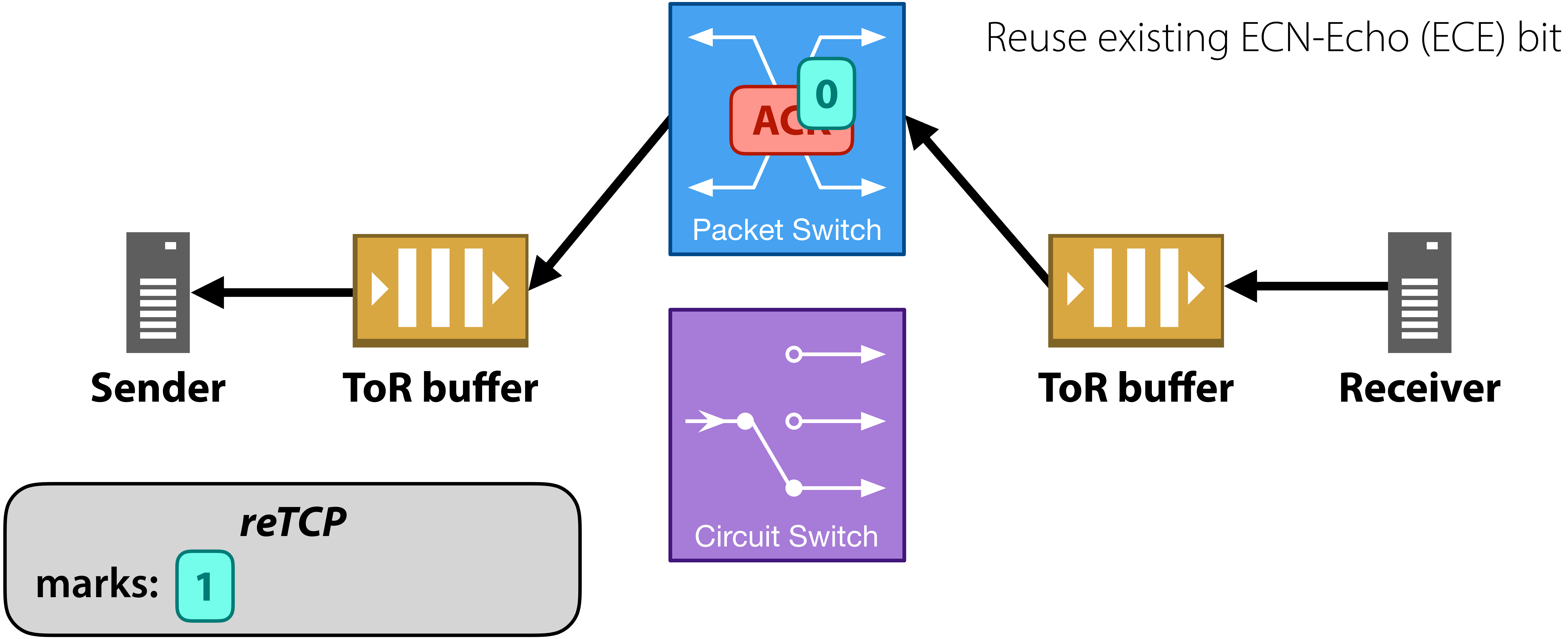

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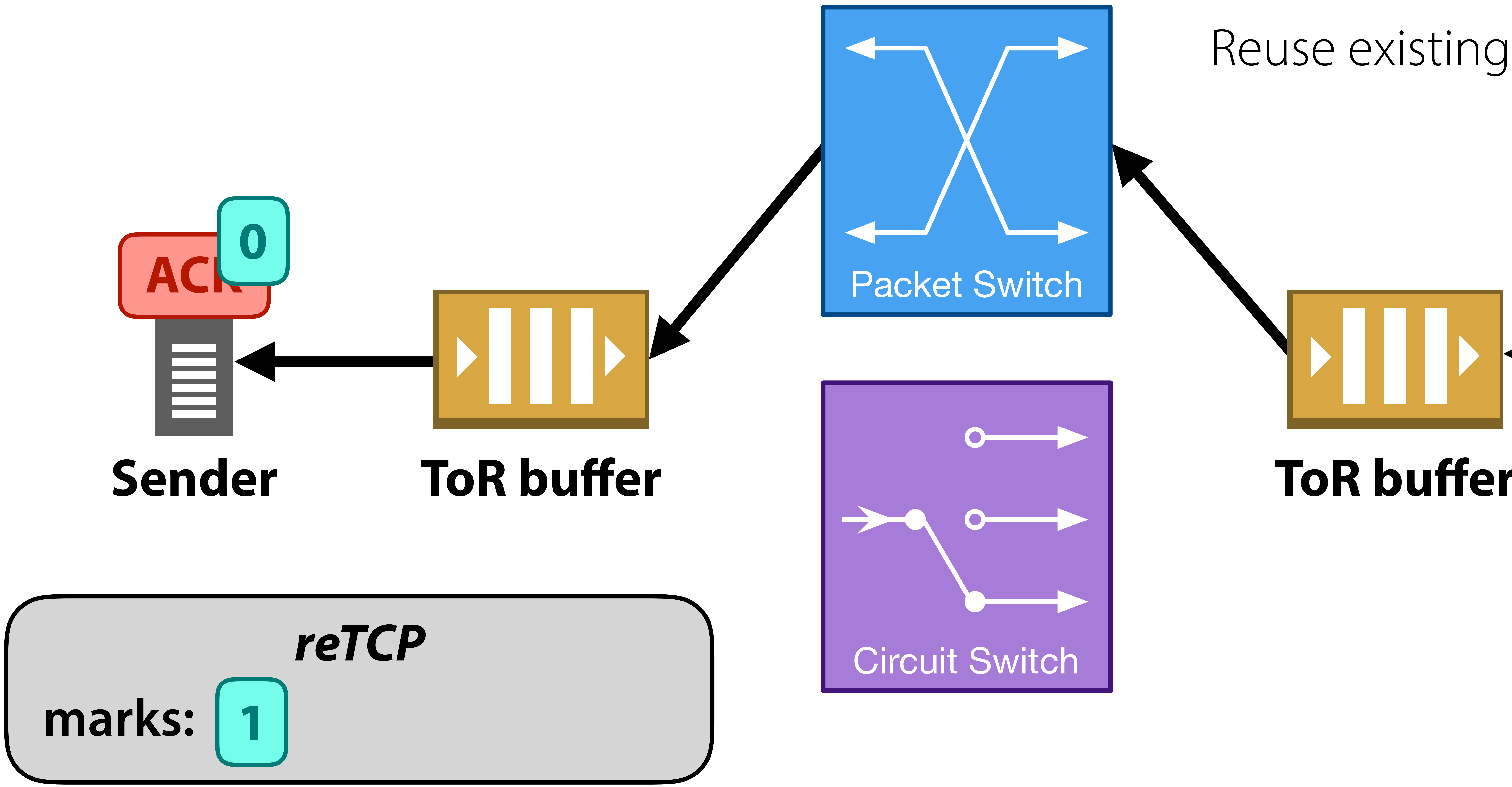

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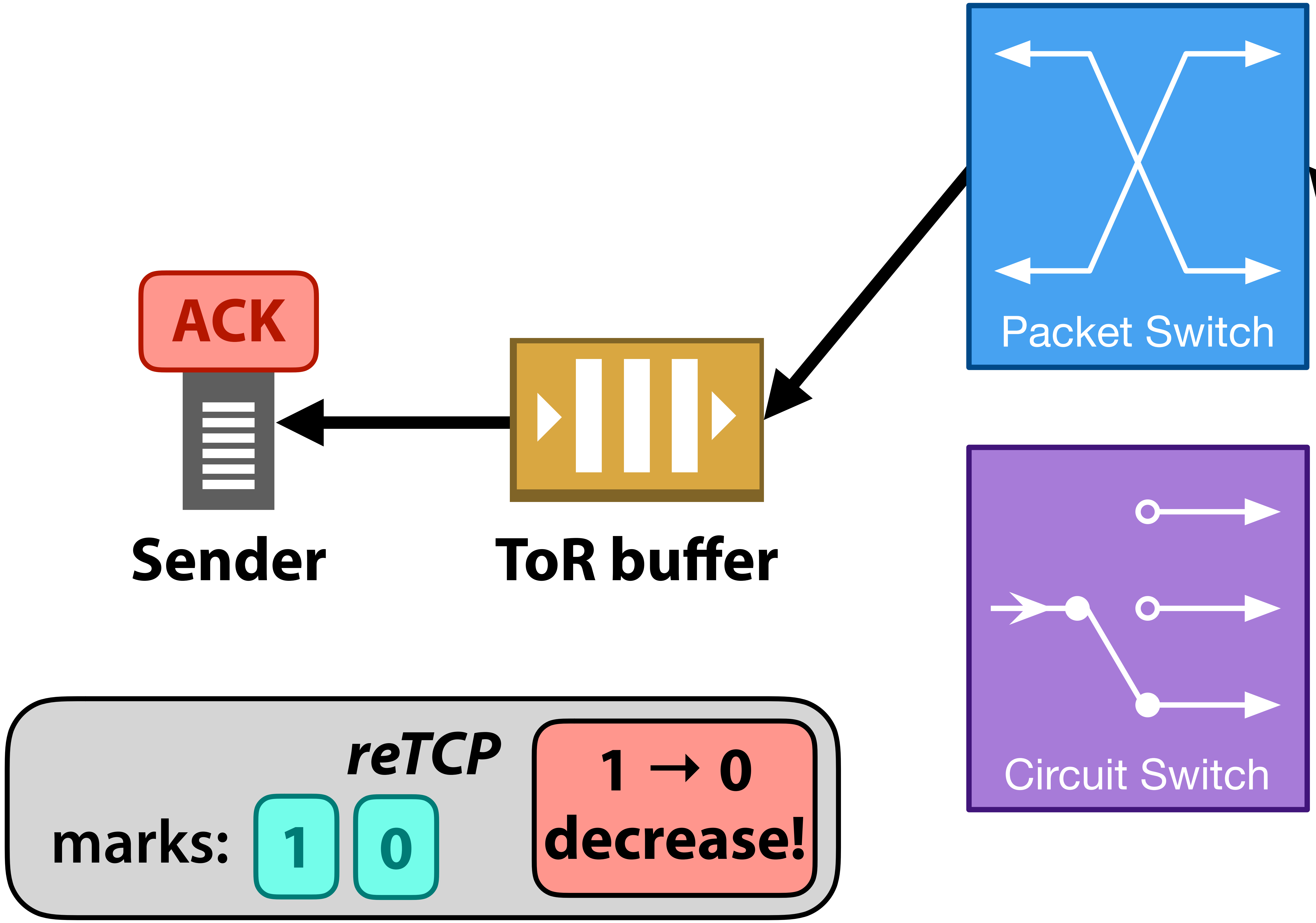


Single multiplicative increase/decrease

On 0 → 1 transitions:

`cwnd = cwnd` × α

On 1 → 0 transitions:

`cwnd = cwnd /` α

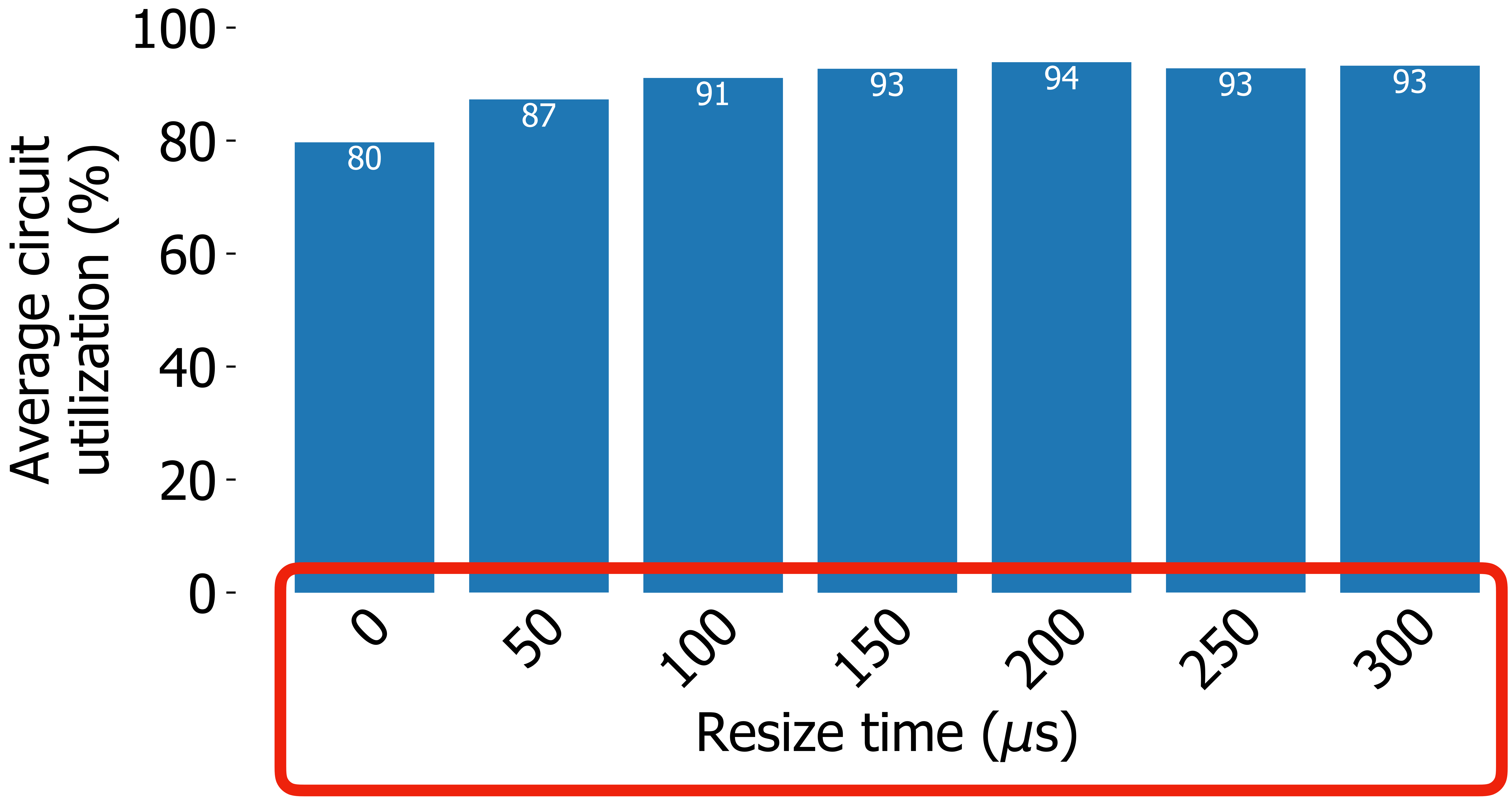
α depends on ratio of circuit BDP to ToR queue capacity:

- Circuit network BDP: 45 packets
- Small ToR queue capacity: 16 packets

We use α `= 2`

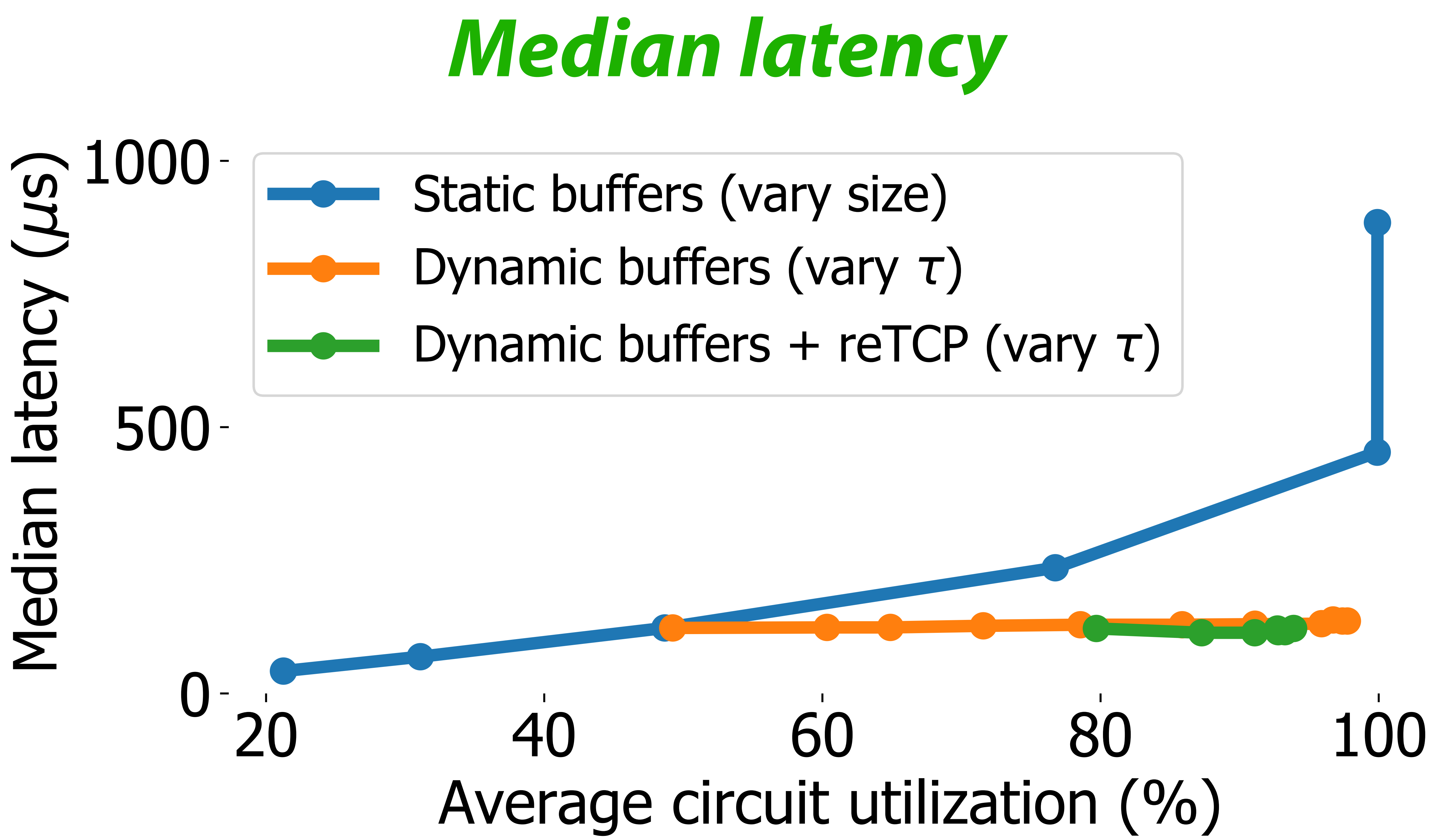
More advanced forms of feedback are possible

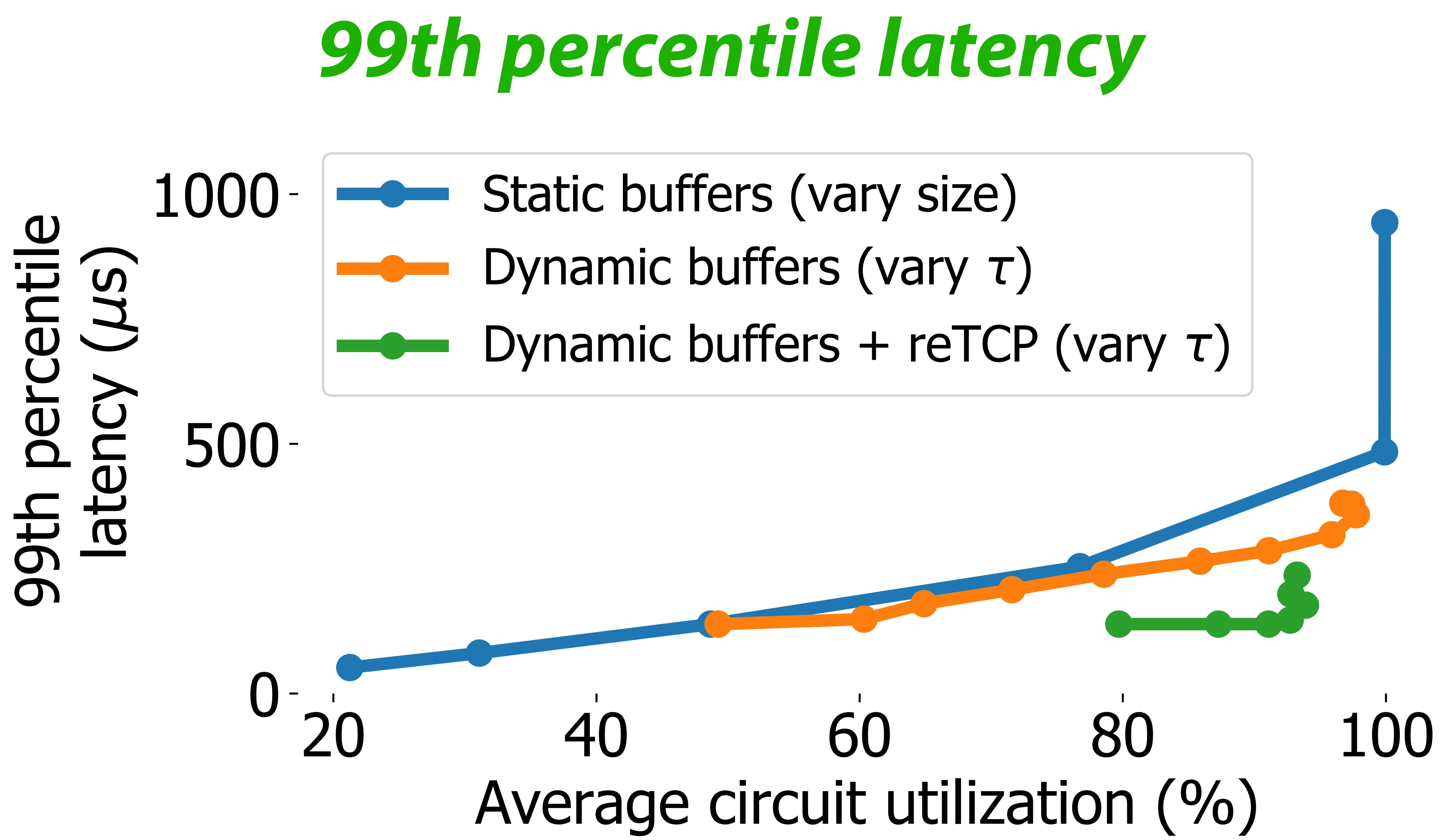
Dynamic buffers + reTCP achieve high utilization



16 flows from rack 1 to rack 2; packet network: 10 Gb/s; circuit network: 80 Gb/s;
small buffers: 16 packets; large buffers: 50 packets

Short prebuffer time means low latency





With 150μs of prebuffering, dynamic buffers + reTCP achieve 93% circuit utilization with an only 1.20x increase in tail latency

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Limitations and future work

Dynamic buffer resizing and reTCP are designed to be minimally invasive

- Higher performance may be possible by involving the end-host further

Our evaluation used a simple traffic pattern to isolate TCP's behavior

- Important to consider complex workloads as well

Is TCP the right protocol for hybrid networks?

Summary: Adapting TCP for RDCNs

Bandwidth fluctuations in reconfigurable datacenter networks break TCP's implicit assumption of relative network stability

Two techniques to ramp up TCP during short-lived circuits

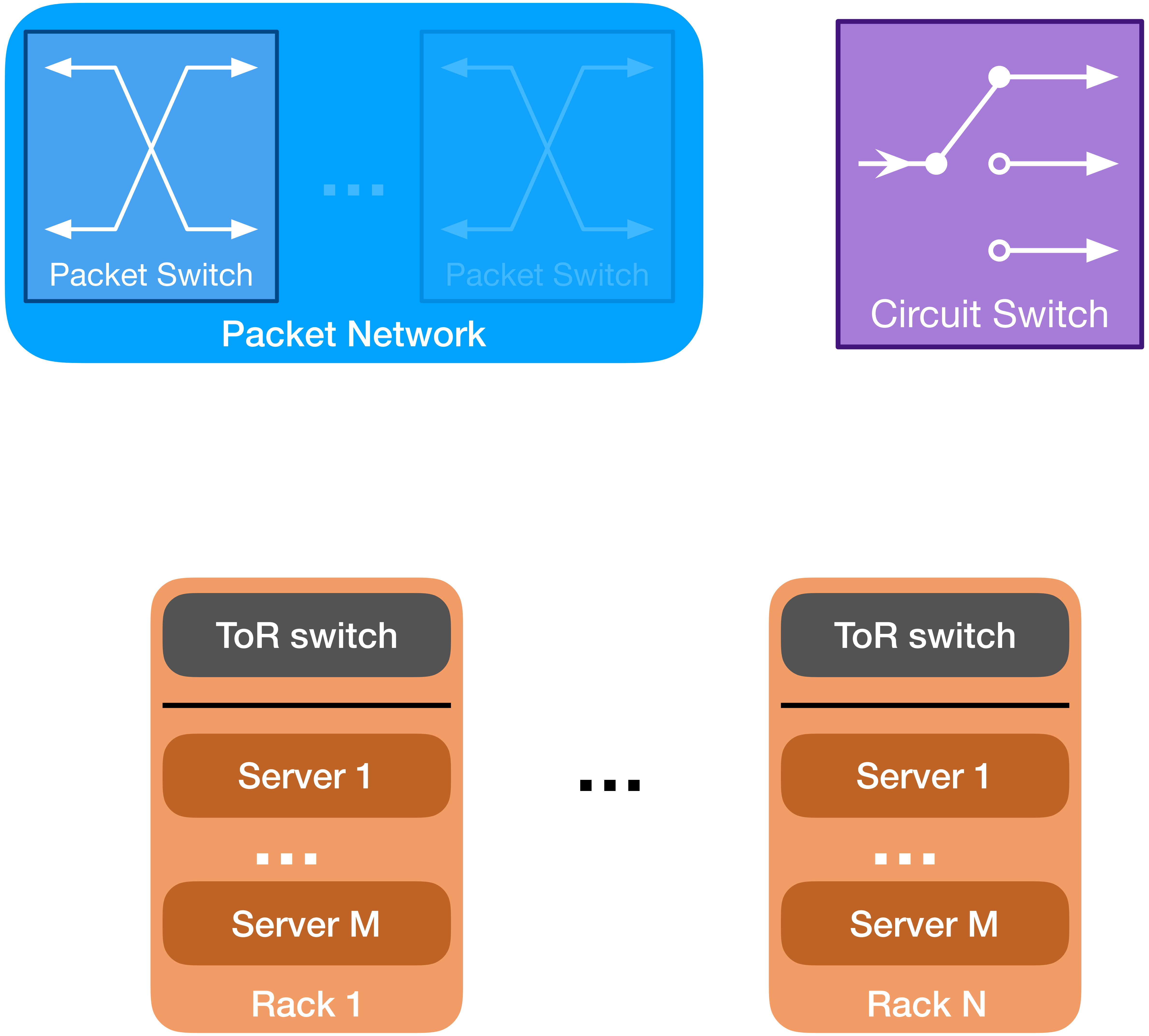
- ***Dynamic buffer resizing:*** Adapt ToR queues to packet or circuit network
- ***reTCP:*** Ramp up aggressively to fill new queue capacity

Etalon emulator open source at: ***github.com/mukerjee/etalon***

Christopher Canel ~ ccanel@cmu.edu

Thank you!

One more thing: *Etalon* emulator



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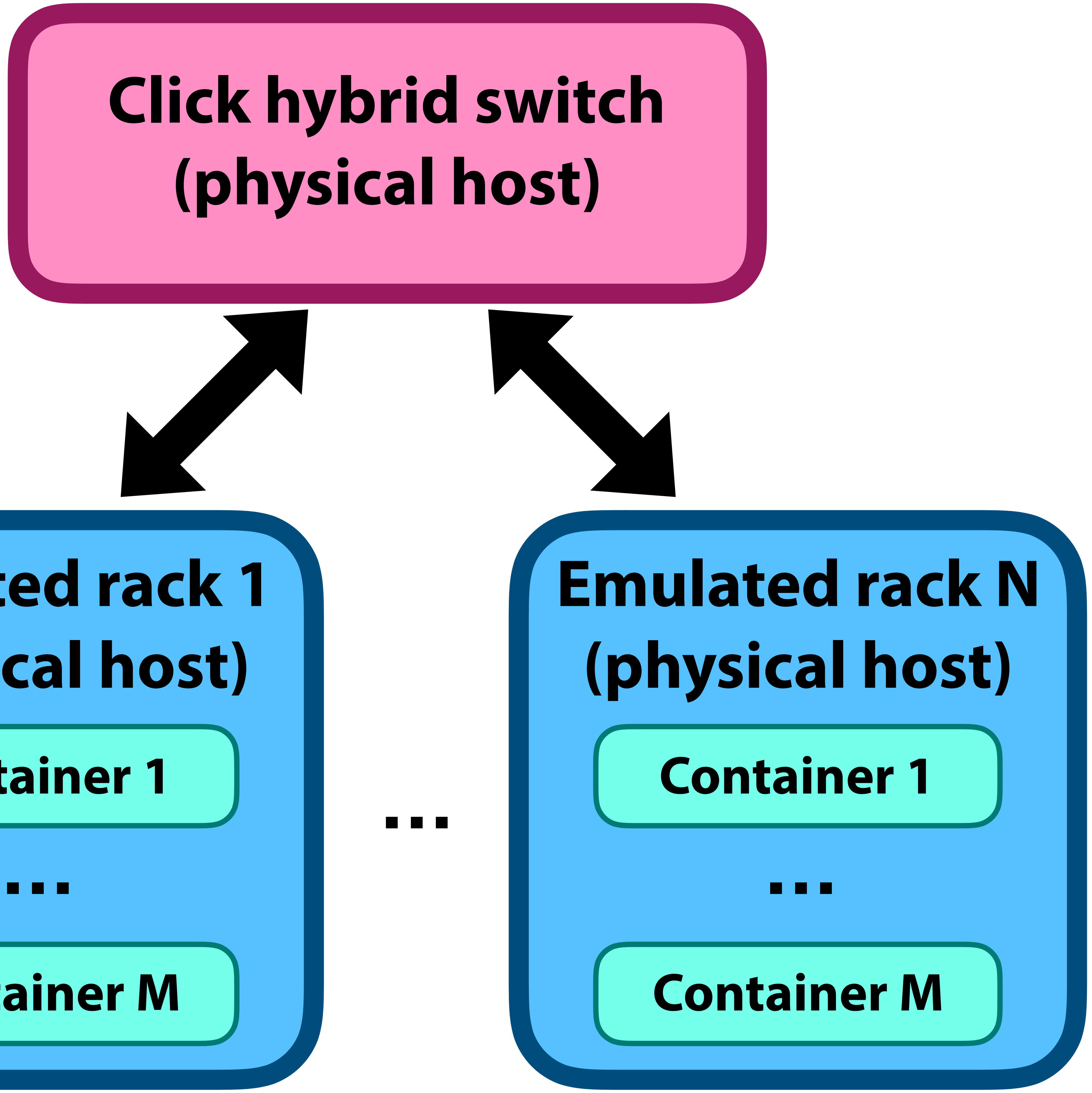


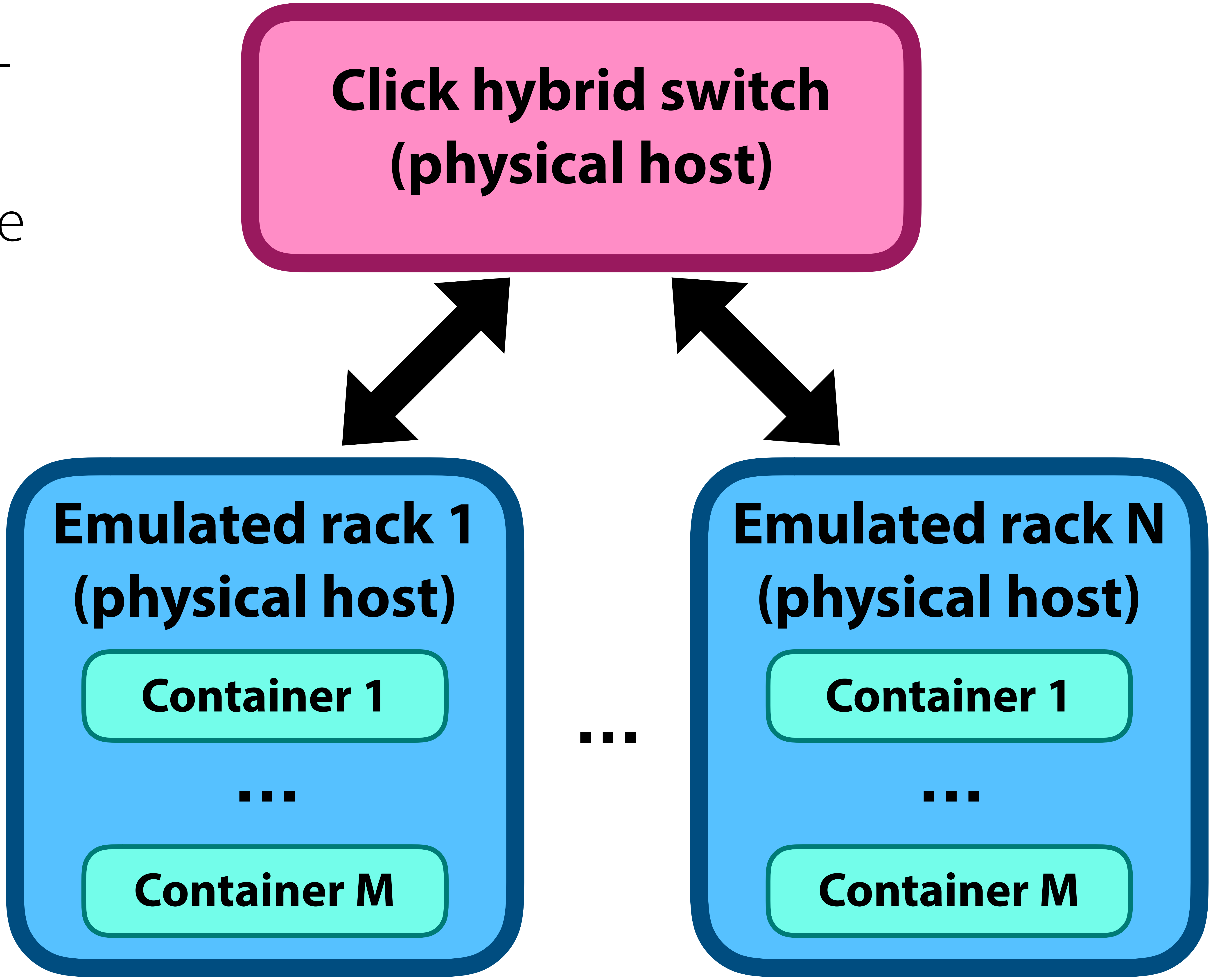
One more thing: *Etalon* emulator

Use ***time dilation*** to emulate high-bandwidth links

- "slows down" rest of the machine
- ***libVT:*** Catches common syscalls

Flowgrind to generate traffic

Strobe schedule: Each rack pair gets a circuit for an equal share



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