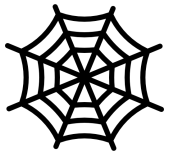
OrbWeaver: 

Using IDLE Cycles in Programmable Networks for Opportunistic Coordination

Liangcheng Yu, John Sonchack, Vincent Liu

Networks are woven from packets

- A primary goal of computer networks: ***deliver packets***
  - ***User application***: video streaming, web browsing, file transfer…
  - ***Non-user application***: control messages, probes about network state, keep alive heartbeats…

Networks are woven from packets

- A primary goal of computer networks: ***deliver packets***
  - ***User application***: video streaming, web browsing, file transfer…
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- Often, two classes of traffic ***multiplex*** the same network

When introducing a new in-band application…

To consume ***extra BW*** for ***fidelity*** *(of the control application)*, or not to?

- *Time synchronization*: clock-sync rate → precision
- *Failure detector*: keep alive message frequency → detection speed
- *Congestion notification*: signaling data and rate → measurement accuracy

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Is the trade-off between fidelity and overhead necessary?

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-
-

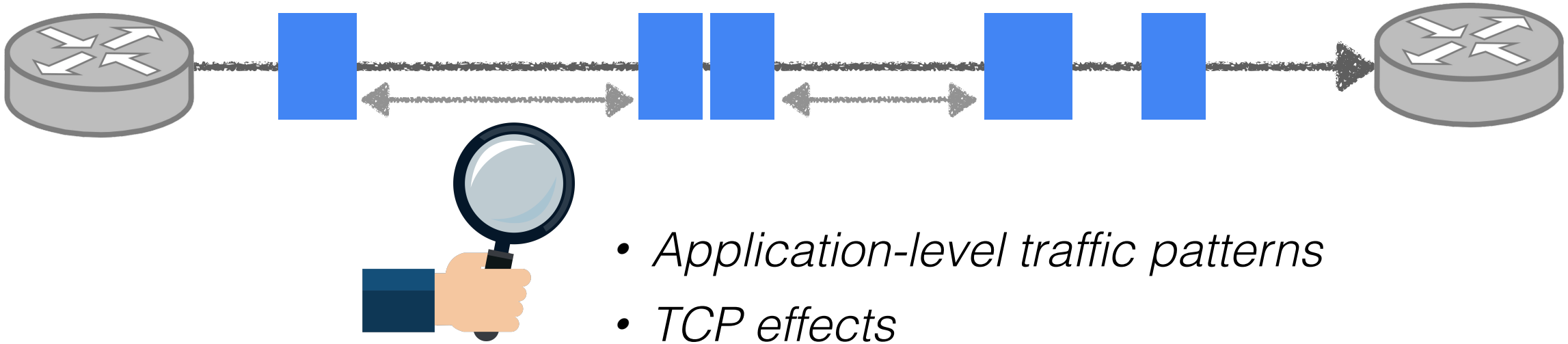
Can we coordinate at **high-fidelity** with a **near-zero cost** (to usable bandwidth, latency…)?

Can we coordinate at **high-fidelity** with a **near-zero cost** to usable bandwidth and latency?

Idea: Weaved Stream

- Exploit ***every gap*** (*O(100ns)*) between user packets opportunistically
- Inject customizable ***IDLE packets*** carrying information across devices

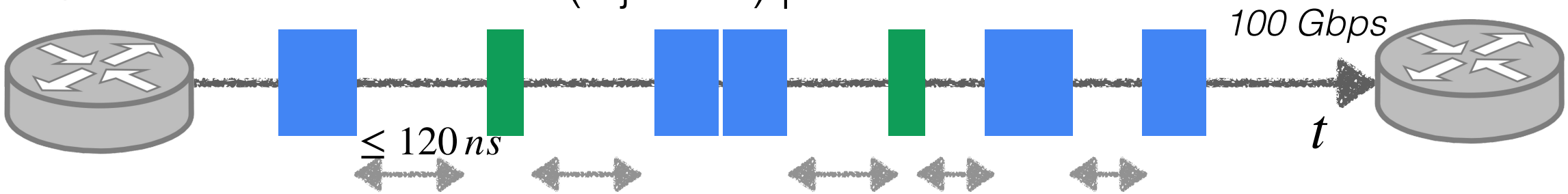
Opportunity: $< \mu s$ gaps are prevalent



- *Application-level traffic patterns*
- *TCP effects*
- *Structural asymmetry*
- *…*

Abstraction: weaved stream

- Union of **user** and **IDLE** (injected) packets:



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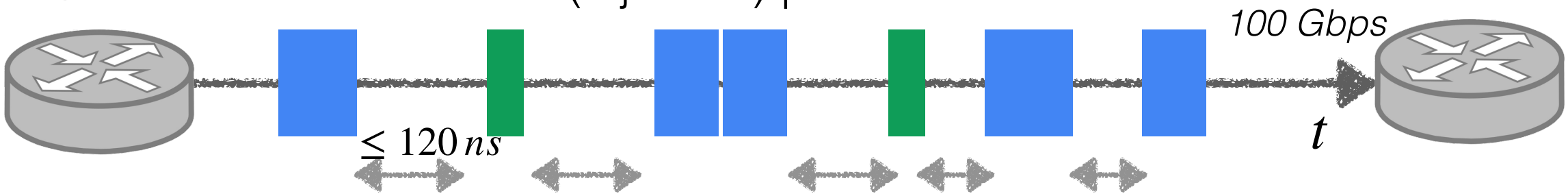

[R1 Predictability] Interval between ***any two consecutive*** packets $\leq \tau$

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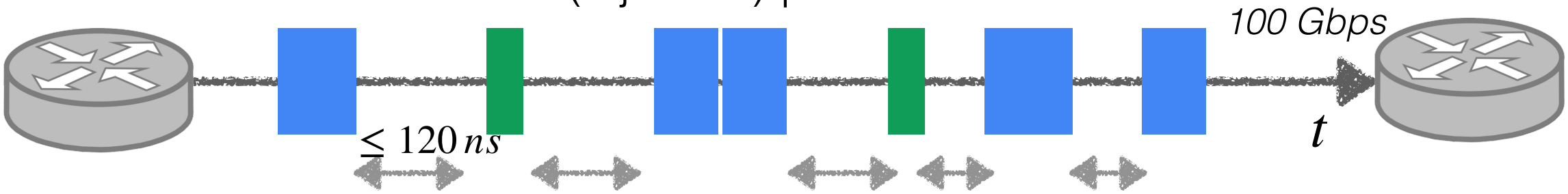


[R1 Predictability] Interval between ***any two consecutive*** packets $\leq \tau$

[R2 Little-to-zero overhead] Not impact user packets or power draw

Abstraction: weaved stream

- Union of user and IDLE (injected) packets:

Implement many ***in-network applications***
(failure detection, clock sync, congestion notification…)
for free!

1. [Predictability] Interval between ***any two consecutive*** packets $\leq \tau$
2. [Little-to-zero overhead] Weaved IDLE packets not impact user packets

Abstraction: weaved stream

- Union of **user** and **IDLE** (injected) packets:

1. Interv
2. Weaved IDLE packets incur ***little-to-zero*** impact to user packets

Crazy idea?

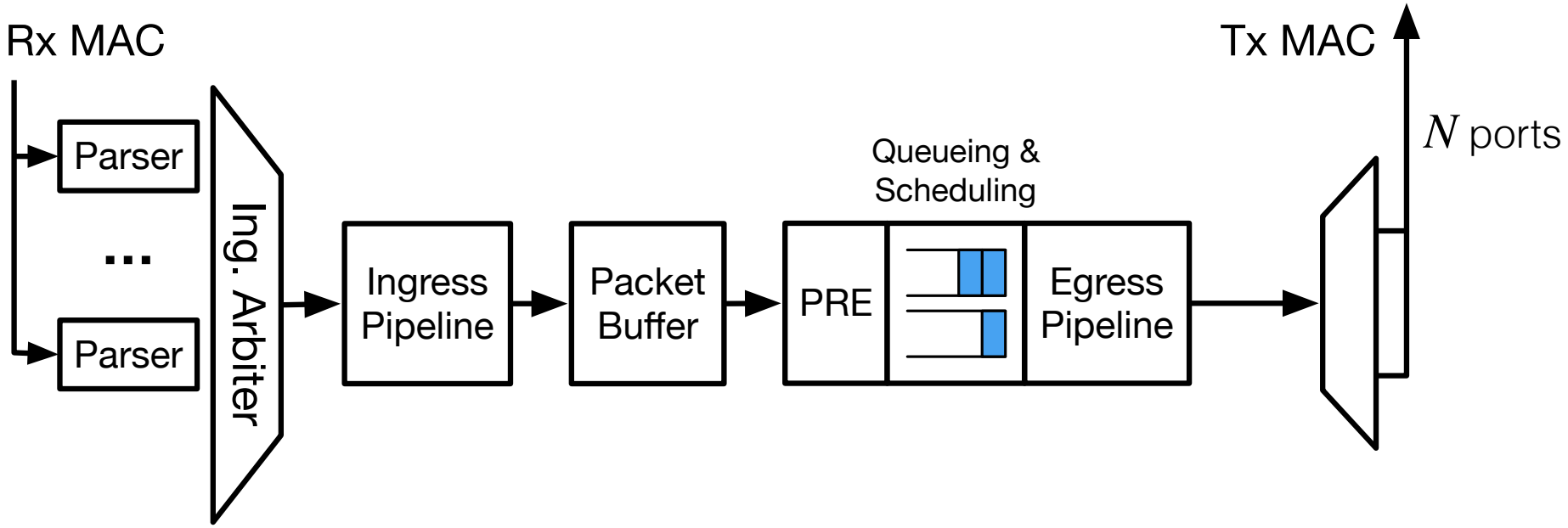
Extending IDLE characters to higher layers

- Data plane packet generator
- Replication engine
- Data plane programmability
- Flexible switch configuration (priorities, buffers…)

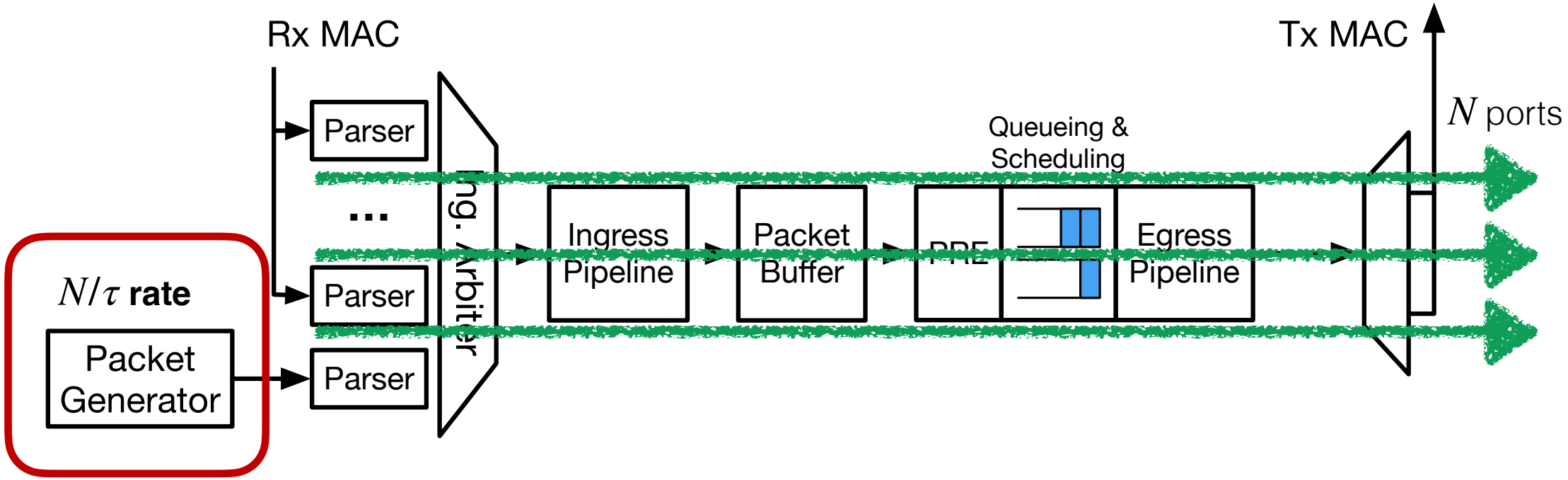
Outline

1. Switch data plane architecture
2. Weaved stream generation
3. OrbWeaver applications

RMT switch model



Naive weaved stream generation



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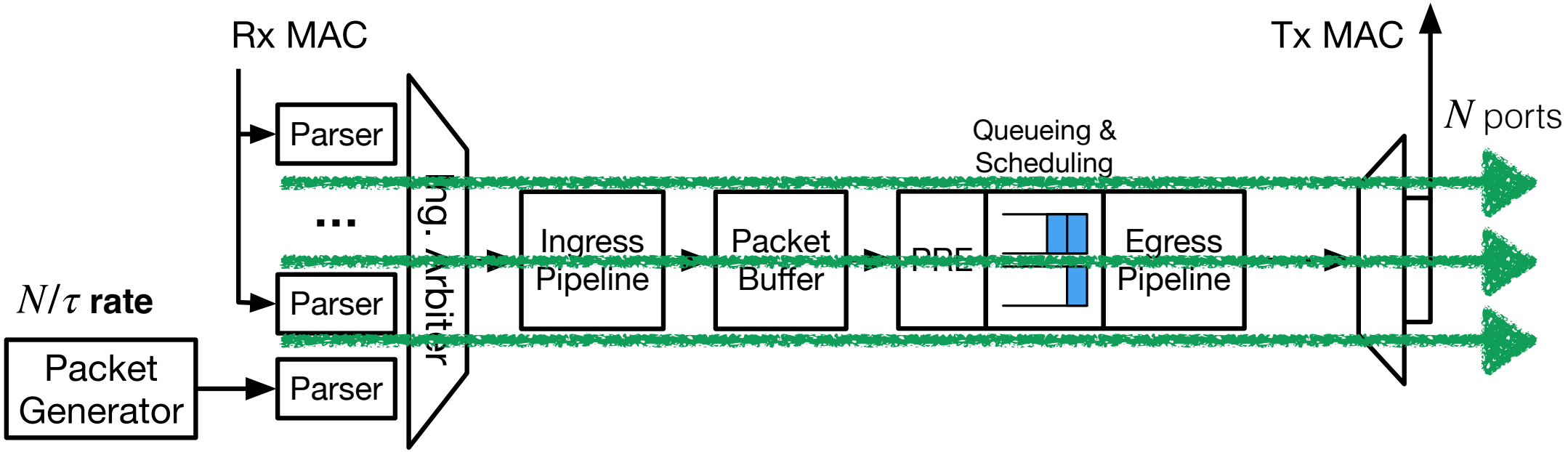
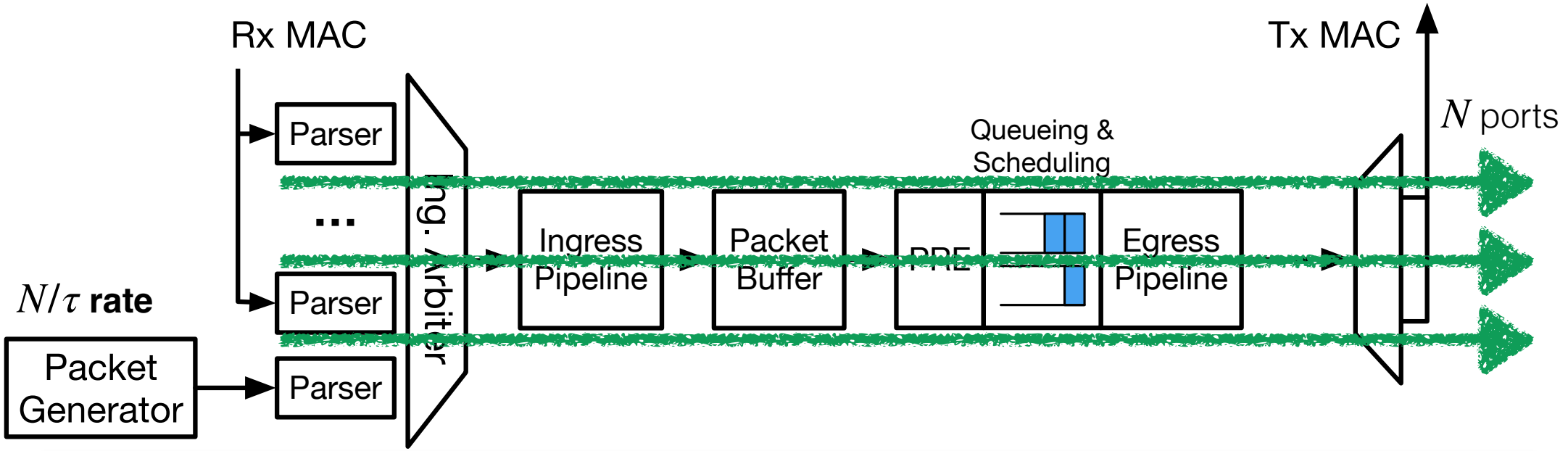


Predictability even there is no user traffic ✅

Problems with blind injection



Scalability: overwhelm packet generator capacity to satisfy target rate

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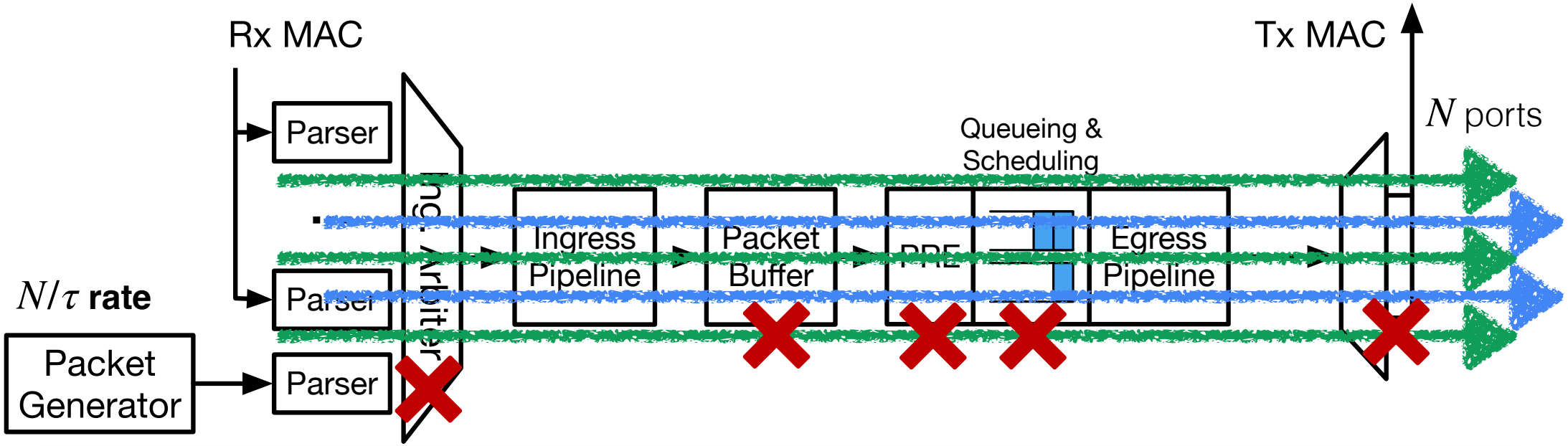
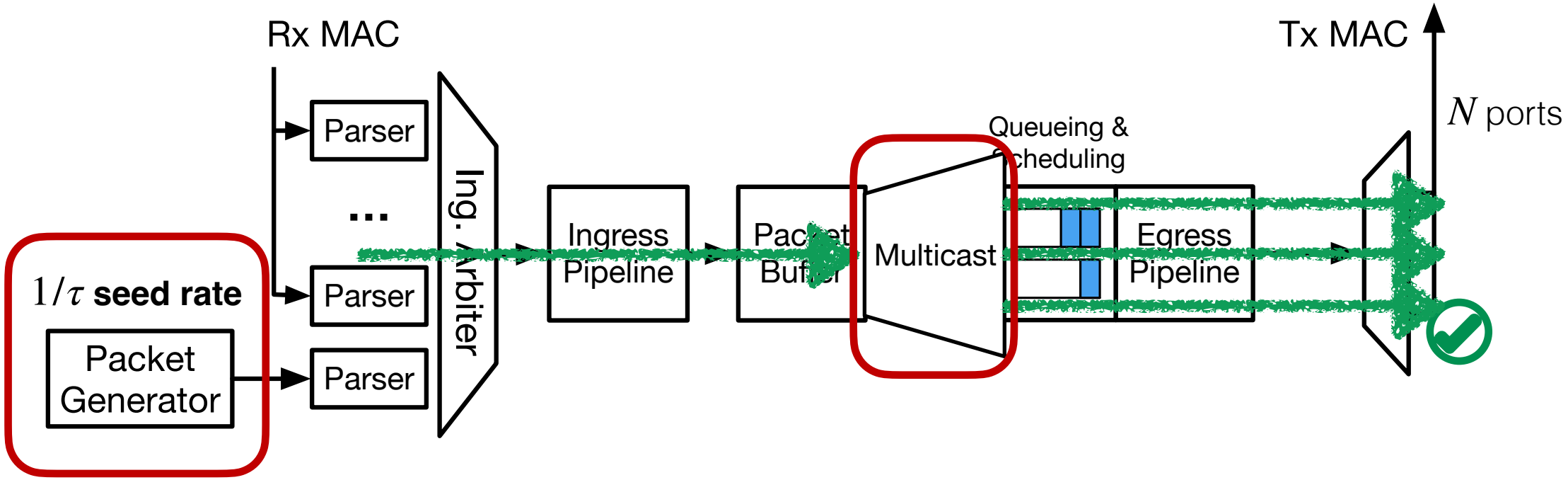


Scalability: overwhelm packet generator capacity to satisfy target rate

Interference upon cross-traffic: throughput, latency, or loss of user traffic!

Amplify seed stream



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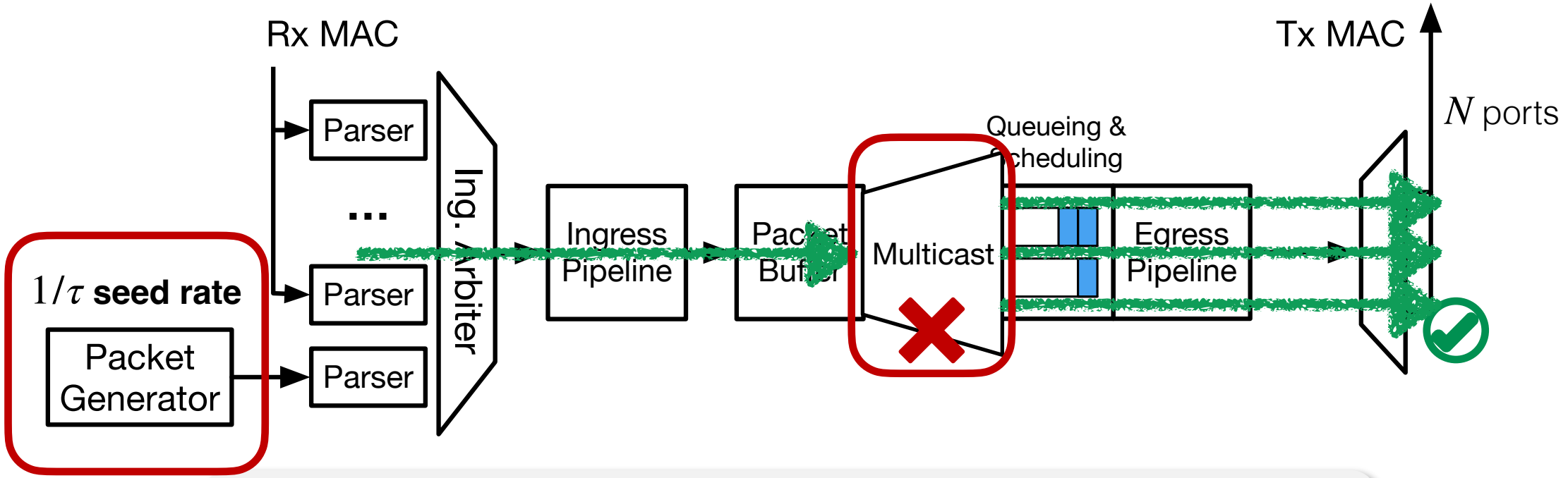
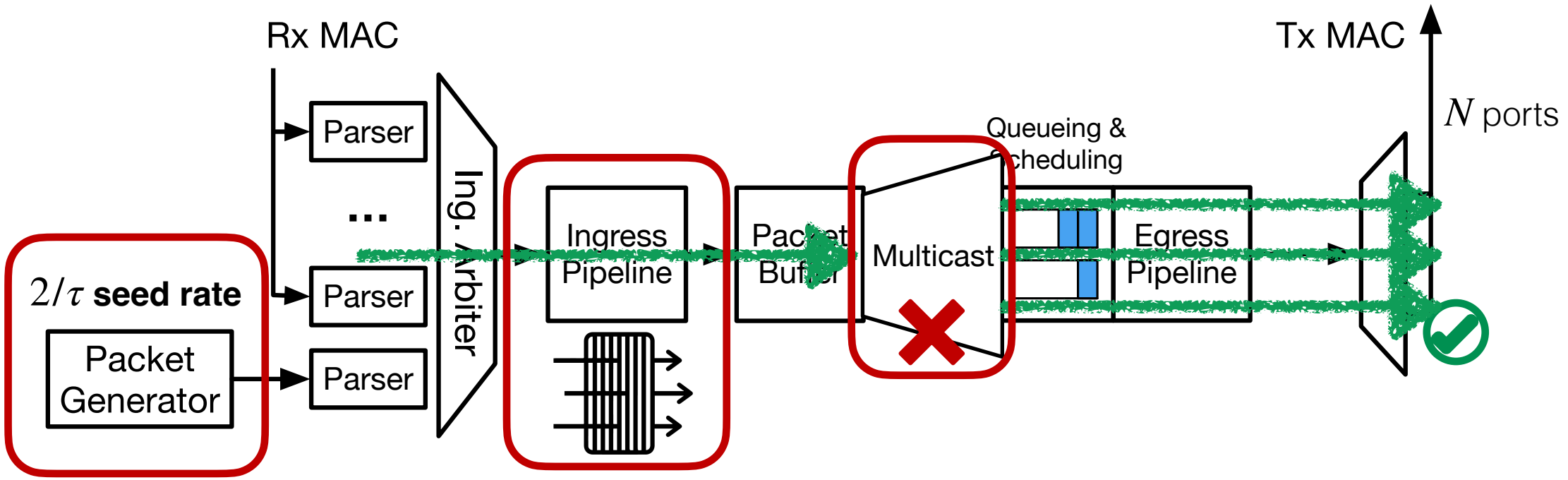


Monopolize usage and waste PRE packet-level BW!

Amplify seed stream on demand



Selective filtering

- (Tiny) sending history state of past cycle to each egress port
- Create an IDLE packet to a port ***only if we need an IDLE packet***

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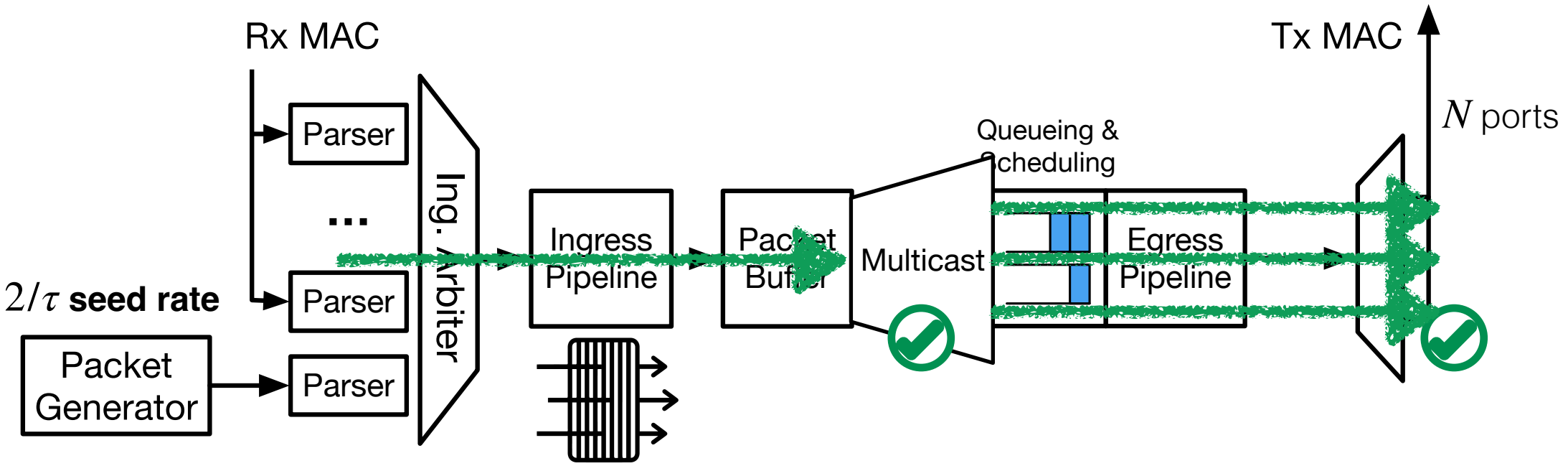

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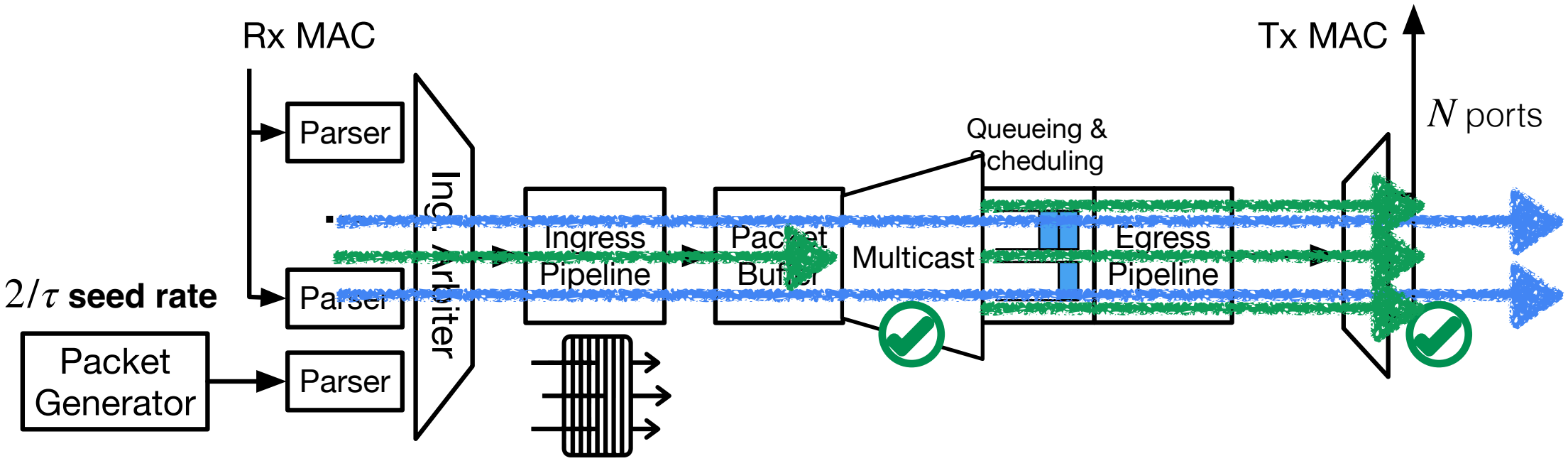
Cross-traffic contention



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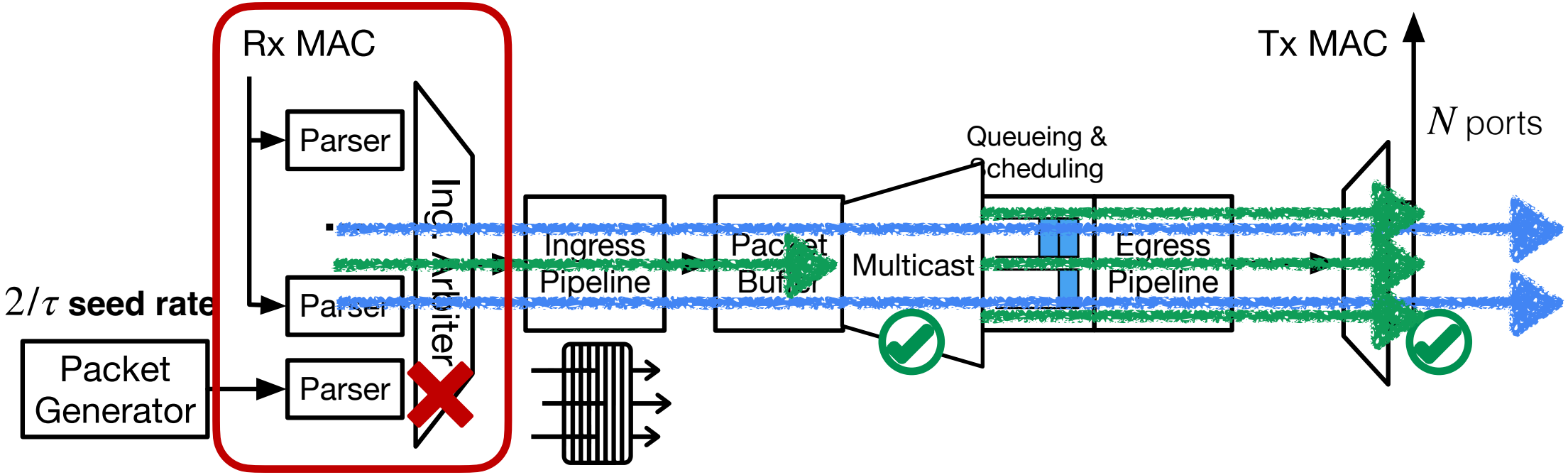
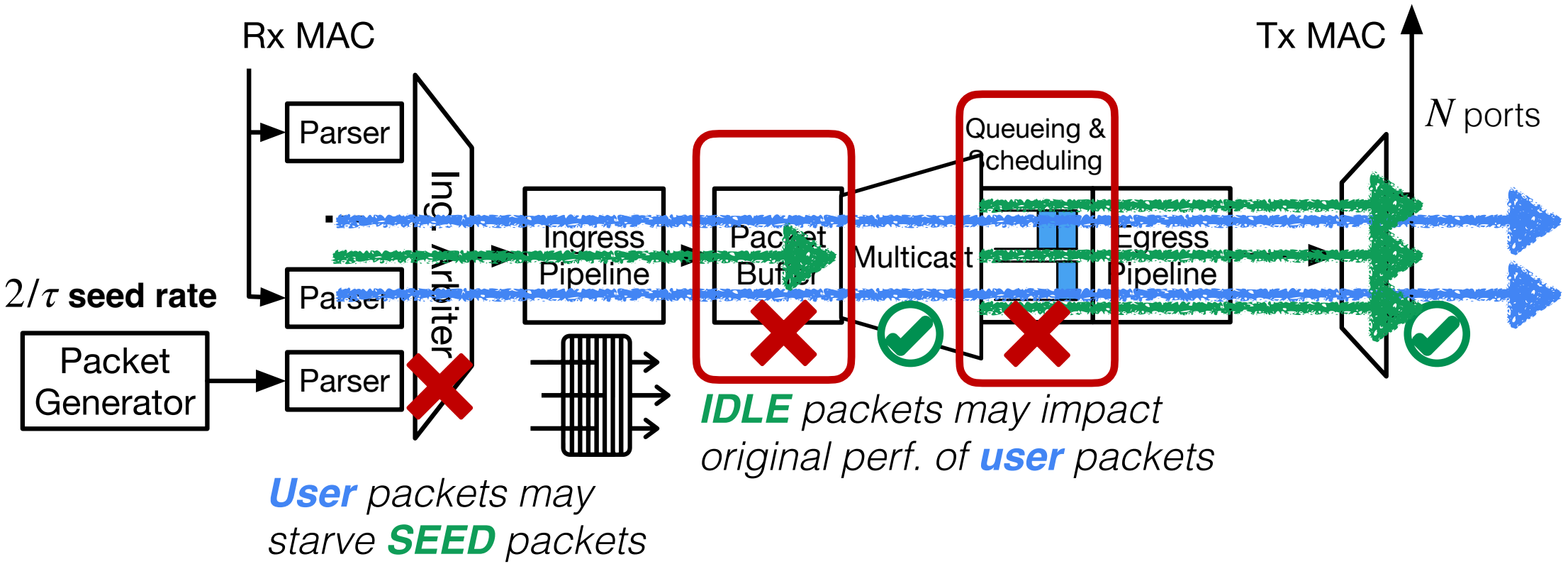
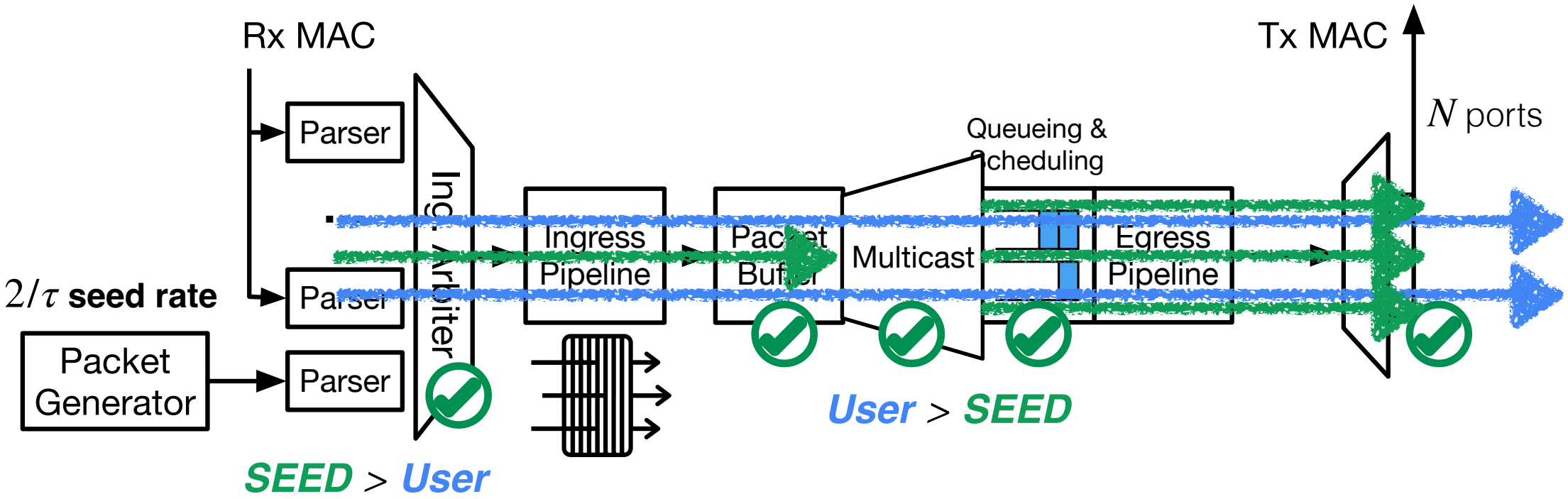


User *packets may starve* ***SEED*** *packets*

Cross-traffic contention



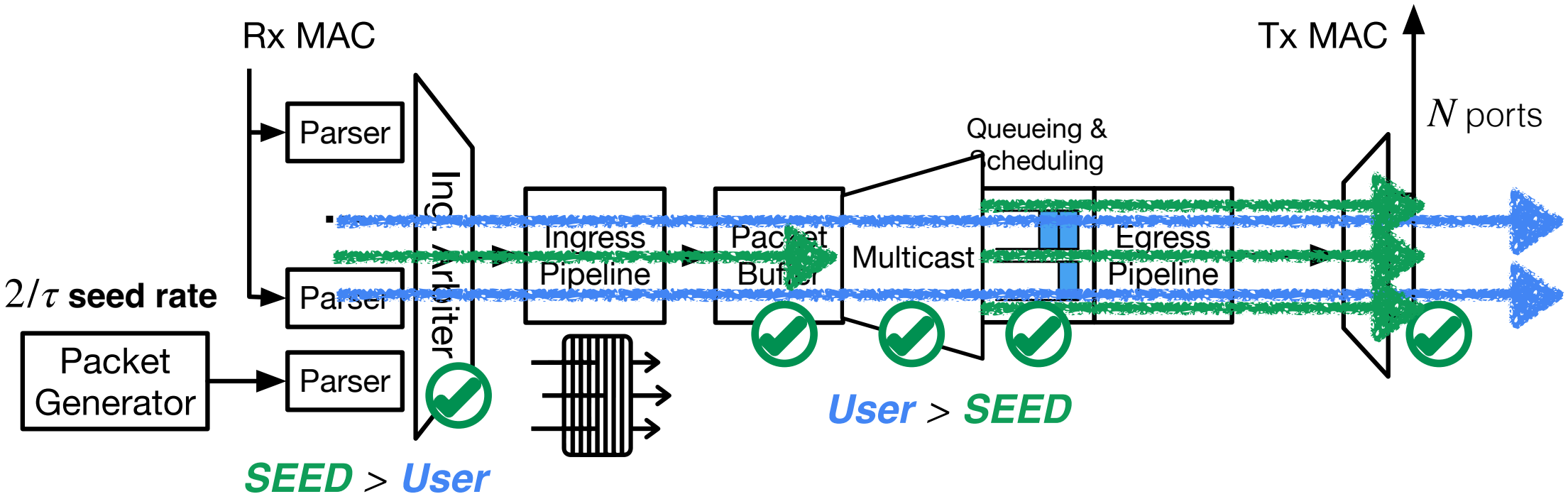
Preventing contention



Rich configuration options for priorities and buffer management

- *Zero impact of weaved stream predictability*
- *Zero impact of **user traffic** throughput or buffer usage*

Preventing contention

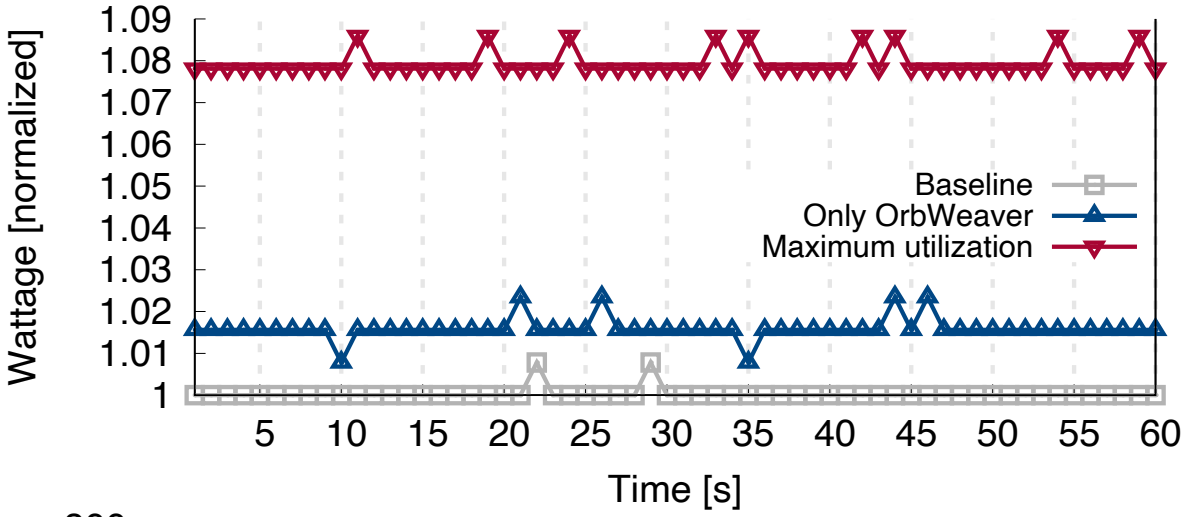


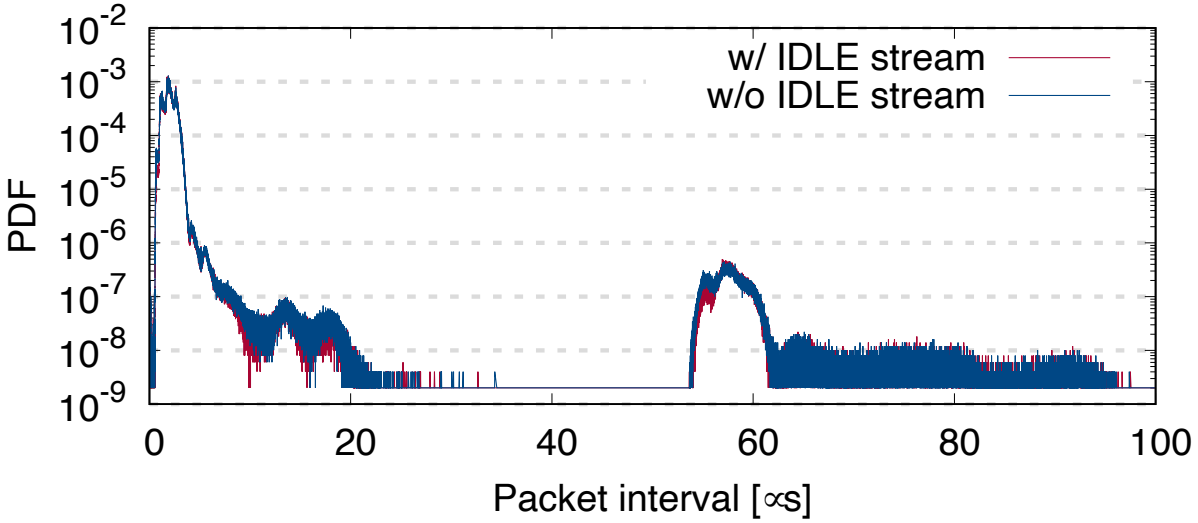
Rich configuration options for priorities and buffer management

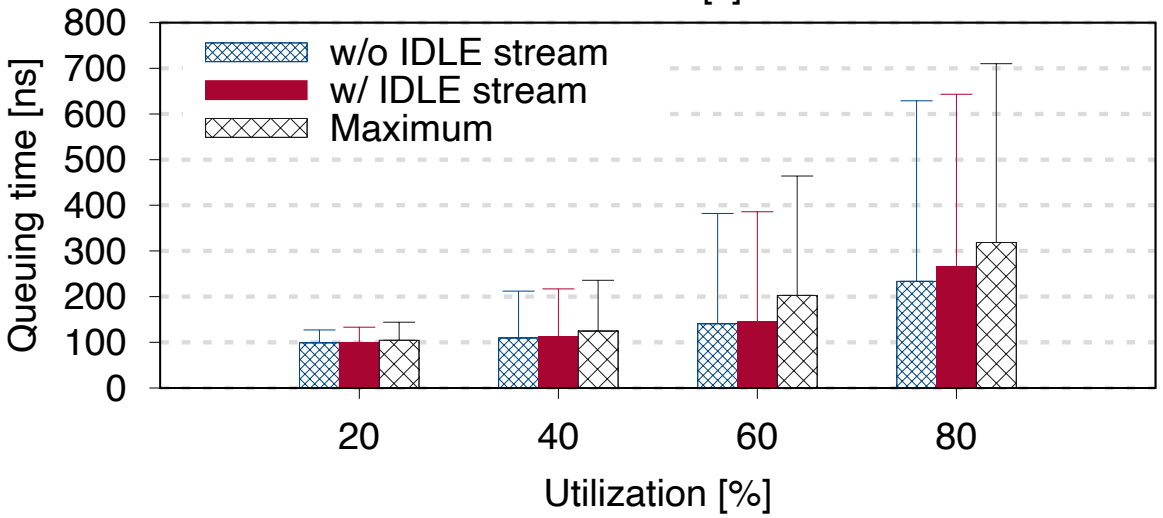
- *Zero impact of weaved stream predictability*
- *Zero impact of **user traffic** throughput or buffer usage*
- *Negligible impact of latency of **user packets***

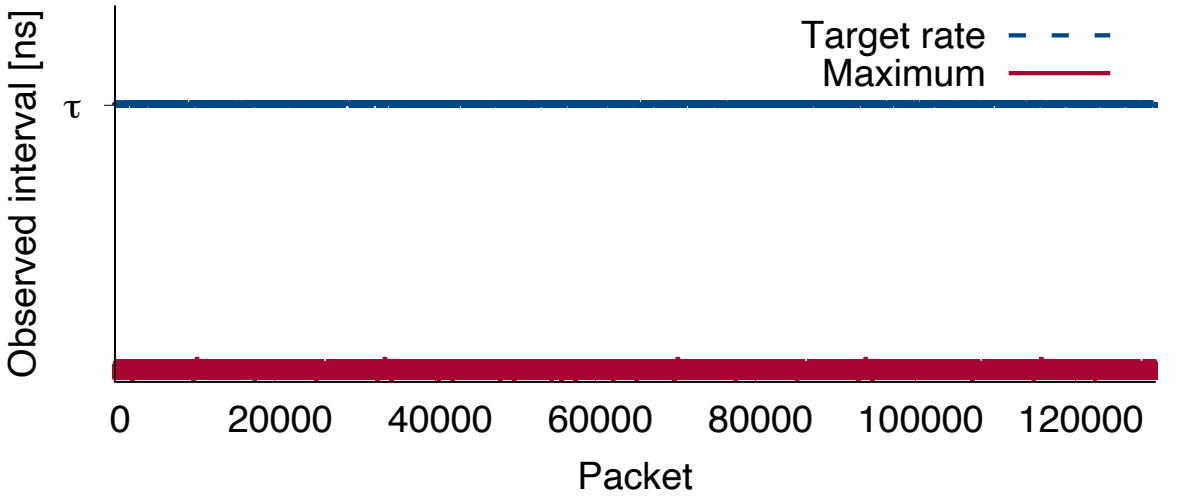
Implementation and evaluation

Hardware prototype on a pair of Wedge100BF-32X Tofino switches



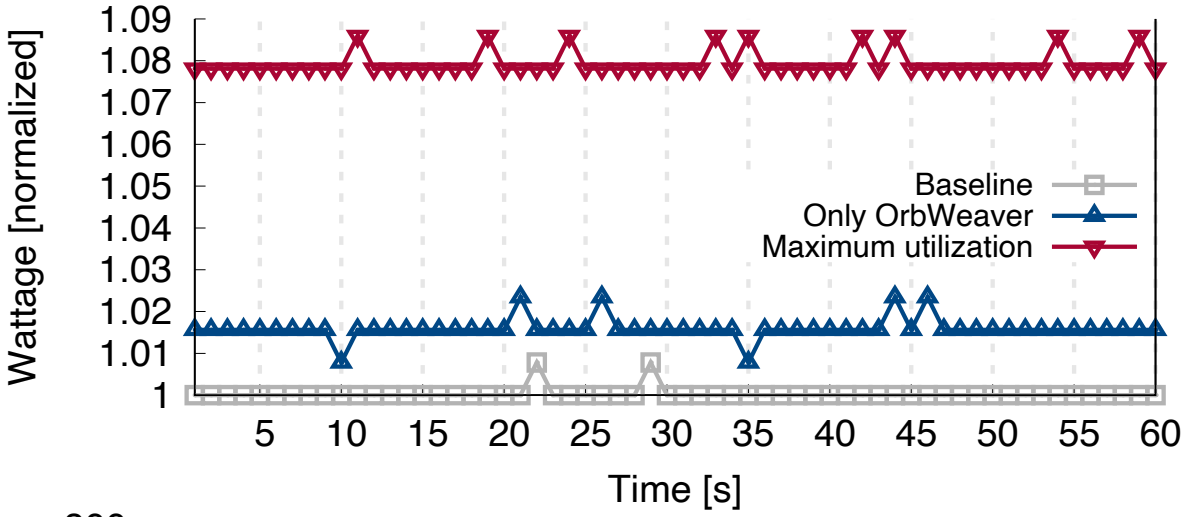


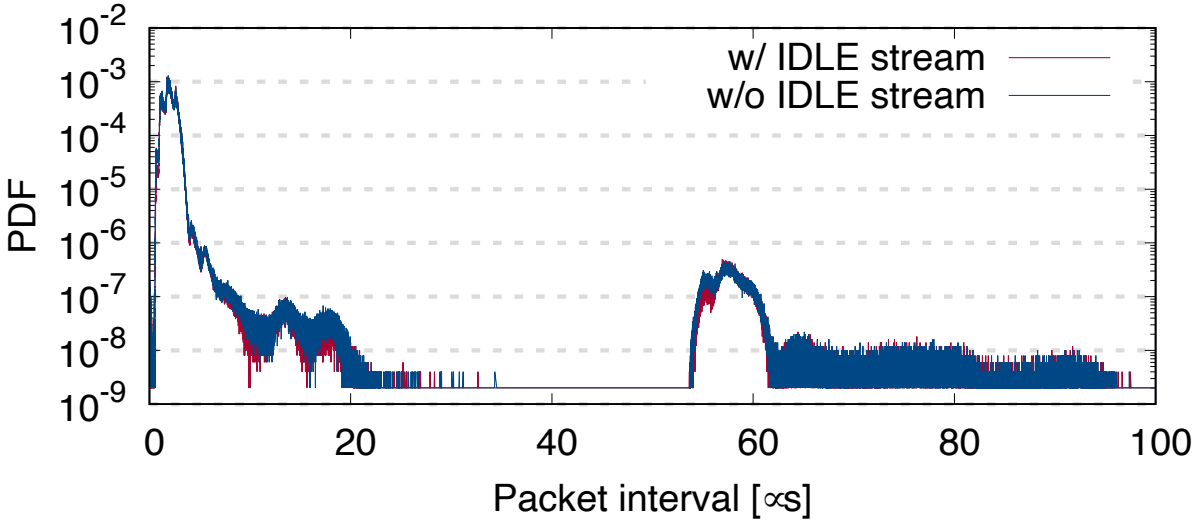


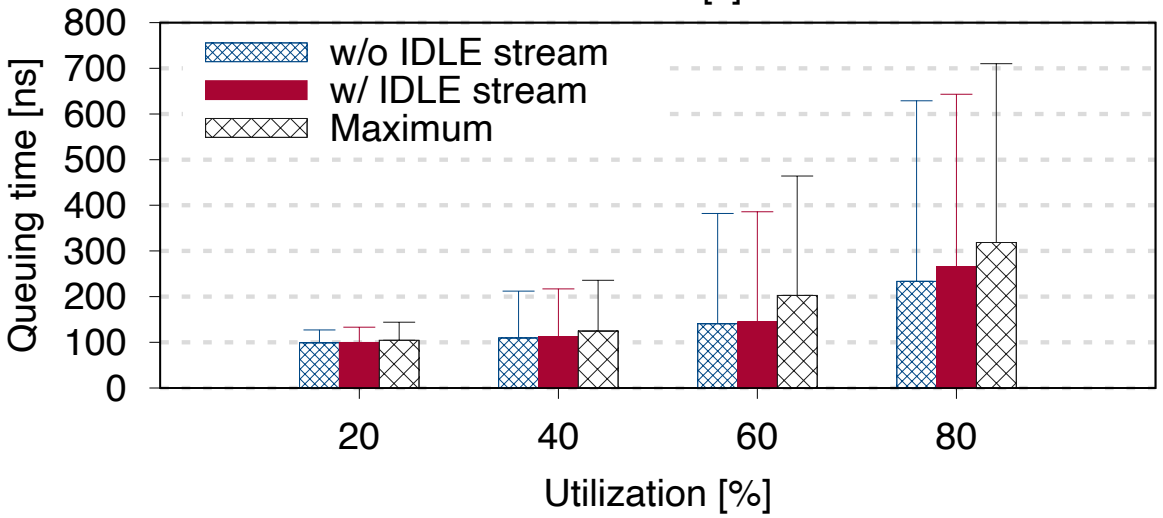


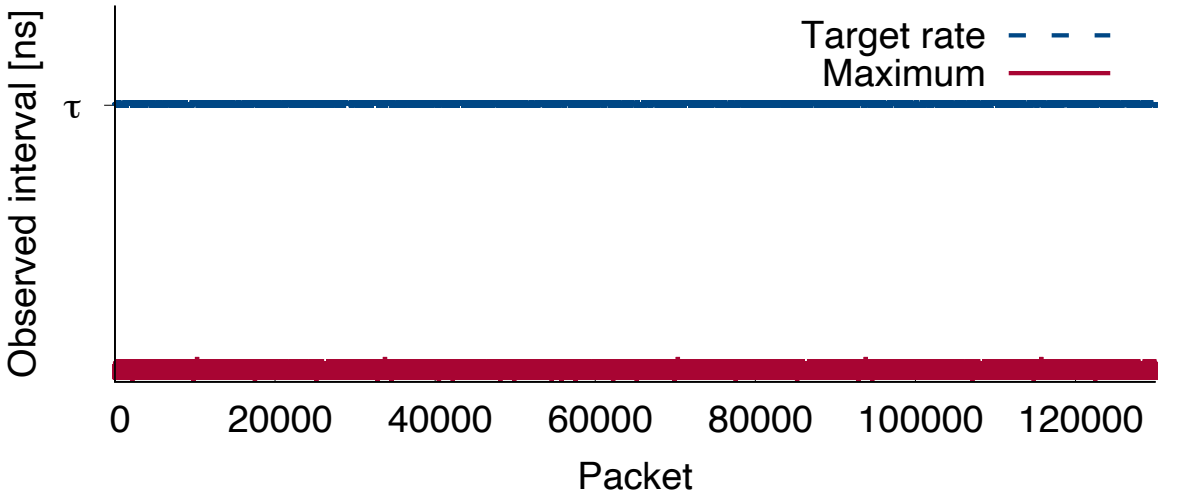
Takeaway: **Little-to-no impact** of power draw, latency, or throughput while guaranteeing **predictability** of the weaved stream!

Hardware prototype on a pair of Wedge100BF-32X Tofino switches









OrbWeaver use cases

Free information dissemination [R2]

Fine-grained network state inference [R1]

Performance aware routing

Flowlet load imbalance

Consistent replicas

Network queries

Latency localization

Header compression

Microburst detection

In-band telemetry

Event-based network control

Failure detection

Network queries

Packet forensics

Clock synchronization

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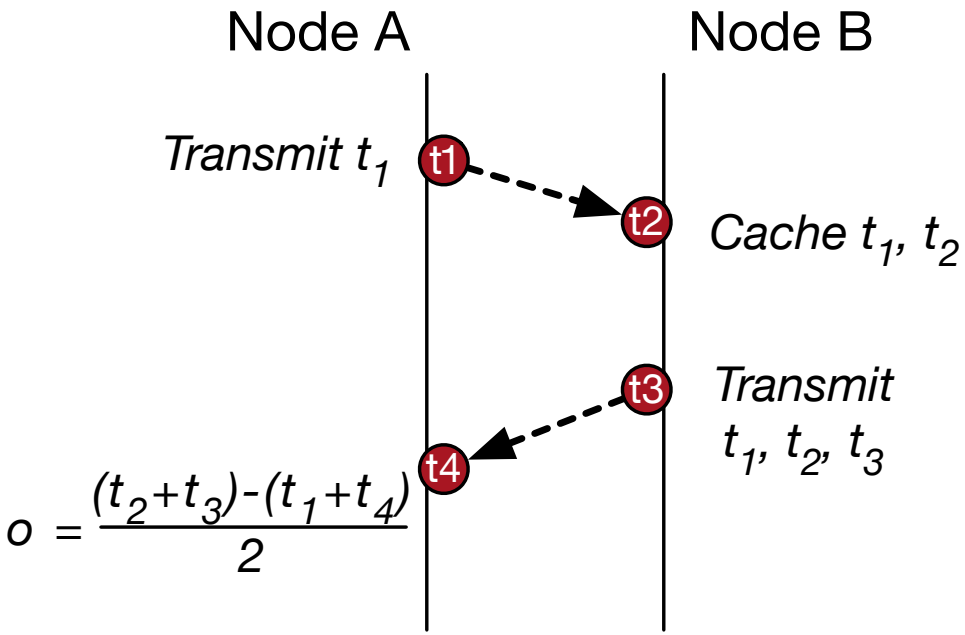
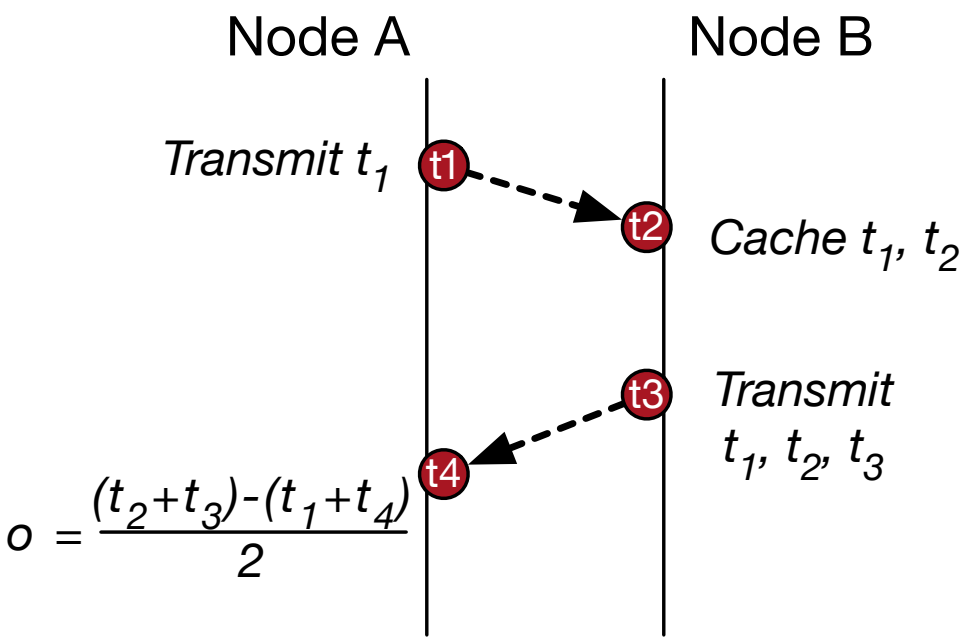
Example: time synchronization



Traditional two-way protocol

Example: time synchronization



Traditional two-way protocol

Existing approaches for high precision

- Require special hardware (such as DTP)
- Require messaging overheads (such as DPTP)

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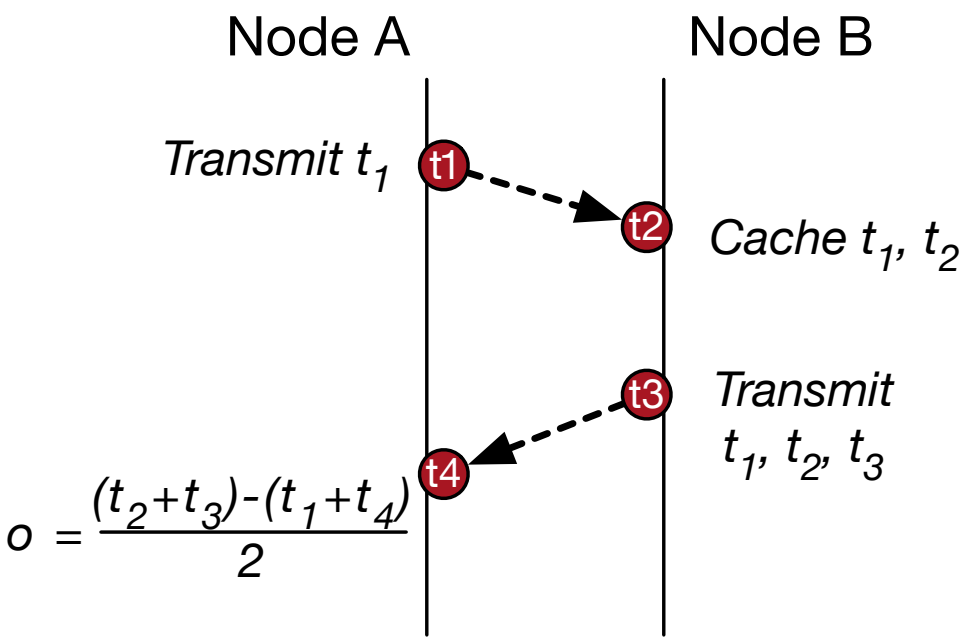

Traditional two-way protocol

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- Require special hardware (such as DTP)
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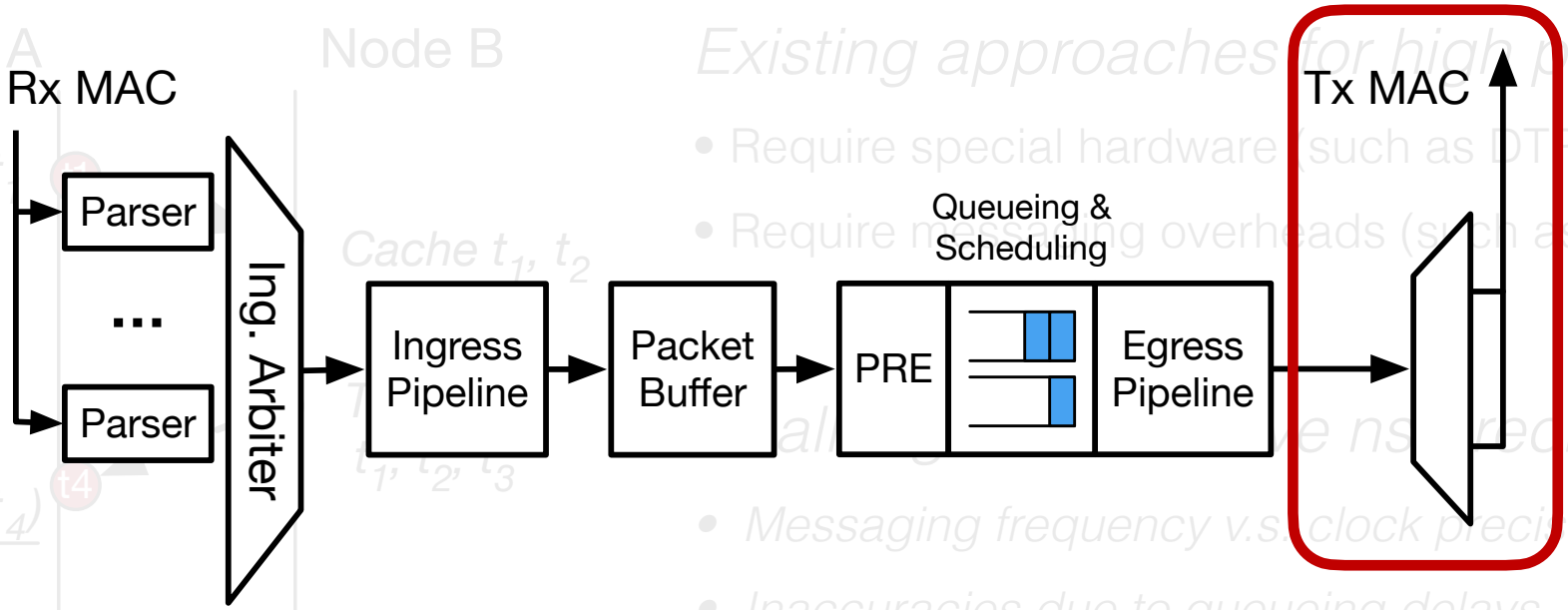
Challenges to achieve ns precision

- *Messaging frequency v.s. clock precision*
- *Inaccuracies due to queueing delays*

Example: time synchronization



Data plane timestamps don't capture the actual point of serialization

OrbWeaver Redesign

Key ideas:

1. Embed timestamp information in **free IDLE packets** [R2]

OrbWeaver Redesign

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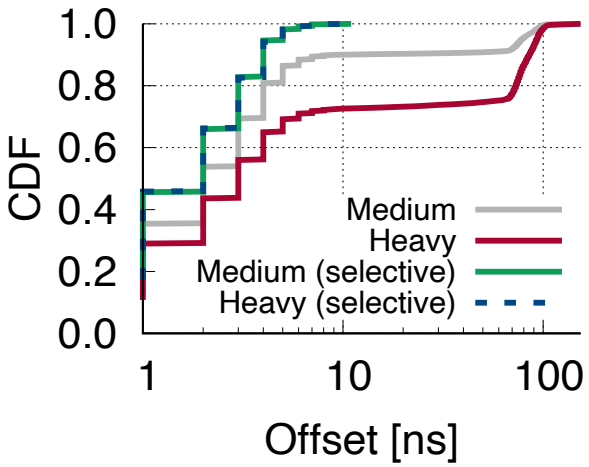
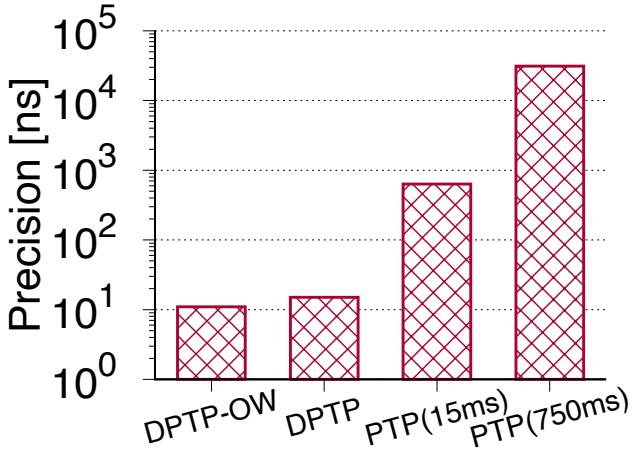




Achieve same or better performance with close-to-zero overheads

Summary

- **Weaved stream abstraction** to harvest IDLE cycles
  - Guarantee predictability with little-to-zero overhead

Summary

- **Weaved stream abstraction** to harvest IDLE cycles
  - Guarantee predictability with little-to-zero overhead
- Generic support of a wide range of data plane applications for free
  - ***Don't*** need to choose between coordination fidelity and bandwidth overhead

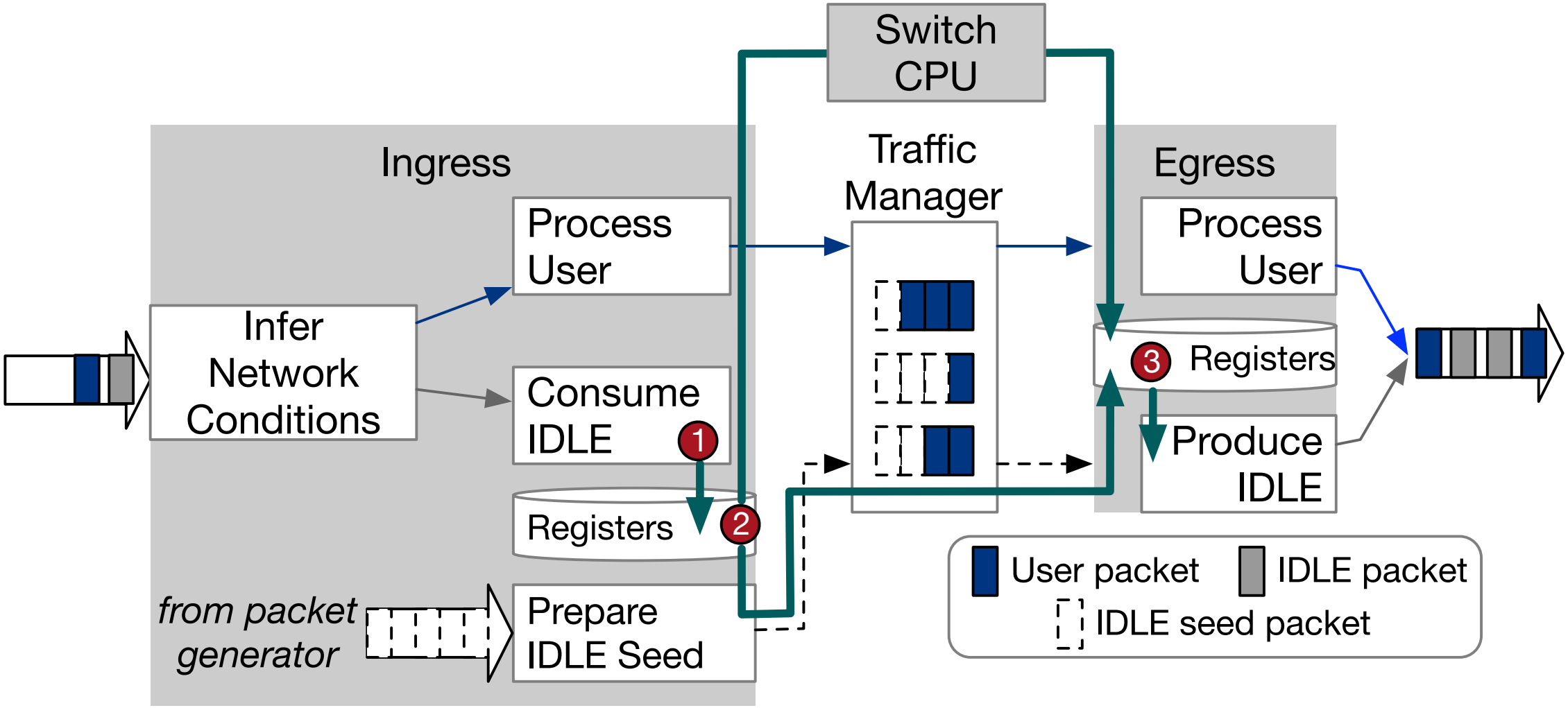
https://github.com/eniac/OrbWeaver

Thank you for your attention!

Q & A

Backup Slides

Using weaved stream



Optimal value of τ

$$\tau = B_{100Gbps}/MTU_{1500B} = 120ns$$