RedPlane: Enabling Fault-Tolerant Stateful In-Switch Applications

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Programmable networks are stateful

Classical switches

Match	Action
IP addr/prefix	Forward (port)

"Stateless" packet processing

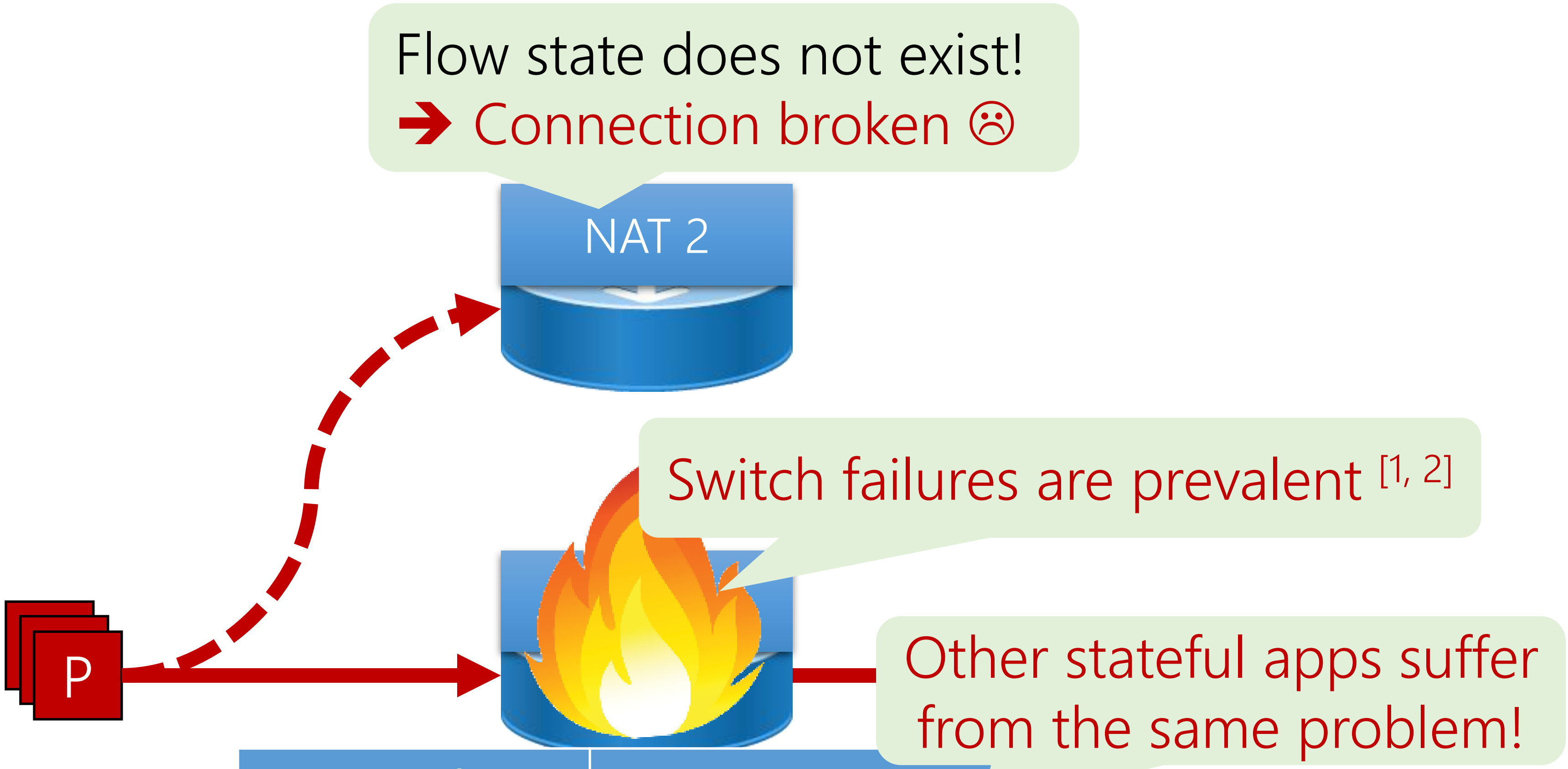
Programmable "data plane" switches

Stateful in-switch applications:
network functions, monitoring, accelerating distributed systems

Match	Stateful action
(IP addr, port)	NAT (IP addr., port)

Programmable switching ASICs
➔ "Stateful" packet processing

Problem: Switch failure

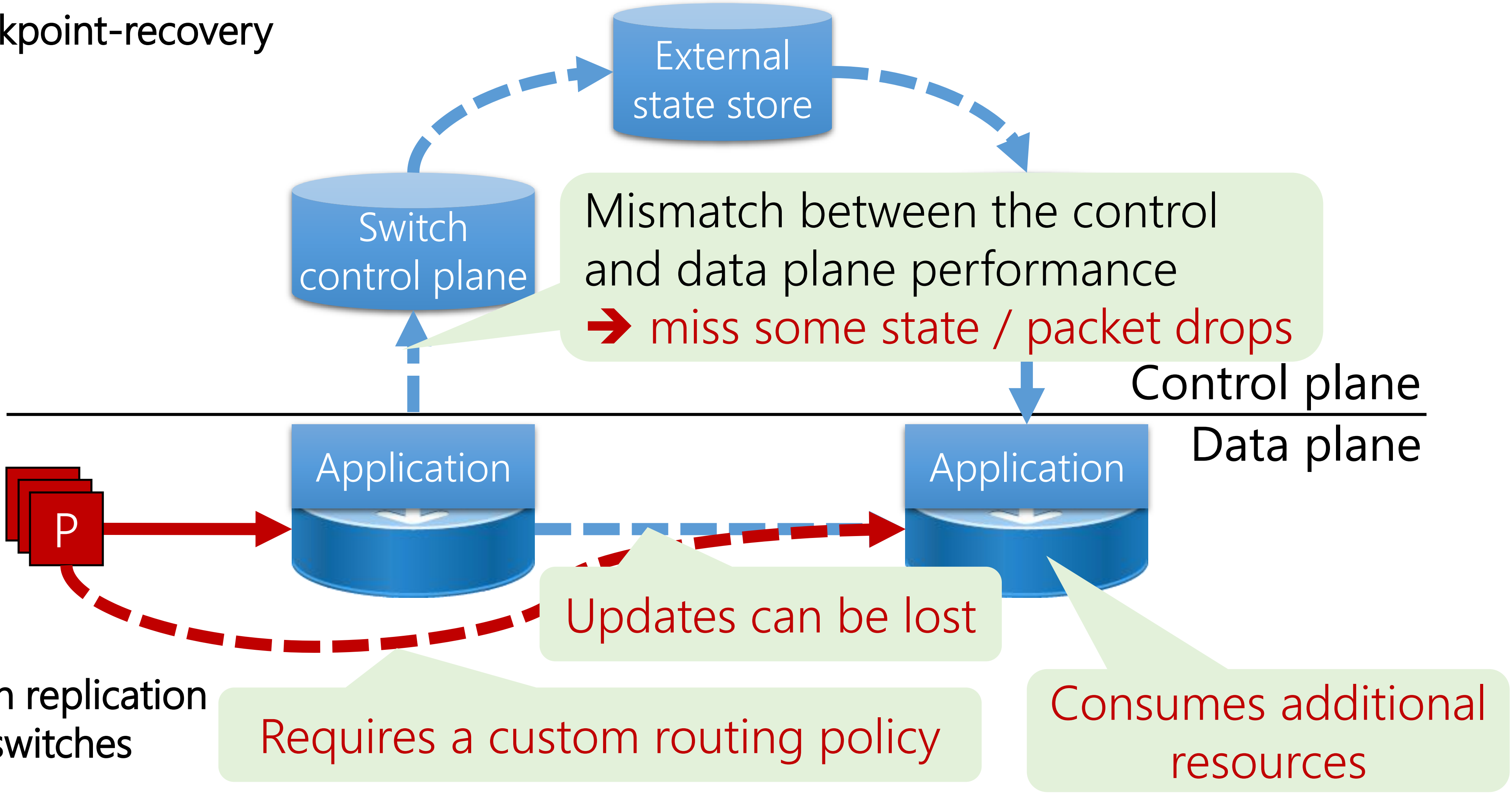


Match (Flow ID)	NAT action (IP, Port)
(10.0.0.1, 4321)	(192.168.10.1, 1234)

[1] Liu et al., Crystalnet: Faithfully emulating large production networks. In ACM SOSP 2017.
[2] Meza et al., A large scale study of data center network reliability. In ACM IMC 2017.

Strawman solutions

S1: Checkpoint-recovery



S2: Chain replication among switches

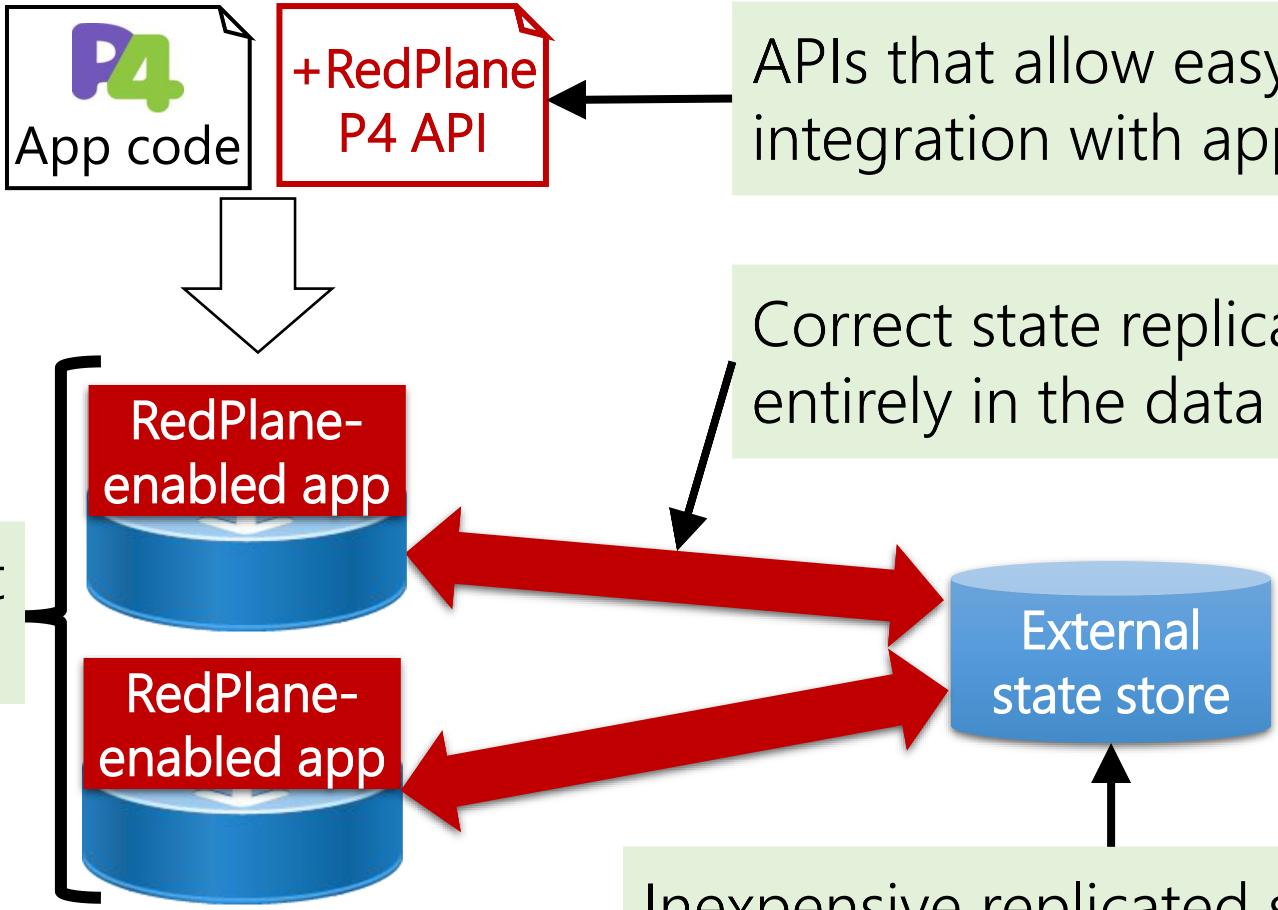
Our work: RedPlane

APIs that allow easy integration with apps

Correct state replication entirely in the data plane

One big fault-tolerant switch abstraction!

Inexpensive replicated state store on commodity servers



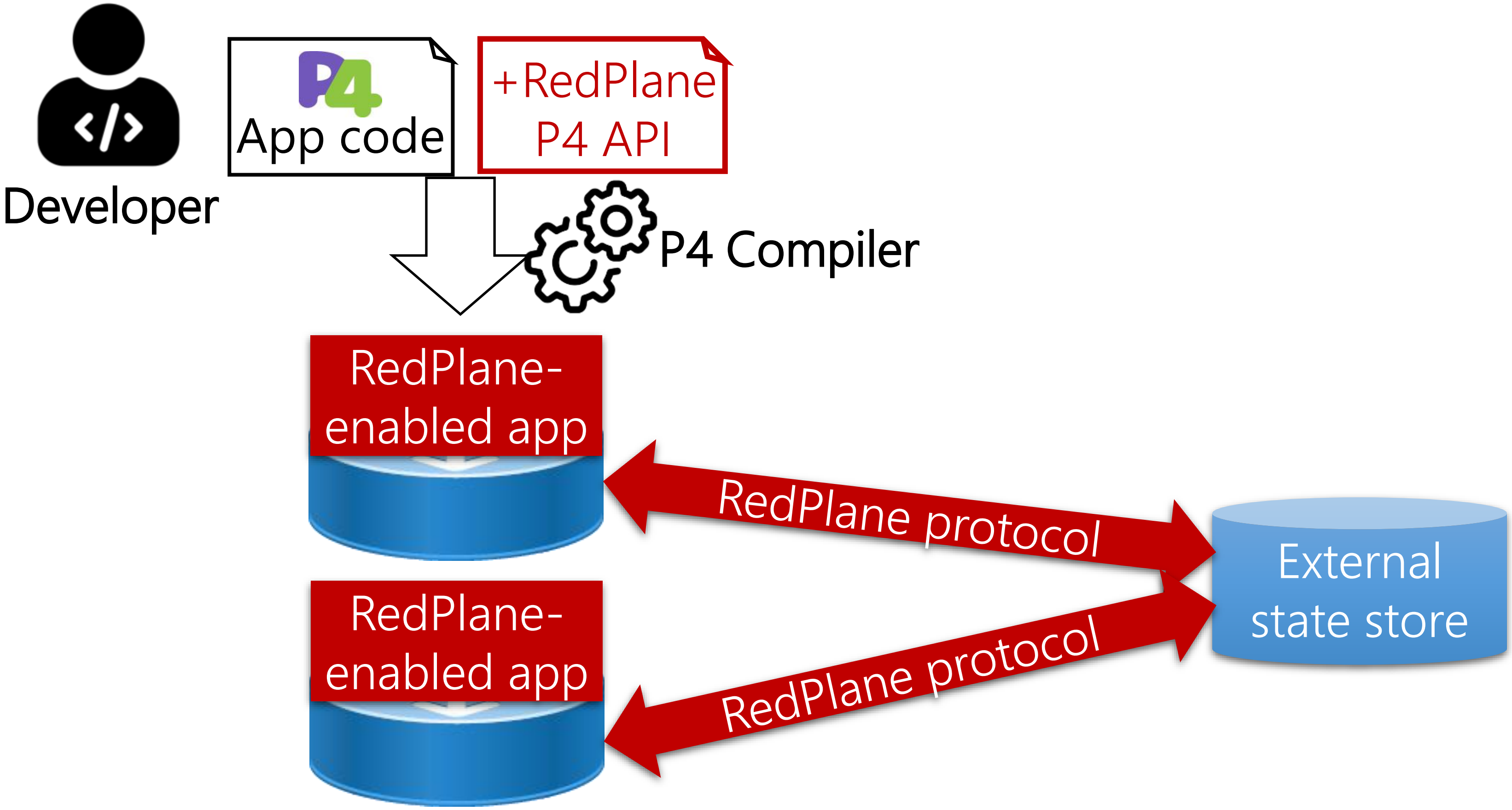
Outline

RedPlane motivation

RedPlane design

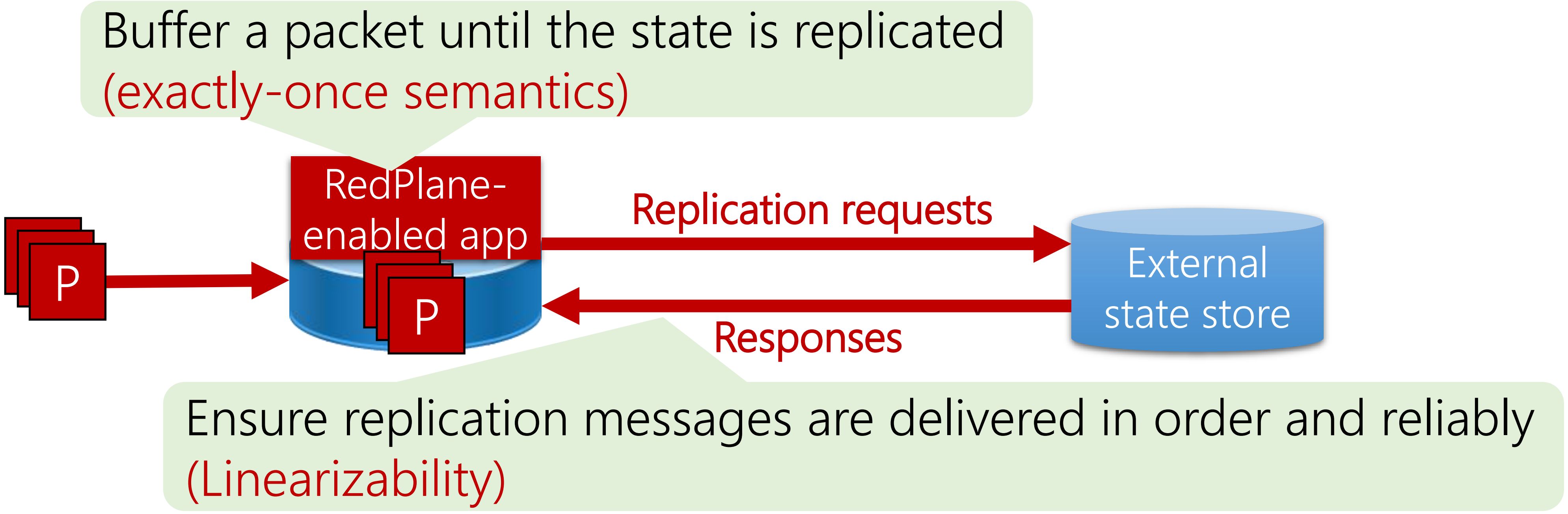
Results

RedPlane design overview



Challenge 1: Correct replication in the data plane

Strawman: strict correctness used in server-based replicated systems



Challenge 1: Correct replication in the data plane

Strawman: strict correctness used in server-based replicated systems

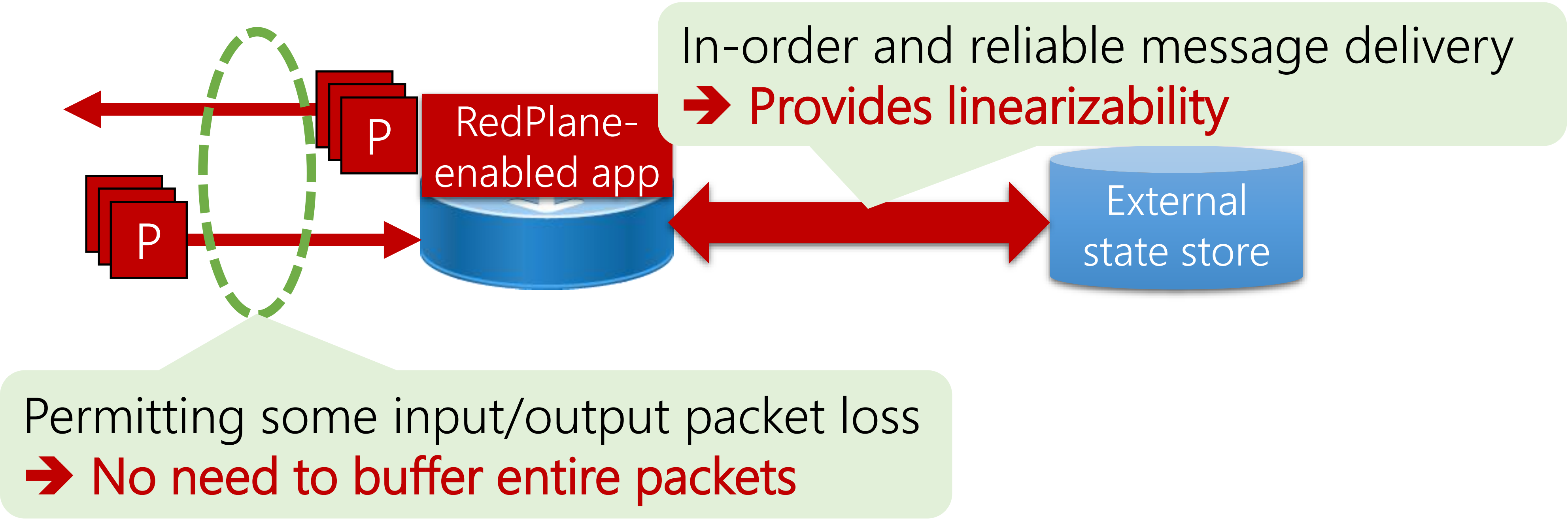
Expensive to buffer entire packets ☹

Expensive to realize reliable transport in the switch data plane ☹

Linearizable mode: Relaxed correctness

Insight: End-to-end network apps already tolerate lossy networks!

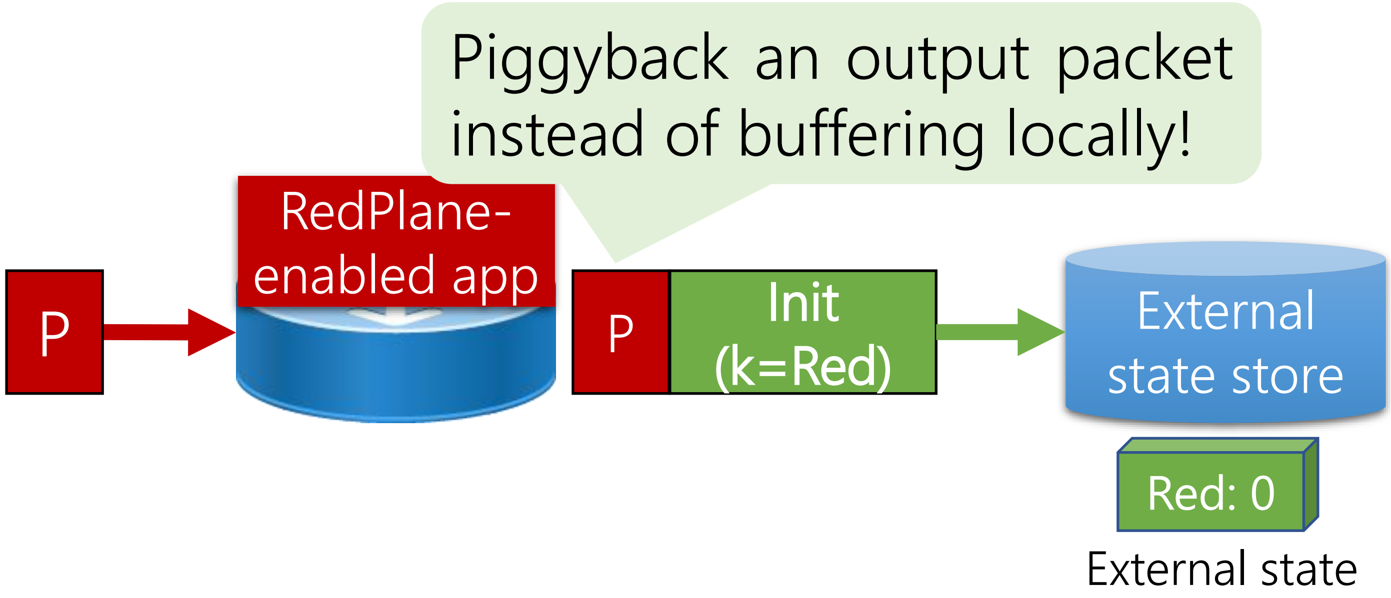
Our approach: Linearizability-based relaxed correctness



Basic RedPlane protocol: Realizing the linearizable mode in the data plane

Example: per-flow packet counter

1. Sends a state initialization request



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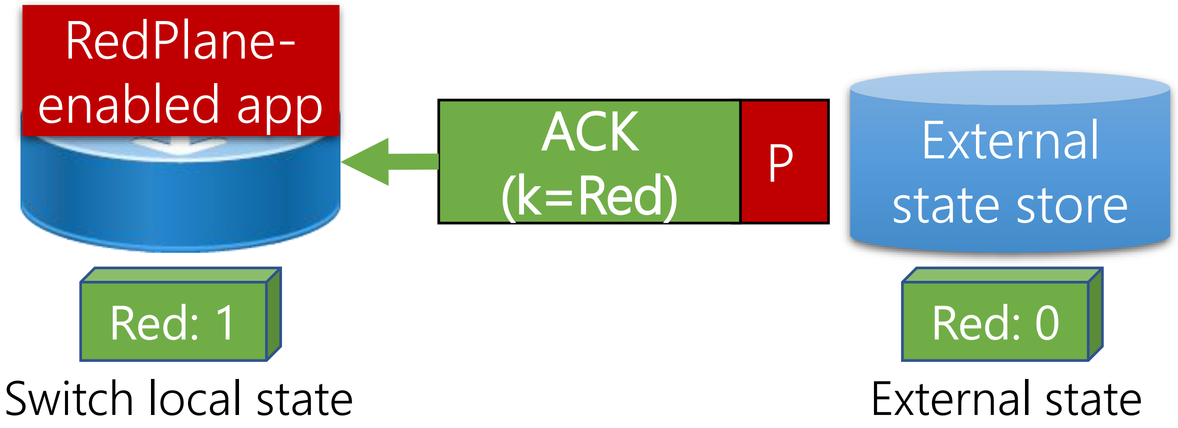

1. Sends a state initialization request
2. Receives an ACK & initializes the local state

Basic RedPlane protocol: Realizing the linearizable mode in the data plane

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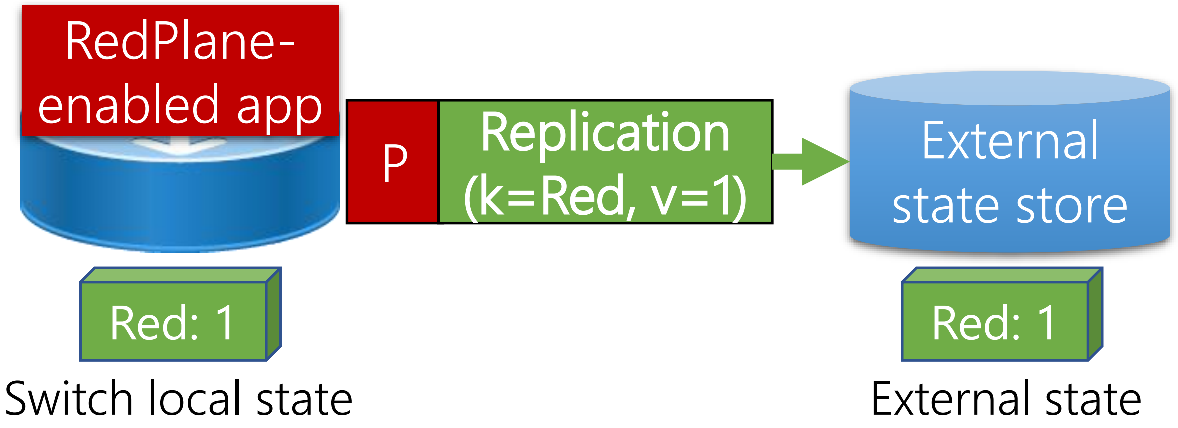

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3. Replicates the updated state

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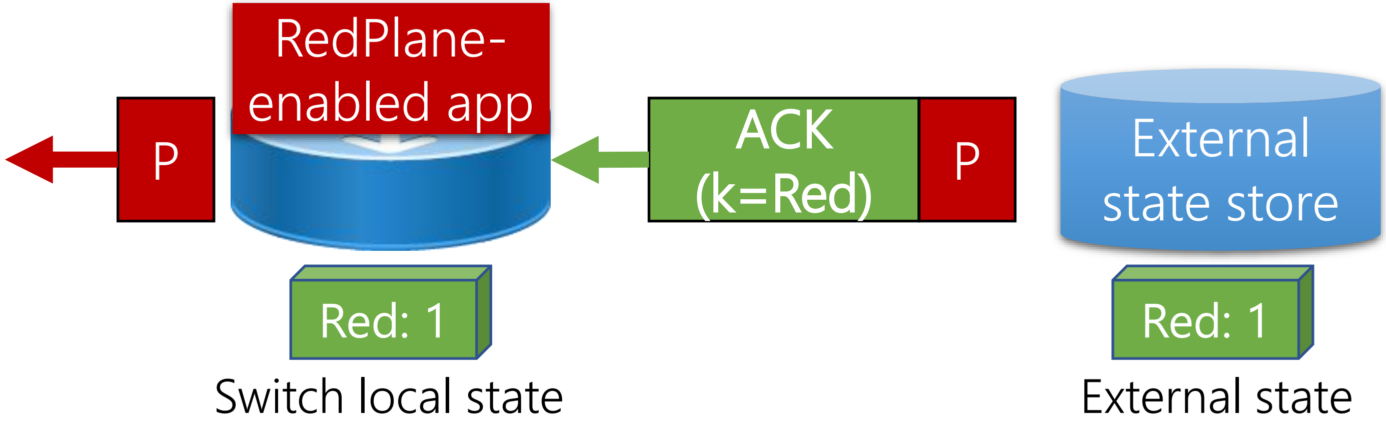
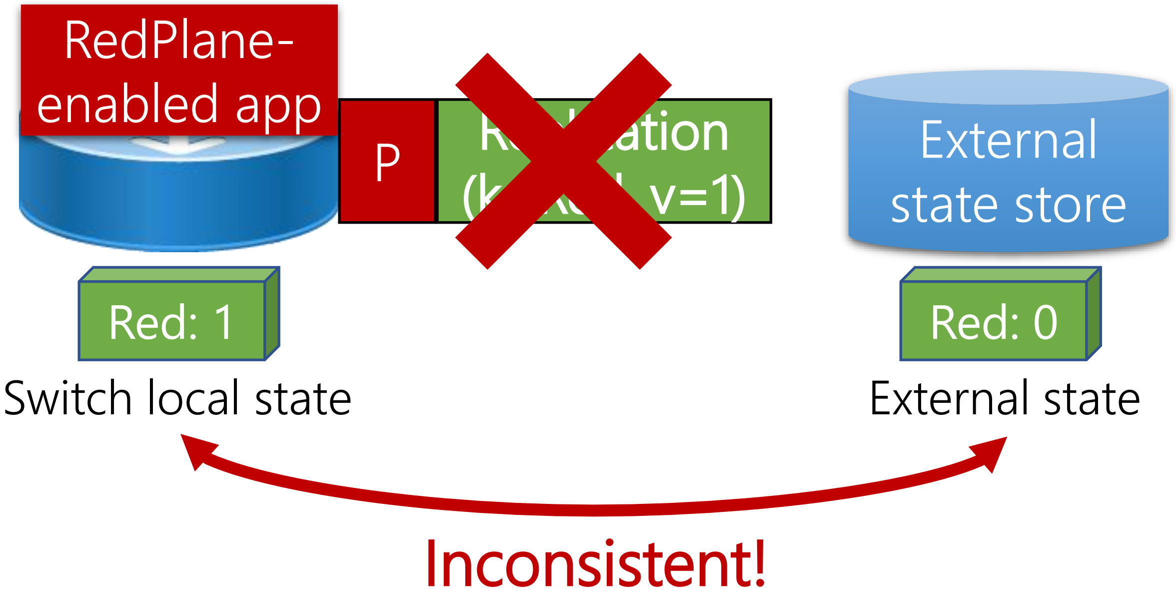


1. Sends a state initialization request
2. Receives an ACK & initializes the local state
3. Replicates the updated state
4. Receives an ACK & releases the output packet

Inconsistency due to unreliable channel

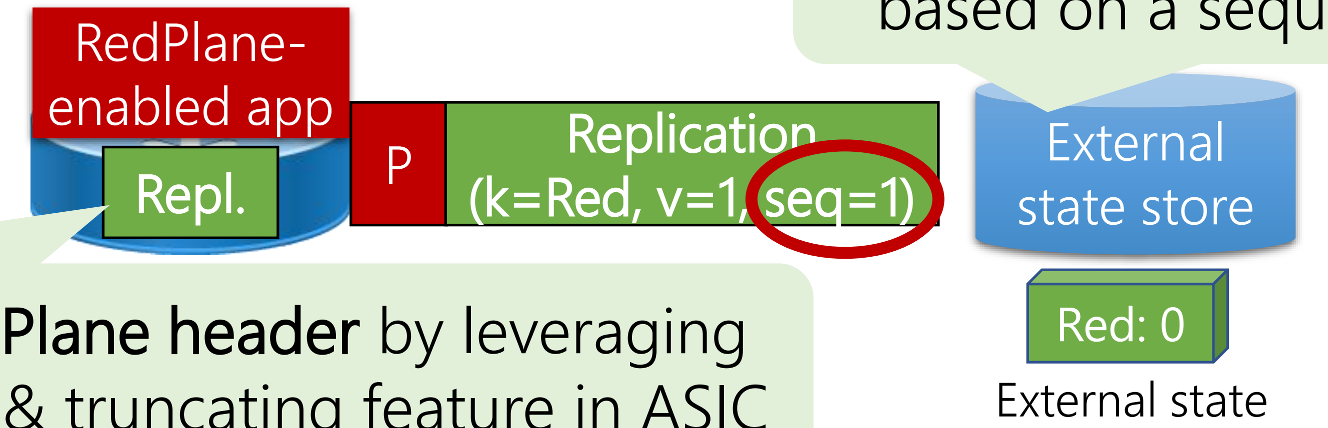
Problem: state in the switch and state store can be inconsistent due to out-of-order requests or request packet loss



Sequencing and lightweight retransmission

Our approach: A simple UDP-based transport with sequencing and lightweight retransmission

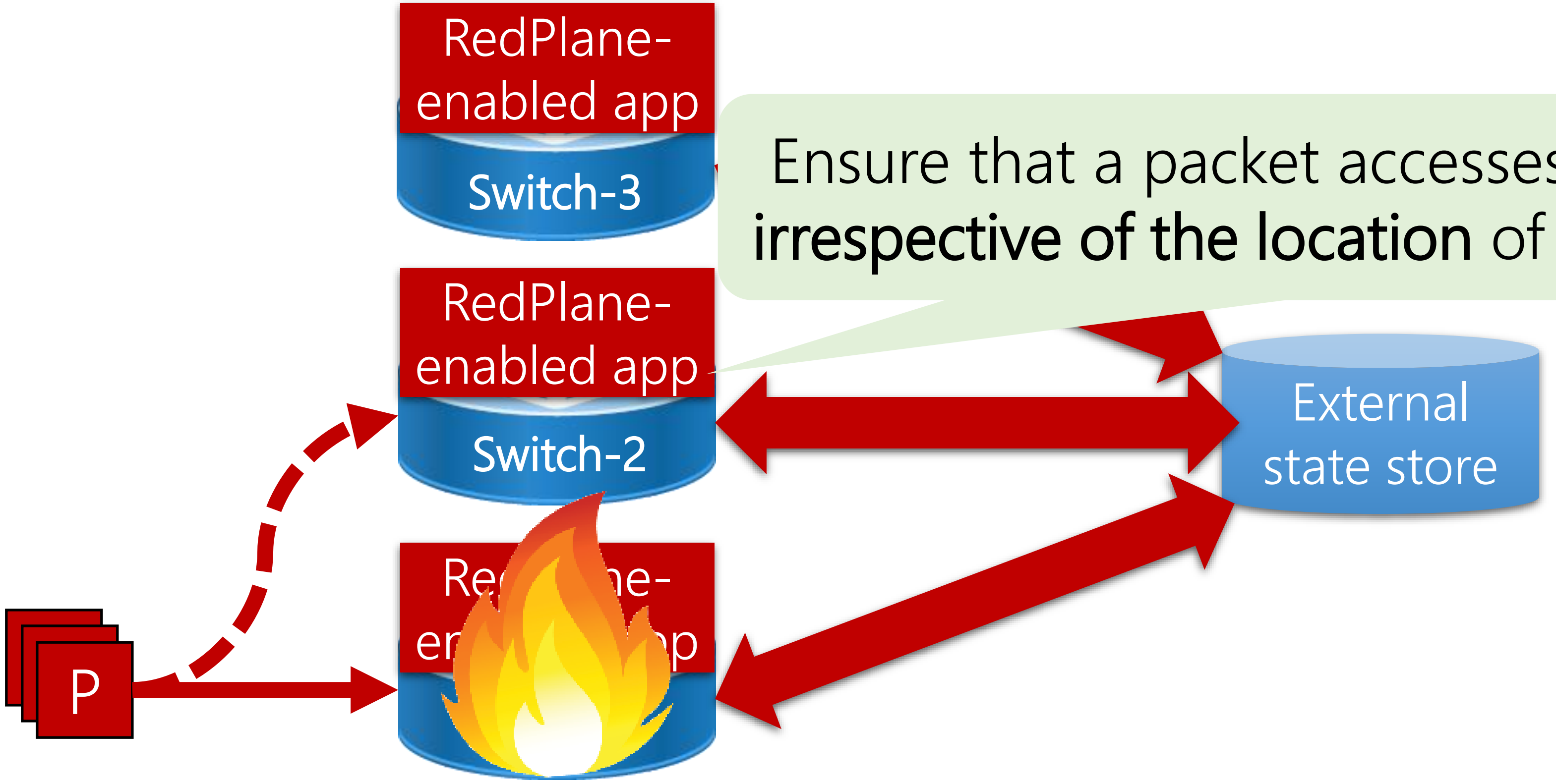
Commits the **latest requests only** based on a sequence number



Buffers **only RedPlane header** by leveraging packet mirroring & truncating feature in ASIC

Challenge 2: Transparent to routing policies

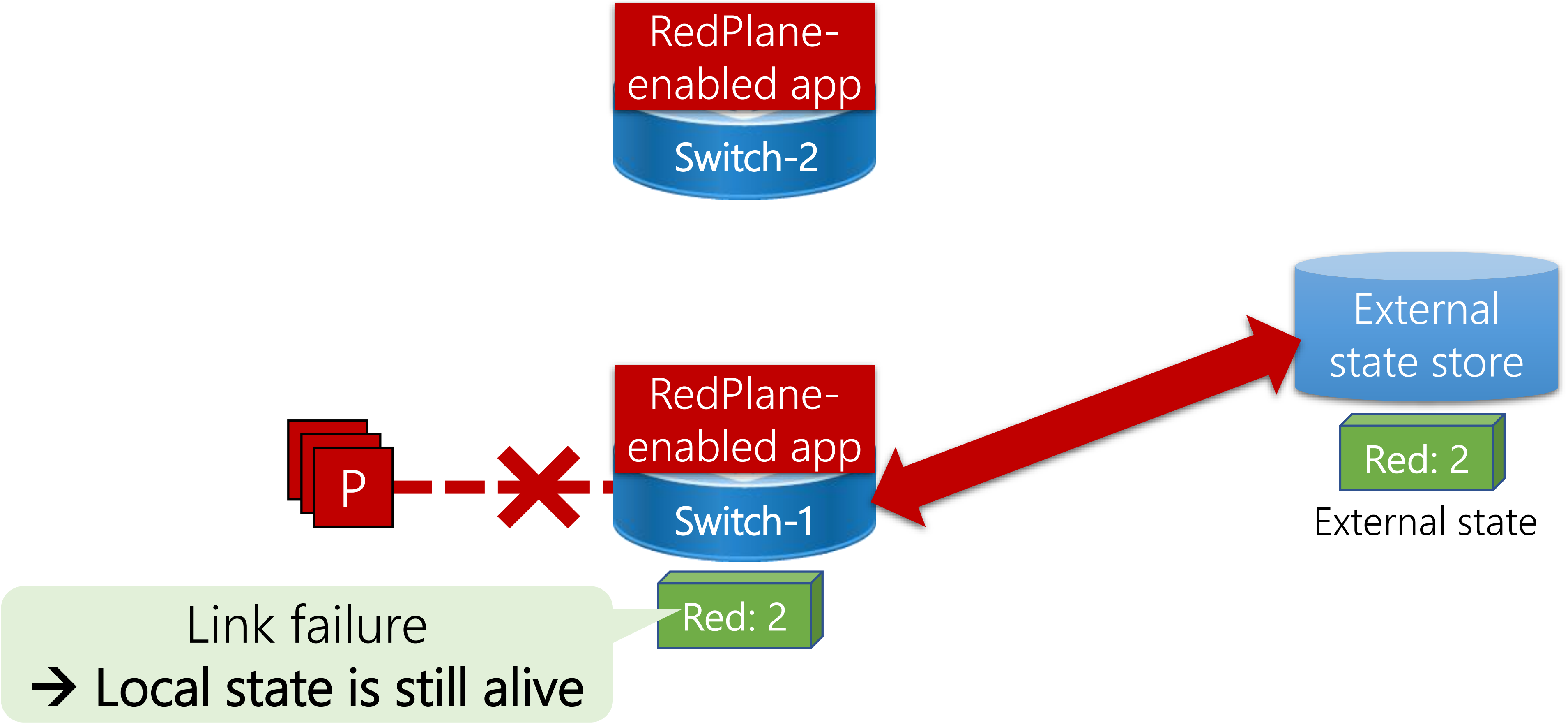
A switch failure or recovery can cause routing traffic to another switch



Ensure that a packet accesses the correct state **irrespective of the location** of the current switch

Accessing stale state

Problem: A packet may access state state during failover or recovery



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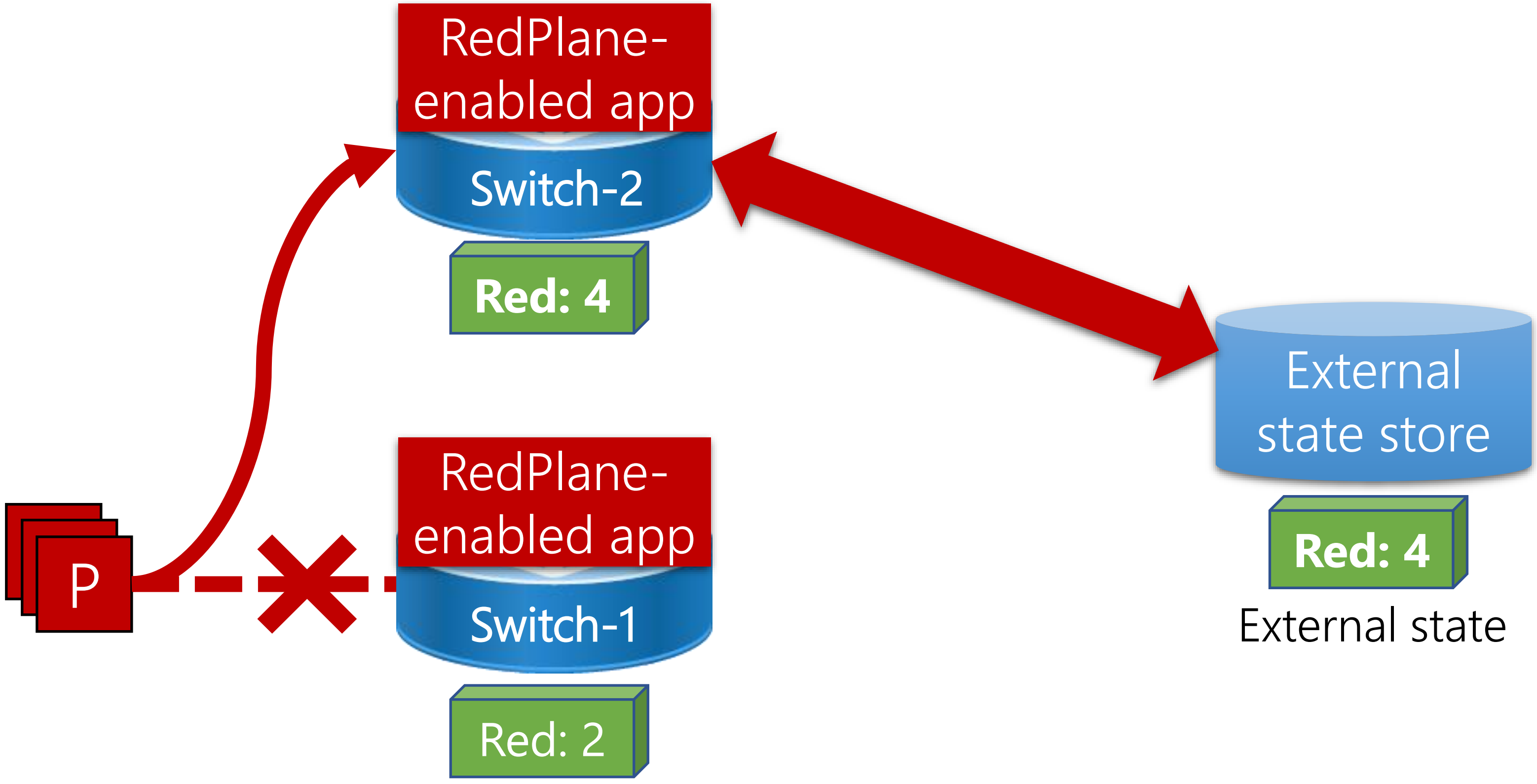

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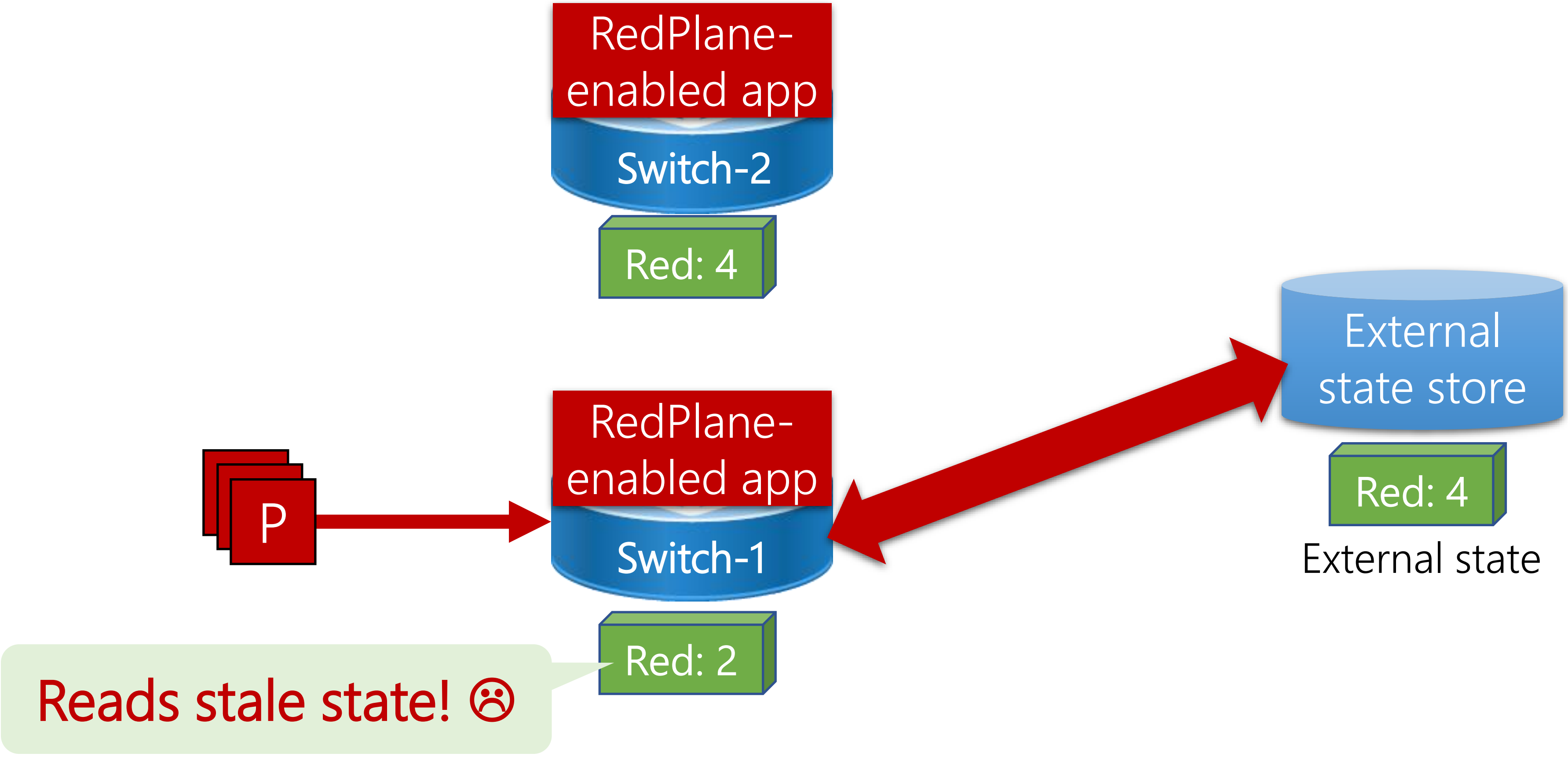
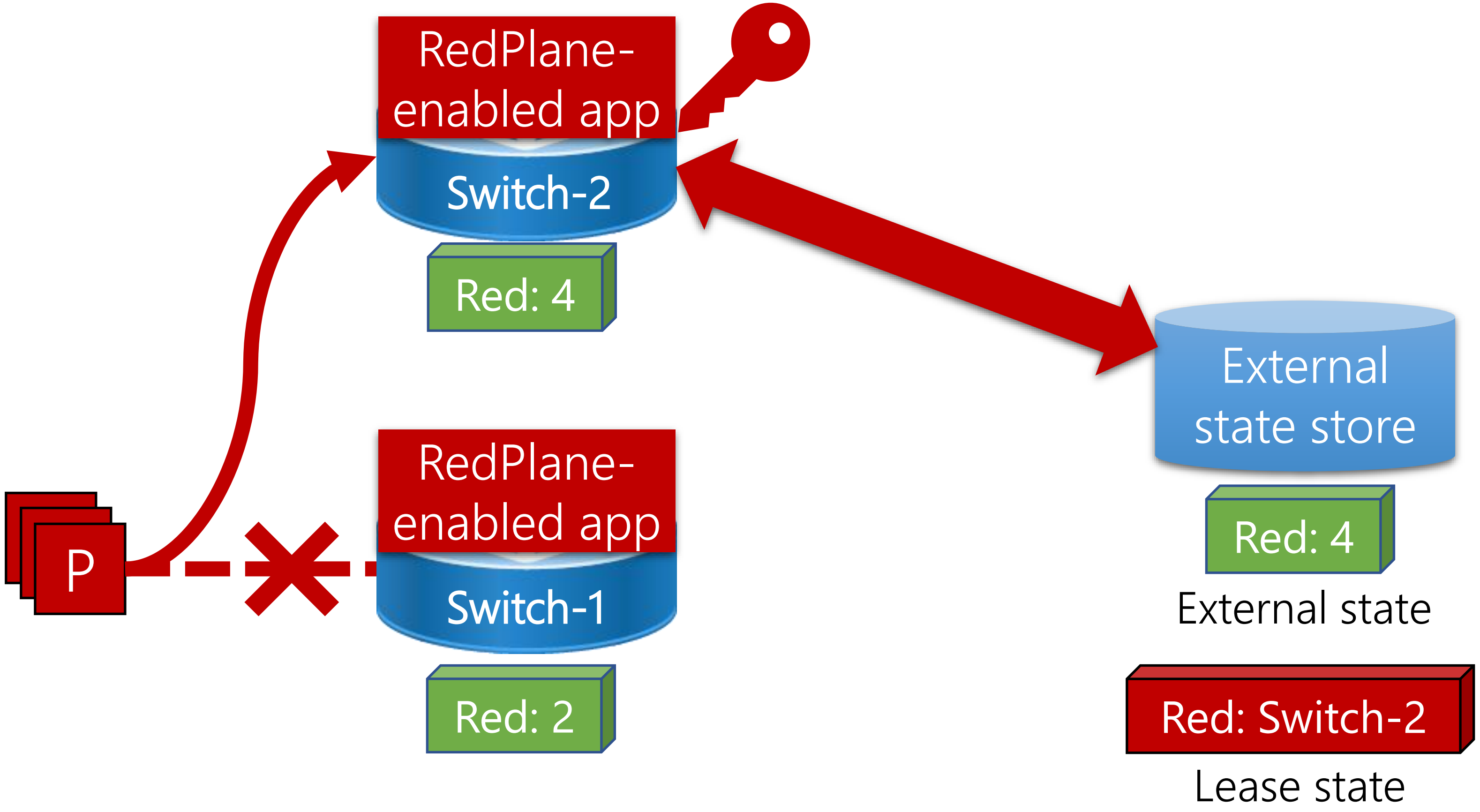


Lease-based state ownership management

Our approach: For a given flow, ensuring only one switch processes packets at a time using leases



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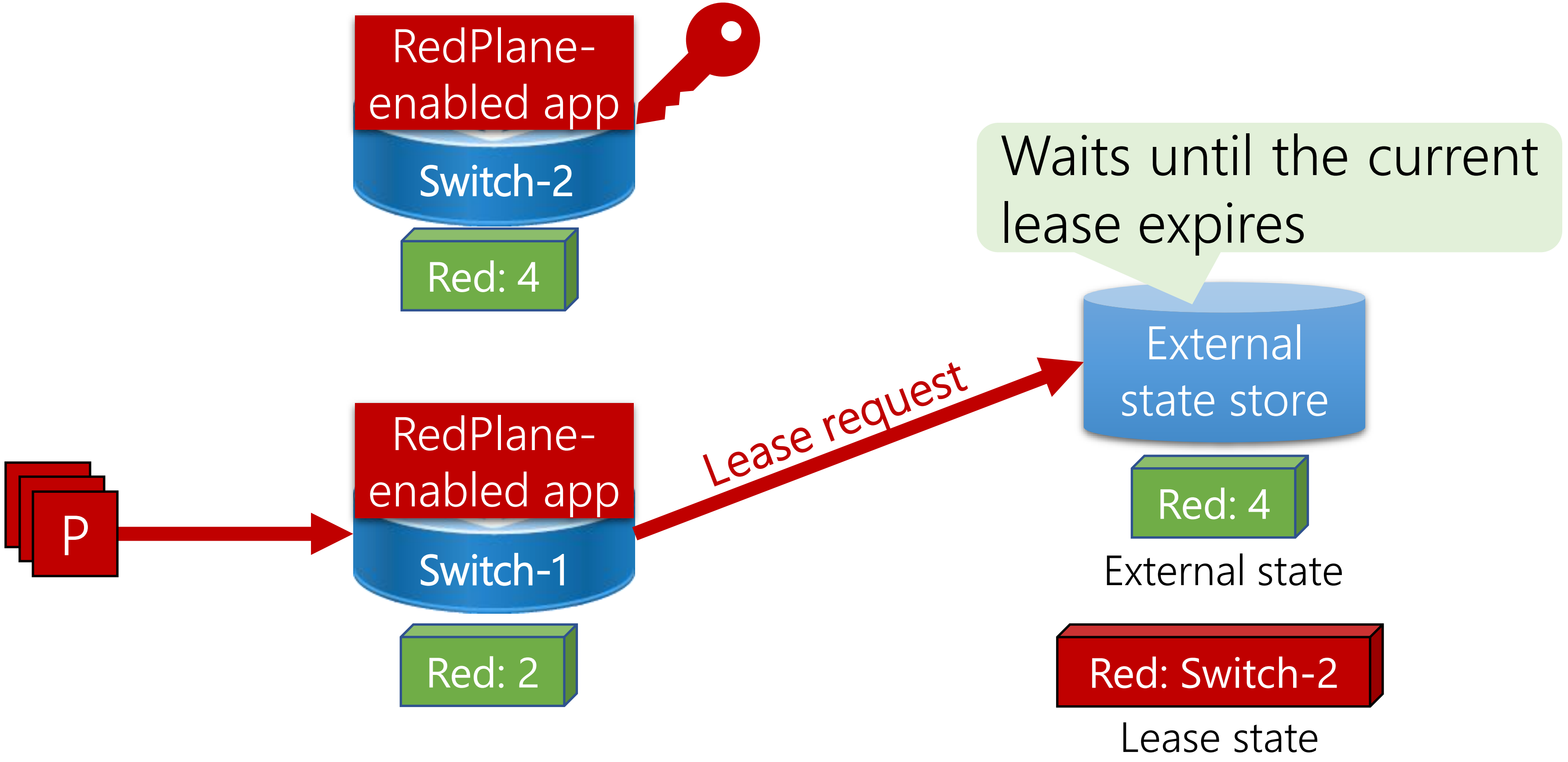

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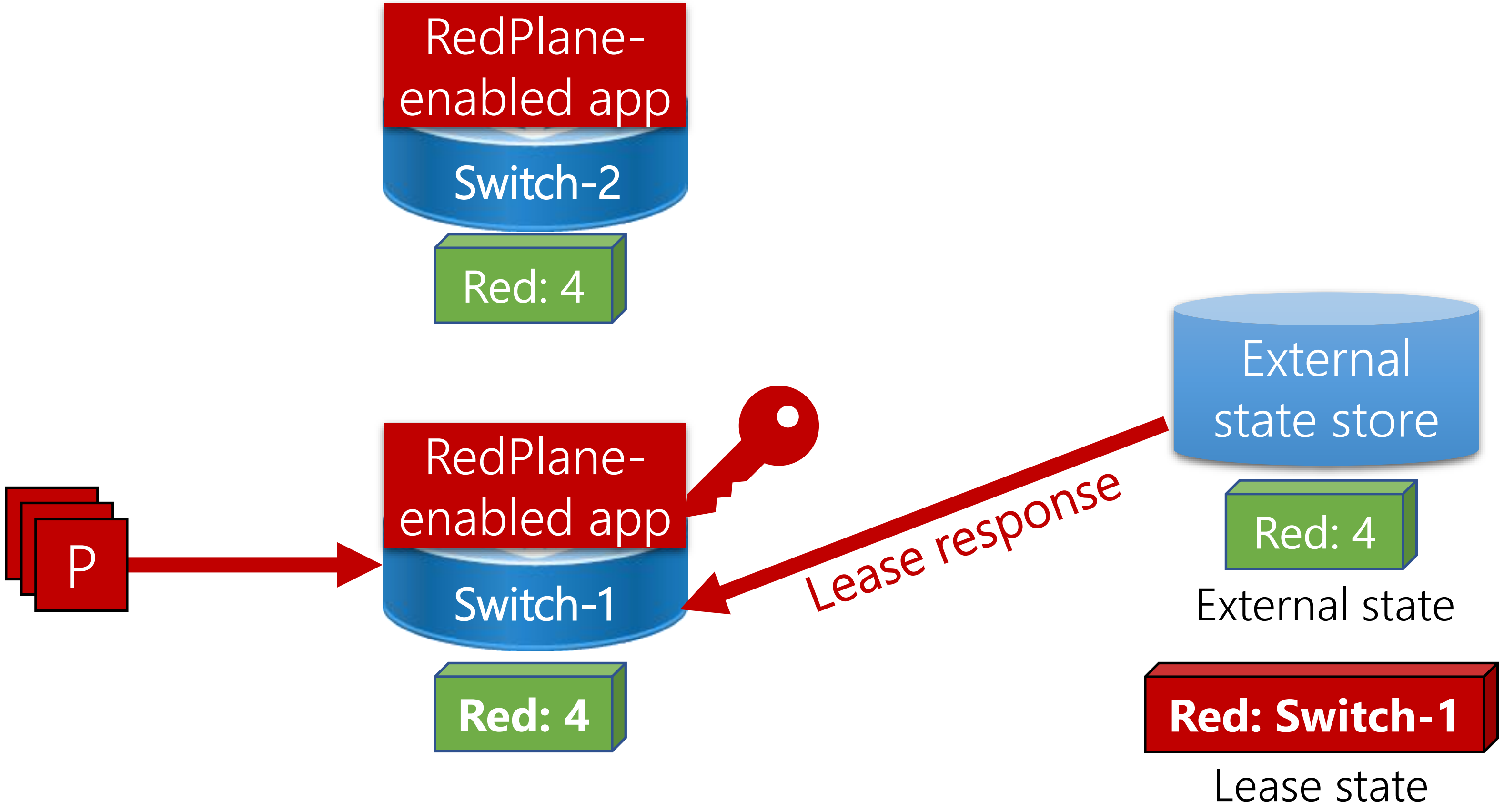
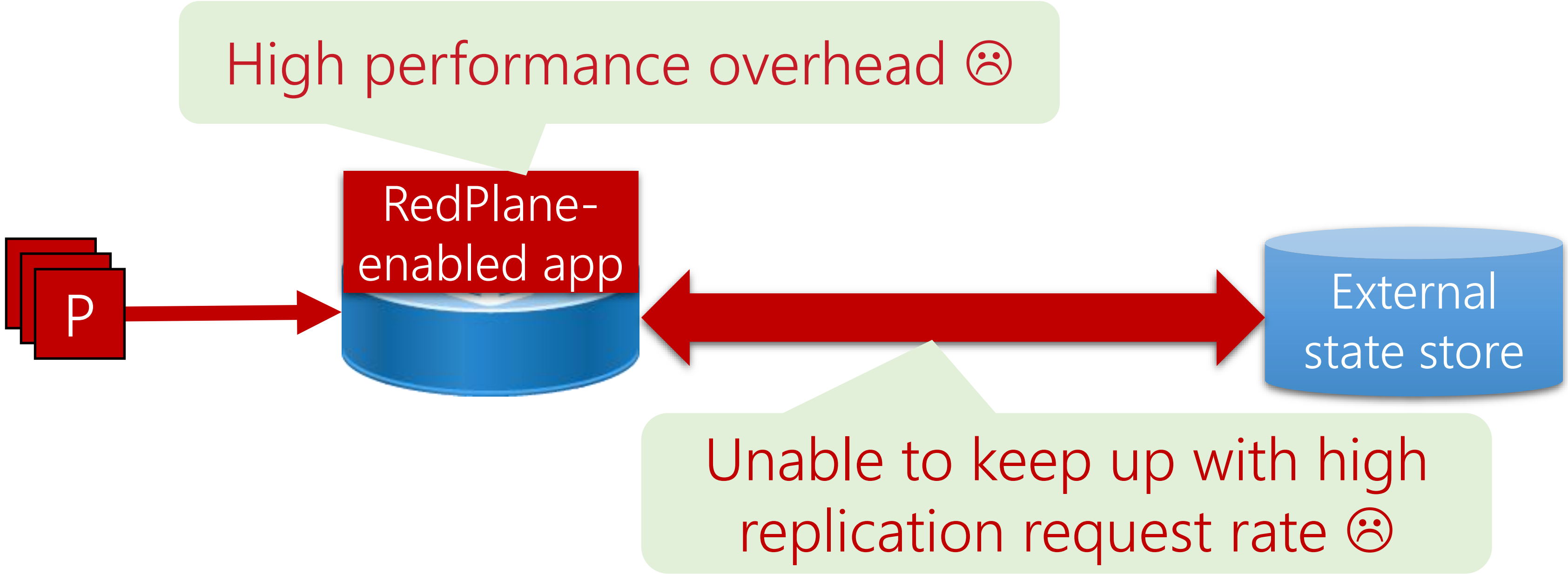


Challenge 3: Handling high traffic volume

Switch data plane operates at up to a few billion packets per second



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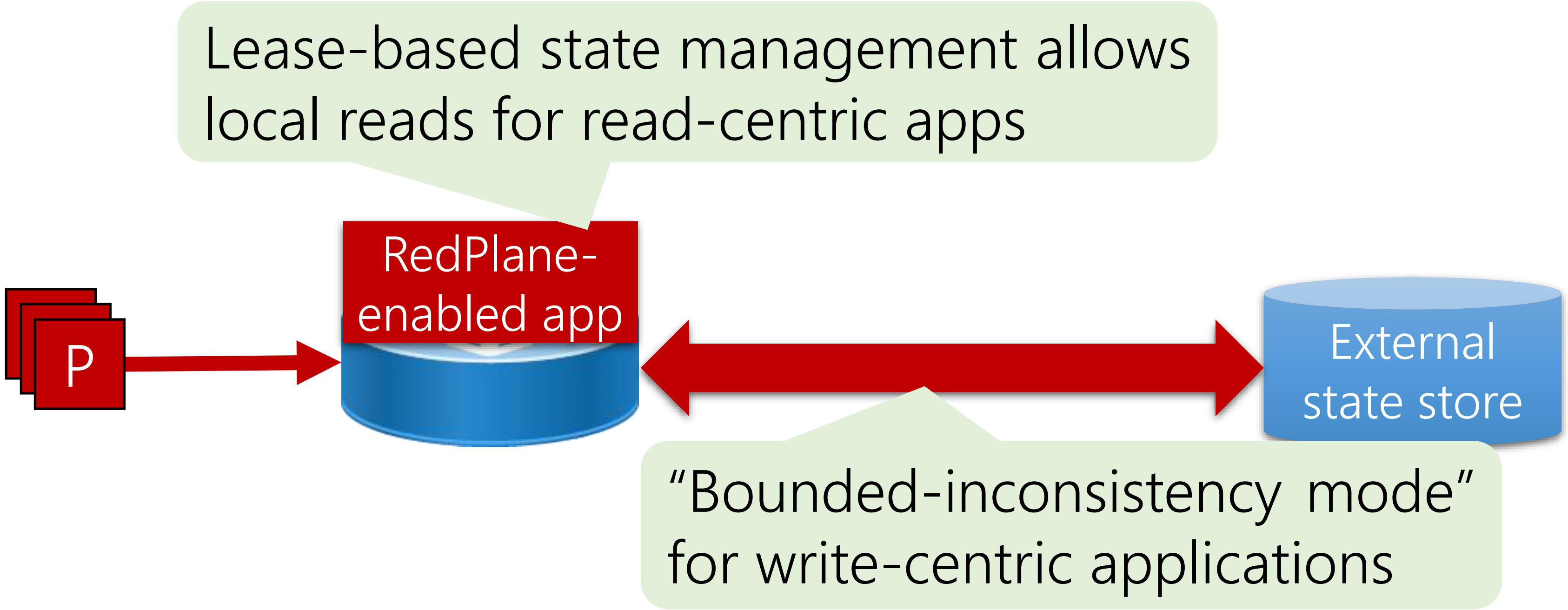
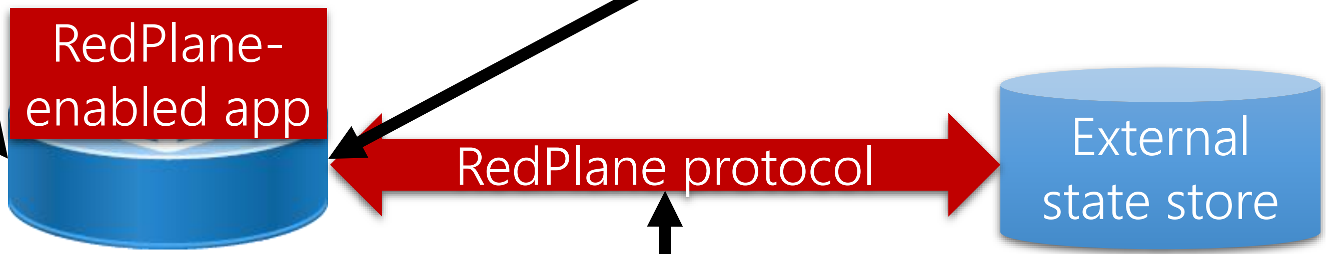


Putting it all together

RedPlane provides **a fault-tolerant state store abstraction** to applications

Sequencing and lightweight retransmission mechanism **(Correctness)**

Lease-based state management **(Routing agnostic, Performance)**



Linearizability-based correctness definition **(Correctness)**
Bounded-inconsistency for write-centric applications **(Correctness, Performance)**

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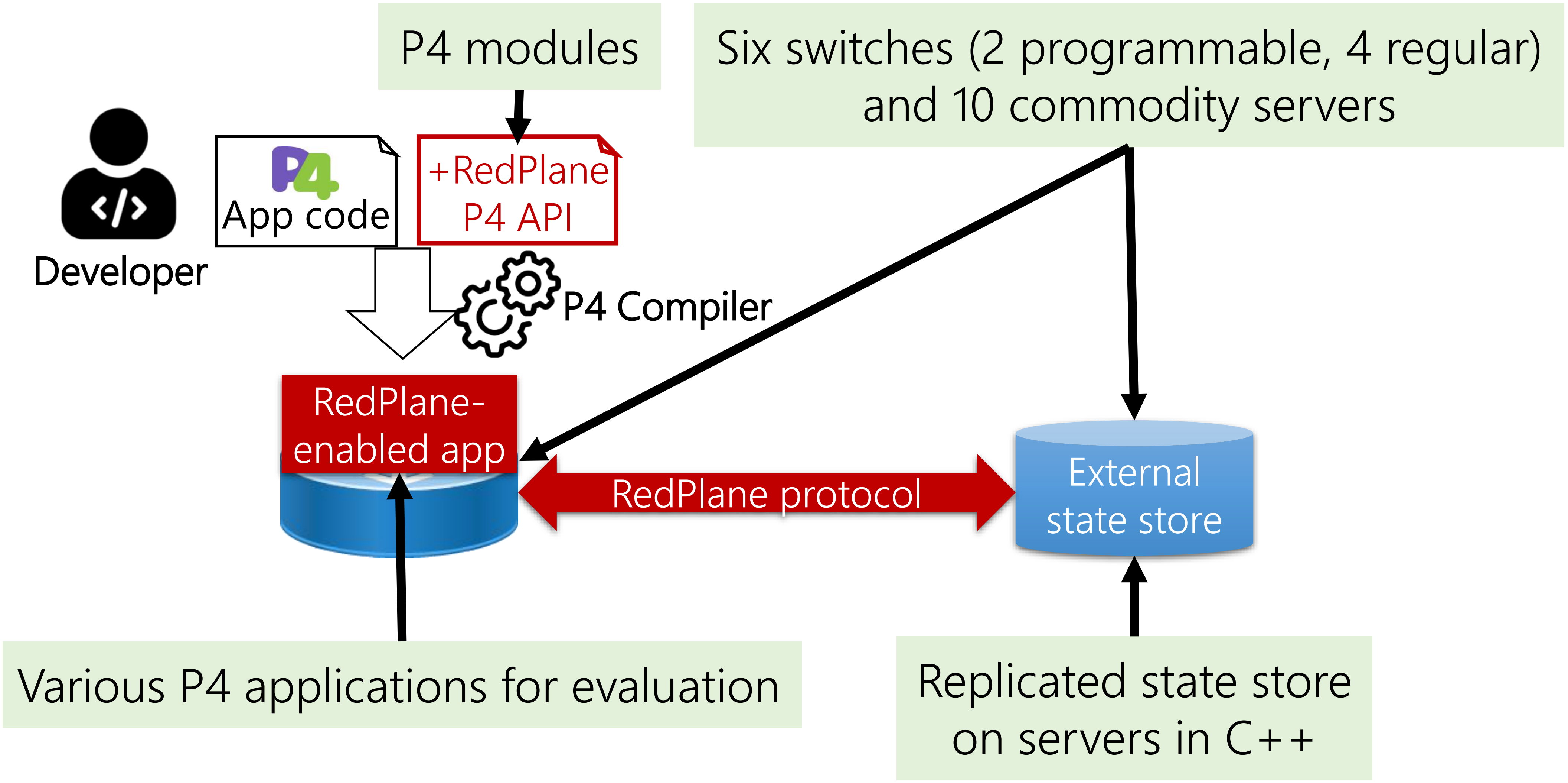
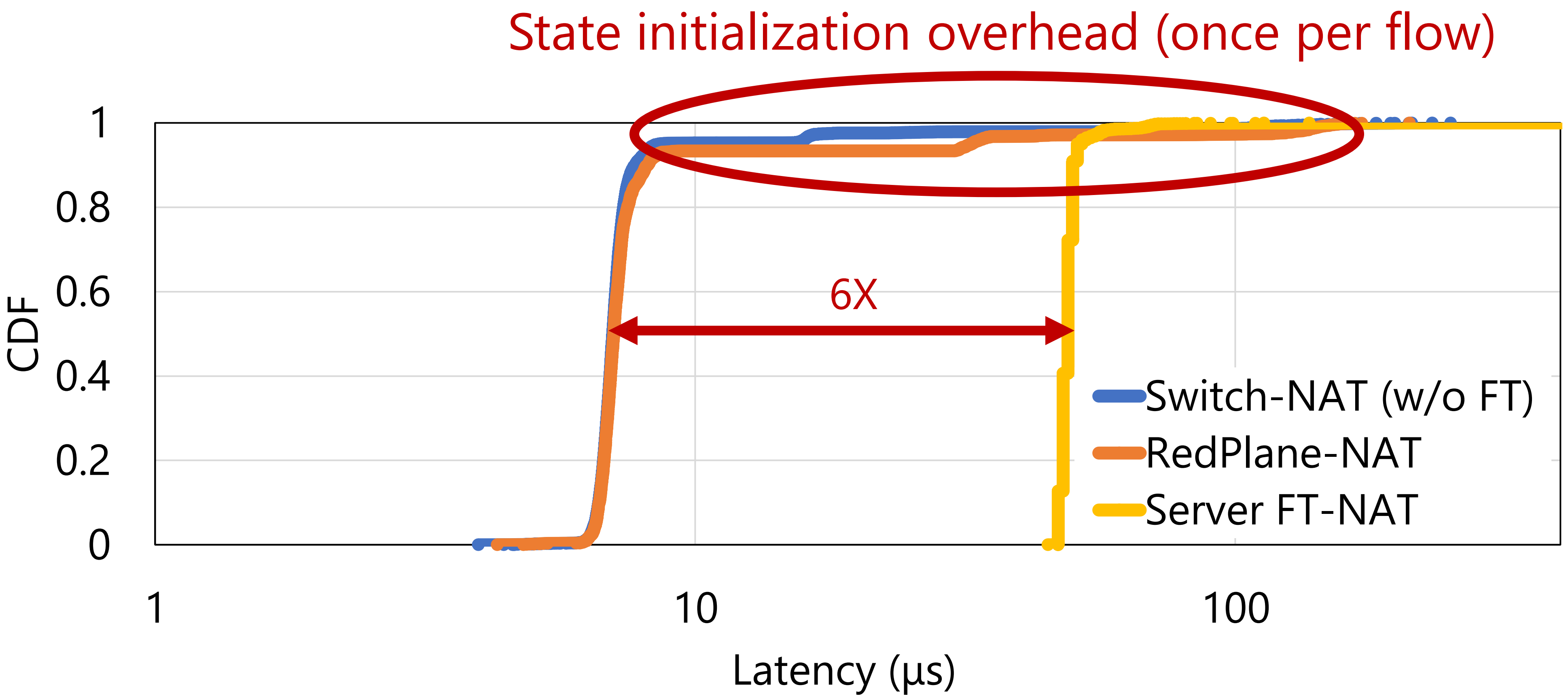
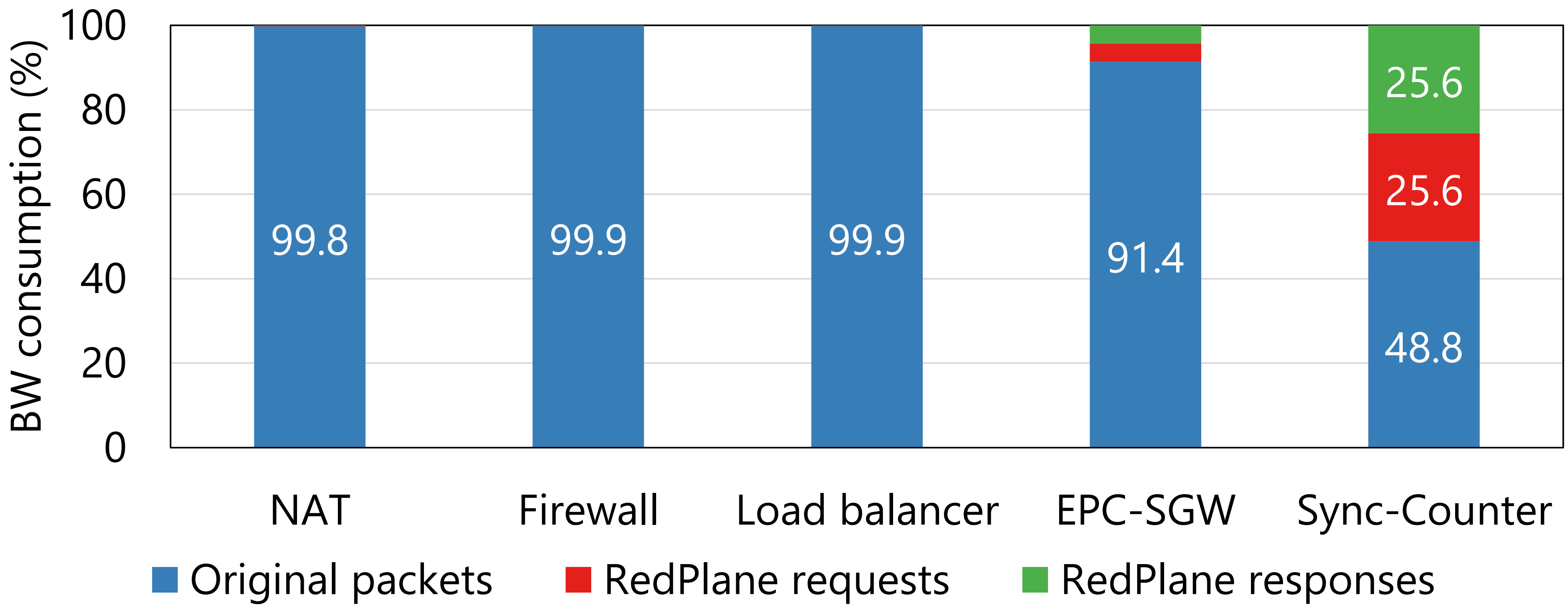
Implementation



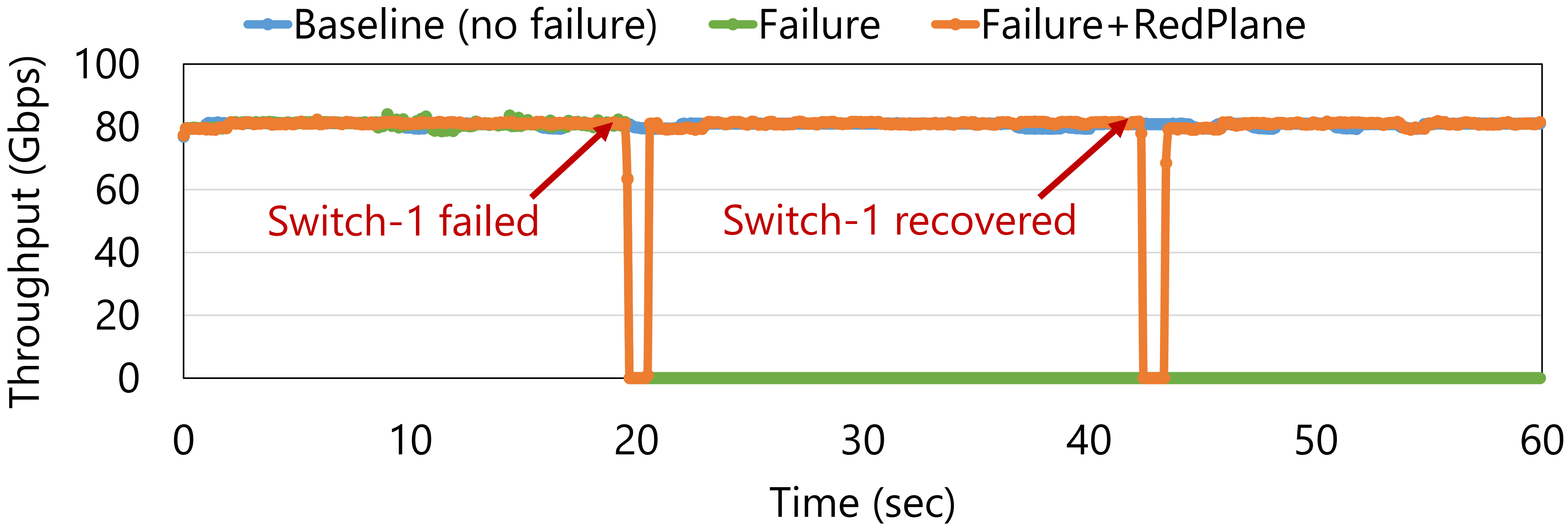
How does RedPlane affect application latency?



How much BW overhead does RedPlane add?



How fast the connectivity can be recovered?



Other results

Throughput of RedPlane-enabled applications

Low switch resource overhead of reliable replication protocol

Less than 13% of switch ASIC resource usage

Model checking for RedPlane protocol by using TLA+

Future directions

Better support for write-centric apps

Supporting non-partitionable states

Automatically enabling fault-tolerance with compiler/language support

Next generation switch architectures for fault-tolerance

Conclusions

Switch failures can affect the correctness of stateful in-switch apps

RedPlane provides a fault-tolerant state store abstraction

- Linearizability-based practical correctness definition for in-switch apps
- Bounded inconsistency mode for write-centric apps
- Sequencing and lightweight retransmission for reliable replication
- Lease-based state ownership management

Offers fault tolerance with minimal performance and resource overhead

- No per-packet latency overhead for read-centric apps
- End-to-end connectivity is recovered within a second

github.com/daehyeok-kim/redplane-public