A change detection primitive for the network data plane

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Problem

Traffic changes might indicate an anomaly in the network.

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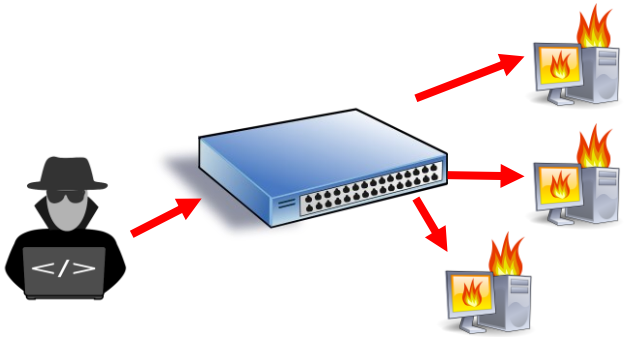
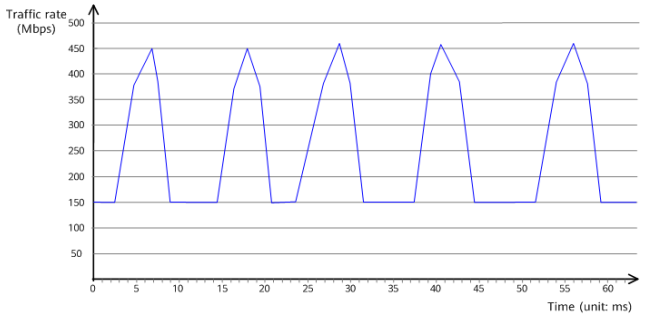
Traffic changes might indicate an **anomaly** in the network.

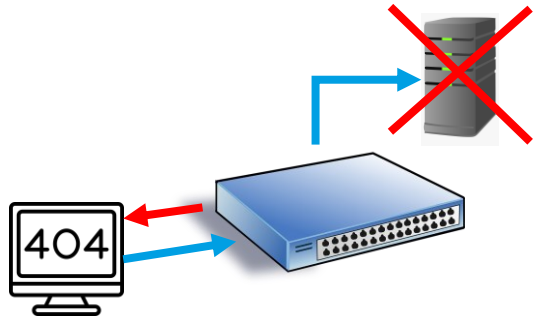
Their **timely detection** is of paramount importance to network operation!



Network Attack



Microburst



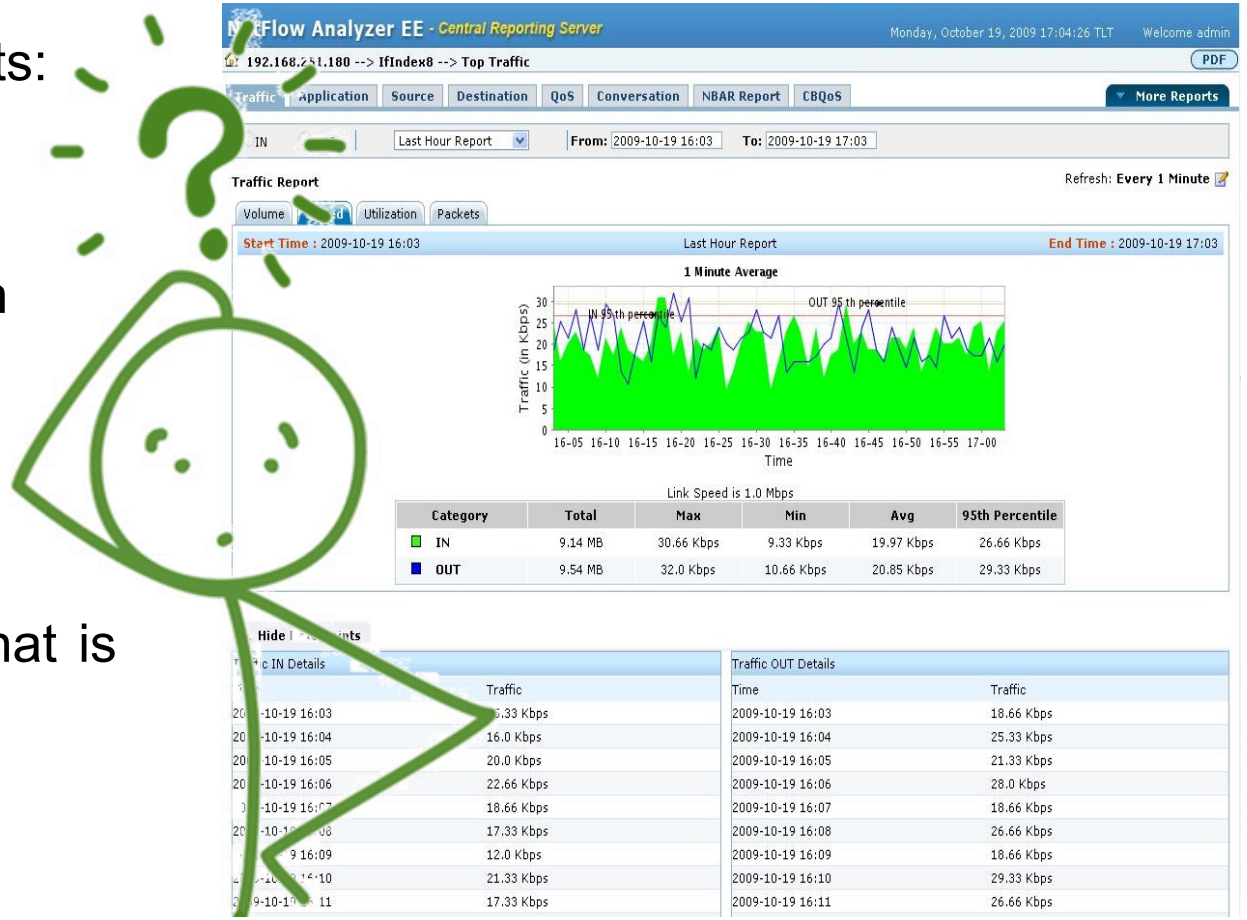
Faulty Hardware

Traditional change detection

Sampling via Flow-based measurements:

- Standard, e.g., Netflow and sFlow
- Sampling → CPU, memory, bandwidth
- Low sampling rate → **Low Fidelity**

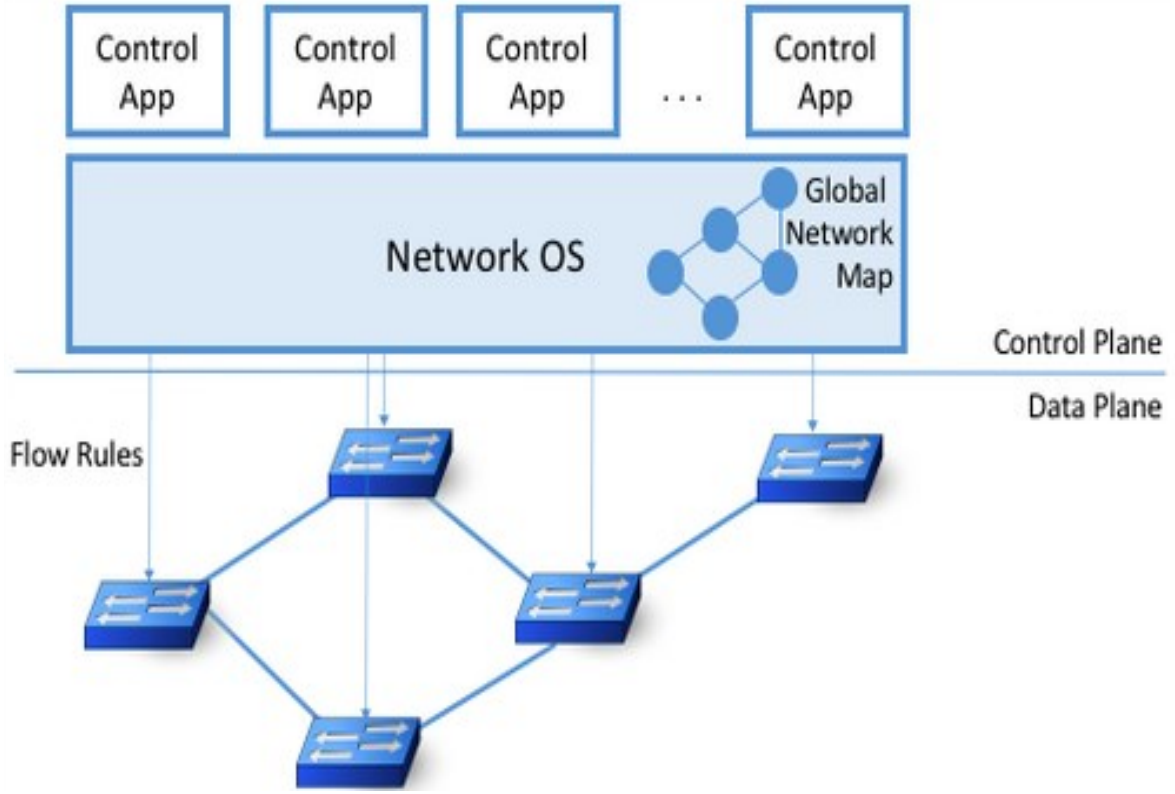
Based on **fixed-function equipment** that is **difficult to manage** and **to configure**.



Networks are changing!

Software Defined Networking (SDN):

- Separation of the network planes.
- Programmability of each plane.



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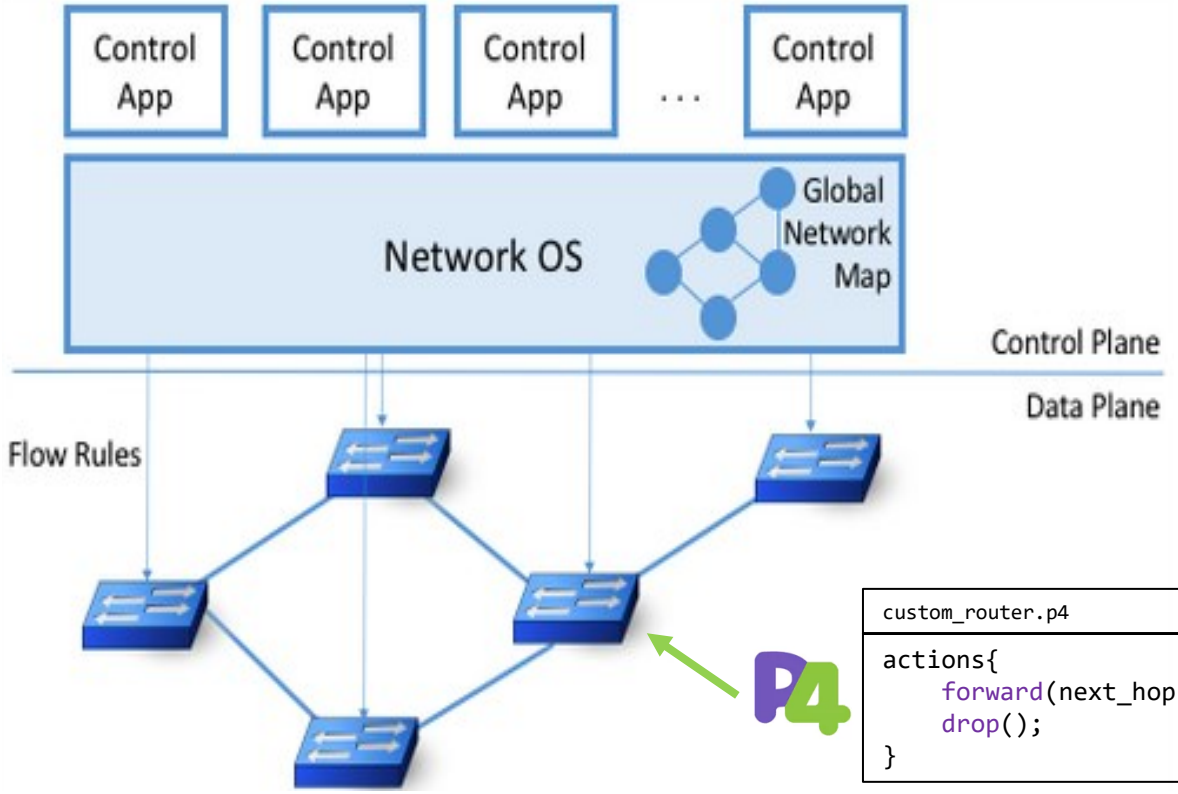
Programmable Switching Chips:

- Detection of traffic changes **inside the data plane**.



In-network change detection

Some solutions already enable change detection using P4 to program the data plane.

However, these are often **heavy-hitter** based.

But sometimes the problem is with smaller flows!

Approach	Tbps performance P4	Heavy-Hitter Change Detection	Generic Change Detection
Hashpipe[1]	X	X	
Elastic Sketch[2]	X	X	
SketchLearn[3]	X	X	
K-ary Sketch[4]		X	X

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Contributions

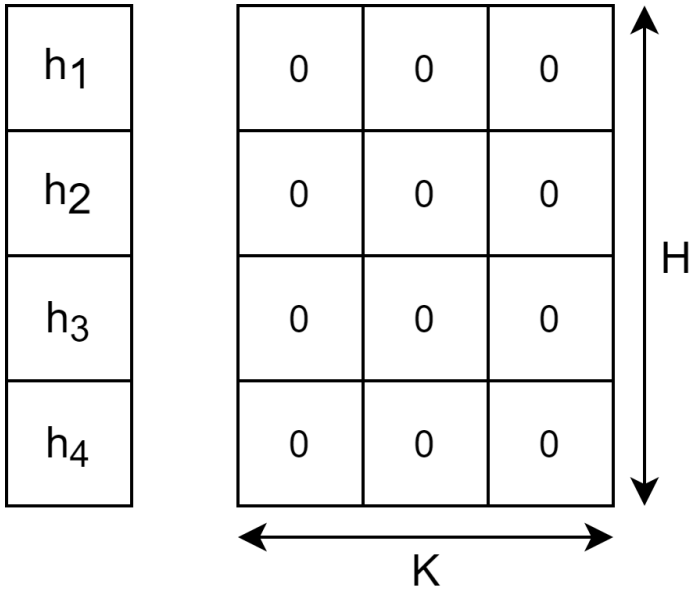
- The design of **K-meleon**, an *online change detection system* that leverages programmable switches.
- The implementation of a **prototype in P4** for Tofino switch.
- An evaluation using the software switch bmv2 that demonstrates K-meleon achieves the same level of **accuracy** as the **k-ary algorithm**.

Design

K-meleon

Sketches

Sketches are **compact summaries of network traffic**, which enable the design of memory-efficient network monitoring systems.



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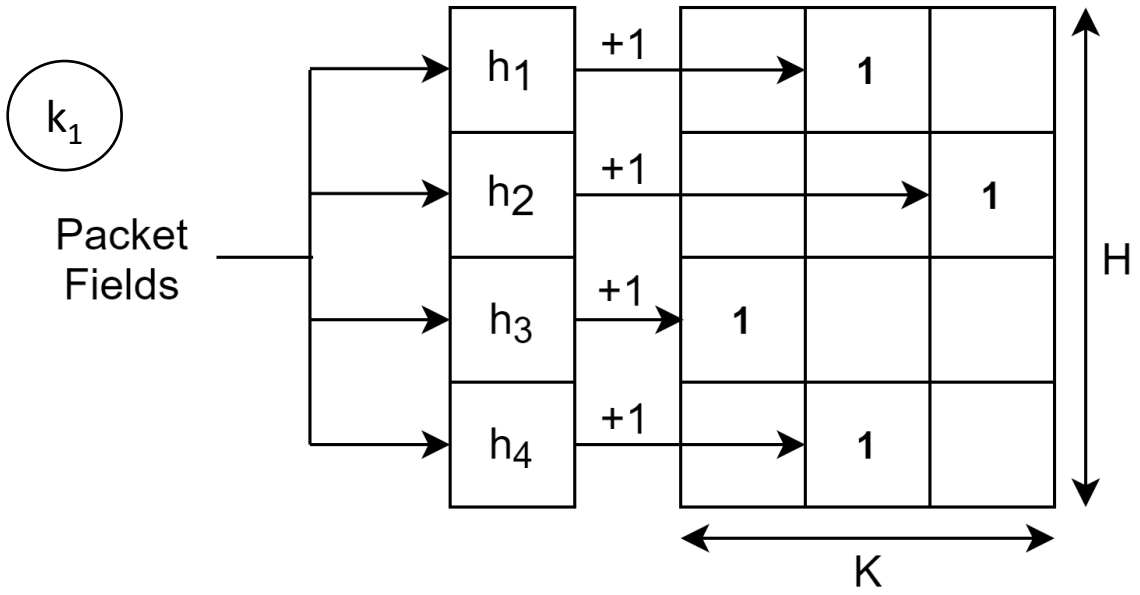

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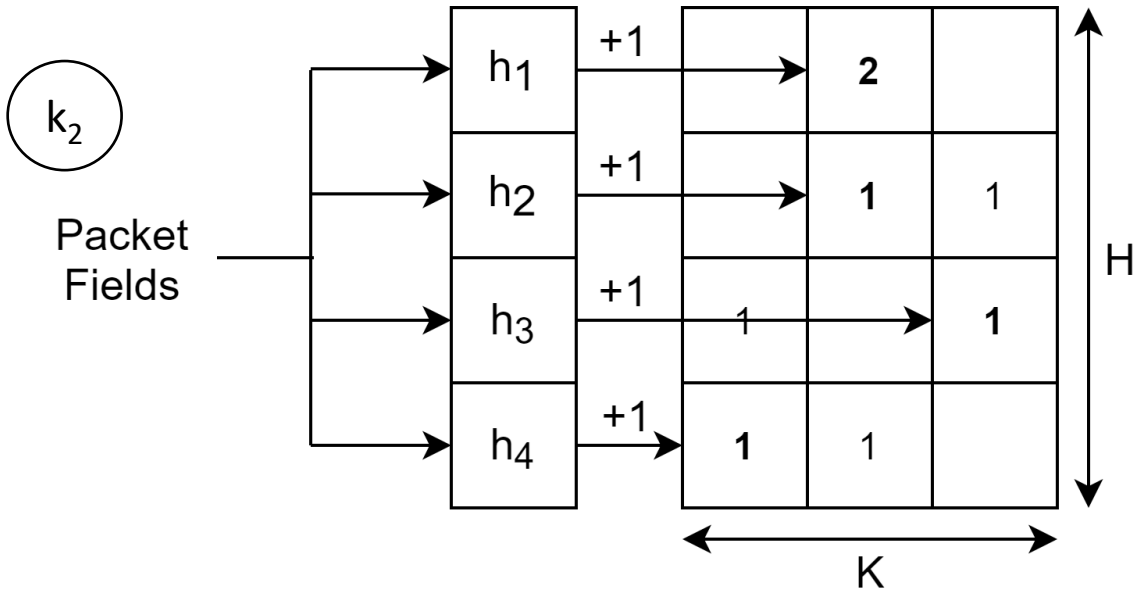

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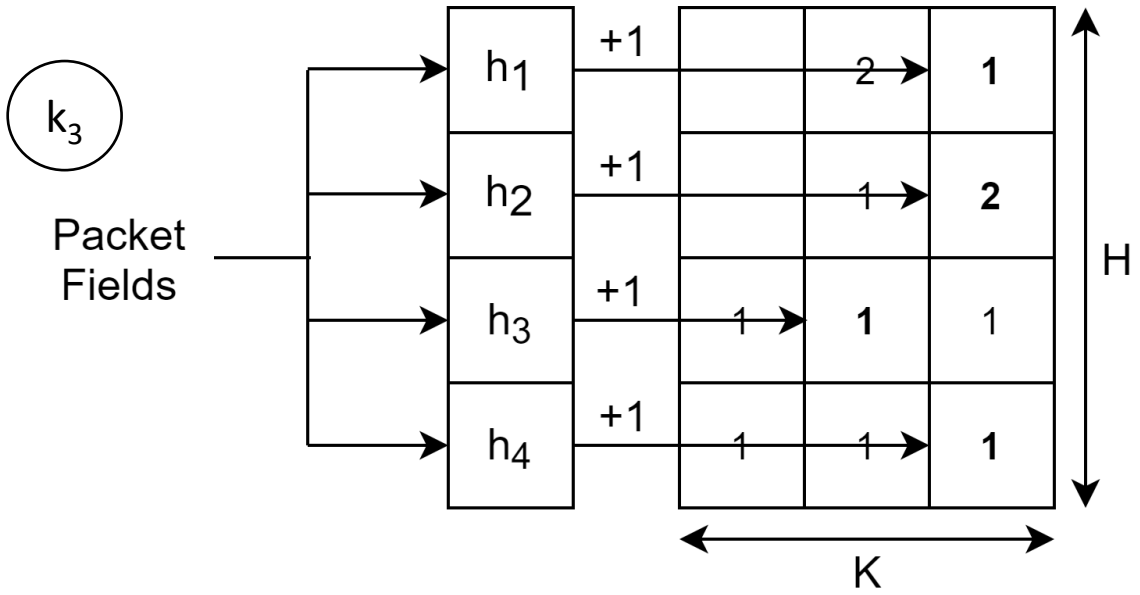

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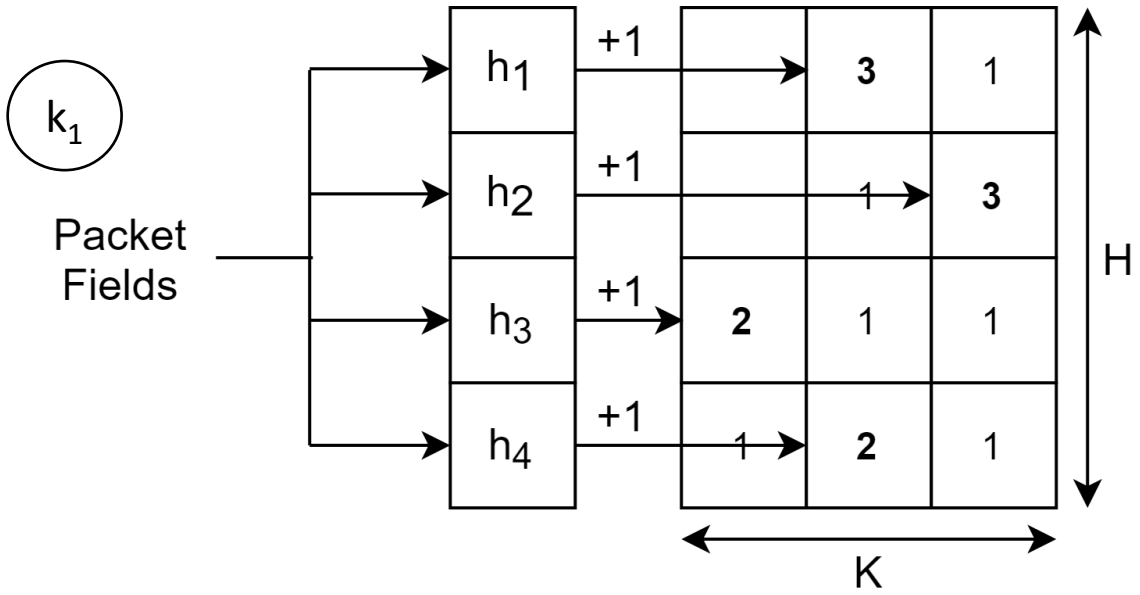

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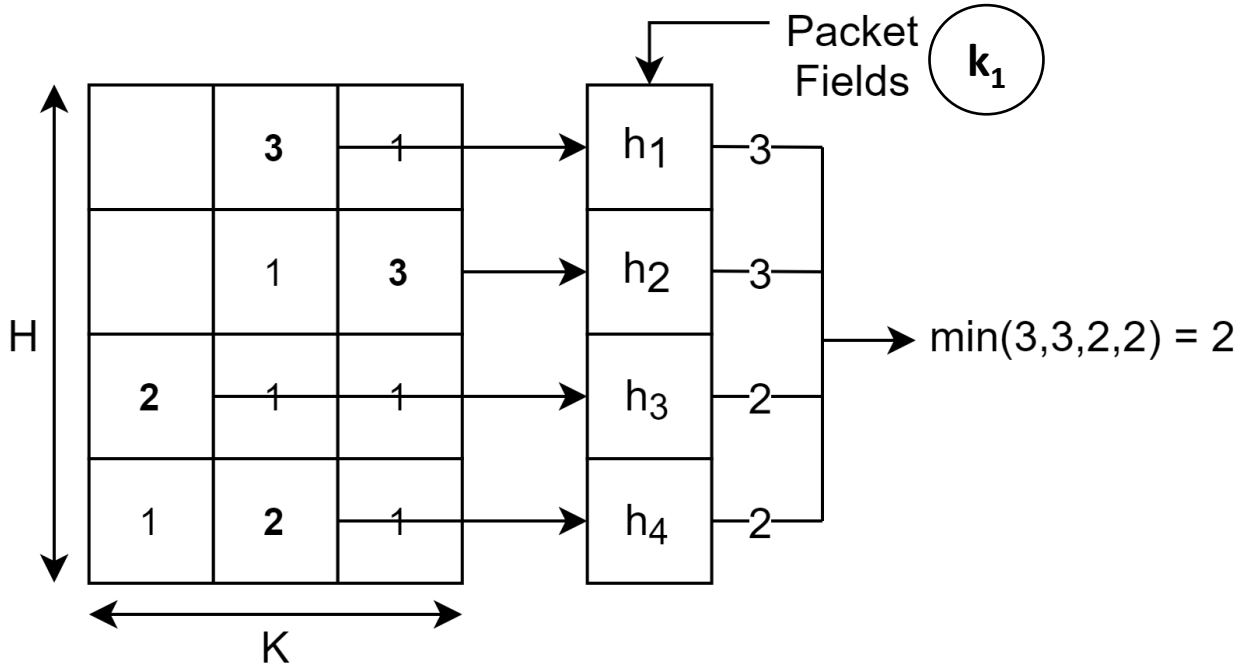
ESTIMATE

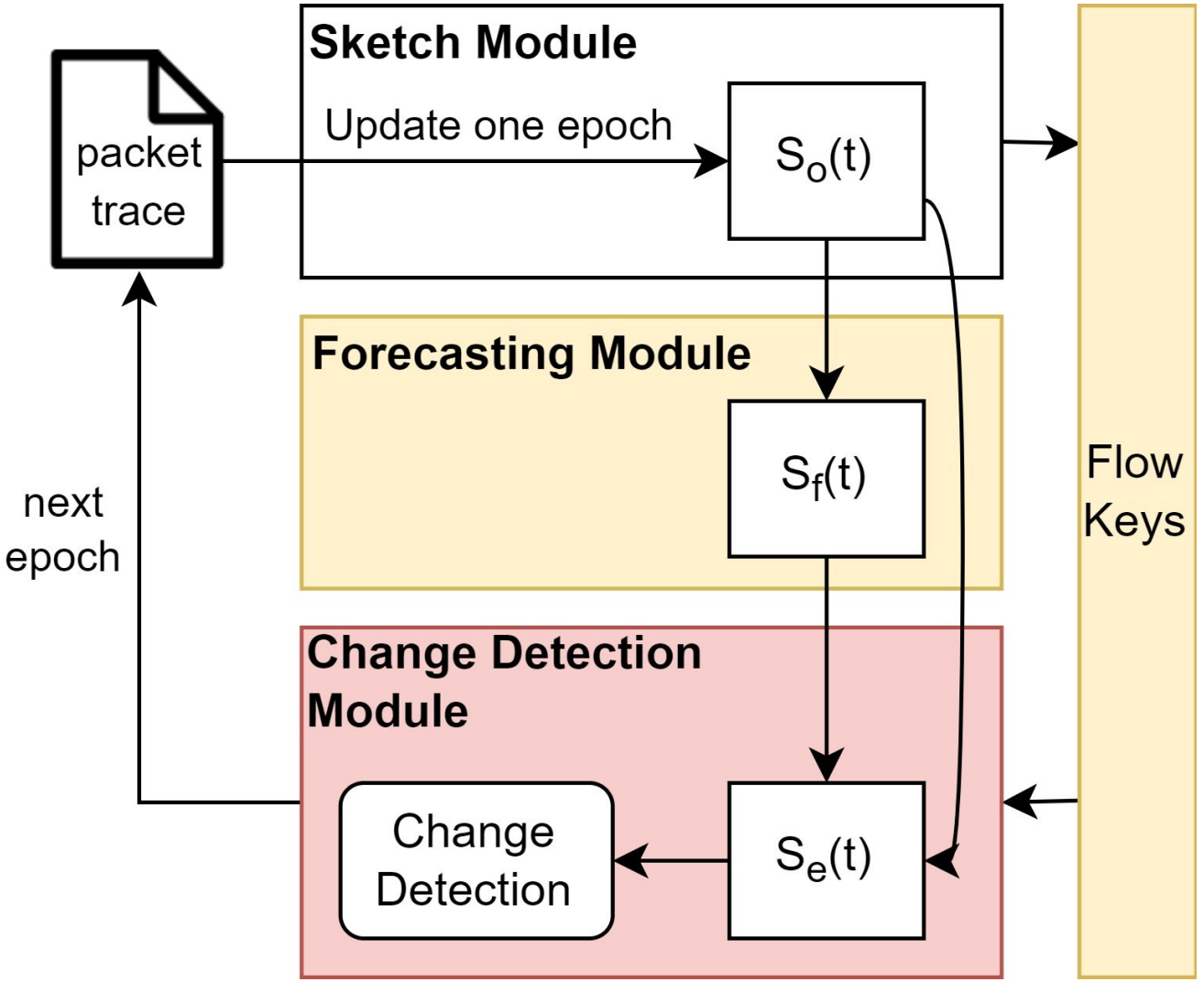
with Count-min



K-ary Algorithm

Batch-based approach.

- Splits time into a series of time intervals, called **epochs**.
- Performs all operations at the end of each epoch.



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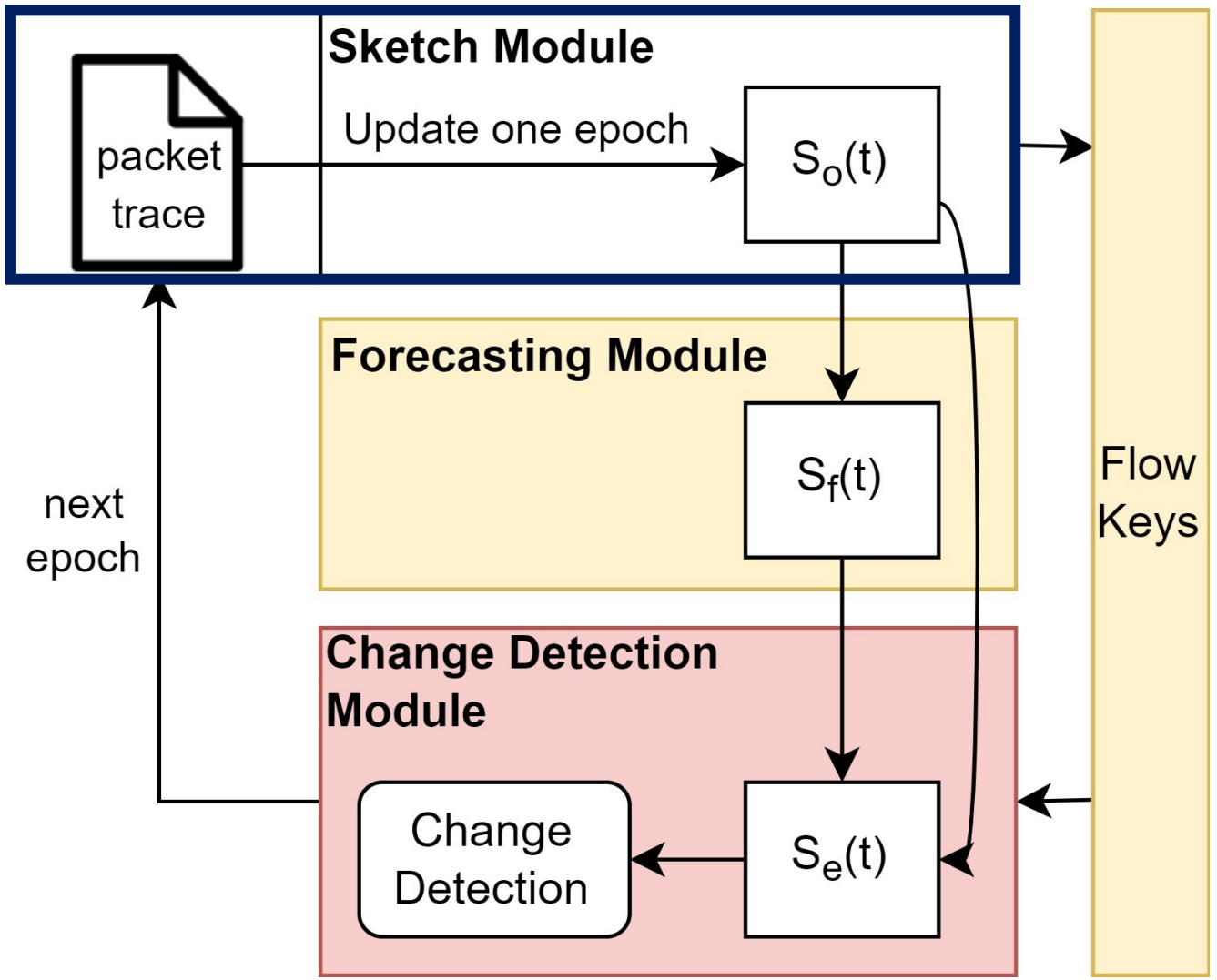

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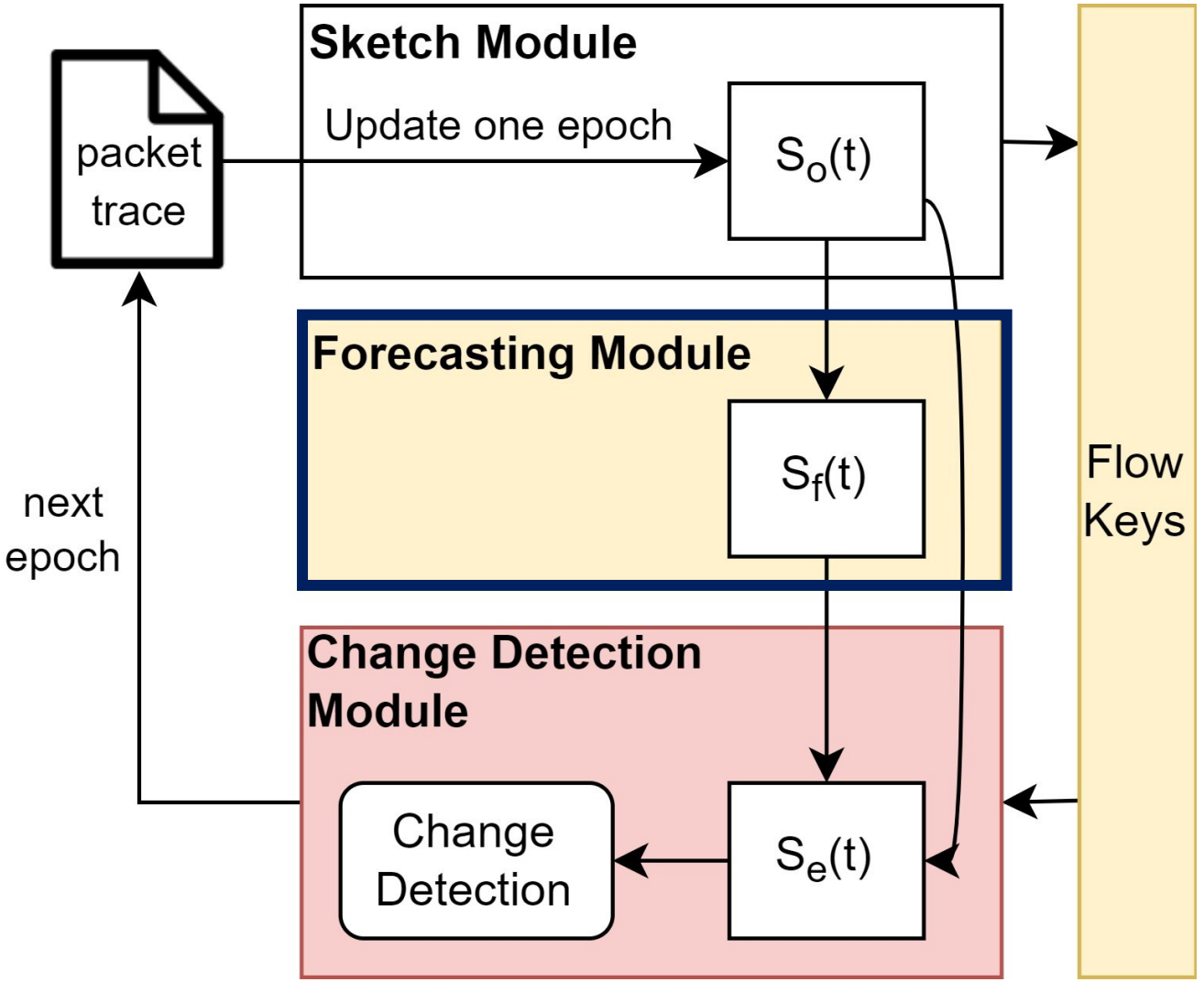

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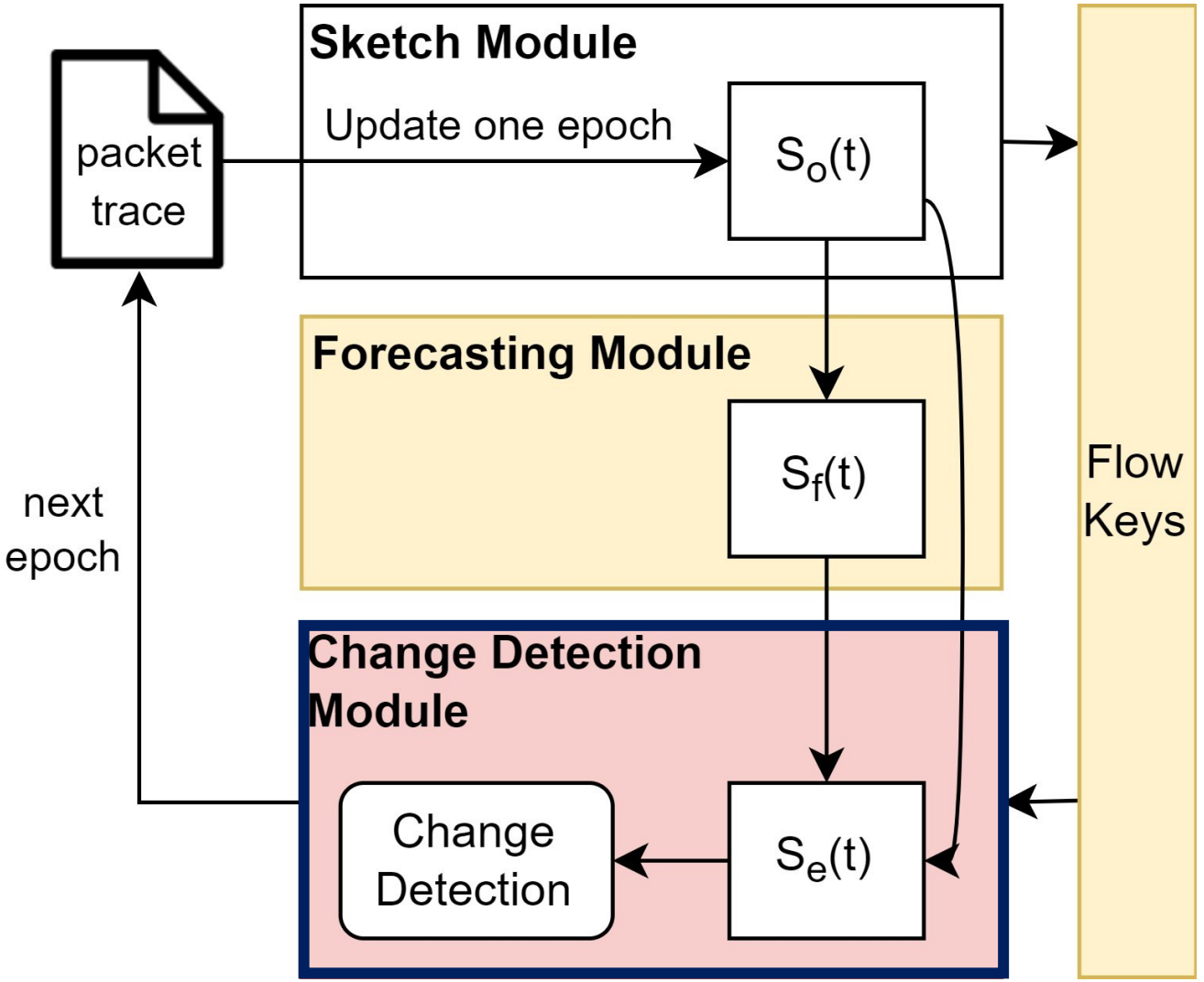


K-ary Operations

The forecasting module uses **forecasting models**, such as the **EWMA**:

$$S_f(t) = \begin{cases} \alpha \cdot S_o(t-1) + (1-\alpha) \cdot S_f(t-1), & t > 2 \\ S_o(1), & t = 2 \end{cases}$$

Floating-point multiplications

The change detection module computes **estimates** on top of the error sketch:

$$v_a^{\text{est}} = \text{median}_{i \in [H]} \{ v_a^{h_i} \}$$

medians

$$F_2^{\text{est}} = \text{median}_{i \in [H]} \{ F_2^{h_i} \}$$

where

$$v_a^{h_i} = \frac{T[i][h_i(a)] - sum(S)/K}{1 - 1/K}$$

Sum of all values in the sketch

where

$$F_2^{h_i} = \frac{K}{K-1} \sum_{j \in [K]} (T_S[i][j])^2 - \frac{1}{K-1} (sum(S))^2$$

squares

Programming the data plane

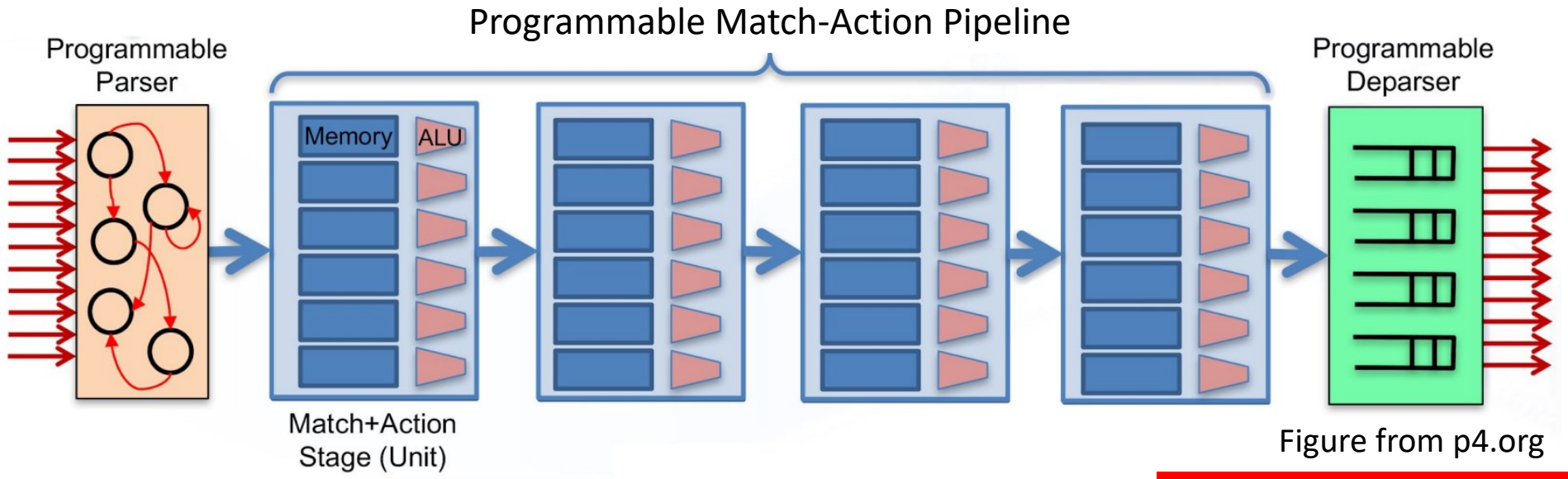


Figure from p4.org

- Protocol-Independent Switch Architecture (PISA)

Memory and budget of operations are limited!

K-ary algorithm - limitations

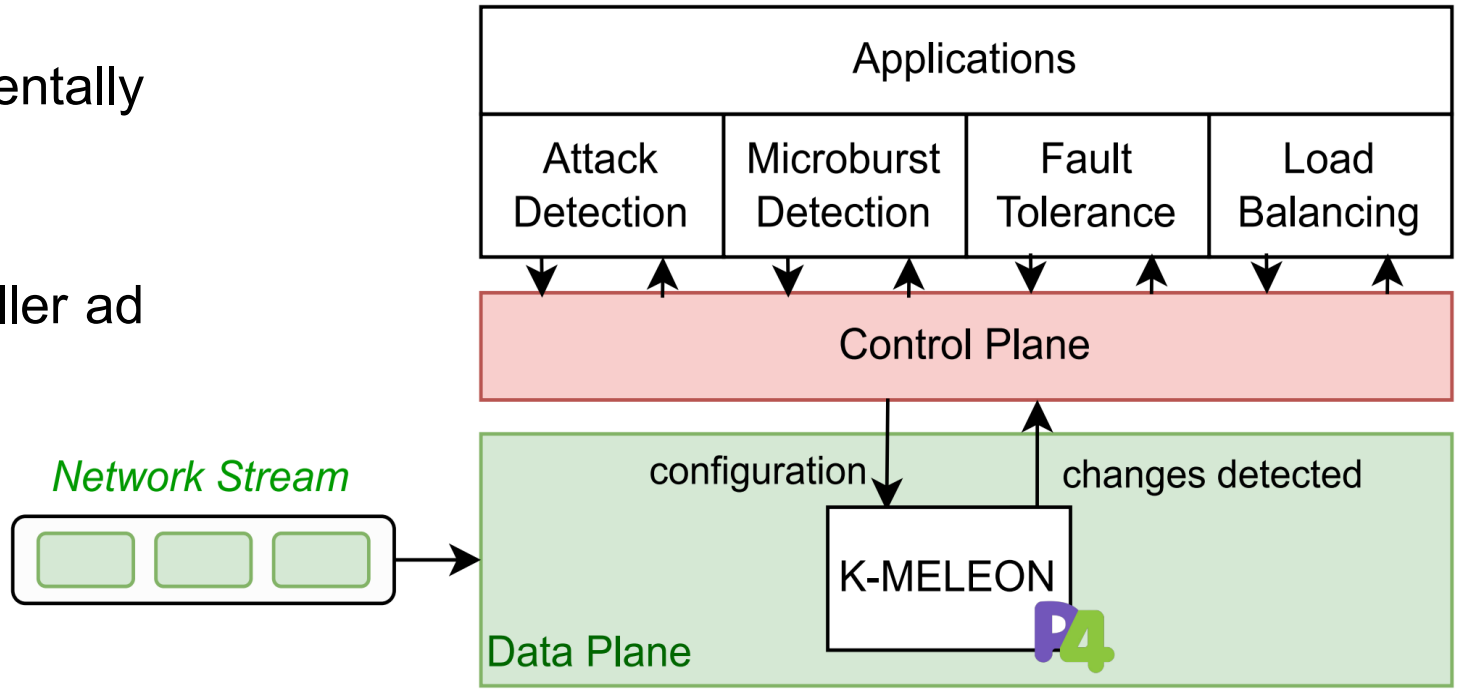
Performs batch-based operations at the end of each epoch, thus;

- Does not fit the **constraints of the data plane** programming model;
- Performs **complex operations** not supported in P4;

The k-meleon

Stream-based approach.

- Performs operations incrementally with each packet.
- Sends changes to the controller ad hoc.



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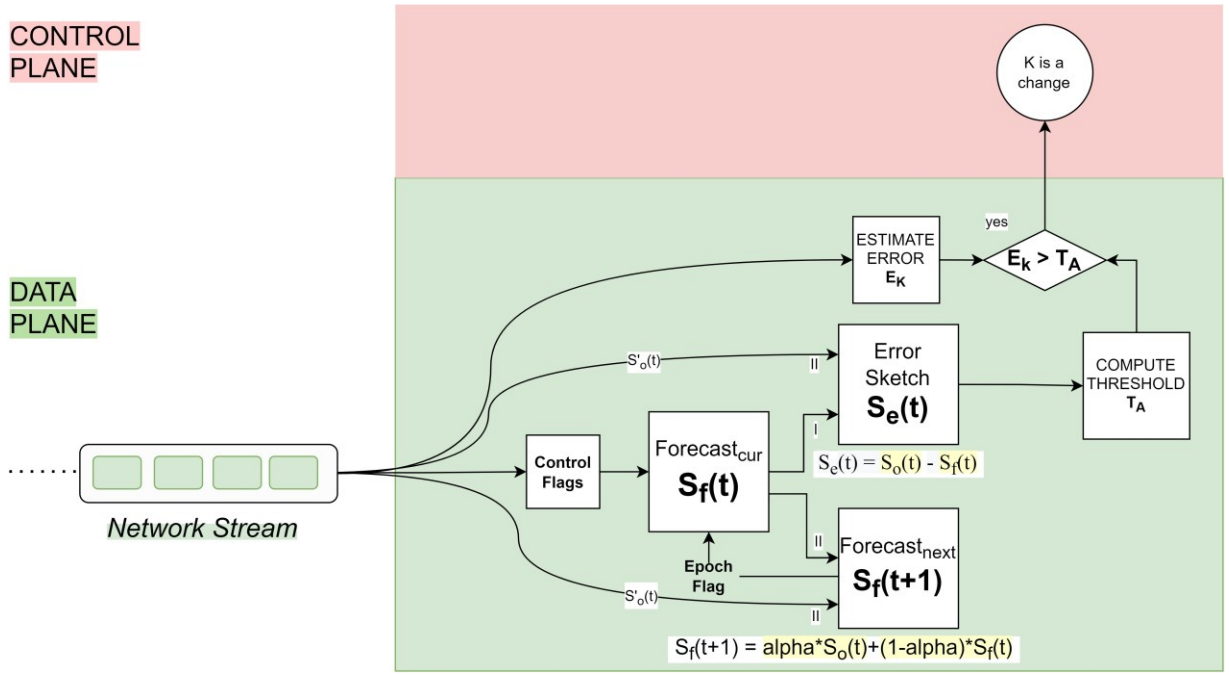
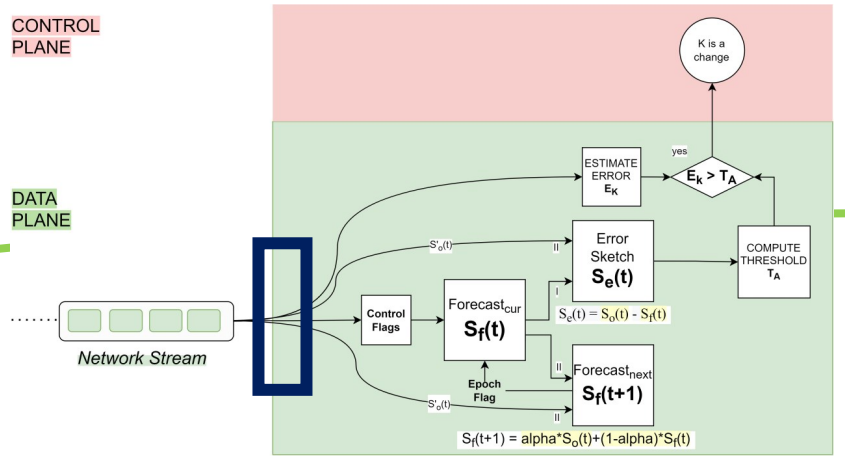
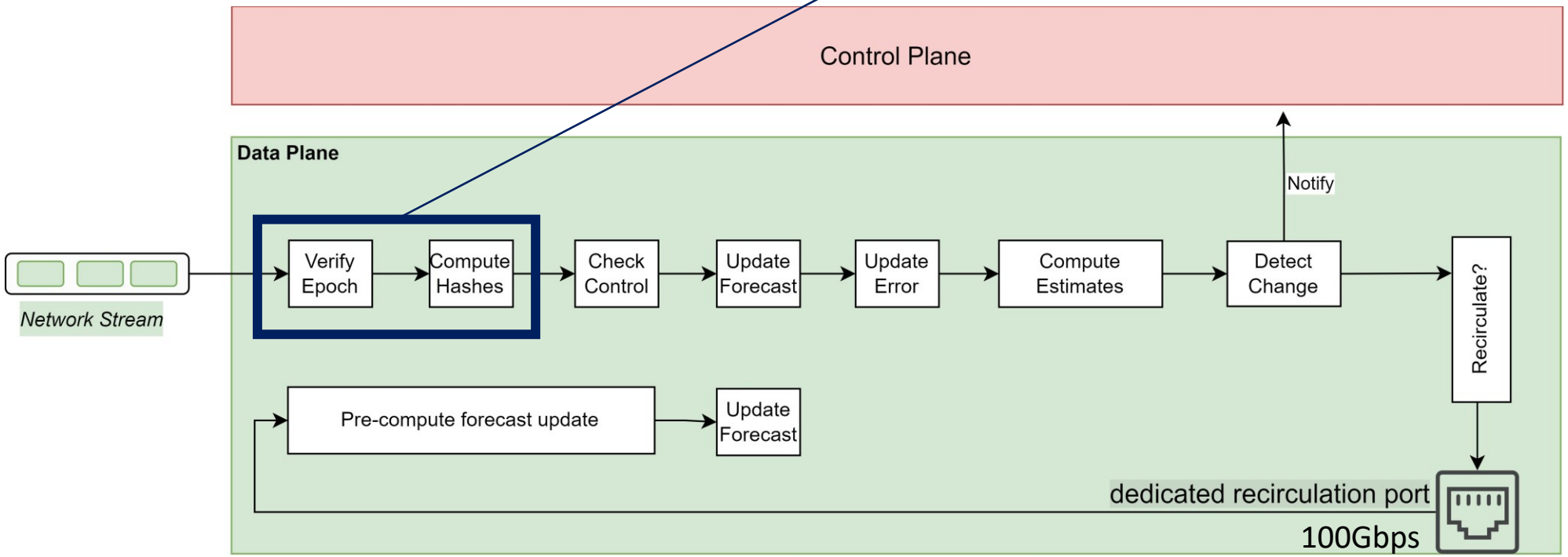


The k-meleon on TNA



Change epoch if needed, compute hashes to index the sketches.



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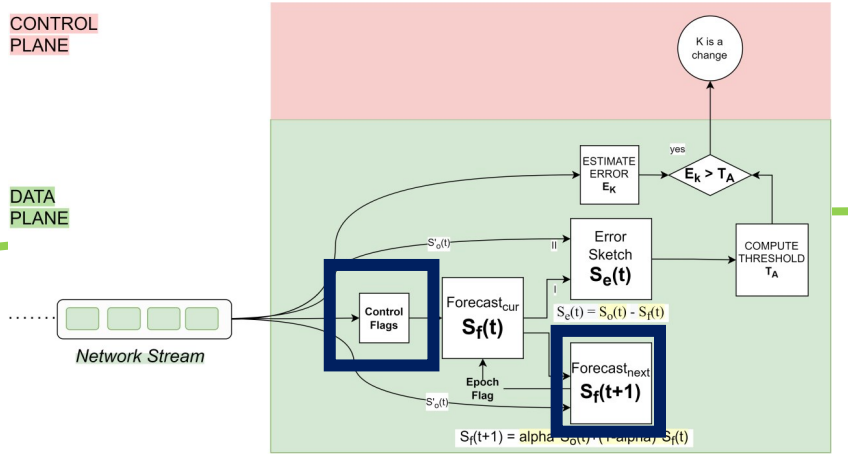
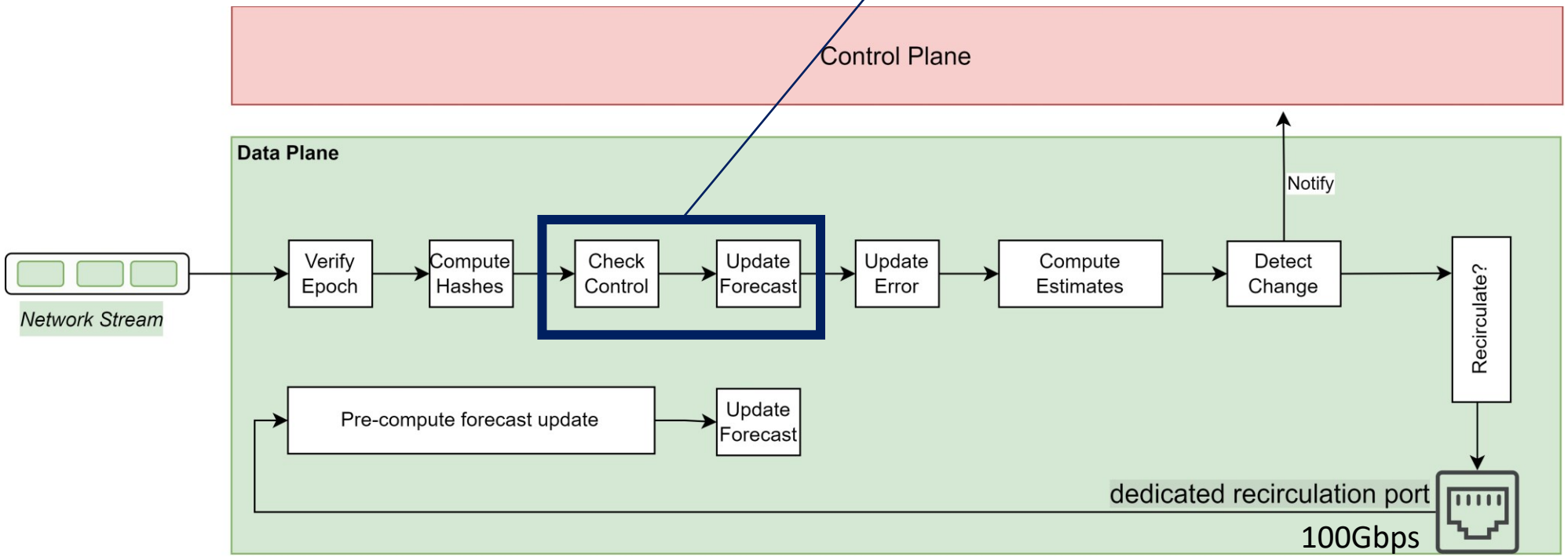
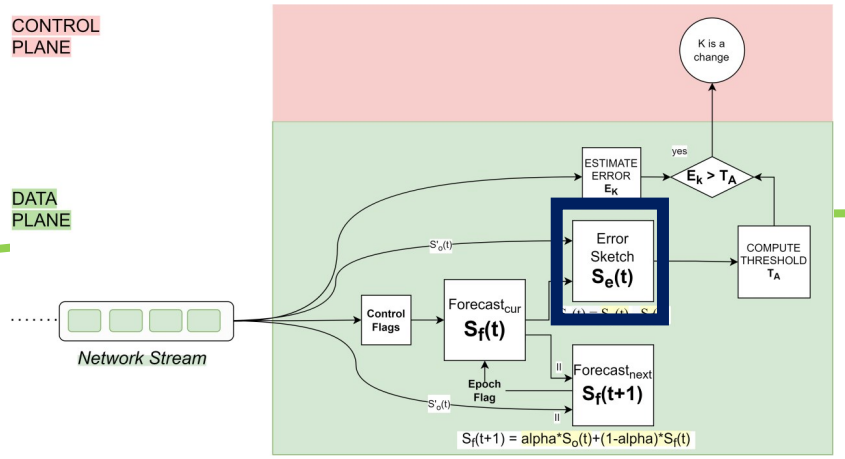


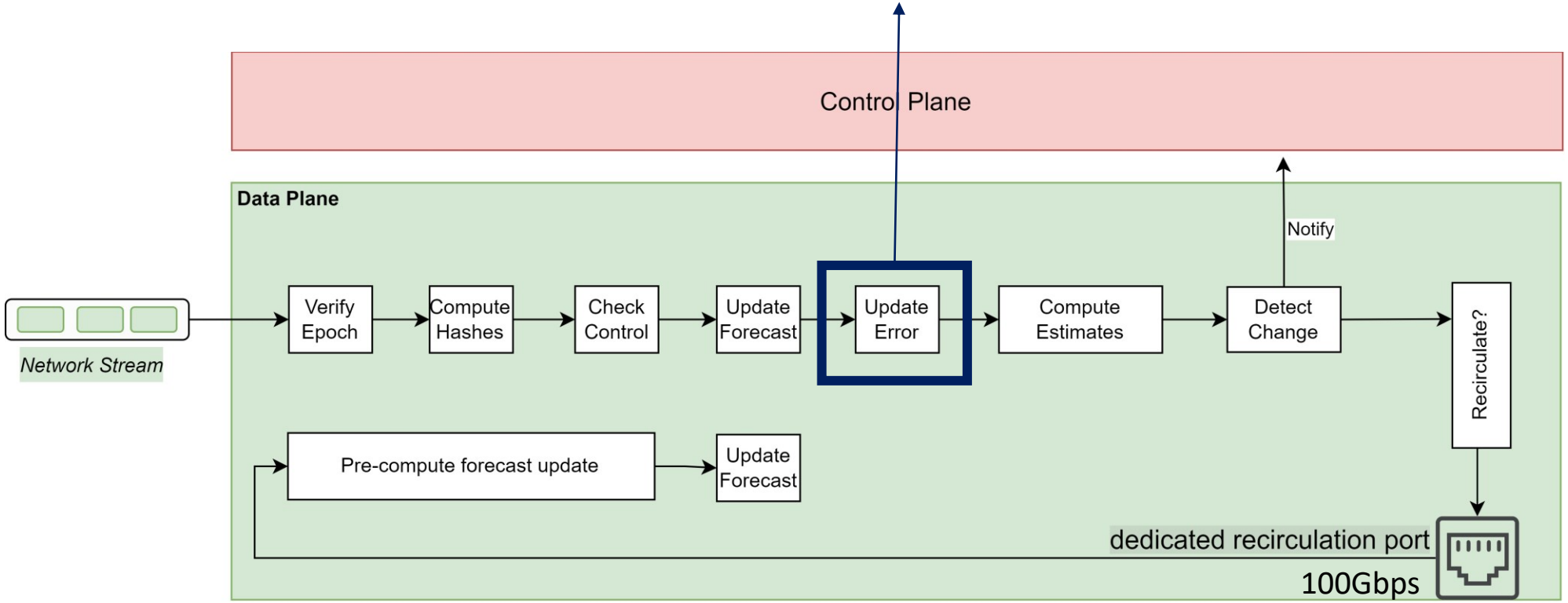
Check if epoch changed, and update forecast sketch accordingly.



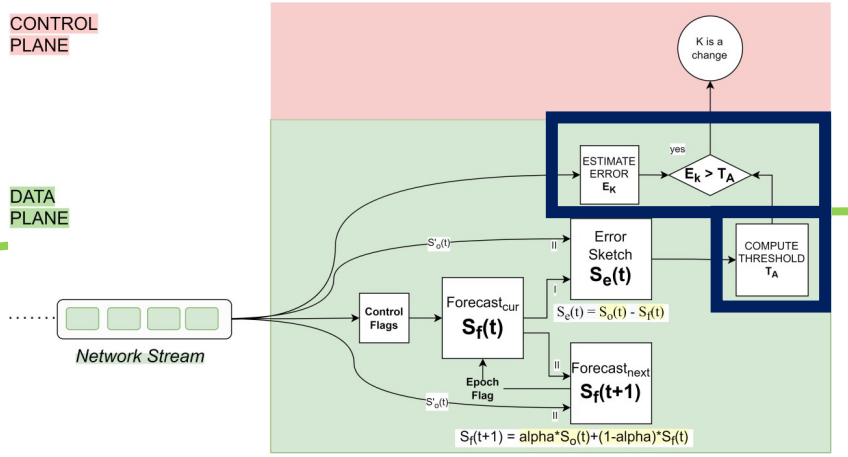
The k-meleon



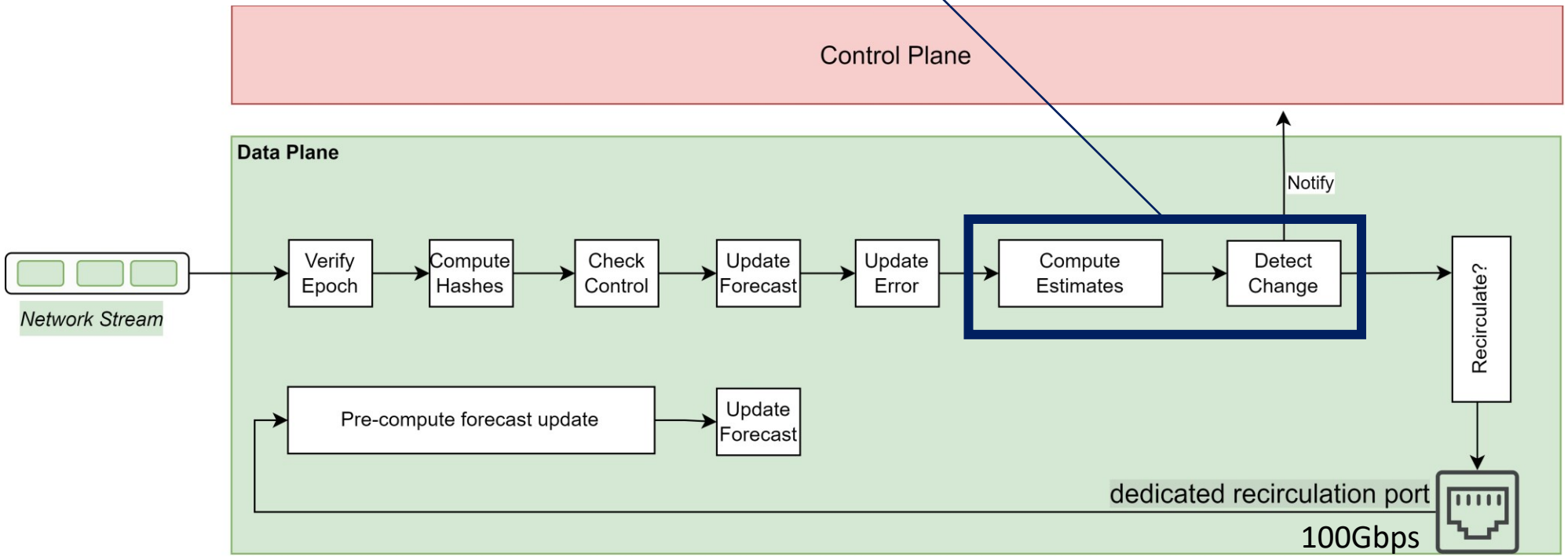
Update error sketch according to the control check.



The k-meleon



Compute estimates and perform detection.



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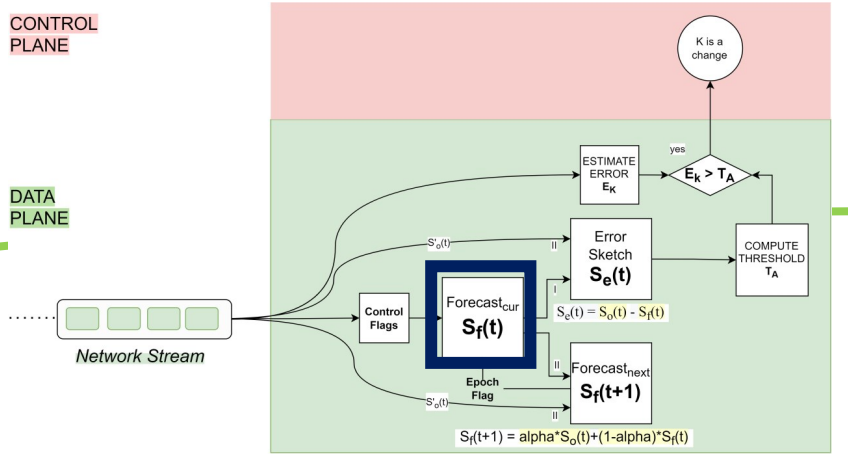
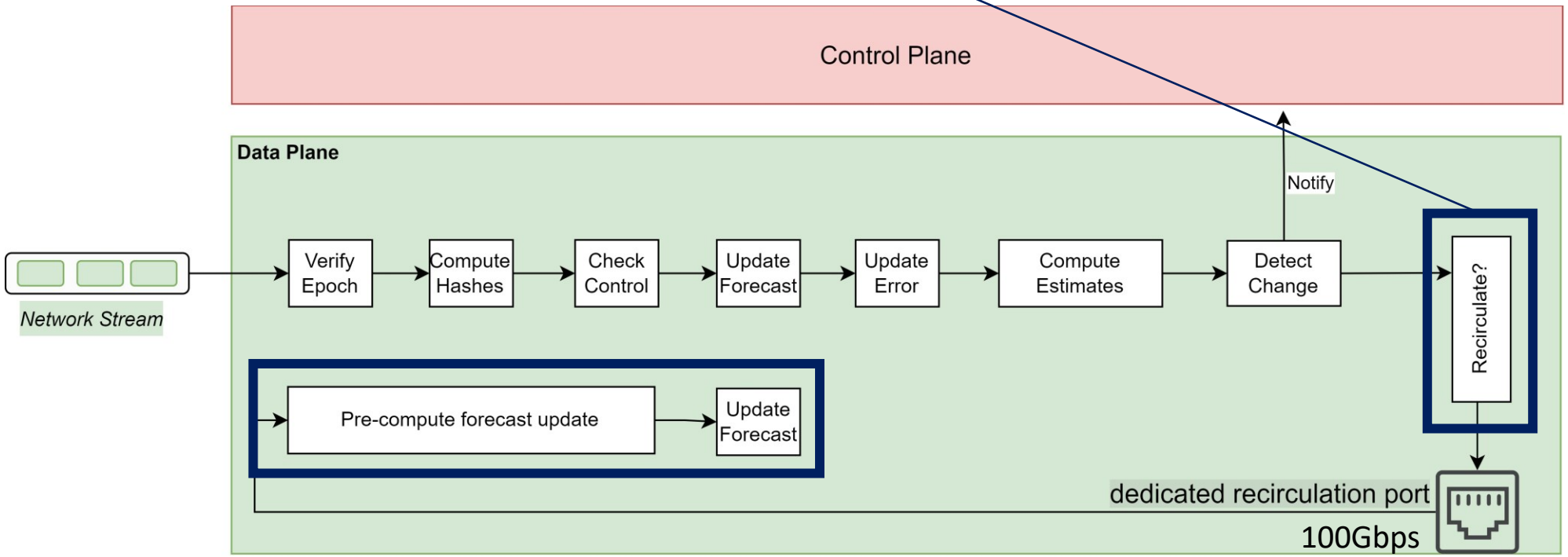


Recirculate to change epoch.



Evaluation

Questions

Q1. How does k-meleon perform compared to k-ary?

Q2. What is the expected performance of k-meleon?

Q3. What is the resource usage of k-meleon?

Experimental setup

The evaluation of k-meleon uses several packet traces from two datasets:

CSE-CIC-IDS2018[5] → Network attacks.

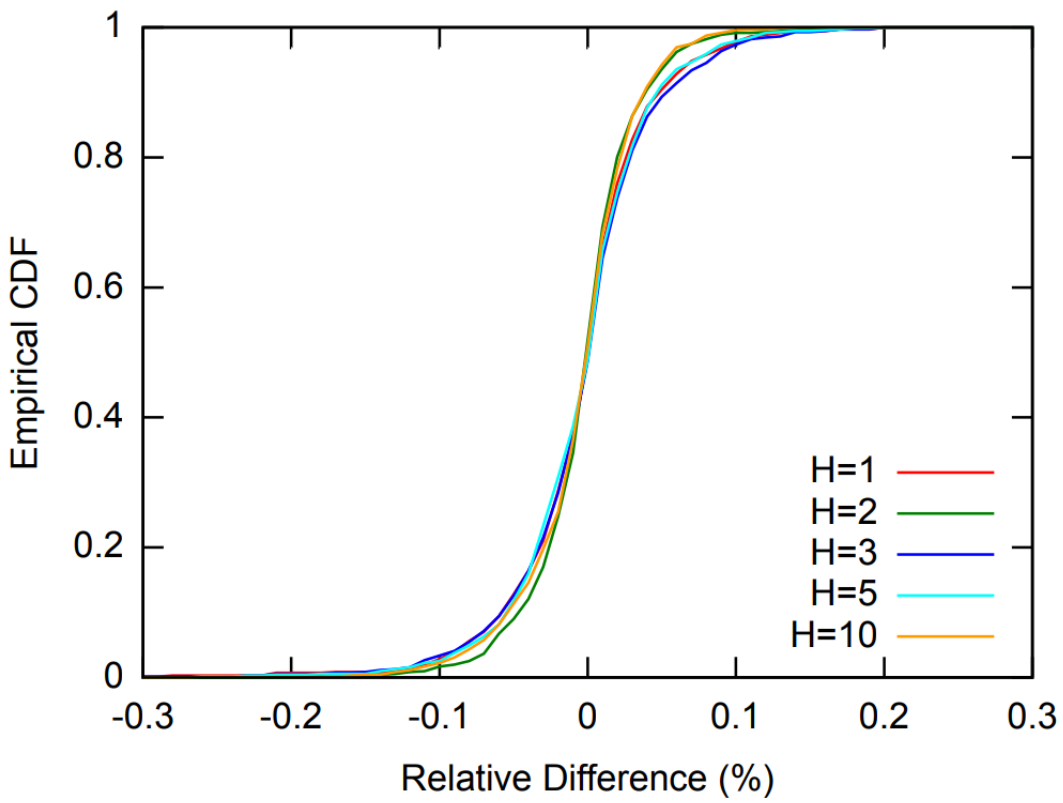
Data-center measurement (UN1)[6] → Microburst events.

Version	Purpose
K-ary in python	Establish a baseline
K-meleon in P4 for bmv2	Verify the correctness
K-meleon in P4 for TNA	Final target - Evaluation

Q1. K-meleon vs. k-ary

We vary the **size of the sketch**, which affects the number of complex computations performed.

Median relative difference is very low for any value of H (<0.2%).

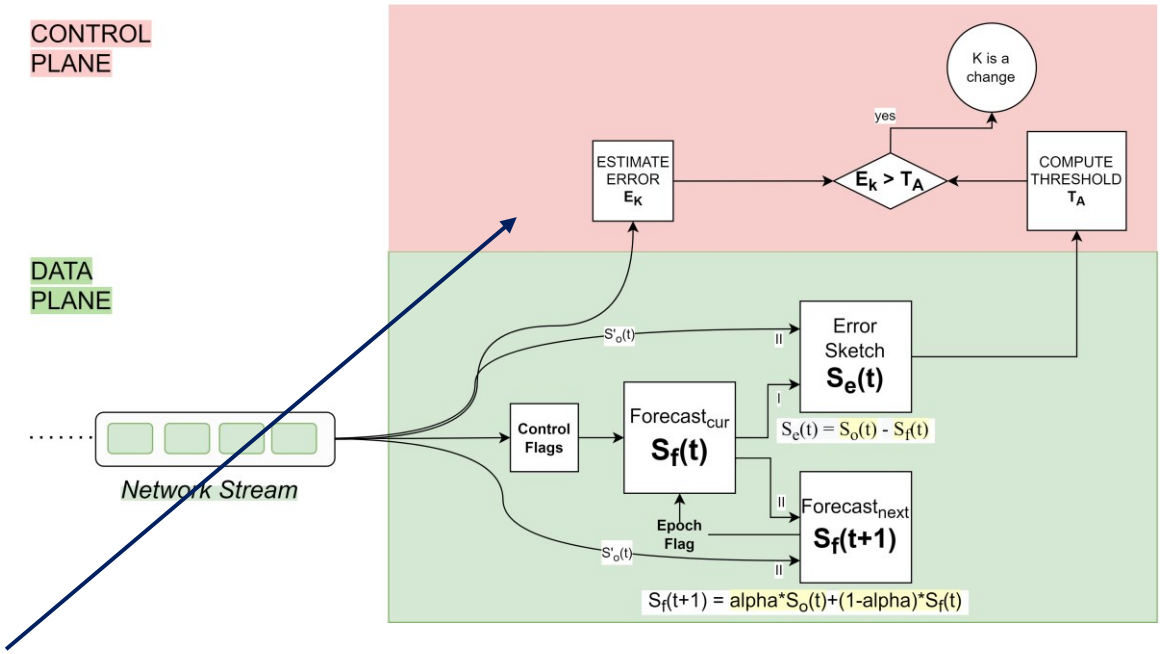


Q2. Performance

Our P4 prototype for TNA compiled successfully.

- Thus, it should run at line-rate, sustaining Tbps net traffic.

However, we have not yet moved all computations to the data plane.



Q3. Resource Usage on TNA

Only 7 stages are used by our preliminary prototype in P4 for TNA.

Only ingress is used for performing computation.

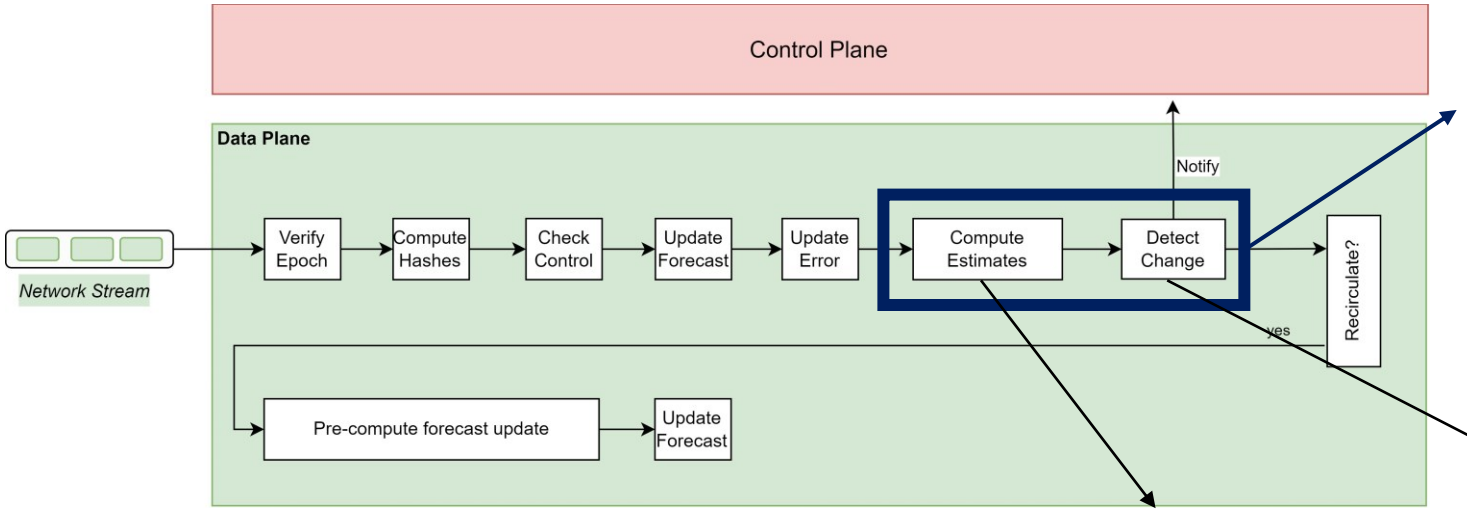
Computing	Usage
Stages	58%
Meter ALU	16.7%
Hash Dist Units	13.9%
VLIWs	4.7%
Memory	**Usage**
SRAM	2%
TCAM	0%

Conclusions

- The design of **K-meleon**, an *online change detection system* that leverages programmable switches.
- The implementation of a **prototype in P4** for Tofino Switch.
- An evaluation using the software switch bmv2 that demonstrates K-meleon achieves the same level of **accuracy** as the **k-ary algorithm**.

Discussion and future work

Detection entirely in the data plane



Still not implemented in the data plane.

But we still have several stages available in the ingress pipeline!

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where

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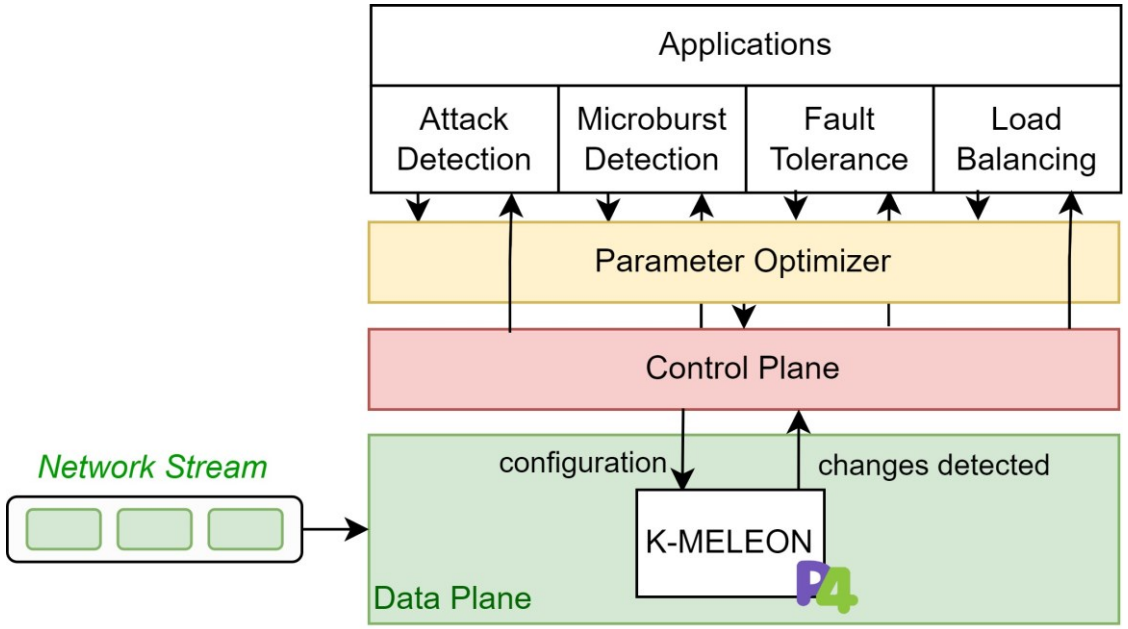
Discussion and future work

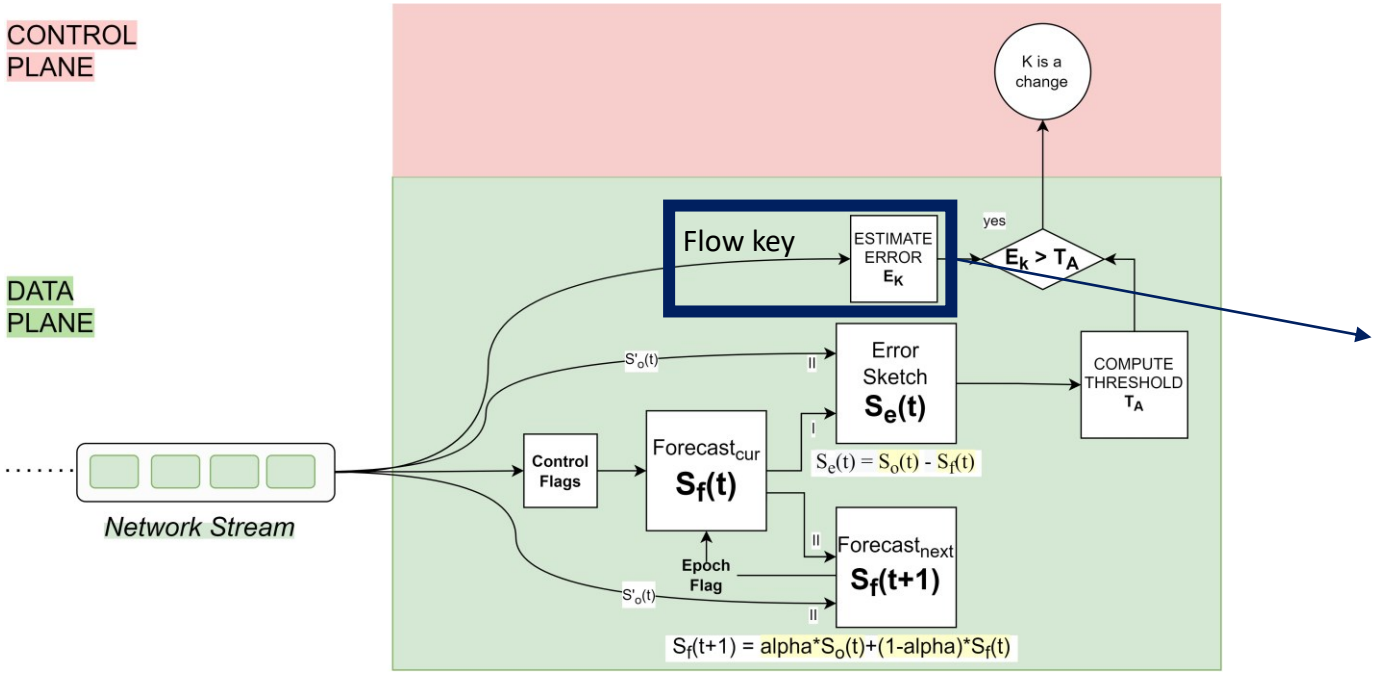
Use Cases



The tuning of some parameters improves detection accuracy of our primitive for different use cases.

Discussion and future work

Reversibility



The K meleon sketch does not maintain the culprit flow keys.

We are considering two options:

a) Using the flow keys directly from packets as they traverse the switch in the subsequent epoch.

b) Using a scheme based on some sort of voting mechanism (e.g., based on the MV Sketch[7]).

Thank You

Questions?

References

[1] Vibhaalakshmi Sivaraman et al. 2017. Heavy-hitter detection entirely in the data plane. In Proc. of ACM SOSR. 164–176.

[2] Tong Yang et al. 2018. Elastic sketch: Adaptive and fast network-wide measurements. In Proc. of ACM SIGCOMM'18. 561–575.

[3] Qun Huang et al. 2018. Sketchlearn: relieving user burdens in approximate measurement with automated statistical inference. In Proc. of ACM SIGCOMM'18. 576–590.

[4] Balachander Krishnamurthy et al. 2003. Sketch-based change detection: Methods, evaluation, and applications. In Proc. of the 3rd ACM IMC. 234–247.

[5] A Realistic Cyber Defense Dataset (CSE-CIC-IDS2018) was accessed from https://registry.opendata.aws/cse-cic-ids2018.

[6] Chen, Xiaoqi, et al. 2018. Catching the microburst culprits with snappy. In Proc. of the Afternoon Workshop on Self-Driving Networks. 22-28.

[7] Lu Tang, et al. 2019. MV-Sketch: A Fast and Compact Invertible Sketch for Heavy Flow Detection in Network Data Streams. In Proc. Of the IEEE INFOCOM 2019. 2026-2034