Towards Generic Traffic Change Detection in the Data Plane

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ABSTRACT

Identifying traffic changes accurately sits at the core of many network tasks, from congestion analysis to intrusion detection. Modern telemetry systems perform traffic change detection but restrict their detection to heavy-hitters, failing to identify relevant traffic changes, including microbursts or low-volume attacks. We present K-MELEON, an in-switch online change detection system that identifies **heavy-changes** – *instead of changes amongst heavy-hitters only*, a subtle but crucial difference. K-MELEON is a variant of the k-ary sketch (a well-known *heavy-change* detector) that leverages programmable switches for detection. To overcome the batch-based design of the original k-ary, K-MELEON features a new stream-based design that matches the switch’s pipelined computation model and fits its tight constraints. The preliminary evaluation of the current prototype shows the potential of K-MELEON in achieving the same level of accuracy for *online* detection as the offline k-ary.

CCS CONCEPTS

• **Networks** → **Network monitoring**; **Programmable networks**; **In-network processing**.

KEYWORDS

change detection, sketch, data plane, software-defined networks

1 INTRODUCTION

The ability to detect traffic changes fast and efficiently is a fundamental requirement of many network operation tasks. Ideally, a change detection mechanism would analyse all packets from every flow and maintain all flow-related information. Such fine-grained approach does not scale well, incurs in very high overheads, and is effectively not tractable without dedicated hardware. The typical change detection mechanisms therefore either rely on coarse-grained counters, like those provided by SNMP, or are sampling-based. The former provide useful aggregate statistics to detect major problems, but give up information that is often necessary to detect relevant changes, which are left sunk inside the aggregated traffic. The latter, common solution deployed in practice today, consists in sampling packets (e.g., NetFlow). However, the processing and bandwidth overheads of sampling make it infeasible to sample network traffic at sufficiently high rates.

An alternative to sampling that has been much explored recently is the use of sketches [3, 9]. Proposed in the database community for summarizing data streaming datasets, sketches have interesting properties for the networking context too: space-efficiency and probabilistic memory-accuracy guarantees. Several sketch-based systems have been recently proposed, running different network monitoring tasks at line rate in commodity switches [4, 5, 7, 8]. These modern systems are, however, restricted to change detection of heavy-hitters. The drawback is that, in practice, not all flows that experience significant changes are “heavy”.

In this paper we present K-MELEON, a sketch-based system for *generic* change detection. Our starting point is the k-ary sketching algorithm [6], an efficient and accurate solution for the general change detection problem, but with some limitations that preclude its deployment. First, *k-ary is an offline solution* based on the analysis of bulk traffic traces. Network operators, however, need detection solutions that enable real-time decisions. Second, *k-ary is software-based*, limiting its performance, response time, and scalability. For instance, k-ary is able to detect changes only in the order of minutes. As a result, it would fail to detect shorter yet relevant events in today’s networks, including microbursts and short duration attacks.

K-MELEON leverages modern P4-programmable switch ASICs [1, 2] to implement a change detection mechanism that aims to be the online equivalent of k-ary, but that runs directly in the data plane. As a result, K-MELEON promises to achieve both generality *and* high performance.

Figure 1: High-level block diagrams of k-ary and K-MELEON.

2 SYSTEM DESIGN

At a high level (Figure 1, left), the k-ary algorithm periodically computes an error $S_e(t)$ by comparing the forecasted values $S_f(t)$ based on past observations against the values currently observed $S_o(t)$ in the traffic stream. Running the logic of the k-ary in the data plane of P4-capable switches raises several challenges. First, the entire observed sketch data structure $S_o(t)$ must be traversed at once at the end of each epoch. P4, however, enforces limited packet-by-packet memory accesses, not event-driven, concurrent accesses. Second, the arithmetic operations required by the forecasting model,

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Figure 2: Empirical CDF values obtained for the relative difference between k-ary and K-MELEON for different sketch heights (H).

and for the computation of the frequency moment estimates by the detection module, are rather complex, and P4 only allows for simple packet processing instructions. Both constraints are not a limitation of the language. They express restrictions that are common across high-throughput packet processing architectures to guarantee Tbps line rate processing.

A high level view of K-MELEON is also illustrated in Figure 1, side-by-side with the original k-ary algorithm. K-MELEON tackles the first problem by computing the forecast $S_f(t)$ and the error $S_e(t)$ sketches in a stream-based fashion. More specifically, K-MELEON modifies these operations, which were originally performed all at once at the end of each epoch, to compute them incrementally with each packet from the network stream. Part of the second problem stems from the Exponentially Weighted Moving Average (EWMA) forecasting model used in k-ary [6]. Applying EWMA, the computation of the forecast sketch in the current epoch is obtained as $S_f(t+1) = \alpha \cdot S_o(t) + (1 - \alpha) \cdot S_f(t)$, thus requiring floating-point arithmetic ($\{\alpha \in \mathbb{R} \mid 0 \leq \alpha \leq 1\}$). K-MELEON converts the floating-point operations to multiplications via bit-shifts with the appropriate α values. The remaining operations include reading the error sketch and the flow-keys observed at the end of each epoch. In the current prototype these are performed by the change detection module that is offloaded to the control plane. We are currently working on moving these also to the data plane (Section 4).

3 PRELIMINARY EVALUATION

The goal of our preliminary evaluation is to understand whether K-MELEON preserves the detection accuracy of the k-ary algorithm, despite the approximations it incorporates. First, we validated the detection effectiveness of k-ary by extensively testing a Python implementation of the algorithm¹ against several real traces containing labelled network attacks. Afterwards, we used the P4-reference software switch *bmv2* and tested our P4 prototype of K-MELEON against the same attack traces.

We computed the *relative difference* as defined in [6] to compare the detection achieved with K-MELEON and k-ary. Figure 2 shows that most of the mass is concentrated around the 0% point on the x-axis, with very few points that differ more than 0.2% from the corresponding k-ary ones. These experiments show K-MELEON achieves a similar level of accuracy as k-ary.

¹We could not find an open-source implementation of the k-ary algorithm proposed in [6], so we have implemented it in Python and made it available at tinyurl.com/ctacawss.

While our prototype has been mainly tested on the *bmv2* software switch, the design of K-MELEON considers a high-speed switching ASIC as the main target platform. We have an early prototype for the Intel/Tofino switch [1] currently under test as part of our ongoing work.

4 ONGOING & FUTURE WORK

Our initial evaluation of K-MELEON suggests that the proposed solution can perform change detection in the data plane of a P4-capable switch, with small loss of accuracy when compared to the original k-ary algorithm. However, there are still some limitations:

Data Plane Detection. The current design of K-MELEON is still bottlenecked at the switch’s CPU. At the end of each epoch, the control plane must read the entire error sketch and the keys stored in the current epoch to perform the detection. Our investigation led us to believe it is possible to overcome this challenge. We are currently exploring solutions that further leverage the processing ability of the data plane, coupled with specialized computing units available in the target switching platform.

Sketch Reversibility. Sketches can compress information about flows very effectively. However, these data structures typically do not preserve the flow keys. This is the case of both the original k-ary and K-MELEON. As a result, these sketch data structures can detect changes but cannot readily recover the culprit flows². We are exploring solutions that enable sketch reversibility by trading-off some memory efficiency.

Configuration space. Several parameters contribute to the detection accuracy of K-MELEON. We have not fully explored this configuration space. Rather, we have so far focused on finding configurations which on average worked well across the tested traces. However, our early experiments confirmed that the tuning of certain parameters may considerably help improve detection accuracy, so this is an avenue we will further explore.

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²Unless by keeping *all* keys in memory, which would defeat the purpose of using memory-efficient sketches in the first place.