CCIT Report #877 January 2015

TIMEFLIP: Scheduling Network Updates with Timestamp-based TCAM Ranges

Technical Report◇, January 2015

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***Abstract*—Network configuration and policy updates occur frequently, and must be performed in a way that minimizes transient effects caused by intermediate states of the network. It has been shown that accurate time can be used for coordinating network-wide updates, thereby reducing temporary inconsistencies. However, this approach presents a great challenge; even if network devices have perfectly synchronized clocks, how can we guarantee that updates are performed at the exact time for which they were scheduled?**

In this paper we present a practical method for implementing *accurate* time-based updates, using TIMEFLIPs. A TIMEFLIP is a time-based update that is implemented using a timestamp field in a Ternary Content Addressable Memory (TCAM) entry. TIMEFLIPs can be used to implement Atomic Bundle updates, and to coordinate network updates with high accuracy. We analyze the amount of TCAM resources required to encode a TIMEFLIP, and show that if there is enough flexibility in determining the scheduled time, a TIMEFLIP can be encoded by a single TCAM entry, using a single bit to represent the timestamp, and allowing the update to be performed with an accuracy on the order of 1 microsecond.

I. INTRODUCTION

A. Background

Network updates are a routine necessity; policy changes or traffic-engineered route changes may occur frequently, and often require network devices to be reconfigured. This challenge is especially critical in Software Defined Networks (SDN), where the control plane is managed by a logically centralized controller, and configuration updates occur frequently. Such configuration updates can involve multiple network devices, potentially resulting in temporary anomalies such as forwarding loops or packet loss.

Network devices such as routers and switches use TCAMs for various purposes, e.g., packet classification, Access Control Lists (ACLs), and forwarding decisions. TCAMs are an essential building block in network devices. A typical example for the importance of TCAMs is OpenFlow [2], [3]. An OpenFlow switch performs its functionality using one or more *flow tables*, most commonly implemented by TCAMs (see, e.g., [4], [5]).

The order of the entries in a TCAM determines their priority. Hence, installing a new TCAM entry often involves rearranging existing entries, yielding high overhead for each TCAM update. It has been shown [6] that the latency of a TCAM rule installation may vary from a few milliseconds to a few seconds.

A recently introduced approach [7], [8] proposes to use accurate time and local clocks as a means to coordinate network updates. By using synchronized clocks, configuration changes can be scheduled in a way that guarantees a coordinated network-wide update, thereby reducing transient anomalies. One of the main challenges in this approach is to guarantee that scheduled updates are performed *accurately* according to the desired schedule. Even if the clocks in the network are perfectly synchronized, performing configuration changes requires a potentially complex procedure that may be completed at an uncertain time.

B. Introducing TIMEFLIPs

In this paper we present a method that uses **TIMEFLIPs** to perform *accurate* time-based network updates. We define a TIMEFLIP to be a scheduled update that is implemented using TCAM ranges to represent the scheduled time of operation. We analyze TCAM lookups (Fig. 1) that take place in network devices, such as switches and routers. We assume that the device maintains a local clock, and that a timestamp T recording the local arrival time is associated with every packet that is received by the device. Typically, TCAM search keys consist of fields from the packet header, as well as some additional metadata. In our setting, the metadata includes a timestamp T. Hence, a TCAM entry can specify a range relative to the timestamp T, as a way of implementing time-based decisions. The timestamp T is not integrated into the packet, as it is only used internally in the device, and thus does not compromise the traffic bandwidth of the network device.

Using a simple microbenchmark, we show that TIMEFLIPs can be performed by existing network devices, and analyze the achievable scheduling accuracy of TIMEFLIPs. Accurate clock synchronization has become a common feature in network devices; the Precision Time Protocol (PTP), based on the IEEE 1588 standard [9], typically provides an accuracy on the order of 1 microsecond [10], [11]. We show that the accuracy at

◇This technical report is an extended version of [1], which was accepted to IEEE INFOCOM '15, Hong Kong, April 2015.

*This work was supported in part by the ISF grant 1520/11.

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