An Implementation of Verifiable Routing on PolKA

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Abstract

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Keywords

Verifiable Routing; Path Verification; Proof-of-transit; In-networking Programming

1. Introduction

Ever since Source Routing (SR) was proposed, there has been a need to ensure that packets traverse the network along the paths selected by the source, not only for security reasons but also to ensure that the network is functioning correctly and correctly configured. This is particularly important in the context of Software-Defined Networking (SDN), where the control plane can select paths based on a variety of criteria.

In this paper, we propose a new P4[1] implementation for a new protocol layer for PolKA[2], able to do verify the actual route used for a packet. It is available on GitHub[1]. This is achieved by using a composition of hash functions on stateless core switches, each using a key to generate a digest that can be checked by the controller which knows the secrets. The controller can then verify that the packet traversed the network along the path selected by the source, ensuring that the network is functioning correctly.

2. Problem Definition

Let i be the source node (**i**ngress node) and e be the destination node (**e**gress node). Let path P be a sequence of nodes:

$$\underset{i \to e}{P} = (i, s_1, s_2, ..., s_{n-1}, s_n, e)$$

where

P Path from i to e.

s_n Core switch n in the path.

[1] https://github.com/Henriquelay/polka-halfsiphash/tree/remake/mininet/polka-example

n Number of core switches in the path.
i Ingress edge (source).
e Egress edge (destination).

In PolKA, the route up to the protocol boundary (usually, the SDN border) is defined in i [3]. i sets the packet header with enough information for each core node to calculate the next hop. Calculating each hop is done using Chinese Remainder Theorem (CRT) and the Residue Number System (RNS)[4], and is out of the scope of this paper. All paths are assumed to be both valid and all information correct unless stated otherwise.

The main problem we are trying to solve is path validation, that is, to have a way to ensure if the packets are actually following the path defined. Notably, it does not require verification, that is, listing the switches traversed is not required.

A solution should be able to identify if:
1. The packet has passed through the switches in the path.
2. The packet has passed through the correct order of switches.
3. The packet has not passed through any switch that is not in the Path.

More formally, given a sequence of switches $\underset{i \to e}{P}$, and a captured sequence of switches actually traversed P_j, a solution should identify if $\underset{i \to e}{P} = P_j$.

3. Solution Proposal

Each node's execution plan is stateless and can alter the header of the packet, which we will use to detect if the path taken is correct. So, a node s_i can be viewed as a function $g_{s_i}(x)$.

In order to represent all nodes by the same function (for implementation purposes), we assign a distinct value k for each s node, and use a bivariate function $f\left(k_{s_i}, x\right) = f_{s_i}(x)$. By using functions in two variables, we force one of the variables to have any uniquely per-node value, ensuring that the function is unique for each switch, that is, $f_{s_y}(x) \neq f_{s_z}(x) \Leftrightarrow y \neq z$.

Using function composition is a good way to propagate errors since it preserves the order-sensitive property of the path, since $f \circ g \neq g \circ f$ in a general case. Each node will execute a single function of this composition, using the previous node's output as input. In this way:

$$\left(f_{s_1} \circ f_{s_2} \circ f_{s_3}\right)(x) = f\left(k_{s_3}, f\left(k_{s_2}, f\left(k_{s_1}, x\right)\right)\right)$$

s_i i-th switch in the path.
$f_{s_i}(x)$ Function representing switch s_i.
k_{s_i} Unique identifier for switch s_i.

3.1. Assumptions

PolKA and the proposed extension are open source, so it is assumed that any attacker can replicate a node perfectly. Protocol boundary is IPv4. This means that PolKA is only used inside this network.

3.2. Setup

All implementation and experiments took place on a VM[2] setup with Mininet-wifi[5], and were targeting Mininet's[6] Behavioral Model version 2 (BMv2)[7]. Wireshark[8] was used to analyze packets, and Scapy[9] was used to parse packets programatically.

[2]Available on PolKA's repository https://github.com/nerds-ufes/polka

3.3. Implementation

By making the function f is a checksum function, and the unique identifier k_{s_i} as the `node_id`, we apply an input data into a chain checksum functions and verify if they match. The controller will act as a validator, since it already has access to all `node_id`. For additional verification, we also integrate the calculated exit port into the checksum, covering some other forms of

It was implemented as a version on PolKA, this means it uses the same protocol identifier `0x1234` and is interoperable with PolKA. Up-to-date PolKA headers were used (and upgraded from the forked version) to ensure compatibility. It uses the `version` header field to differentiate between regular PolKA version packets and what we call *probe* packets. PolKA packets uses version `0x01`, and probe packets uses version `0xF1`.

Figure 1 shows the used topology used in the experiments.

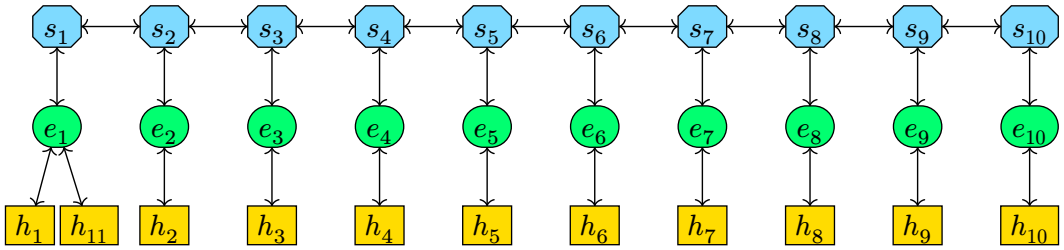

Figure 1: Topology setup.
s_n are core switches, e_n are edge switches, h_n are hosts.

3.3.1. Parsing

Parsing is done in edge nodes as follows:

- If an IPv4 protocol EtherType is detected (`0x0800`), it must be a packet from outside the network, it must be wrapped and routed by the same edge node that parsed it. Let call this process be called *encapsulation*;
- If a PolKA protocol EtherType is detected (`0x1234`), it must be a packet from inside the network, since the protocol boundary is IPv4, the original IPv4 packet must be unwrapped. Let this process be caleld *decapsulation*.

3.3.2. Encapsulation

Polka headers consists of the route polynomial (`routeid`), along with `version`, `ttl` and `proto` (stores the original EtherType). `route_id` calculation is out of the scope of this paper.

An additional header, added by this work, is added for probe packets, containing a 32 bit `key` and 32 bit `l_hash`.

During encapsulation of a probe packet, a random number is generated, and is used as `key`, for reproducibility. Edge nodes does not execute checksum functions and only repeats the key into the checksum field.

3.3.3. Composition

Every core node does checksum trying to congregate the previous `l_hash`, the calculated next hop port and it's own `node_id` into the 32 bit field. Currently, it is implemented as such:

$$\texttt{l\_hash} \leftarrow \text{CRC}_{32}(\text{exit port} \oplus \texttt{l\_hash} \oplus \texttt{node\_id})$$

The CRC_{32} checksum function used is the one available by BMv2 standard library, and through testing, it was found out to be ISO HDLC, by comparing results.

The algorithm was verified externally through another program written in Rust, with source also available[3], making use of the `crc` library.

3.3.4. Decapsulation

At the egress node, PolKA headers are dropped and the packet becomes an identical packet to what the ingress node received.

This detects {{X Y Z}}

4. Limitations

- Replay attack is undetectable if timing is not considered.

5. Future Work

- Rotating key for switches for detecting replay attacks (holy shit this is hard)
- Include entrance port in checksum

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