Demo: A Proof-of-Concept Implementation of Guard Secure Routing Protocol

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Abstract—Skip Graphs belong to the family of Distributed Hash Table (DHT) structures that are utilized as routing overlays in various peer-to-peer applications including blockchains, cloud storage, and social networks. In a Skip Graph overlay, any misbehavior of peers during the routing of a query compromises the system functionality. Guard is the first authenticated search mechanism for Skip Graphs, enables reliable search operation in a fully decentralized manner. In this demo paper, we present a proof-of-concept implementation of Guard on Skip Graph nodes as well as a deployment demo scenario.

I. INTRODUCTION

As a DHT-based overlay, Skip Graphs [1] provide efficient routing functionality for peer-to-peer (P2P) systems including distributed cloud storage [2], social networks [3], and blockchains [4]. Each peer of a P2P system corresponds to a Skip Graph node with a unique identifier. In a Skip Graph with n nodes, each node needs to know only O(log n) other nodes known as neighbors. Nodes benefit from their neighbor list to locate each others (using their identifiers) in a fully decentralized manner. That is, a search query gets handed across a certain number of nodes that utilize their neighbor list to forward the query closer to the destination. The entire procedure has the message complexity of O(log n) [1, 5]. Search queries are the fundamental operation in Skip Graphs that enable the nodes to join the overlay as well as to build up complex cooperative P2P applications, e.g., P2P cloud storage.

The malicious nodes along a search path can jeopardize the safety of the system by conducting routing attacks namely, by dropping, manipulating, misdirecting or falsifying a search query that they are intended to route. Skip Graphs do not intrinsically preserve the correctness of routing in the presence of malicious actors. Besides, the applicable DHT-based solutions on Skip Graphs either degrade its decentralization [6, 7, 8], or increase its communication complexity [9].

To address the security of Skip Graphs against the mentioned routing attacks, we proposed Guard [10], which is the first fully decentralized authenticated search mechanism for Skip Graphs. In Guard, each of the nodes involved in the routing of a search query generates and piggybacks a proof to the search message that asserts the honest behavior of that node. This enables both the search initiator as well as the nodes on the search path to verify the validity of the search result. In a Guard-enabled Skip Graph, no malicious node can deliberately deviate from the search protocol without being detected and caught by others.

In this demo paper, as the original contribution, we present an open-source proof-of-concept implementation of our software architecture and implementation of Guard (in Java) [11], and its interaction with the Skip Graph nodes it operates on. We also present the demo scenario of deploying our Guard implementation in the production-level cloud computing environment of Amazon Web Services’ Elastic Compute Cloud service (AWS EC2).

II. SOFTWARE ARCHITECTURE

The layered software architecture of our proof-of-concept implementation of Guard is depicted in Figure 1. In this figure, the double-sided vertical arrows represent the internal interactions among the layers of a node. Similarly, the horizontal arrows show the interactions between levels of the same type on two different nodes. The layers of a node from the top to the bottom are called User Interface, Overlay, Authentication, and Communication, respectively.

User Interface interacts with the user that runs the underlying peer (i.e., device) of the node. This layer receives the control commands from the user, passes them to the Overlay layer for process, and displays the obtained result from the Overlay layer. The supported operations by the User Interface layer are join and search. A join places the underlying peer as a Skip Graph node with a unique identifier and address in the decentralized Skip Graph overlay. A search returns the address of the node that holds the closest identifier to the search target [1, 5].
Overlay layer implements a Skip Graph node, and provides the User Interface with join and search operations. The join is done by receiving a unique identifier for the target node. The identifier of a peer is the hash value of its (IP) address. The search enables the overlay layer of different nodes to search for each others’ identifiers in a fully decentralized manner. As the result of searching for a node’s identifier, the overlay returns (IP) address of the node that holds the search result according to the search protocol [1], [5].

Authentication layer is where the core operational logic of Guard resides. It receives an overlay operation (i.e., join or search), generates authentication metadata for it and passes it to the underlying network through the Communication layer. Also, it receives the authenticated messages that are meant for the Overlay layer of the node to route or receive. Upon receiving such messages, it verifies the authentication metadata generated by the Guard instance on the intermediate nodes, and passes the message up only if the authentication metadata is validated correctly. Structuring the software of the node in this way, both the overlay and user interface only receive messages and results that are validated against the correct execution of Skip Graph protocols on other nodes.

Communication provides direct node-to-node communication through the underlying network. The Communication instance of each node is uniquely identified by an (IP) address and port number. The Communication layer implements the Java Remote Method Invocation (RMI) [12] interface. This enables Communication instance of one node to directly exchange messages with the Communication instance of another node via Java RMI through the underlying network.

III. Sample Demo Scenario

```java
public class Parameters {
    // search queries conducted by each node
    public static final int MESSAGE_COUNT = 1000;
    // maximum delay between consecutive queries at each node (seconds)
    public static final int WAIT_TIME = 5;
    // payload size of each message
    public static final int MESSAGE_LENGTH = 300;
    // address of simulation CONTROLLER
    public static final string CONTROLLER = <address>;
    // ...
}
```

Listing 1: A sample simulation schema of Guard

Configuration: In Guard, a simulation is configured by setting the Parameters class of the nodes. Listing 1 shows a sample simulation configuration of the Guard demo. Each node initiates one search query for a random target within the system (at most) every 5 seconds for a total of 1000 queries. Each query message contains 300 bytes of payload. Note that payload of the messages is distinct than their routing information overhead (routing information are generated based on the path they are taking). To keep track of the simulation state, we define a special process known as the CONTROLLER, which is external to the Skip Graph overlay. There exists only a single instance of a CONTROLLER node for a simulation of Guard. CONTROLLER acts as a centralized point of trust that synchronizes the overlay nodes with each other. Guard is a fully decentralized protocol that operates on asynchronous communication model [13] where there is no known bound over the message transmission delay among the nodes. Nevertheless, we found having a CONTROLLER a convenient solution only to establish large scale implementation of its proof-of-concept over cloud in a reliable manner, as well as closely tracking the simulation performance. Address of CONTROLLER is hardcoded in the Parameters class of each node.

Initialization: Upon running up, each new node initiates the decentralized Skip Graph join protocol [1]. This protocol enables the node to interact with other nodes of the system in a fully decentralized manner and build up the overlay collaboratively. Once each node joins the overlay successfully, it registers itself to the CONTROLLER. Once all nodes join the system and the Skip Graph overlay is shaped completely, the CONTROLLER starts the initialization phase of Guard [10] on each node. During this phase, the Skip Graph nodes construct the authentication metadata, which is later on frequently utilized to authenticate the search queries they route. It is worth noting that the original solution of Guard [10] assumes no churn in the Skip Graph, i.e., once a Skip Graph node initiates the join protocol, it remains available the entire time and does not go offline or fail [14]. We will address handling churn for Guard in our future works.

Experiments: Once the initialization is complete, CONTROLLER broadcasts an experiment request message to every node in the system. For the sake of demonstration and to perform a fair comparison, each node performs 1000 pairs of searches during this time upon receiving an experiment request message. The value 1000 corresponds to the MESSAGE_COUNT field of the configuration file in Listing 1. In each pair of searches, the node chooses a random identifier uniformly as the search target. It then performs an unauthenticated search followed by an authenticated one. As there is no churn in the system, both searches follow the same search path. Note that Guard has provable security in the presence of malicious colluding adversaries aiming on breaking the authenticity of search proofs [10]. This implies that no probabilistic polynomial node on a search path can deviate from the search protocol while successfully forging a search proof that covers up for its deviation. Hence, at the level of the proof-of-concept, having the searches in pairs of authenticated and unauthenticated ones provides a fair comparison of the time overhead that Guard applies to make the searches authenticated. To avoid congestion, however, each node waits between conducting every two consecutive pairs of searches for a period that is uniformly drawn between 1 to 5 (i.e., WAIT_TIME). This phase is complete when every node performs the assigned 1000 pairs of search queries and receives their results.

Measurements: Once the Experiment phase is over, Controller collects the log file of every node and merges them into a single file. The individual log files of the nodes contain all the details of every event that has happened in
their Initialization and Experiment phases. The log files are in csv format, which allow to make any arbitrary query and extract any parameter of interest, for example, the average query latency, the average local computation time of a node upon routing a message, and the average message size. All measurements are done in both authenticated and unauthenticated modes by filtering their corresponding logs.

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