KTH Royal Institute of Technology

School of Electrical Engineering and Computer Science

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Performance analysis of the SCION protocol

Author
Emil Ståhl

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Abstract

The delivery of IP packets on the Internet depends on inter-domain routing protocols. With ever-increasing demands on the performance and security of data transfers, legacy protocols such as BGP fails to meet desired requirements. By utilizing stateless source-selected path-aware routing, the SCION protocol offers an architecture better suited for the modern Internet. This work investigates the performance of the SCION architecture in terms of latency and throughput. The obtained results show that SCION lacks behind the legacy TCP/IP stack in terms of performance. However, with some clever optimizations, SCION can achieve high throughput data transfers at speeds required for it to serve as the main inter-domain routing protocol for the next-generation Internet.

1 Introduction

Since the year of 1994, the Internet has relied on the complex interactions between a set of autonomous systems (ASes) that exchange routing information about IP prefix destinations utilizing the Border Gateway Protocol (BGP). The growth and innovation related to the Internet has far exceeded even the most optimistic expectations. As a result of this, the current Internet infrastructure is not designed to handle today's ever-increasing demands for high availability, efficiency, scalability, and confidentiality[1, 2]. For the past decades, researchers, organizations, and companies have been applying various patches to overcome the shortcomings of the Internet protocol stack. However, many researchers believe it to be insufficient to resolve the challenges facing today's Internet without rethinking the fundamental assumptions and design decisions underlying the current architecture. This is known as the *Clean-Slate Design* initiative of the modern Internet[3]. One such design solution is the next-generation inter-domain routing architecture known as SCION, developed by researchers at ETH Zurich and is currently being explored by the IETF research group for path-aware networking[4, 5]. The initiative aims to address the flaws of BGP by replacing it with a clean-slate approach where the focus lies on improving availability, efficiency, scalability, extensibility, transparency, and control, as well as supporting global heterogeneous trust among entities[6, 4].

1.1 Problem

Given the various extensions to the SCION architecture in comparison to BGP, analyzing the performance of data exchanges with SCION is key to tackling the high-performance demands associated with the large-scale in which inter-domain routing protocols operates[7, 5]. Today, there exist over 800,000 destination prefixes that are announced through BGP[8]. Since inter-domain routing is one of the most essential parts of the Internet architecture on which society relies these protocols must be highly functioning and ensure maximum performance, flexibility, stability, confidentiality, and compatibility[1].

1.2 Purpose

The purpose of this work is to analyze the performance of the SCION protocol by quantifying at what rate it is capable of exchanging data across a network compared with the legacy equivalent that is TCP/IP. By analyzing how different parts of the SCION protocol perform, one can use this work for tailoring network configurations to optimize for performance. The results are potentially of interest for network research organizations, operators, and the open-source community.

1.3 Goal

The goal of this work is to run a set of experiments to better understand the potential benefits and limitations of the next generation inter-domain routing infrastructure that is SCION. The results are then going to be described, analyzed, and discussed to determine if there are any bottlenecks regarding SCION's capability of exchanging data at high speeds.

1.4 Benefits and Sustainability

Many possible benefits may result from understanding the performance of Internet protocols. Since inter-domain routing protocols are part of the Internet's core infrastructure, which most of the modern society relies on, it is crucial to understand the underlying technology used to optimize for performance, uptime, and security[9].

2 Background

For the past decades, BGP has been the de facto inter-domain routing protocol on which the Internet relies on. Conventional routing protocols such as BGP make use of routing tables that need to be kept consistent between routers which require announcing prefixes. Consequently, routing tables turn out to be a bottleneck for SDN as well as up-time of a network[7, 10]. Another shortcoming of BGP is that the sender of a set of packets does not have any control or even knowledge over which path its packets take on the Internet[1]. One solution to these problems is Segment Routing (SR), which is highly compatible with SDN applications[11, 12, 13]. This allows a sender of a packet to specify the route which the packets are to take. Benefits of SR includes simplicity and robustness[14, 15]. However, although there is ongoing work on extending SR to inter-domain routing protocols, this is only a mere extension of BGP and not a solution[1, 3, 7]. This is where SCION (Scalability, Control, and Isolation on next-generation Networks) comes in. SCION has similarities with SR since both rely on stateless source routing architectures. However, since they target different network and routing environments they differ in how their control planes are designed[4, 16, 17]. The two main challenges of interconnecting ASes on a global scale are scalability and confidentiality, which both are problems that BGP struggles with[16, 4, 7].

2.1 Isolation Domains

SCION aims to solve the scalability and confidentiality issues of BGP by introducing the concept of Isolation Domains (ISDs). One or more legacy ASes make up a single ISD to isolate different parts of the SCION network based on jurisdictions or other common characteristics[16]. A consortium of ASes within an ISD agrees and has complete control over its configurations including policies, authorities, and keys. For an AS to communicate with other parts of the ISD, it must accept the agreed-upon trust root configuration and have access to a certificate issued by the ISD[16, 17, 4]. Moreover, SCION applies stateless source-selected path-aware network routing where end-hosts need a good understanding of the network topology to choose the optimal route from a list of offered paths. The available path segments are then embedded into the SCION packet headers[5]. This path awareness allows for multi-path communication resulting in high availability and instant failover in case of network partitions[5]. By grouping multiple ASes into a single ISD, SCION reduces the number of control plane messages that BGP suffers from. This design choice makes the routing system instant-convergence, meaning that the network is always in a consistent state since, unlike BGP, SCION does not have to spend time announcing prefixes between border routers[16, 5, 17, 4].

2.2 Control and Data plane

SCION separates the control and data plane. In particular, the control plane consists of the SCION Daemon and Control Service, while SCION Dispatcher and Border Router make up the data plane[16, 17, 1]. The Control Service is responsible for tasks such as path exploration, registration, and lookups. Due to that SCION does not offer any kernel integration the user space Dispatcher becomes a key component of SCION[16]. Its responsibility is encapsulation and decapsulation of SCION packets. Since SCION consists of multiple modules, each SCION host only needs to run the SCION Daemon and Dispatcher providing the host with both control and data plane interfaces[16, 17, 5, 6].

2.3 Cryptography

To cryptographically sign all routing messages between ASes, BGPSEC relies on a single-entity administered RPKI, such as ICANN[1, 7]. Whereas SCION allows individual ISDs to sign control plane messages based on the central trust root configuration protecting the ISD from foreign miscellaneous usage[18, 16, 5, 4].

3 Methodology

In this chapter, we explain the different parts of the theoretical method used to understand the performance limits of SCION. Specifically, we begin with Section 3.1 that describes the benchmarking environment used to perform the experiments. Section 3.2 continues by presenting the metrics used to evaluate the performance of SCION.

3.1 Benchmarking environment

The chosen benchmarking environment for performing the experiments consists of a 10-core server utilizing a 500 Mbit/s Internet connection, the server is running a Linux virtual machine with the SCIONLab package installed. SCIONLab is a global research network to test and experiment with the SCION internet architecture[17]. It provides access to various tools including a bandwidth test client as well as the SCION Control Message Protocol (SCMP) which is analogous to ICMP. With SCIONLab, we can create our own AS that connects to the global SCION network of inter-connected ASes, where some are configured to act as an *Attachment Point* (AP). By establishing an overlay link using the legacy Internet to one of these APs, we create an uplink to the SCION network for our AS[17].

3.2 Benchmarking metrics

When connected to the SCION network, we run a set of experiments that benchmarks the following metrics of the SCION protocol:

- **Latency** using SCMP
- **Throughput** using the bandwidth test client of SCIONLab
- **Loss rate** of data transfers

These metrics are going to be compared with the legacy equivalents using the traditional TCP/IP stack. However, once the traffic is in the SCION overlay one cannot know which IP addresses are used since the ASes are logically connected by tunnels[17]. This means that we are unable to ping the same end host as in the SCION benchmark. To overcome this issue, we look at the IPv4 traffic to see how our AS is connected to the other SCION ASes and use the last publicly known IPv4 address from the output of **SCION traceroute** as an approximation for our TCP/IP benchmarks. An IP lookup of these IPv4 addresses reveals that the addresses belong to various European universities where the hostname includes the name SCION. This means that the IPv4 interfaces should be reasonably close to the actual SCION host. Table 1 shows the SCION and IPv4 addresses of the ASes used in our various benchmarks.

Address	**141.44.17.129**	**192.33.93.195**	**128.2.24.125**
16-ffaa:0:1001	scionlab.ovgu.de		
17-ffaa:0:1107		ETH Zurich	
18-ffaa:0:1206			scion-core.cylab.cmu.edu

Table 1: SCION and IPv4 addresses of each SCION AS used for benchmarking

Moreover, since we do not have direct control over the SCION ASes that we use in our benchmarks, we are unable to perform a benchmark of the throughput achieved with the TCP/IP stack. Our solution to this problem is to use the results from the RTT benchmarks of ICMP and Mathis equation to calculate a theoretical throughput limit for the TCP/IP stack. The Mathis Equation states that the maximum throughput that can be achieved by a TCP connection can be calculated by dividing MSS by RTT and multiplying the result by 1 over the square root of p, where p represents the packet loss[19]. In our benchmarks, we use a MSS of 1448 since we have the 12-byte TCP Timestamp option enabled.

4 Results

This chapter presents the results of the performed benchmarks. Section 4.1-4.3 visualizes the result from the benchmarks of latency and throughput.

4.1 Latency

Table 2 shows the average RTT of 10 SCMP messages sent from our AS to each SCION AS specified in Table 1. Secondly, Table 3 deals with the average RTT of 10 ICMP messages sent from our AS to each IPv4 interface specified in Table 1.

Address	**16-ffaa:0:1001**	**17-ffaa:0:1107**	**18-ffaa:0:1206**
RTT	273.316 ms		
RTT		41.177 ms	
RTT			191.945 ms

Table 2: RTT for SCMP messages

Address	141.44.17.129	192.33.93.195	128.2.24.125
RTT	31.250 ms		
RTT		25.983 ms	
RTT			116.80 ms

Table 3: RTT for ICMP messages

4.2 Throughput

Next, we have Table 4 showing what throughput that was achieved in our benchmarks of the SCION protocol. The first row of this table shows the attempted bandwidth to each of the three ASes specified in the first column of the table. Next, Table 5 shows the maximum throughput limit to each of the IPv4 interfaces based on the ICMP RTT benchmark of TCP/IP shown in Table 3.

Attempted bandwidth	1 Mbps	10 Mbps	500 Mbps
16-ffaa:0:1001	1.00/1.00 Mbps	8.14/8.13 Mbps	7.03/5.70 Mbps
17-ffaa:0:1107	1.00/1.00 Mbps	6.50/3.93 Mbps	4.36/4.15 Mbps
18-ffaa:0:1206	1.00/1.00 Mbps	8.02/8.39 Mbps	3.10/3.94 Mbps

Table 4: Achieved throughput (down/up) to each of the ASes using SCION

Address	141.44.17.129	192.33.93.195	128.2.24.125
Throughput limit	3706.88 Mbps		
Throughput limit		4458.30 Mbps	
Throughput limit			991.78 Mbps

Table 5: Theoretical throughput limit to each of the ASes using TCP/IP

4.3 Loss rate

Finally, following the same general structure as Table 4, Table 6 shows the loss rate of each SCION data transfer. Since we used the Mathis Equation to calculate the TCP/IP throughput, we have no data regarding the TCP/IP loss rate. However, in our calculations, we used a loss rate of $10^{-6}\%$.

4.4 Summary of results

The results of our benchmarks clearly shows that the average RTT for SCMP is 64%-880% higher when compared with ICMP. Regarding the throughput of

Attempted bandwidth	1 Mbps	10 Mbps	500 Mbps
16-ffaa:0:1001	0.0%/0.0%	18.7%18.6%	98.6%/98.9%
17-ffaa:0:1107	0.0%/0.0%	35.0%/60.7%	99.1%/99.2%
18-ffaa:0:1206	0.0%/0.0%	19.8%/16.1%	99.4%/99.2%

Table 6: Loss rate (down/up) of SCION data transfers to each of the ASes

data transfers using the SCION protocol, the results shows that the protocol is able to handle very small amounts of data well but fails to achieve a higher throughput than 8 Mbps. This results in a loss rate of up to 99.2% when the attempted bandwidth is 500 Mbps. When compared with the TCP/IP stack, our results clearly shows that SCION fails to match both the latency and throughput performance of the TCP/IP stack. This is further discussed in Section 5.

5 Discussion

The data presented in Chapter 4 clearly shows a discrepancy between the performance of SCION and TCP/IP. The latency and throughput of SCION are in our results several magnitudes lower than what is achieved using TCP/IP. To begin with, it is possible that the virtual machine in which we run SCIONLab negatively affects the performance. However, one could argue that the difference compared with TCP/IP is too large for the virtualization to be the only reasonable explanation. Regarding the actual properties of SCION, the fact that all packets are cryptographically signed does introduce some overhead which decreases the performance. However, this should be weighed against the security benefits that encryption may result in. Furthermore, the fact that SCION is still in an early research state and not yet widely adopted by network operators and organizations results in a limited topology that is not as richly connected as the legacy Internet with its many peer-to-peer links. Fortunately, the topology of the SCION network should improve if more network operators and organizations choose to adopt the inter-domain routing protocol. As the majority of links in the current SCIONLab topology are overlay connections, it can be expected that there is overhead such as queuing and processing delays generated by the software-defined SCIONLab applications[17]. Moreover, since SCION is a stateless path-aware routing protocol, it needs to embed all of the routing information into its packet headers resulting in that every single packet needs separate processing. When examining the source code of the SCION protocol, we note that the packet processing is done in conditional source code which requires memory references[20]. Depending on the complexity of this code, which we have not studied in detail, this may impact the performance of header parsing. However, this should according to the work by Perrig et al. lead to faster and more efficient routers due to the absence of complex longest prefix matching[18]. When comparing our results to the related work "*Performance Comparison of SCION* *with Routed IP on Virtual Machines*" by Dheeraj Chandrashekar at Aalto university in Finland, we note that both studies found a comparatively higher RTT for SCMP compared with ICMP[21]. Regarding throughput, the work by Chandrashekar found that SCION achieved a throughput of 150 Mbps with a 0% loss rate while an attempted bandwidth of 1 Gbps resulted in a loss rate of 86%. These numbers are considerably better than our results on throughput. However, it should be said that Chandrashekar used a benchmarking environment with SCION end-hosts located within Finland which may have resulted in a closer distance to the SCION hosts used for benchmarking and consequently better performance. Despite this, the bigger picture remains the same as both studies found that SCION fails to match the latency of ICMP and achieve a throughput that exceeds 300 Mbps[21].

5.1 Optimizations

Due to that SCION is still in a research state, there is ongoing work regarding how the protocol can be optimized to achieve better performance. For example, researchers at SIDN Labs have in their work "*Future Internet at Terabit Speeds: SCION in P4*" managed to achieve high speed data transfers using SCION by applying advanced optimizations to the SCION protocol. These optimizations include using the P4 programming language to implement SCION for switches based on the Intel Tofino ASIC using match-action tables. This makes it possible to perform certain actions based on what the SCION packet contains and allows for matching at line speed in the data plane. To optimize encryption, a table containing the set of all valid hop fields is used to verify the hop field of each incoming packet against this table. Finally, changes to the structure of the SCION header were made for simpler and more efficient parsing of specific header fields. With these optimizations applied, the SCION protocol was able to move traffic through the switch at 100 Gbps[22]. For future research purposes, one should consider performing similar benchmarks as in this work but with the optimized SCION protocol. Another direction is to research if the path-awareness of SCION leads to improved performance compared with BGP which may not choose the best latency path. One final suggestion for future research is to investigate whether multi-path communication lead to a better use of the available link capacity or exacerbate the exhaustion of the shared network resources, which may impact all the network participants. To conclude, the SCION protocol offers various interesting improvements that lays the foundation for the next-generation Internet. However, this work shows that SCION is yet to match the performance of the TCP/IP stack. Fortunately, there is promising ongoing work that aims to optimize the performance of the SCION protocol. Additionally, there are also a plethora of various research directions regarding how the performance of SCION may benefit from its path-aware architecture.

6 Research conclusion

Inter-domain routing is a critical component of the Internet infrastructure. With ever-increasing demands on scalability and efficiency, BGP has proven to be unsuccessful in meeting these demands[1]. SCION is a stateless source-selected path-aware routing protocol that offers improvements including scalability, efficiency, and control[5]. This research has performed a set of benchmarks to reveal the performance of the SCION protocol. The benchmarking methodology consisted of using SCIONLab to run latency and throughput tests. The results show that SCION fails to match the performance of the legacy TCP/IP stack. This may be due to factors such as the limited topology of the SCION network, encryption overhead, and the stateless nature of the protocol. However, other researchers have managed to reach high-speed data transfers with SCION by making optimizations to the protocol[22]. Finally, there are also various other dimensions to explore regarding how SCION may benefit from its stateless source-selected path-aware routing architecture. Therefore, we conclude that SCION offers an interesting and promising foundation for the next-generation Internet.

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