Cloud Onload® NGINX Proxy Cookbook

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Introduction

This chapter introduces you to this document. See:

- About this document on page 1
- Intended audience on page 2
- Registration and support on page 2
- Download access on page 2
- Further reading on page 2.

1.1 About this document

This document is the NGINX Proxy Cookbook for Cloud Onload. It gives procedures for technical staff to configure and run tests, to benchmark NGINX as a proxy server utilizing Solarflare's Cloud Onload and Solarflare NICs.

This document contains the following chapters:

- Introduction on page 1 (this chapter) introduces you to this document.
- Overview on page 3 gives an overview of the software distributions used for this benchmarking.
- Summary of benchmarking on page 6 summarizes how the performance of NGINX has been benchmarked, both with and without Cloud Onload, to determine what benefits might be seen.
- Evaluation on page 10 describes how the performance of the test system is evaluated.
- Benchmark results on page 17 presents the benchmark results that are achieved.

and the following appendixes:

- Cloud Onload profiles on page 23 contains the Cloud Onload profiles used for this benchmarking.
- Installation and configuration on page 30 describes how to install and configure the software distributions used for this benchmarking.
1.2 Intended audience

The intended audience for this *NGINX Proxy Cookbook* are:

- software installation and configuration engineers responsible for commissioning and evaluating this system
- system administrators responsible for subsequently deploying this system for production use.

1.3 Registration and support

Support is available from support@solarflare.com.

1.4 Download access

Cloud Onload can be downloaded from: https://support.solarflare.com/.

Solarflare drivers, utilities packages, application software packages and user documentation can be downloaded from: https://support.solarflare.com/.

The scripts and Cloud Onload profiles used for this benchmarking are available on request from support@solarflare.com.

Please contact your Solarflare sales channel to obtain download site access.

1.5 Further reading

For advice on tuning the performance of Solarflare network adapters, see the following:

  This is available from: https://support.solarflare.com/.

For more information about Cloud Onload, see the following:

  This is available from: https://support.solarflare.com/.
2 Overview

This chapter gives an overview of the software distributions used for this benchmarking. See:

- NGINX overview on page 3
- Wrk2 overview on page 4
- Cloud Onload overview on page 4.

2.1 NGINX overview

Open source NGINX [engine x] is an HTTP and reverse proxy server, a mail proxy server, and a generic TCP/UDP proxy server.

NGINX Plus is a software load balancer, web server, and content cache built on top of open source NGINX. NGINX has exclusive enterprise-grade features beyond what’s available in the open source offering, including session persistence, configuration via API, and active health checks.

Open source NGINX is used for this benchmarking.

NGINX is heavily network dependent by design, so its performance can be significantly improved through enhancements to the underlying networking layer.
2.2 Wrk2 overview

Wrk2 is a modern HTTP benchmarking tool capable of generating significant load when run on a single multi-core CPU. It combines a multithreaded design with scalable event notification systems such as epoll and kqueue.

Figure 1: Wrk2 architecture

2.3 Cloud Onload overview

Cloud Onload is a high performance network stack from Solarflare (https://www.solarflare.com/) that dramatically reduces latency, improves CPU utilization, eliminates jitter, and increases both message rates and bandwidth. Cloud Onload runs on Linux and supports the TCP network protocol with a POSIX compliant sockets API and requires no application modifications to use. Cloud Onload achieves performance improvements in part by performing network processing at user-level, bypassing the OS kernel entirely on the data path.

Cloud Onload is a shared library implementation of TCP, which is dynamically linked into the address space of the application. Using Solarflare network adapters, Cloud Onload is granted direct (but safe) access to the network. The result is that the application can transmit and receive data directly to and from the network, without any involvement of the operating system. This technique is known as “kernel bypass”.

Cloud Onload NGINX Proxy Cookbook

Overview
When an application is accelerated using Cloud Onload it sends or receives data without access to the operating system, and it can directly access a partition on the network adapter.

Figure 2: Cloud Onload architecture
Summary of benchmarking

This chapter summarizes how the performance of NGINX as a proxy server has been benchmarked, both with and without Cloud Onload, to determine what benefits might be seen. See:

- Overview of NGINX benchmarking on page 6
- Architecture for NGINX benchmarking on page 7
- NGINX benchmarking process on page 8.

3.1 Overview of NGINX benchmarking

The NGINX benchmarking uses two servers:

- The load server runs multiple instances of wrk2 to generate requests, and multiple instances of NGINX webservers to service requests.
- The proxy server runs multiple instances of NGINX acting as a proxy. It receives the requests that originate from wrk2 on the load server, and proxies those requests to an NGINX webserver on the load server.

Various benchmark tests are run, with the NGINX proxy using the Linux kernel network stack.

The tests are then repeated, using Cloud Onload to accelerate the NGINX proxy. Two different Cloud Onload profiles are used, that have different priorities:

- The balanced profile gives excellent throughput, with low latency. It has reduced CPU usage at lower traffic rates.
- The performance profile is latency focused. It constantly polls for network events to achieve the lowest latency possible, and so has higher CPU usage.

The results using the kernel network stack are compared with the results using the two different Cloud Onload profiles.
3.2 Architecture for NGINX benchmarking

Benchmarking was performed with two Dell R640 servers, with the following specification:

<table>
<thead>
<tr>
<th>Server</th>
<th>Dell R640</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>192GB</td>
</tr>
<tr>
<td>NICs</td>
<td>2 × X2541 (single port 100G):</td>
</tr>
<tr>
<td></td>
<td>• Each NIC is affinitized to a separate NUMA node.</td>
</tr>
<tr>
<td>CPU</td>
<td>2 × Intel® Xeon® Gold 6148 CPU @ 2.40GHz:</td>
</tr>
<tr>
<td></td>
<td>• Each CPU is on a separate NUMA node</td>
</tr>
<tr>
<td></td>
<td>• There are 20 cores per CPU</td>
</tr>
<tr>
<td></td>
<td>• Hyperthreading is enabled to give 40 hyperthreads per NUMA node</td>
</tr>
<tr>
<td>OS</td>
<td>Red Hat Enterprise Linux Server release 7.6 (Maipo)</td>
</tr>
<tr>
<td>Software</td>
<td>NGINX 1.17</td>
</tr>
<tr>
<td></td>
<td>wrk2 4.0.0</td>
</tr>
</tbody>
</table>

Each server is configured to leave as many CPUs as possible available for the application being benchmarked.

Each server has 2 NUMA nodes. 2 Solarflare NICs are fitted, each affinitized to a separate NUMA node, and connected directly to the corresponding NIC in the other server:

![Figure 3: Architecture for NGINX benchmarking](image-url)
3.3 NGINX benchmarking process

These are the high-level steps we followed to complete benchmarking with NGINX:

- Install and test NGINX on both servers.
- Install wrk2 on the first server.
- Start NGINX web servers on the first server.
  All iterations of the test use the same configuration for consistency:
  - 40 NGINX web servers are used.
  - Each web server runs a single NGINX worker process.
  - Each NGINX worker process is assigned to a dedicated CPU, distributed across theNUMA nodes.
  - Each NGINX worker process uses the NIC that is affinitized to the local NUMA node for its CPU.
  - Each NGINX worker process uses a dedicated port.
  - Each NGINX web server is accelerated by Cloud Onload, to maximize the responsiveness of the proxied server.
- Start NGINX proxy servers on the other server:
  - One NGINX proxy server is used per NUMA node on the server.
    The setup used has 2 NUMA nodes, and so 2 proxy servers are started.
    - The first iteration of the test uses a single worker process per proxy server.
- Start wrk2 on the first server to generate load.
  All iterations of the test use the same configuration for consistency:
  - 20 wrk2 processes are used.
  - Each wrk2 process is assigned to a dedicated CPU, distributed across the NUMA nodes.
  - Each wrk2 process uses the NIC that is affinitized to the local NUMA node for its CPU.
  - Each wrk2 process is accelerated by Cloud Onload, to maximize the throughput of each connection going to the NGINX proxy server.
- Record the response rate of the proxied web server, as the number of requests per second.
- Increase the number of NGINX worker processes on each proxy server, and repeat the test.
  - Each NGINX worker process is assigned to a dedicated CPU, distributed across the NUMA nodes.
  - Each NGINX worker process uses the NIC that is affinitized to the local NUMA node for its CPU.

Continue doing this until the number of NGINX worker processes is the same on both servers. For the setup used, this is 40 processes.
Repeat all tests, accelerating the NGINX proxy with Cloud Onload. These steps are detailed in the remaining chapters of this Cookbook.

The scripts and Cloud Onload profiles used for this benchmarking, that perform the above steps, are available on request from support@solarflare.com.
4 Evaluation

This chapter describes how the performance of the test system is evaluated. See:

- General server setup on page 10
- wrk2 client (on Load server) on page 11
- NGINX backend webservers (on Load server) on page 12
- NGINX proxy (on Proxy server) on page 13
- Graphing the benchmarking results on page 16.

4.1 General server setup

Each server is setup using a script that does the following:

1. Create a file that makes new module settings:
   ```
   cat > /etc/modprobe.d/proxy.conf <<EOL
   options sfc \n   performance_profile=throughput \n   rss_cpus=20 \n   rx_irq_mod_usec=90 \n   irq_adapt_enable=N \n   rx_ring=512 \n   piobuf_size=0
   options nf_conntrack_ipv4 \n   hashsize=524288
   EOL
   ```

   **NOTE:** This script is required only when running the NGINX proxy server with the kernel network stack (i.e. without Cloud Onload).

2. Reload the drivers to pick up the new module settings:
   ```
   onload_tool reload
   ```

3. Use the network-throughput tuned profile:
   ```
   tuned-adm profile network-throughput
   ```

4. Stop various services:
   ```
   systemctl stop irqbalance
   systemctl stop iptables
   systemctl stop firewalld
   ```

5. Increase the sizes of the OS receive and send buffers:
   ```
   sysctl net.core.rmem_max=16777216 net.core.wmem_max=16777216
   ```

6. Configure huge pages:
   ```
   sysctl vm.nr_hugepages=4096 > /dev/null
   ```
7 Ensure the connection tracking table is large enough:
   sysctl net.netfilter.nf_conntrack_max=$(( $(sysctl --values net.netfilter.nf_conntrack_buckets) * 4 )) > /dev/null

8 Increase the system-wide and per-process limits on the number of open files:
   sysctl fs.file-max=8388608 > /dev/null
   sysctl fs.nr_open=8388608 > /dev/null

9 Increase the range of local ports, so that the server can open lots of outgoing network connections:
   sysctl -w net.ipv4.ip_local_port_range="2048 65535" > /dev/null

10 Increase the number of file descriptors that are available:
   ulimit -n 8388608

11 Exclude from IRQ balancing the CPUs that are used for running the NGINX proxy servers. For example, to exclude CPUs 0 to 39:
   IRQBALANCE_BANNED_CPUS=ff,ffffffff irqbalance --oneshot

4.2 wrk2 client (on Load server)

Set up 20 instances of wrk2, running on cores 40 to 59, and start them all. An example command line for the first instance (core 40) is below.

```
EF_CLUSTER_SIZE=10 \
   taskset -c 40 \
   onload -p wrk-profile.opf \
   /opt/wrk2/wrk \
   -R 500000 \
   -c 100 \
   -d 60 \n   -t 1 \n   http://192.168.0.101:1080/1024.bin
```

This example runs a Requests per second test using a payload size of 1024 bytes (HTTP GET with keepalive).

- The taskset -c parameter is changed for each instance, to use cores 40 to 59.
- Instances on the even cores (NUMA node 0) use the IP address for the NIC that is affinitized to NUMA node 0 on the proxy server.
- Instances on the odd cores (NUMA node 1) use the IP address for the NIC that is affinitized to NUMA node 1 on the proxy server.
- The port number is fixed at 1080. This is the port listened to by the proxy server.
- **EF_CLUSTER_SIZE** is set to the number of wrk2 instances which share the same IP address (i.e. 10 per NUMA node in this case).
4.3 NGINX backend webservers (on Load server)

Create a set of 40 backend webservers, with similar configuration for each webservice, and start them all. An example command line to start the first webserver (port 1050 of the NIC that is affinitized to NUMA node 0) is below:

```
onload -p nginx-server.opf sbin/nginx -c nginx-server-node0_1050.conf
```

The corresponding `nginx-server-node0_1050.conf` configuration file is shown below.

```
cat >nginx-server-node0_1050.conf <<EOL
worker_processes       1;
worker_rlimit_nofile   8388608;
worker_cpu_affinity    auto 00000000000000000000000000000001;
pid                    /var/run/nginx-node0_1050.pid;

events {
  multi_accept          off;
  accept_mutex          off;
  use                   epoll;
  worker_connections    200000;
}

error_log              logs/error-node0_1050.log debug;

http {
  default_type          application/octet-stream;
  access_log            off;
  error_log             /dev/null crit;
  keepalive_timeout     300s;
  keepalive_requests    1000000;

  server {
    listen               192.168.0.100:1050 reuseport;
    server_name          localhost;

    open_file_cache      max=100000 inactive=20s;
    open_file_cache_valid 30s;
    open_file_cache_errors off;

    location = /0 {
      return 204;
    }
    location / {
      root   html-node0_1050;
      index  index.html;
    }
    location = /upload {
      return 200 'Thank you';
    }
  }
}
EOL
```
The worker_cpu_affinity is changed for each instance, to use cores 0 to 39.

Instances on the even cores (NUMA node 0) have the IP address in http \server \listen set to use the NIC that is affinitized to NUMA node 0, and the port address incrementing from 1050 upwards.

Instances on the odd cores (NUMA node 1) have the IP address in http \server \listen set to use the NIC that is affinitized to NUMA node 1, and the port address also incrementing from 1050 upwards.

The pid is changed for each instance.

The error_log is changed for each instance.

The server location root is changed for each instance.

Static files for webservers

Each webserver serves static files from within the install directory, in a subdirectory that is configured by the root directive. Each webserver instance uses its own subdirectory, to avoid filesystem contention, and to model more closely a farm of separate servers.

The static files used range from 400B to 1MB. They were generated using dd. The example below creates the necessary files for the server that uses the above configuration file:

```bash
# mkdir -p /opt/nginx/html-node0_1050
# for payload in 400 1024 10240 32768 65536 102400 131072 262144 1024000
> do
> dd if=/dev/urandom of=/opt/nginx/html-node0_1050/$payload bs=$payload count=1 > /dev/null 2>&1
> done
```

4.4 NGINX proxy (on Proxy server)

Start various numbers of NGINX proxy worker processes (2, 8, 16, 24, 32 or 40), using either the kernel network stack, or one of two different Onload-accelerated network stacks. A total of 18 iterations are required.

Example command lines to start 16 worker processes are below:

- To start the proxy server with the kernel network stack, use the following:
  ```bash
  sbin/nginx -c nginx_proxy-node0_16.conf
  sbin/nginx -c nginx_proxy-node1_16.conf
  ```

- To start the proxy server with an Onload-accelerated network stack, use one of the following, for the two different Onload profiles under test:
  ```bash
  onload -p nginx-proxy-balanced.opf sbin/nginx -c nginx_proxy-node0_16.conf
  onload -p nginx-proxy-balanced.opf sbin/nginx -c nginx_proxy-node1_16.conf
  onload -p nginx-proxy-performance.opf sbin/nginx -c nginx_proxy-node0_16.conf
  onload -p nginx-proxy-performance.opf sbin/nginx -c nginx_proxy-node1_16.conf
  ```
The corresponding nginx_proxy-node0_16.conf configuration file is shown below.

cat >nginx_proxy-node0_16.conf <<EOL
worker_processes 8;
worker_rlimit_nofile 8388608;
worker_cpu_affinity auto 00000000000000010101010101010101
pid /var/run/nginx-node0_16.pid;

events {
    multi_accept off;
    accept_mutex off;
    use epoll;
    worker_connections 200000;
}

error_log logs/error-node0_16.log debug;

http {
    default_type application/octet-stream;
    access_log off;
    error_log /dev/null crit;
    sendfile on;
    proxy_buffering off;
    keepalive_timeout 300s;
    keepalive_requests 100000;

    server {
        listen 192.168.0.101:1080 reuseport;
        server_name localhost;

        error_page 500 502 503 504 /50x.html;

        location = /50x.html {
            root html;
        }
        location / {
            proxy_pass http://backend;
            proxy_http_version 1.1;
            proxy_set_header Connection "";
        }
    }
}
upstream backend {
server 192.168.0.100:1050 ;
server 192.168.0.100:1051 ;
server 192.168.0.100:1052 ;
server 192.168.0.100:1053 ;
server 192.168.0.100:1054 ;
server 192.168.0.100:1055 ;
server 192.168.0.100:1056 ;
server 192.168.0.100:1057 ;
server 192.168.0.100:1058 ;
server 192.168.0.100:1059 ;
server 192.168.0.100:1060 ;
server 192.168.0.100:1061 ;
server 192.168.0.100:1062 ;
server 192.168.0.100:1063 ;
server 192.168.0.100:1064 ;
server 192.168.0.100:1065 ;
server 192.168.0.100:1066 ;
server 192.168.0.100:1067 ;
server 192.168.0.100:1068 ;
server 192.168.0.100:1069 ;
   keepalive 500;
}
EOL
• The worker_processes is set to the number of worker processes which share the same NUMA node (i.e. half the number of worker processes in the test).
• The worker_cpu_affinity is set to use one core per worker process, all on the same NUMA node (alternate bits set in this case).

For the corresponding nginx_proxy-node1_16.conf configuration file, the lower 16 bits are reversed:
   worker_cpu_affinity auto 00000000000000101010101010101010 ;
• Instances on the even cores (NUMA node 0) have the IP addresses set as follows:
  - http → server → listen is set to use the NIC that is affinitized to NUMA node 0, with the port number set to 1080.
  - http → upstream backend → server is set to use the NIC that is affinitized to NUMA node 0 on the load server, with all port numbers in the range 1050-1069.
• Instances on the odd cores (NUMA node 1) have the IP addresses set as follows:
  - http → server → listen is set to use the NIC that is affinitized to NUMA node 1, with the port number set to 1080.
  - http → upstream backend → server is set to use the NIC that is affinitized to NUMA node 1 on the load server, with all port numbers in the range 1050-1069.
• The pid is changed for each instance.
• The error_log is changed for each instance.
4.5 Graphing the benchmarking results

The results from each pass of wrk2 are now gathered and summed, so that they can be further analyzed. They are then transferred into an Excel spreadsheet, to create graphs from the data.
This chapter presents the benchmark results that are achieved. See:

- Results on page 18
- Analysis on page 22.
5.1 Results

Connections per second

![Graph showing connections per second for NGINX](image)

**Figure 5: NGINX connections per second**

Table 1 below shows the results that were used to plot the graph in Figure 5 above.

<table>
<thead>
<tr>
<th>Worker processes</th>
<th>Kernel</th>
<th>Onload balanced</th>
<th>Onload performance</th>
<th>Onload balanced gain</th>
<th>Onload performance gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>70957.35</td>
<td>187431.36</td>
<td>189503.89</td>
<td>164%</td>
<td>167%</td>
</tr>
<tr>
<td>8</td>
<td>257003.65</td>
<td>772494.71</td>
<td>772756.36</td>
<td>200%</td>
<td>200%</td>
</tr>
<tr>
<td>16</td>
<td>410795.52</td>
<td>1507558.1</td>
<td>1504750.5</td>
<td>266%</td>
<td>266%</td>
</tr>
<tr>
<td>24</td>
<td>509656.37</td>
<td>2098591.5</td>
<td>2157234.8</td>
<td>311%</td>
<td>323%</td>
</tr>
<tr>
<td>32</td>
<td>509396.24</td>
<td>2348479.4</td>
<td>2373220.1</td>
<td>361%</td>
<td>365%</td>
</tr>
<tr>
<td>40</td>
<td>511137.83</td>
<td>2287115.4</td>
<td>2383646.32</td>
<td>347%</td>
<td>366%</td>
</tr>
</tbody>
</table>
Requests per second

![Figure 6: NGINX requests per second](image)

Table 2 below shows the results that were used to plot the graph in Figure 6 above.

<table>
<thead>
<tr>
<th>Worker processes</th>
<th>Kernel</th>
<th>Onload balanced</th>
<th>Onload performance</th>
<th>Onload balanced gain</th>
<th>Onload performance gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>107704.26</td>
<td>256210.07</td>
<td>256858.82</td>
<td>137%</td>
<td>138%</td>
</tr>
<tr>
<td>8</td>
<td>401871.84</td>
<td>1009312.55</td>
<td>1011250.65</td>
<td>151%</td>
<td>151%</td>
</tr>
<tr>
<td>16</td>
<td>761825.71</td>
<td>2163700.25</td>
<td>2181539.11</td>
<td>184%</td>
<td>186%</td>
</tr>
<tr>
<td>24</td>
<td>1092638.24</td>
<td>3273655.22</td>
<td>3326961.9</td>
<td>199%</td>
<td>204%</td>
</tr>
<tr>
<td>32</td>
<td>1382586.62</td>
<td>4194785.8</td>
<td>4175574.83</td>
<td>203%</td>
<td>202%</td>
</tr>
<tr>
<td>40</td>
<td>1616827.43</td>
<td>4599771.22</td>
<td>4586751.76</td>
<td>184%</td>
<td>183%</td>
</tr>
</tbody>
</table>
Throughput

Table 3 below shows the results that were used to plot the graph in Figure 7 above.

<table>
<thead>
<tr>
<th>Worker processes</th>
<th>Kernel</th>
<th>Onload balanced</th>
<th>Onload performance</th>
<th>Onload balanced gain</th>
<th>Onload performance gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.71113728</td>
<td>8.96106496</td>
<td>9.4035968</td>
<td>90%</td>
<td>99%</td>
</tr>
<tr>
<td>8</td>
<td>19.1726387</td>
<td>36.51264512</td>
<td>37.5843226</td>
<td>90%</td>
<td>96%</td>
</tr>
<tr>
<td>16</td>
<td>32.3158016</td>
<td>66.90340864</td>
<td>67.2515686</td>
<td>107%</td>
<td>108%</td>
</tr>
<tr>
<td>24</td>
<td>48.0385434</td>
<td>99.10771712</td>
<td>100.310794</td>
<td>106%</td>
<td>108%</td>
</tr>
<tr>
<td>32</td>
<td>53.2519322</td>
<td>127.4857062</td>
<td>124.255437</td>
<td>139%</td>
<td>133%</td>
</tr>
<tr>
<td>40</td>
<td>55.9471002</td>
<td>114.7304346</td>
<td>113.028792</td>
<td>105%</td>
<td>102%</td>
</tr>
</tbody>
</table>
Latency

![Graph showing latency in ms (99 percentile) against load]

**Figure 8: NGINX latency**

Table 4 below shows the results that were used to plot the graph in Figure 8 above.

<table>
<thead>
<tr>
<th>Requests per second</th>
<th>Kernel</th>
<th>Onload balanced</th>
<th>Onload performance</th>
<th>Onload balanced gain</th>
<th>Onload performance gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>100000</td>
<td>3100</td>
<td>2070</td>
<td>1980</td>
<td>49%</td>
<td>56%</td>
</tr>
<tr>
<td>250000</td>
<td>2000</td>
<td>2110</td>
<td>1750</td>
<td>-6%</td>
<td>14%</td>
</tr>
<tr>
<td>500000</td>
<td>2240</td>
<td>2080</td>
<td>1810</td>
<td>7%</td>
<td>23%</td>
</tr>
<tr>
<td>750000</td>
<td>2540</td>
<td>2150</td>
<td>1990</td>
<td>18%</td>
<td>27%</td>
</tr>
<tr>
<td>1000000</td>
<td>2680</td>
<td>2280</td>
<td>2040</td>
<td>17%</td>
<td>31%</td>
</tr>
<tr>
<td>1100000</td>
<td>2650</td>
<td>2210</td>
<td>2040</td>
<td>19%</td>
<td>29%</td>
</tr>
<tr>
<td>1200000</td>
<td>70010</td>
<td>2380</td>
<td>2150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1300000</td>
<td>231000</td>
<td>2440</td>
<td>2220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1400000</td>
<td>11190000</td>
<td>2690</td>
<td>2300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500000</td>
<td>16440000</td>
<td>2760</td>
<td>2410</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000000</td>
<td>23450000</td>
<td>3220</td>
<td>2910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2500000</td>
<td>29920000</td>
<td>2420</td>
<td>2580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000000</td>
<td>34870000</td>
<td>2360</td>
<td>2490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000000</td>
<td>40530000</td>
<td>1620</td>
<td>2370</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kernel cannot maintain requested packet rate. Gain is meaningless.
5.2 Analysis

When compared with the kernel stack, Cloud Onload delivers significant improvements to all metrics.

Connections per second

The connections per second shows great improvement with Cloud Onload, peaking at an improvement of 366% over the kernel stack. With large numbers of proxy workers (32 to 40) the Cloud Onload performance levels out. This is most likely because the load server is unable to generate and measure any more traffic, but might be because the proxy server itself is saturated.

Requests per second

The requests per second also shows great improvement with Cloud Onload, peaking at an improvement of 204% over the kernel stack. With 40 worker processes, results continue to improve, indicating that further performance is available from Cloud Onload.

Throughput

The throughput shows significant improvement with Cloud Onload, peaking at an improvement of 139% over the kernel stack. With large numbers of proxy workers (32 to 40) the Cloud Onload performance again levels out, either because the load server cannot generate any more traffic, or because the proxy server itself is saturated.

Latency

The latency figures are as output by wrk2, and show the time from when the should have been sent (according to the configured packet rate), until when the packet was actually received. The 99 percentile figure is reported.

When the kernel stack packet rate is raised above 1.1 million requests per second, it can no longer maintain this rate. Jitter increases, the number of outliers exceeds 1%, and so the reported latency suddenly and dramatically increases. Any further small increase in load would make the server appear completely unresponsive to an end user.

In contrast, Cloud Onload continues to deliver low latency with 4 million requests per second, and is actually trending towards even lower latency. The stable and low value for the 99th percentile of latency indicates low jitter and predictable performance.
Cloud Onload profiles

This appendix contains the Cloud Onload profiles used for this benchmarking. See:

- The wrk-profile Cloud Onload profile on page 23
- The nginx-server Cloud Onload profile on page 24
- The nginx-proxy Cloud Onload profiles on page 25.

These profiles, along with the scripts used for this benchmarking, are available on request from support@solarflare.com.

A.1 The wrk-profile Cloud Onload profile

The wrk-profile.opf Cloud Onload profile is as follows:

```plaintext
onload_set EF_SOCKET_CACHE_MAX 40000
onload_set EF_TCP_CONSTRUCT_MSL 1
onload_set EF_TCP_FIN_TIMEOUT 15
onload_set EF_HIGH_THROUGHPUT_MODE 1
onload_set EF_LOG_VIA_IOCTL 1
onload_set EF_NO_FAIL 1
onload_set EF_UDP 0

#ensure sufficient resources
onload_set EF_MAX_PACKETS 205000
onload_set EF_MAX_ENDPOINTS 400000
onload_set EF_FDTABLE_SIZE 8388608
onload_set EF_USE_HUGE_PAGES 2
onload_set EF_MIN_FREE_PACKETS 50000

#environment variable can overwrite
onload_set EF_LOAD_ENV 1

#spinning configuration
onload_set EF_POLL_USEC 100000
onload_set EF_SLEEP_SPIN_USEC 50
onload_set EF_EPOLL_SPIN 1

#scalable filters with clustering for outgoing connections
onload_set EF_SCALABLE_FILTERS 'any=rss:active'
onload_set EF_SCALABLE_FILTERS_ENABLE 1
onload_set EF_CLUSTER_NAME 'load'
onload_set EF_CLUSTER_SIZE 12 #needs to overwritten by environment

#shared local ports to improve rate of socket recycling
onload_set EF_TCP_SHARED_LOCAL_PORTS_MAX 28000
onload_set EF_TCP_SHARED_LOCAL_PORTS 28000
onload_set EF_TCP_SHARED_LOCAL_PORTS_PER_IP 1
```
onload_set EF_TCP_SHARED_LOCAL_PORTS_REUSE_FAST 1
onload_set EF_TCP_SHARED_LOCAL_PORTS_NO_FALLBACK 1

#epoll configuration
onload_set EF_UL_EPOLL 3
onload_set EF_EPOLL_MT_SAFE 1

#reduce transmit CPU load
onload_set EF_TX_PUSH 0
onload_set EF_PIO 0
onload_set EF_CTPIO 0

# Adjustments for potentially-lossy network environment
onload_set EF_TCP_INITIAL_CWND 14600
onload_set EF_DYNAMIC_ACK_THRESH 4
onload_set EF_TAIL_DROP_PROBE 1
onload_set EF_TCP_RCVBUF_MODE 1

A.2 The nginx-server Cloud Onload profile

The nginx-server.opf Cloud Onload profile is as follows:

onload_set EF_ACCEPTQ_MIN_BACKLOG 400
onload_set EF_SOCKET_CACHE_MAX 40000
onload_set EF_TCP_TCONST_MSL 1
onload_set EF_TCP_FIN_TIMEOUT 15
onload_set EF_TCP_SYNRECV_MAX 90000
onload_set EF_TCP_BACKLOG_MAX 400
onload_set EF_HIGH_THROUGHPUT_MODE 1
onload_set EF_LOG_VIA_IOCTL 1
onload_set EF_NO_FAIL 1
onload_set EF_UDP 0

#ensure sufficient resources
onload_set EF_MAX_PACKETS 205000
onload_set EF_MAX_ENDPOINTS 400000
onload_set EF_USE_HUGE_PAGES 2
onload_set EF_MIN_FREE_PACKETS 50000

#epoll configuration
onload_set EF_UL_EPOLL 3
onload_set EF_EPOLL_MT_SAFE 1

#don't use clustering when SO_REUSEPORT is set
onload_set EF_CLUSTER_IGNORE 1

#environment variable can overwrite
onload_set EF_LOAD_ENV 1

#spinning configuration
onload_set EF_POLL_USEC 100000
onload_set EF_SLEEP_SPIN_USEC 50
onload_set EF_EPOLL_SPIN 1

#reduce transmit CPU load
onload_set EF_TX_PUSH 0
onload_set EF_PIO 0
onload_set EF_CTPIO 0

# Adjustments for potentially-lossy network environment
onload_set EF_TCP_INITIAL_CWND 14600
onload_set EF_DYNAMIC_ACK_THRESH 4
onload_set EF_TAIL_DROP_PROBE 1
onload_set EF_TCP_RCVBUF_MODE 1

A.3 The nginx-proxy Cloud Onload profiles

There are two nginx-proxy Cloud Onload profiles.

- The balanced profile gives excellent throughput, with low latency. It has reduced CPU usage at lower traffic rates.
- The performance profile is latency focused. It constantly polls for network events to achieve the lowest latency possible, and so has higher CPU usage.

The differences between these profiles are minor, and are in the profile files. See:

- The nginx-proxy-balanced profile on page 25
- The nginx-proxy-performance profile on page 25.

The majority of the settings are common to both profiles, and are in separate shared files that each profile sources or includes. See:

- The nginx-proxy-config profile fragment on page 26.
- The reverse-proxy-throughput profile fragment on page 28.

The nginx-proxy-balanced profile

The nginx-proxy-balanced.opf Cloud Onload profile is as follows:

```
. ${PROXY_CONFIG_DIR}/nginx-proxy-config.opf-fragment
onload_import ${PROXY_CONFIG_DIR}/reverse-proxy-throughput.opf-fragment
```

The nginx-proxy-performance profile

The nginx-proxy-performance.opf Cloud Onload profile is as follows:

```
.onload_set EF_TX_PUSH 1
.onload_set EF_SLEEP_SPIN_USEC 0
.onload_import ${PROXY_CONFIG_DIR}/reverse-proxy-throughput.opf-fragment
```
The nginx-proxy-config profile fragment

The nginx-proxy-config .opf-fragment file, sourced by both the above profiles, is as follows:

```bash
### User may supply the following environment variables:
#
#   NGINX_NUM_WORKERS        - the number of workers that nginx is
classified to use. Overrides value
# automatically detected from nginx
#
set -o pipefail

# For diagnostic output
module="nginx profile"

# Regular expressions to match nginx config directives
worker_processes_pattern="(\'|;)(worker_processes\s+(\w+)(\s+\s*)?;)/"
include_pattern="(\'|;)(include\s+(\S+)(\s+\s*)?;)/"

# Identify the config file that nginx would use
identify_config_file() {
    local file
    # Look for a -c option
    local state="IDLE"
    for option in "$@"
    do
        if [ "$state" = "MINUS_C" ]
            then
                file=$option
                state="FOUND"
        elif [ "$option" = "-c" ]
            then
                state="MINUS_C"
        fi
    done
    # Extract the compile-time default if config not specified on command line
    if [ "$state" != "FOUND" ]
        then
            file=$($1 -h 2>&1 | perl -ne 'print $1 if "$worker_processes_pattern" $1')
    fi
    [ -f "$file" ] && echo $file
}

# Recursively look in included config files for a setting of worker_processes.
# NB If this quantity is set in more than one place then the wrong setting might
# be found, but this would be invalid anyway and is rejected by Nginx.
read_config_file() {
    local setting
    local worker_values=$(perl -ne 'print "$2 " if "$worker_processes_pattern" $1')
    local include_values=$(perl -ne 'print "$2 " if "$include_pattern" $1')
    # First look in included files
```
for file in $include_values
  do
    local possible=$(read_config_file $file)
    if [ -n "$possible" ]
      then
        setting=$possible
      fi
  done

# Then look in explicit settings at this level
for workers in $worker_values
  do
    setting=$workers
  done
  echo $setting
}

# Method to parse configuration files directly
try_config_files() {
  local config_file=$(identify_config_file "$@")
  [ -n "$config_file" ] && read_config_file $config_file
}

# Method to parse configuration via nginx, if supported
try_nginx_minus_t() {
  "$@" -T | perl -ne 'print "$2" if "$worker_processes_pattern"'
}

# Method to parse configuration via tengine, if supported
try_tengine_minus_d() {
  "$@" -d | perl -ne 'print "$2" if "$worker_processes_pattern"'
}

# Determine the number of workers nginx will use
determine_worker_processes() {
  # Prefer nginx's own parser, if available, for robustness
  local workers=$(try_nginx_minus_t "$@" || try_tengine_minus_d "$@" || try_config_files "$@")
  if [ "$workers" = "auto" ]
    then
      # Default to the number of process cores
      workers=$(nproc)
    fi
  echo $workers
}

# Define the number of workers
num_workers=${NGINX_NUM_WORKERS:-$(determine_worker_processes "$@")}
if ! [ -n "$num_workers" ]; then
  fail "ERROR: Environment variable NGINX_NUM_WORKERS is not set and worker count cannot be determined from nginx configuration"
fi
log "$module: configuring for $num_workers workers"
The reverse-proxy-throughput profile fragment

The reverse-proxy-throughput.opf-fragment file, included by both the above profiles, is as follows:

```
## User may supply the following environment variables:
#
#   NGINX_NUM_WORKERS - the number of workers that nginx is
#                        configured to use. Overrides value
#                        automatically detected from nginx
#                        configuration
#
set -o pipefail
# For diagnostic output
module="nginx profile"

# Regular expressions to match nginx config directives
worker_processes_pattern="/(^|\;)\s*worker_processes\s+(\w+)\s*;/
include_pattern="/(^|\;)\s*include\s+(\S+)\s*;/

# Identify the config file that nginx would use
identify_config_file() {
    local file
    # Look for a -c option
    local state="IDLE"
    for option in "$@"
    do
        if [ "$state" = "MINUS_C" ]
        then
            file=$option
            state="FOUND"
        elif [ "$option" = "-c" ]
        then
            state="MINUS_C"
        fi
    done
    # Extract the compile-time default if config not specified on command line
    if [ "$state" != "FOUND" ]
    then
        file=$($1 -h 2>&1 | perl -ne 'print $1 if "$worker_processes_pattern" $1')
    fi
    [ -f "$file" ] && echo $file
}

# Recursively look in included config files for a setting of worker_processes.
# NB If this quantity is set in more than one place then the wrong setting might
# be found, but this would be invalid anyway and is rejected by Nginx.
read_config_file() {
    local setting
    local worker_values=$(perl -ne 'print "$2 " if "$worker_processes_pattern" $1')
    local include_values=$(perl -ne 'print "$2 " if "$include_pattern" $1')
    # First look in included files
```
for file in $include_values
do
    local possible=$(read_config_file $file)
    if [ -n "$possible" ]
        then
            setting=$possible
    fi
done

# Then look in explicit settings at this level
for workers in $worker_values
do
    setting=$workers
    done
    echo $setting

# Method to parse configuration files directly
try_config_files() {
    local config_file=$(identify_config_file "$@")
    [ -n "$config_file" ] && read_config_file $config_file
}

# Method to parse configuration via nginx, if supported
try_nginx_minus_t() {
    "$@" -T | perl -ne 'print "$2" if "$worker_processes_pattern"'
}

# Method to parse configuration via tengine, if supported
try_tengine_minus_d() {
    "$@" -d | perl -ne 'print "$2" if "$worker_processes_pattern"'
}

# Determine the number of workers nginx will use
determine_worker_processes() {
    # Prefer nginx's own parser, if available, for robustness
    local workers=$(try_nginx_minus_t "$@" || try_tengine_minus_d "$@" || try_config_files "$@")
    if [ "$workers" = "auto" ]
        then
            # Default to the number of process cores
            workers=$(nproc)
        fi
    echo $workers
}

# Define the number of workers
num_workers=${NGINX_NUM_WORKERS:-$(determine_worker_processes "$@")}
if ! [ -n "$num_workers" ]; then
    fail "ERROR: Environment variable NGINX_NUM_WORKERS is not set and worker count cannot be determined from nginx configuration"
fi
log "$module: configuring for $num_workers workers"
Installation and configuration

This appendix describes how to install and configure the software distributions used for this benchmarking. See:

- Installing NGINX on page 30
- Installing wrk2 on page 32

B.1 Installing NGINX

This section describes how to install and configure NGINX.

Installation

NOTE: For a reference description of how to install NGINX, see https://docs.nginx.com/nginx/admin-guide/installing-nginx/installing-nginx-open-source/.

In summary:

1. If you already have an old NGINX installation on your system:
   a) Back up your configs and logs:
      # cp -a /etc/nginx /etc/nginx-plus-backup
      # cp -a /var/log/nginx /var/log/nginx-plus-backup
   b) Remove the old installation:
      # rm -rf /opt/nginx

2. Create a new NGINX directory:
   mkdir -p /opt/nginx

3. Change to a temporary directory:
   cd $( mktemp -d )

4. Clone NGINX from its git repository:
   git clone https://github.com/nginx/nginx

5. Configure NGINX:
   ./auto/configure --prefix=/opt/nginx

6. Make and install NGINX:
   make install
7 Check the NGINX binary version to ensure that you have NGINX installed correctly:

```
# nginx -v
nginx version: nginx/1.17
```

8 Start NGINX:

```
# systemctl start nginx
```

or just:

```
# nginx
```

9 Verify access to Web Server

```
10.20.128.35
```

**Welcome to nginx!**

If you see this page, the nginx web server is successfully installed and working. Further configuration is required.

For online documentation and support please refer to [nginx.org](http://nginx.org).
Commercial support is available at [nginx.com](http://nginx.com).

Thank you for using nginx.
B.2 Installing wrk2

This section describes how to install and configure wrk2.

Installation


In summary:

1. If the build tools are not already installed, install them:
   # yum groupinstall 'Development Tools'

2. If the OpenSSL dev libs are not already installed, install them:
   # yum install -y openssl-devel

3. If git is not already installed, install it:
   # yum install -y git

4. Create a directory to hold wrk2:
   # mkdir -p Onload_Testing/WRK2
   # cd Onload_Testing/WRK2

5. Use git to download wrk2:
   # git clone https://github.com/giltene/wrk2.git

6. Build wrk2:
   # cd wrk2
   # make

7. Copy the wrk2 executable to a location on your PATH. For example:
   # cp wrk2 /usr/local/bin

B.3 Installing Cloud Onload

For instructions on how to install and configure Cloud Onload, refer to the Onload User Guide (SF-104474-CD). This is available from https://support.solarflare.com/.