Nginx Performance Evaluation

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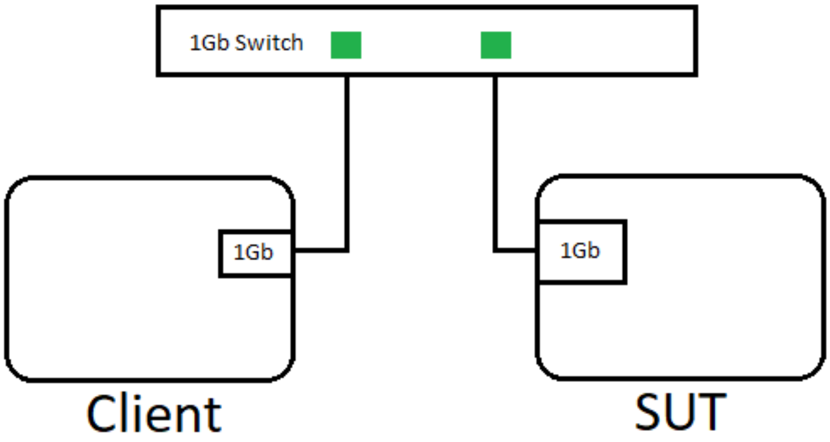
Detailed information in every step:

1. Purpose

This is a performance test on latest version of plain nginx, find bottleneck, and solve it.
A simple approach is to saturate a single core in my SUT workstation, because my 1Gb NIC can only generate very limited workload
But it will show you how to easily scale-up if you have 10Gb NIC + 10-core CPU, or more easily scale-out if you have 10x servers with single 10Gb NIC + 10-core CPU.
And the CPU saturation will help you to see the bottleneck directly, not just guessing, or trying randomly.

2. Environment



SUT Hardware:

NIC: Intel Corporation Ethernet Connection (7) I219-LM (No RSS)
CPU: Intel(R) Xeon(R) E-2186G CPU @ 3.80GHz (HT=off)
Memory：32GB x2 (2666MHz)

Software:

OS: Red Hat Enterprise Linux Server release 7.5 (Maipo)
Kernel：3.10.0-862.11.6.el7.x86_64 (with Meldown & Spectre patches)
nginx-1.15.5 + zlib-1.2.11 + pcre-8.42 + jemalloc-5.1.0

3. Setup

Download the latest version of Nginx from http://nginx.org/download/nginx-1.15.5.tar.gz
Compilation requires zlib-1.2.11 + pcre-8.42 (jemalloc-5.1.0)

4. Environment Check

NIC bandwidth:

```
[root@dr1 ~]# iperf3 -c www.example.com &
[ ID] Interval         Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec   114 MBytes   958 Mbits/sec    0    543 Kbytes
```

looks good

Stop SUT Services:

systemctl stop ***, after doing this step, we can check system remaining services:

```
[root@st50 www]# systemctl -a |grep running
  session-113.scope          loaded    active   running   Session 113 of user root
  session-2.scope            loaded    active   running   Session 2 of user root
  auditd.service             loaded    active   running   Security Auditing Service
  dbus.service               loaded    active   running   D-Bus System Message Bus
  getty@tty1.service         loaded    active   running   Getty on tty1
  polkit.service             loaded    active   running   Authorization Manager
  sshd.service               loaded    active   running   OpenSSH server daemon
  dbus.socket                loaded    active   running   D-Bus System Message Bus Socket
```

Enable Client irqbalance service:

```
[root@dr1 www]# systemctl start irqbalance
```

5. Compile Nginx

```
[root@st50 nginx-1.15.5]# ./configure  --prefix=/home/www/nginx0 --with-pcre=/home/www/pcre-8.42 --with-zlib=/home/www/zlib-1.2.11 --with-debug
```

6. Tuning system

check irq #

```
[root@st50 www]# cat /proc/interrupts |grep eno1
 123:     27700        1        0        2        0        0        0        0        0        6        0        0  IR-PCI-MSI-edge      eno1
```

bind irq to single logical core #2:

```
echo 4 > /proc/irq/123/smp_affinity
```

slightly enlarge the ring cache :

```
ethtool -G eno1 rx 8192
```

reduce softirq a little:

```
ethtool -C eno1 adaptive-tx off adaptive-rx off rx-usecs 400  # rx-frames 15   # in microseconds or packets
```

Disable THP:

```
echo madvise > /sys/kernel/mm/transparent_hugepage/enabled
echo madvise > /sys/kernel/mm/transparent_hugepage/defrag
```

add following 2 lines into /etc/security/limits.conf

```
* hard nofile 655350
* soft nofile 655350
```

Change kernel parameters listed below:

```
fs.file-max=500000                              #open files
kernel.sysrq = 0                                #sysrq keys disabled
kernel.core_uses_pid = 1                        #coredump
kernel.msgmnb = 65536                           #max bytes
kernel.msgmax = 65536                           #max length
kernel.shmmax = 68719476736                     #single share memory segment max size
kernel.shmall = 4294967296                      #pages
net.core.wmem_default = 8388608                 #tx window
net.core.rmem_default = 8388608                 #rx window
net.core.wmem_max = 16777216                    #tx window
net.core.rmem_max = 16777216                    #rx window
net.core.netdev_max_backlog = 40960             #rx queue len
net.core.somaxconn = 40960                      #connection
#net.core.default_qdisc=fq                      #google congestion control
#net.ipv4.tcp_congestion_control=bbr            #google congestion control
net.ipv4.ip_forward = 0                         #disable ip forward
net.ipv4.conf.default.rp_filter = 1             #reverse path filter, same port io
net.ipv4.tcp_syncookies = 1                     #avoid syn flood
net.ipv4.tcp_max_tw_buckets = 6000              #TIME_WAIT #
net.ipv4.tcp_sack = 1                           #selective acknowledge
net.ipv4.tcp_window_scaling = 1                 #64k window
net.ipv4.tcp_rmem = 4096        87380   4194304              #rx window: min/def/max
net.ipv4.tcp_wmem = 4096        16384   4194304              #tx window: min/def/max
net.ipv4.tcp_mem = 94500000 915000000 927000000    #sys tcp mem
net.ipv4.tcp_max_orphans = 3276800                   #sockets
net.ipv4.tcp_max_syn_backlog = 40960                 #syn queue
net.ipv4.tcp_timestamps = 0                          #better than resend
net.ipv4.tcp_synack_retries = 1                      #hand shake#
net.ipv4.tcp_syn_retries = 1                         #
net.ipv4.tcp_tw_recycle = 1                          #
net.ipv4.tcp_tw_reuse = 1                            # TIME-WAIT sockets reuse
net.ipv4.tcp_fin_timeout = 1                         #close timeout
net.ipv4.tcp_keepalive_time = 30                     #default 2h
net.ipv4.tcp_slow_start_after_idle=0                 #
net.ipv4.ip_local_port_range = 1024    65000
vm.zone_reclaim_mode=0                               #alloc remote page when used up local
kernel.kptr_restrict=0                               #perf
```

Change nginx.conf:

```
user  www;
worker_processes  10;
#worker_cpu_affinity 000000000100 000000000100;
error_log  /dev/null ;

events {
  use epoll;
  worker_connections 4096;
}

http {
    include       mime.types;
    default_type  application/octet-stream;
    #open_file_cache         max=10 inactive=5m;
    #open_file_cache_valid    2m;
    #open_file_cache_min_uses 1;
    #access_log  logs/access.log  main;
    access_log off;
    server_names_hash_bucket_size 128;
    client_header_buffer_size 2k;
    large_client_header_buffers 4 4k;
    client_max_body_size 8m;

    sendfile       on;                         #skip user space
    tcp_nopush     on;                         #merge bundle
    tcp_nodelay    on;                         #disable nagle
    keepalive_timeout  60;
    gzip  on;
    #gzip_static on;
    gzip_proxied expired no-cache no-store private auth;
    gzip_min_length  1k;
    gzip_buffers     16 8k;
    gzip_http_version 1.1;
    gzip_comp_level 4;
    gzip_types       text/plain application/x-javascript text/css application/xml image/svg+xml;
    gzip_vary on;

    server {
        listen       80;
        server_name  www.example.com;
        #access_log off;
        location / {
            root   html;
            index  index.html index.htm;
        }
        error_page   500 502 503 504  /50x.html;
        location = /50x.html {
            root   html;
        }
    }
```

7. Run test

start nginx on the core #2:

```
numactl -C 2 --localalloc nginx/sbin/nginx
```

Validate logo.svg

```
wget http://www.example.com/logo.svg
```

run ab test:

```
ab -n 800000 -c 100 http://www.example.com/logo.svg
This is ApacheBench, Version 2.3 <$Revision: 1430300 $>
Copyright 1996 Adam Twiss, Zeus Technology Ltd, http://www.zeustech.net/
Licensed to The Apache Software Foundation, http://www.apache.org/

Benchmarking www.example.com (be patient)
Completed 80000 requests
Completed 160000 requests
Completed 240000 requests
Completed 320000 requests
Completed 400000 requests
Completed 480000 requests
Completed 560000 requests
Completed 640000 requests
Completed 720000 requests
Completed 800000 requests
Finished 800000 requests

Server Software:        nginx/1.15.5
Server Hostname:        www.example.com
Server Port:            80

Document Path:          /logo.svg
Document Length:        2649 bytes

Concurrency Level:      100
Time taken for tests:   23.820 seconds
Complete requests:      800000
Failed requests:        0
Write errors:           0
Total transferred:      2328000000 bytes
HTML transferred:       2119200000 bytes
Requests per second:    33585.56 [#/sec] (mean)
Time per request:       2.977 [ms] (mean)
Time per request:       0.030 [ms] (mean, across all concurrent requests)
Transfer rate:          95443.35 [Kbytes/sec] received

Connection Times (ms)
              min  mean[+/-sd] median   max
Connect:        0    1   0.3      1       6
Processing:     0    2   0.5      2      22
Waiting:        0    2   0.5      1      22
Total:          1    3   0.7      3      25

Percentage of the requests served within a certain time (ms)
  50%      3
  66%      3
  75%      3
  80%      3
  90%      4
  95%      4
  98%      5
  99%      5
 100%     25 (longest request)
```

8. Monitor

Network: sar -n DEV 2 4
CPU: mpstat -P ALL 2 4
Memory: numactl -H
Cache/TLB: perf stat --cpu=2 -dd
Syscall utility:

```
perf probe 'tcp_recvmsg'
perf probe -x /lib64/libc.so.6 malloc
perf record -e probe:tcp_recvmsg -e probe_libc:malloc -a
```

Hotspot capture: perf record ; perf top ; perf stat
Memory access utility: perf mem -D record

9. Analyze

CPU usage: (from mpstat)

```
Average:    CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
Average:      2    24.28   0.00    45.06   0.00     0.00   30.66   0.00     0.00     0.00    0.00
```

Network usage: (from sar -n DEV)

```
02:51:19 PM     IFACE   rxpck/s   txpck/s    rxkB/s    txkB/s   rxcmp/s   txcmp/s  rxmcst/s   %ifutil
02:55:25 PM      eth0 188525.00 196267.50  15738.66 106685.75      0.00      0.00      2.00     87.40
```

Syscall usage in 8 seconds: (from perf record -e probe_libc:malloc -e probe:tcp_recvmsg)

```
       1,027,994      probe_libc:malloc
         256,699      probe:tcp_recvmsg
```

TLB usage: (from perf stat -dd)

```
    6,543,139,385      dTLB-loads              #  817.829 M/sec                  (71.49%)
        6,057,670      dTLB-load-misses        #    0.09% of all dTLB cache hits   (57.20%)
```

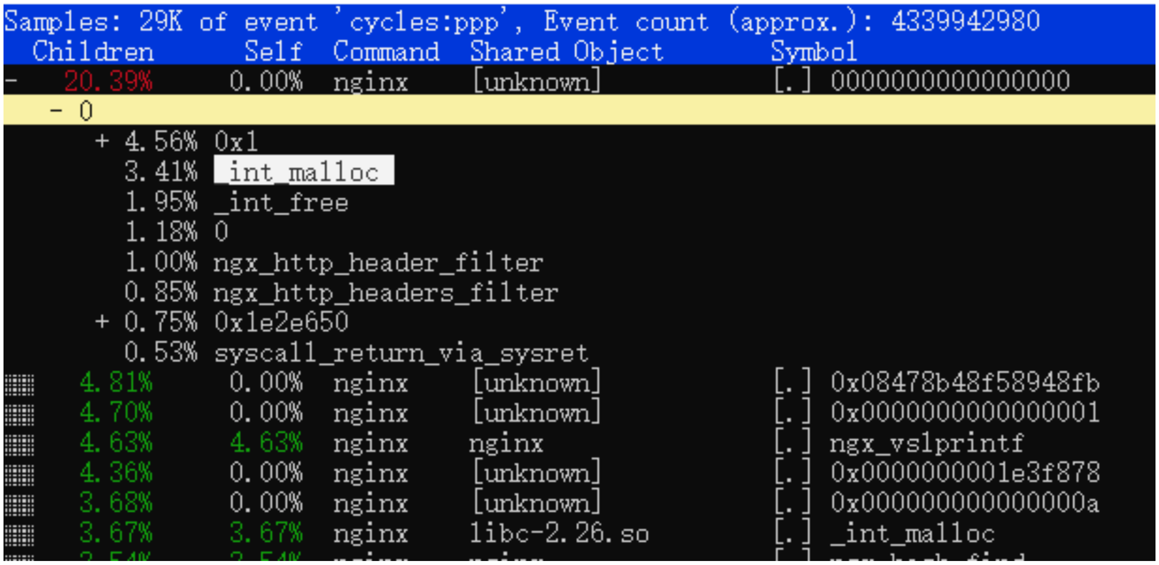
Memory usage: (from numactl -H)

```
node 0 size: 65371 MB
node 0 free: 63229 MB
```

Memory access samples in 8 seconds: (perf mem -D record)

```
total:  134024 samples
36K cpu/mem-loads,ldlat=30/P
97K cpu/mem-stores/P
```

the bottleneck is memory allocator (can be misleading on RHEL 7.5 with kernel 3.10)
Move to SLES-15 with new kernel 4.12, lots of perf improvements
perf record -a -g --all-kernel (all net relative)
perf record -a -g --all-user (yeah)



```
Samples: 29K of event 'cycles:ppp', Event count (approx.): 4339942980
  Children      Self  Command  Shared Object        Symbol
-   20.39%     0.00%  nginx    [unknown]            [.] 0000000000000000
   - 0
      + 4.56% 0x1
        3.41% _int_malloc
        1.95% _int_free
        1.18% 0
        1.00% ngx_http_header_filter
        0.85% ngx_http_headers_filter
      + 0.75% 0x1e2e650
        0.53% syscall_return_via_sysret
     4.81%     0.00%  nginx    [unknown]            [.] 0x08478b48f58948fb
     4.70%     0.00%  nginx    [unknown]            [.] 0x0000000000000001
     4.63%     4.63%  nginx    nginx                [.] ngx_vslprintf
     4.36%     0.00%  nginx    [unknown]            [.] 0x000000001e3f878
     3.68%     0.00%  nginx    [unknown]            [.] 0x000000000000000a
     3.67%     3.67%  nginx    libc-2.26.so         [.] _int_malloc
```

And I got malloc usage data for this scenario:

```
st250:/home/www # perf record -e probe_libc:malloc -e probe:tcp_recvmsg -aR -g --output=/tmp/perf-probes.data -- sleep 8
st250:/home/www # perf script -i /tmp/perf-probes.data 2>/dev/null | grep malloc | awk '{a[$1]++;}END{for (i in a)print i, a[i];}' | sort -rnk2 > libc.malloc.sys
st250:/home/www # cat libc.malloc.sys
nginx 998487
sleep 832
systemd 345
dbus-daemon 300
systemd-journal 254
sadc 212
systemd-logind 182
sshd 171
mpstat 62
sar 50
perf 2
```

10. Introduce jemalloc

Compile jemalloc:

```
[root@www jemalloc-5.1.0]# ./autogen.sh
[root@www jemalloc-5.1.0]# make & make install
```

Compile nginx with jemalloc:

```
[root@st50 nginx-1.15.5]# ./configure  --prefix=/home/www/nginx0 --with-pcre=/home/www/pcre-8.42 --with-zlib=/home/www/zlib-1.2.11 --with-debug --with-ld-opt="-ljemalloc"
```

Restart Nginx:

```
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/lib
```

```
numactl -C 2 --localalloc nginx/sbin/nginx

#keep all other settings same
```

11. Redo ab test

```
[root@dr1 www]# ab -n 800000 -c 300 http://www.example.com/logo.svg
This is ApacheBench, Version 2.3 <$Revision: 1430300 $>
Copyright 1996 Adam Twiss, Zeus Technology Ltd, http://www.zeustech.net/
Licensed to The Apache Software Foundation, http://www.apache.org/

Benchmarking www.example.com (be patient)
Completed 80000 requests
Completed 160000 requests
Completed 240000 requests
Completed 320000 requests
Completed 400000 requests
Completed 480000 requests
Completed 560000 requests
Completed 640000 requests
Completed 720000 requests
Completed 800000 requests
Finished 800000 requests

Server Software:        nginx/1.15.5
Server Hostname:        www.example.com
Server Port:            80

Document Path:          /logo.svg
Document Length:        2649 bytes

Concurrency Level:      300
Time taken for tests:   22.148 seconds
Complete requests:      800000
Failed requests:        0
Write errors:           0
Total transferred:      2328000000 bytes
HTML transferred:       2119200000 bytes
Requests per second:    36120.88 [#/sec] (mean)
Time per request:       8.305 [ms] (mean)
Time per request:       0.028 [ms] (mean, across all concurrent requests)
Transfer rate:          102648.20 [Kbytes/sec] received

Connection Times (ms)
              min  mean[+/-sd] median   max
Connect:        0    4  24.6      3    1007
```

```
Processing:     1    4   6.0      4     225
Waiting:        0    4   5.6      4     209
Total:          1    8  25.3      7    1015
```

```
Percentage of the requests served within a certain time (ms)
  50%      7
  66%      8
  75%      8
  80%      8
  90%      8
  95%      9
  98%     11
  99%     12
 100%   1015 (longest request)
```

12. Analyze for jemalloc

CPU usage: (from mpstat)

```
Average:     CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
Average:       2   19.54    0.00   35.12    0.00    0.00   32.18    0.00    0.00    0.00   13.15
```

Network usage: (from sar -n DEV)

```
02:51:19 PM     IFACE   rxpck/s   txpck/s    rxkB/s    txkB/s   rxcmp/s   txcmp/s  rxmcst/s   %ifutil
02:51:21 PM      eth0 211446.00 222039.50  17673.09 120630.16      0.00      0.00      0.00     98.82
```

Syscall usage in 8 seconds: (from perf record -e probe:tcp_recvmsg -e probe_libc:malloc)

```
             840      probe_libc:malloc
         289,287      probe:tcp_recvmsg
```

TLB usage: (from perf record)

```
     6,861,897,872      dTLB-loads                #  857.666 M/sec                    (76.95%)
        18,741,425      dTLB-load-misses          #    0.27% of all dTLB cache hits   (61.60%)
```

Memory usage: (from numactl -H)

```
node 0 size: 65371 MB
node 0 free: 63200 MB
```

Memory access samples in 8 seconds: (perf mem -D record)

```
total:  113608 samples
30K cpu/mem-loads,ldlat=30/P
82K cpu/mem-stores/P
```

And malloc usage data now:

```
st250:/home/www # perf record -e probe_libc:malloc -e probe:tcp_recvmsg -aR -g --output=/tmp/perf-probes.data -- sleep 8
st250:/home/www # perf script -i /tmp/perf-probes.data 2>/dev/null | grep malloc | awk '{a[$1]++;}END{for (i in a)print i, a[i];}' | sort -rnk2 > libc.malloc.sys.jemalloc
st250:/home/www # cat libc.malloc.sys.jemalloc
```

```
nginx 6883
systemd 901
dbus-daemon 635
systemd-journal 462
sleep 416
systemd-logind 208
sshd 165
perf 2
```

perf top shows NO memory allocator any more ~~ (actually CPU is not bottleneck)

```
  6.29%  nginx      [kernel.vmlinux]   [k] system_call
  5.05%  nginx      [kernel.vmlinux]   [k] sysret_check
  1.14%  swapper    [kernel.vmlinux]   [k] memcpy
  1.14%  nginx      [kernel.vmlinux]   [k] _raw_spin_lock
  1.02%  nginx      [e1000e]           [k] e1000_xmit_frame
  0.97%  nginx      libc-2.17.so       [.] __memcpy_ssse3_back
```

13. Conclusion

Memory allocation latency is critical to nginx, glibc malloc is blamed for years, and TCmalloc and jemalloc is developed to resolve this performance issue.

As a simple comparison before and after introducing jemalloc,

RPS is increased from 33585.56 to 36087.54 (+8%)
CPU %idle is increased from 0% to 13.15% (13%) while workload is +8% (total jemalloc > 20%)
CPU %sys is reduced from 45.50% to 35.12% (-10%) while workload is +8% heavier
Network util: increased from 87.40% to 98.82% (+11%) Saturated
TLB-loads is increased from 819.362 to 857.666 M/sec (+5%) while workload is +8% heavier
Syscall probe_libc:malloc is reduced from 926,719 to 840 (99%?) …… Deviation ?
Syscall tcp_recvmsg increased from 231K to 289K, (+25%), why >8%? Deviation ?
99% latency has been reduced from 12ms to 12ms (0%) while workload is +8% heavier

14. Future works

This is a very simple test to resolve malloc performance bottleneck by introducing jemalloc
It demonstrates the iteration of simplifying the problem, finding performance bottleneck, fixing problem, and verifying it. And then continue this iteration into a higher performance state.

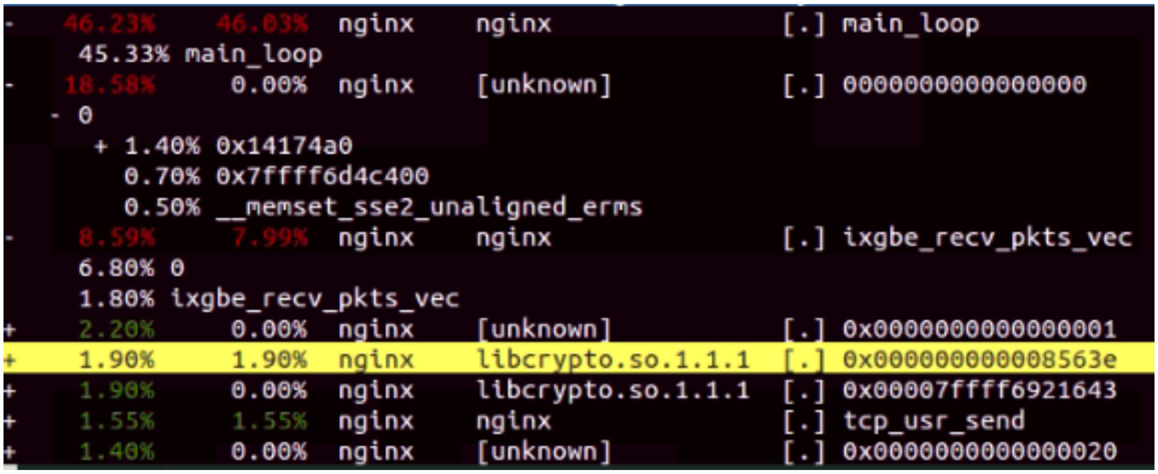
Will do more research on DPDK user-space TCP stack, because the later profile shows that bottleneck is in tcp stack of Linux kernel. I know it could be something complicated, but it’s worthy to try, there is no free lunch.

15. DPDK

Finally got a chance to have a look at DPDK on my server.

I chose the F-Stack implementation: https://github.com/f-stack/f-stack

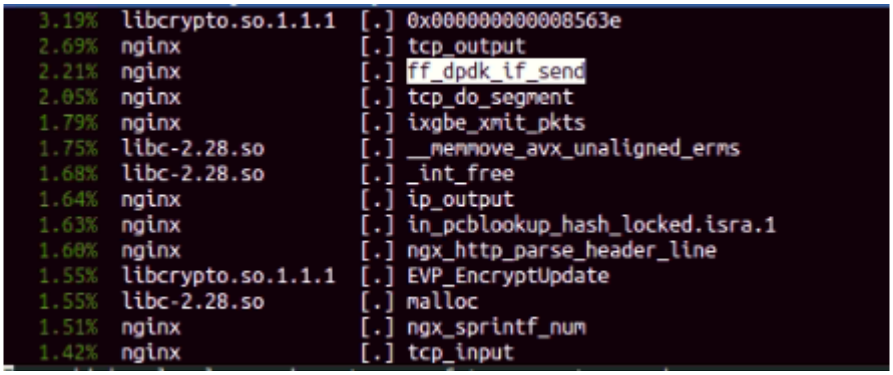
The first glance of the readiness state is 99% CPU on my cores, it surprised me a bit. A minute later, I realize that it is in User Space Mode: means it should be a busy loop, and then I was released.
And the profile looks like this:



```
-   46.23%    46.03%  nginx    nginx              [.] main_loop
     45.33% main_loop
-   18.58%     0.00%  nginx    [unknown]          [.] 0000000000000000
   - 0
      + 1.40% 0x14174a0
        0.70% 0x7ffff6d4c400
        0.50% __memset_sse2_unaligned_erms
-    8.59%     7.99%  nginx    nginx              [.] ixgbe_recv_pkts_vec
     6.80% 0
     1.80% ixgbe_recv_pkts_vec
+    2.20%     0.00%  nginx    [unknown]          [.] 0x0000000000000001
+    1.90%     1.90%  nginx    libcrypto.so.1.1.1 [.] 0x000000000008563e
+    1.90%     0.00%  nginx    libcrypto.so.1.1.1 [.] 0x00007ffff6921643
+    1.55%     1.55%  nginx    nginx              [.] tcp_usr_send
+    1.40%     0.00%  nginx    [unknown]          [.] 0x0000000000000020
```

It looks like not saturated, but my driver side still using interrupt, and usage of CPU0 is 100%, I need to start multiple ab processes, let's say 10, and we can add the throughput altogether.

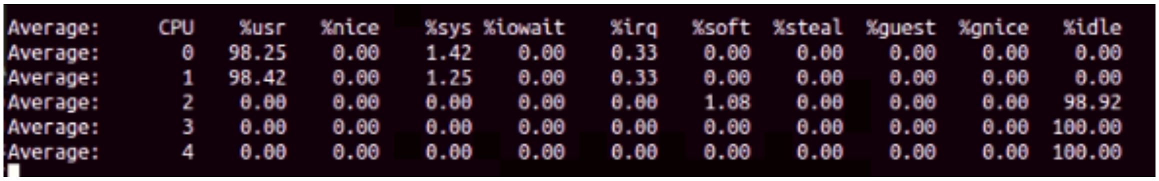
And I got this:



```
   3.19%  libcrypto.so.1.1.1  [.] 0x000000000008563e
   2.69%  nginx               [.] tcp_output
   2.21%  nginx               [.] ff_dpdk_if_send
   2.05%  nginx               [.] tcp_do_segment
   1.79%  nginx               [.] ixgbe_xmit_pkts
   1.75%  libc-2.28.so        [.] __memmove_avx_unaligned_erms
   1.68%  libc-2.28.so        [.] _int_free
   1.64%  nginx               [.] ip_output
   1.63%  nginx               [.] in_pcblookup_hash_locked.isra.1
   1.60%  nginx               [.] ngx_http_parse_header_line
   1.55%  libcrypto.so.1.1.1  [.] EVP_EncryptUpdate
   1.55%  libc-2.28.so        [.] malloc
   1.51%  nginx               [.] ngx_sprintf_num
   1.42%  nginx               [.] tcp_input
```

The total throughput is 91,595. Then I tried more ab, 20, 30, the throughput stays at 91k. I know the throughput of nginx server on a single logical core has reached it ceiling.

I then increase the server logical cores to 2, the throughput goes up to 183,180, well the scaling is not bad, and most importantly: there is nearly no sys & irq:



```
Average:     CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
Average:       0   98.25    0.00    1.42    0.00    0.33    0.00    0.00    0.00    0.00    0.00
Average:       1   98.42    0.00    1.25    0.00    0.33    0.00    0.00    0.00    0.00    0.00
Average:       2    0.00    0.00    0.00    0.00    0.00    1.08    0.00    0.00    0.00   98.92
Average:       3    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00  100.00
Average:       4    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00  100.00
```

The %usr shown here is very noticeable, since there is a idle_sleep(ms) in “while (1)” of main_loop function

If set idle_sleep=0, the $usr will be constantly equal to 97-99, and set idle_sleep=1 $usr will cost about 3%, but the throughput will decrease from 183,180 -> 181,563 (about 1% drop)

I feel super tired today, will try other options later