Nginx Performance Evaluation

Steps:

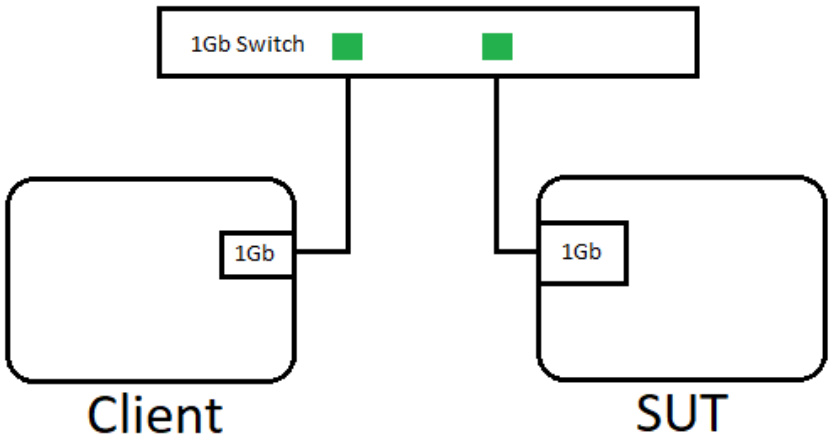
1. **Purpose**
2. **Environment**
3. **Setup**
4. **Environment Check**
5. **Compile Nginx**
6. **Tune system**
7. **Run ab test**
8. **Monitor**
9. **Analyze**
10. **Introduce jemalloc**
11. **Redo ab test**
12. **Analyze for jemalloc**
13. **Conclusion**
14. **Future works**
15. **DPDK**

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%)

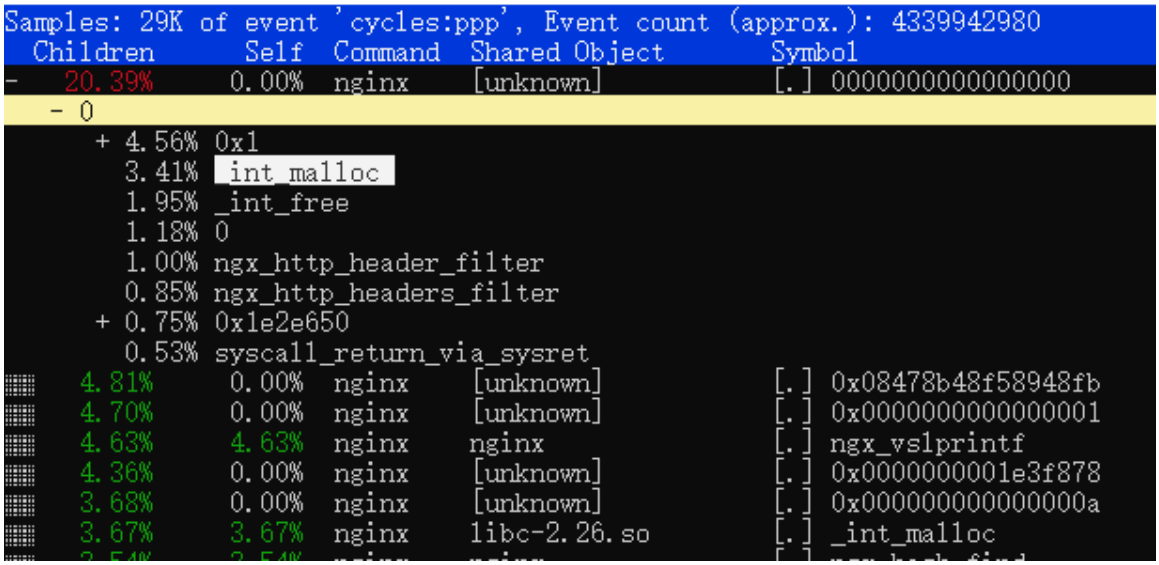
Memory usage: (from numactl -H)

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)



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.

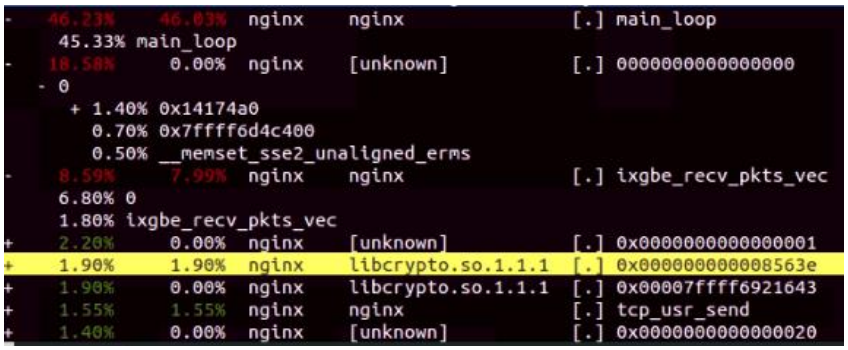
Will do more research on DPDK user-space TCP stack, because the later profile shows that bottleneck is in tcp stack of Linux kernel. I know it could be something complicated, but it's worthy to try, there is no free lunch.

15. DPDK

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

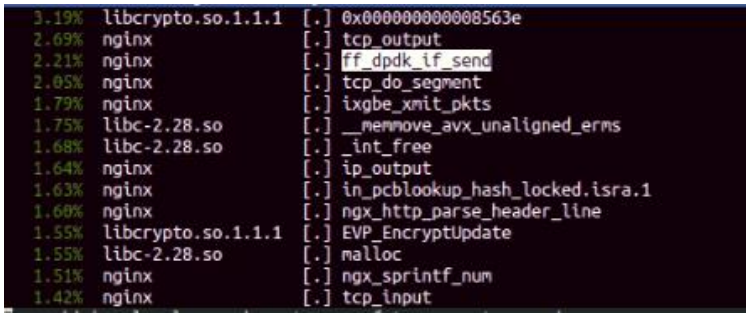
I chose the F-Stack implementation: https://github.com/f-stack/f-stack

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:



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:



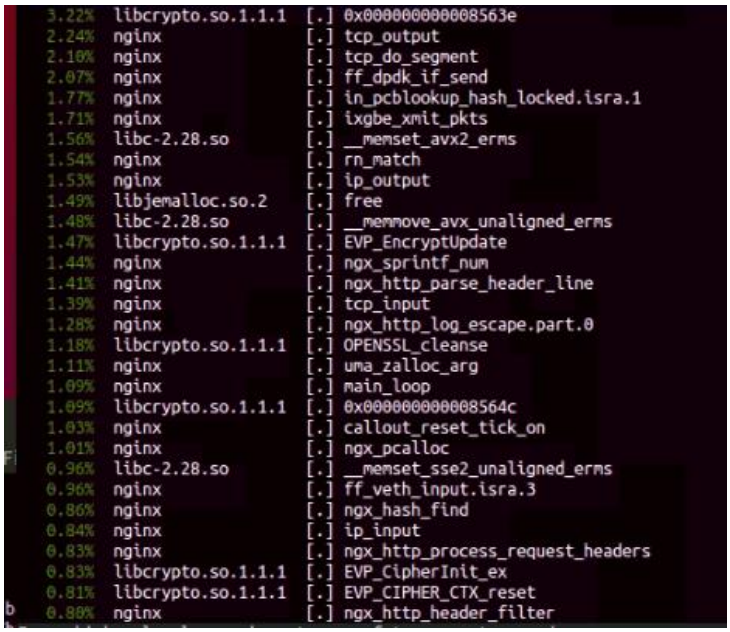
The total throughput is 91,595. Then I tried more ab, 20, 30, the throughput stays at 91k. I know the throughput of nginx server on a single logical core has reached it ceiling.

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:

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% when idle, but the throughput will decrease from 183,180 -> 181,563 (-1%), I will keep this anyway, since it will show me the real workload.

Enabling jemalloc increased RPS from 181,563 to 184,589 (+1.7%)



Then, I turn on gzip in nginx.conf, even though the transfer rate reduced from 13 to 3 (MB/s). it is not surprising, small packets didn't bring any performance benefit, since the network bandwidth is not current bottleneck.

When I extend to 4 lcore, each CPU avg usage is only about 40%, I checked the hugepages were used up.

echo 2048 > /sys/devices/system/node/node0/hugepages/hugepages-2048kB/nr_hugepages

Doubling large page memory will give the CPU usage up to 80%, continue to add

echo 40960 > /sys/devices/system/node/node0/hugepages/hugepages-2048kB/nr_hugepages

Let's add to 40960, which I assume it may support about 40 lcores, and add ab clients to 40.

And now, with 4 lcores, RPS goes up to 368,615, scaling factor = 2, not bad

Meanwhile the in/out %ifutil is about 15%

Average:	IFACE	rxpck/s	txpck/s	rxkB/s	txkB/s	rxcmp/s	txcmp/s	rxmcst/s	%ifutil
Average:	enp0s20u1u5	1.06	1.06	0.08	0.10	0.00	0.00	0.00	0.00
Average:	eno2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average:	ens1f1	0.06	1812744.69	0.02	150540.41	0.00	0.00	0.00	12.33
Average:	eno3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average:	eno4	70.19	62.94	7.15	9.95	0.00	0.00	4.19	0.01
Average:	eno1	5.62	0.00	1.61	0.00	0.00	0.00	4.31	0.00
Average:	ens1f0	1806853.75	0.75	192683.14	0.05	0.00	0.00	0.00	15.78

Noticeably, if I enabled the Hyper Threading in ab side, the latency on the extra lcores is much higher than the pcores only: 99% latency increases from 8ms to 200ms,

(Update) today, I change my client from ab to dpdk(https://github.com/ansyun/dpdk-httpperf)

PROC	CONN	RPSavg	RPSmax	LAT50	LAT75	LAT90	LAT99	LATmax	CPU_c	CPU_s
1	128	111.42k	113.75k	521us	678us	772us	0.89ms	1.22ms	99+0	97+2
1	64	109.68k	112.85k	297us	346us	378us	424us	1.12ms	99+1	98+1
1	32	104.45k	110.06k	165us	194us	227us	271us	832us	100+0	100+0
1	16	86.93k	87.78k	146us	164us	178us	196us	737us	93+7	99+1
1	8	58.84k	60.74k	106us	133us	158us	176us	571us	100+0	100+0
1	4	39.63k	39.93k	82us	90us	94us	110us	564us	92+7	98+2
1	2	19.84k	19.97k	87us	89us	91us	104us	424us	94+6	99+0
1	1	9.92k	9.98k	92us	92us	93us	99us	150us	96+4	100+0
2	128	80.02k	218.51k	400us	475us	533us	631us	0.99ms	98+1	94+5
2	64	77.72k	106.01k	240us	277us	304us	363us	823us	96+3	95+5
2	32	52.35k	78.08k	155us	175us	195us	239us	621us	100+0	100+0
2	16	43.99k	47.43k	141us	159us	173us	197us	730us	92+8	97+3
2	8	37.13k	39.03k	84us	96us	115us	148us	257us	88+12	98+1
2	4	0.00	0.00	0us	0us	0us	0us	0us	100+0	100+0
2	2	9.82k	9.89k	91us	96us	98us	106us	411us	94+6	99+0
4	128	49.80k	67.16k	329us	384us	431us	525us	1.23ms	96+3	95+5
4	64	44.32k	50.19k	226us	258us	286us	335us	822us	92+8	95+5
4	32	36.09k	41.95k	176us	193us	208us	239us	816us	81+18	95+5
4	16	19.90k	22.85k	149us	163us	174us	199us	779us	100+0	100+0
4	8	0.96k	1.00k	91us	96us	99us	105us	121us	100+0	100+0
4	4	9.92k	9.98k	88us	93us	98us	108us	447us	87+13	98+1
6	128	27.53k	39.74k	361us	458us	538us	668us	1.45ms	96+3	96+3
6	64	27.02k	35.93k	231us	282us	331us	424us	0.95ms	89+10	96+3
6	32	22.26k	23.73k	179us	196us	211us	244us	584us	76+24	96+3
6	16	13.05k	15.40k	130us	150us	162us	182us	724us	100+0	100+0
6	8	9.74k	9.92k	97us	98us	99us	108us	0.86ms	95+4	99+0
8	128	18.85k	25.46k	388us	492us	576us	729us	1.22ms	95+4	96+3
8	64	17.88k	25.78k	237us	280us	322us	412us	727us	90+9	95+4
8	32	15.33k	17.62k	183us	206us	228us	275us	457us	100+0	100+0
8	16	11.90k	12.51k	142us	159us	171us	196us	558us	69+31	96+3
8	8	9.24k	9.79k	85us	94us	109us	143us	237us	100+0	100+0

I got an optimized latency row on single lcore, when I set both side with options: pkt_tx_delay=0, tso=1, idle_sleep=0

This is just a traditional network setup with normal switch sitting in the middle, the lat99 is 99us, with a normal 10Gg NIC. meanwhile, the client/server side CPU are both saturated, it will be commonly assumed that while reducing the CPU load, latency will drop to around 20us.

Many vendors provided the Ultra-Low-Latency class NICs, but compare to kernel bypass solutions like DPDK/Seastar the latency is certainly high. as a result, few solution vendors can achieve 1us latency on back-back config.

I feel super tired today, will try more lcores & other options later