# STYX: Exploiting SmartNIC Capability to Reduce Datacenter Memory Tax

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# SmartNIC

- consists of a network interface controller, CPU, ASIC- and/or FPGA-based accelerator, memory and IO subsystem
- used to offload network functions
  - TCP/IP network stack
- can carry out customised functionalites
  - gpu communication through network bypassing cpu
- saves host cpu resource

# Memory Optimization Kernel Feature

## ksm/kernel same-page merge

- compare two pages and determine whether they contain the same content
- calculate 32-bit checksum of a page
- perform byte-to-byte comparison of two pages

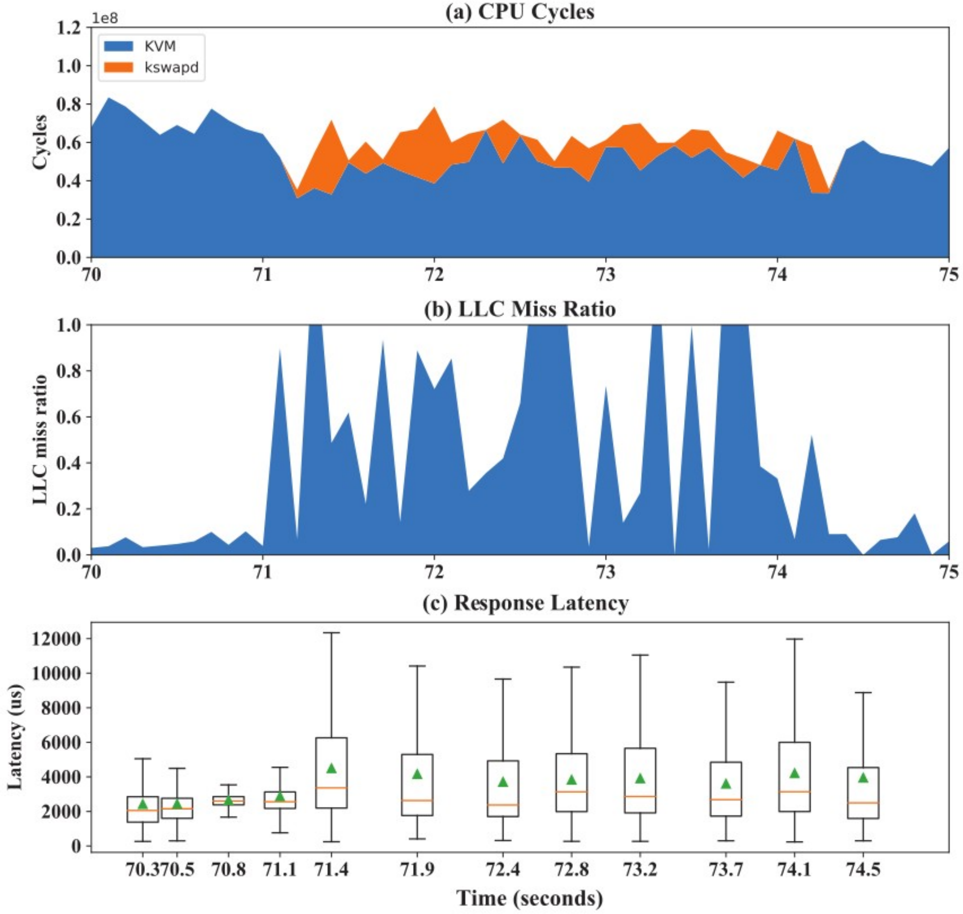
## zswap

- compression backend for kswapd
- compress pages to avoid swap
- decompress when page fault happens
- synchronous direct/asynchronous backgroud

# Impact of Kernel Feature

Both ksm and zswap are memory-intensive and CPU-intensive

- bring large amount of cold data into cache, causing increased cache misses ratio
- consume cpu cycles
- interfere with co-running applications



A snapshot of (a) consumed CPU cycles, (b) LLC miss ratio, and (c) response latency before and after invoking kswapd while running Redis

# STYX overview

Ksm and zswap follow such a pattern:

1) Determine memory regions to operate on
2) Load memory regions to cpu cache from memory
3) Operate on the memory regions
4) Make a decision for the next step according to the result

which can be decomposed into data plane(step 2 and 3) and control plane(step 1 and 4), like a network application.

STYX leaves control plane operations on host cpu and offloads data plane operations to SNIC.

# STYX overview

## How STYX works

1) The host cpu determines memory regions to operate on;
2) Memory regions are copied from host memory to SNIC memory using RDMA;
3) The SNIC operates on the memory regions;
4) The SNIC transfers back the result to the host memory;
5) The host cpu decides the next step.

# STYX overview

STYX relies on SNICs:

- SNIC is capable of data transfering using its RDMA engine to copy data from host memory
- SNIC is capable of computing using its cpu cores
- SNIC is widely deployed in data centers
- SNIC's cpu cores are not yet fully utilized(?), therefore STYX could offload host operations without dramatically interfering with network applications runing on the SNIC.

# STYX workflow

## (1) Setup

- decide which kernel features to be offloaded
- setup RDMA connection between host cpu and SNIC and allocate resources(one connection for each function)
- use descriptors on host and SNIC to record information

## (2) Submission

- update descriptors to with memory regions to operate on
- the host posts a RDMA send request to SNIC, then the host waits on recv
- RDMA operations can be one-sided or two-sided

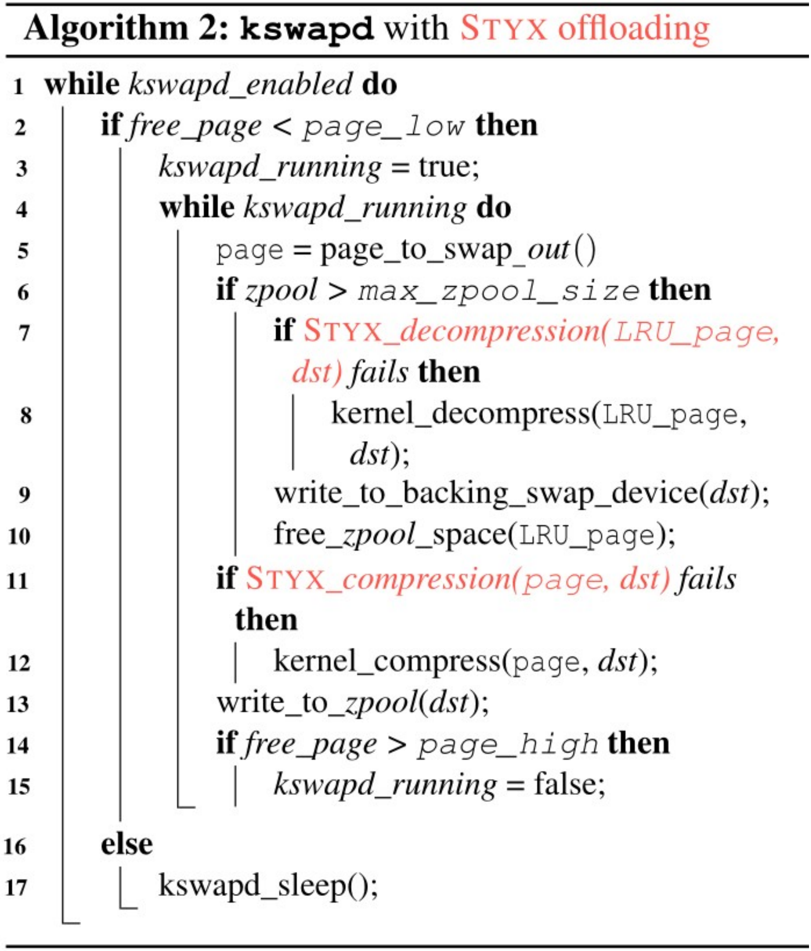
# STYX workflow

## (3) Remote Executation

- STYX on SNIC copies data from host memory
- STYX on SNIC operates on the data
- may interferes with applications on SNIC

## (4) Completion

- STYX on SNIC posts a RDMA send request to host
- The host receives result from SNIC, and resumes execution
- STYX on SNIC waits on recv
- RDMA operations can be one-sided or two-sided



**Algorithm 2: kswapd with STYX offloading**

```
while kswapd_enabled do
    if free_page < page_low then
        kswapd_running = true;
        while kswapd_running do
            page = page_to_swap_out()
            if zpool > max_zpool_size then
                if STYX_decompression(LRU_page, dst) fails then
                    kernel_decompress(LRU_page, dst);
                write_to_backing_swap_device(dst);
                free_zpool_space(LRU_page);
            if STYX_compression(page, dst) fails then
                kernel_compress(page, dst);
            write_to_zpool(dst);
            if free_page > page_high then
                kswapd_running = false;
    else
        kswapd_sleep();
```

# Evaluation Setup

Workload:

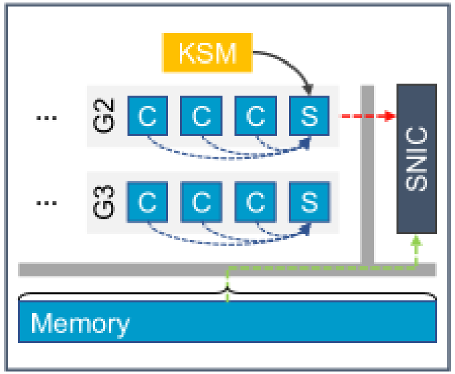
yahoo! Cloud Serving-Benchmark on Redis

(a) update heavy

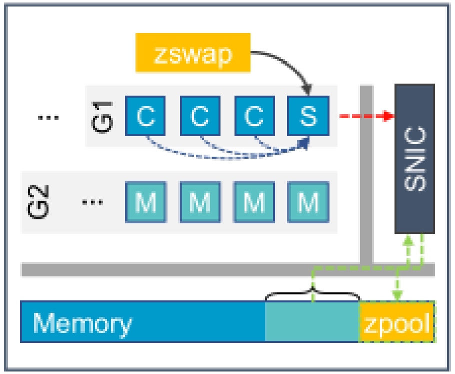
(b) read heavy

(c) read only

(d) read latest



(a) Setup for **ksm**



(b) Setup for **zswap**

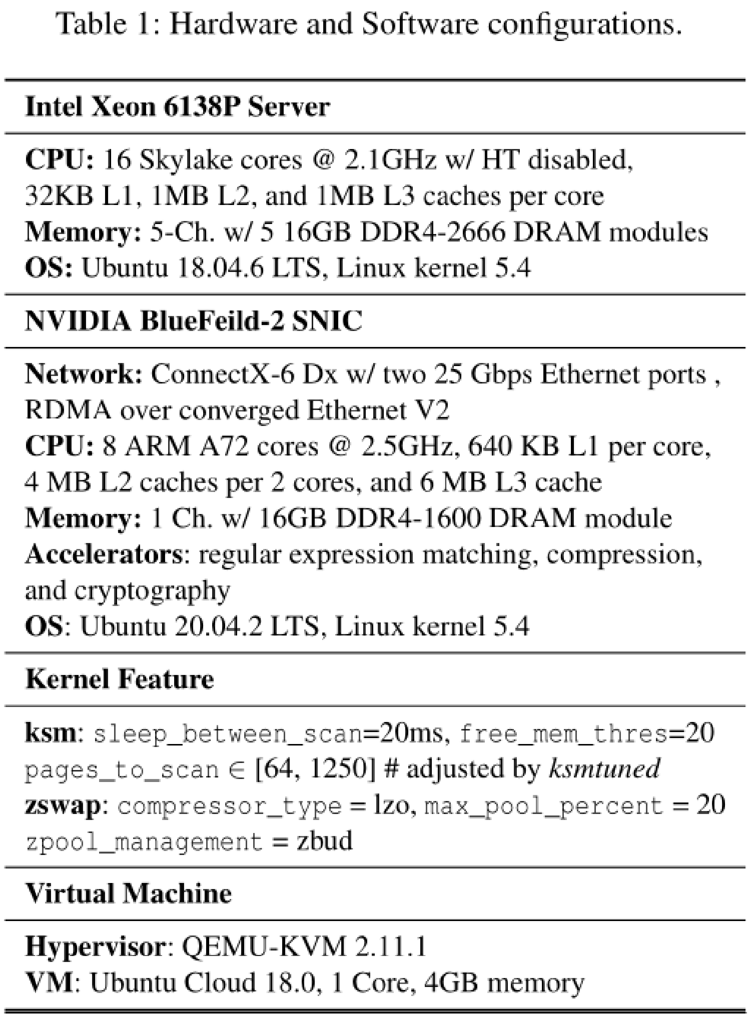
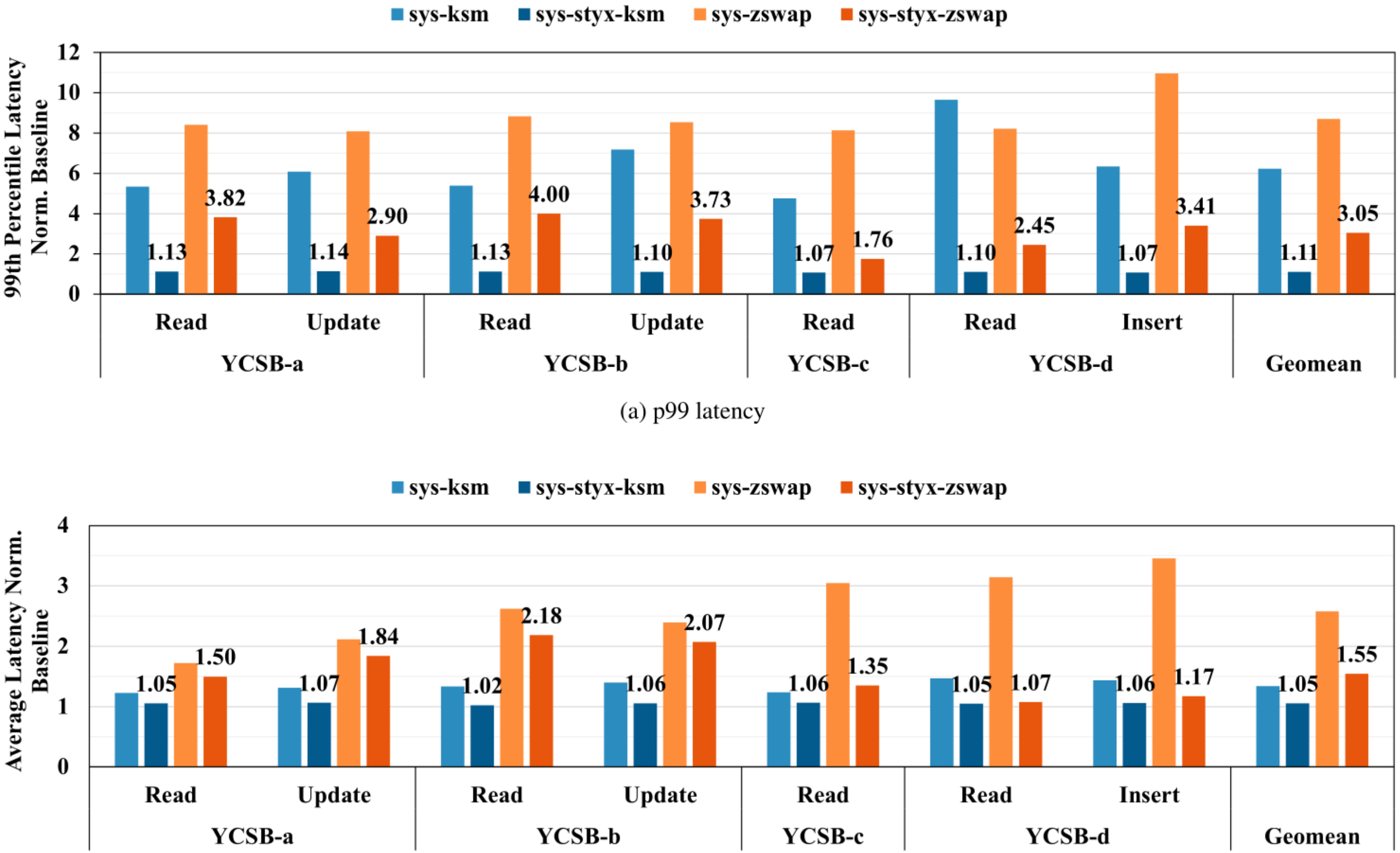


Table 1: Hardware and Software configurations.

| **Intel Xeon 6138P Server** |
|---|
| **CPU:** 16 Skylake cores @ 2.1GHz w/ HT disabled, 32KB L1, 1MB L2, and 1MB L3 caches per core<br>**Memory:** 5-Ch. w/ 5 16GB DDR4-2666 DRAM modules<br>**OS:** Ubuntu 18.04.6 LTS, Linux kernel 5.4 |
| **NVIDIA BlueFeild-2 SNIC** |
| **Network:** ConnectX-6 Dx w/ two 25 Gbps Ethernet ports , RDMA over converged Ethernet V2<br>**CPU:** 8 ARM A72 cores @ 2.5GHz, 640 KB L1 per core, 4 MB L2 caches per 2 cores, and 6 MB L3 cache<br>**Memory:** 1 Ch. w/ 16GB DDR4-1600 DRAM module<br>**Accelerators**: regular expression matching, compression, and cryptography<br>**OS**: Ubuntu 20.04.2 LTS, Linux kernel 5.4 |
| **Kernel Feature** |
| **ksm**: `sleep_between_scan`=20ms, `free_mem_thres`=20 `pages_to_scan` ∈ [64, 1250] # adjusted by *ksmtuned*<br>**zswap**: `compressor_type` = lzo, `max_pool_percent` = 20 `zpool_management` = zbud |
| **Virtual Machine** |
| **Hypervisor**: QEMU-KVM 2.11.1<br>**VM**: Ubuntu Cloud 18.0, 1 Core, 4GB memory |

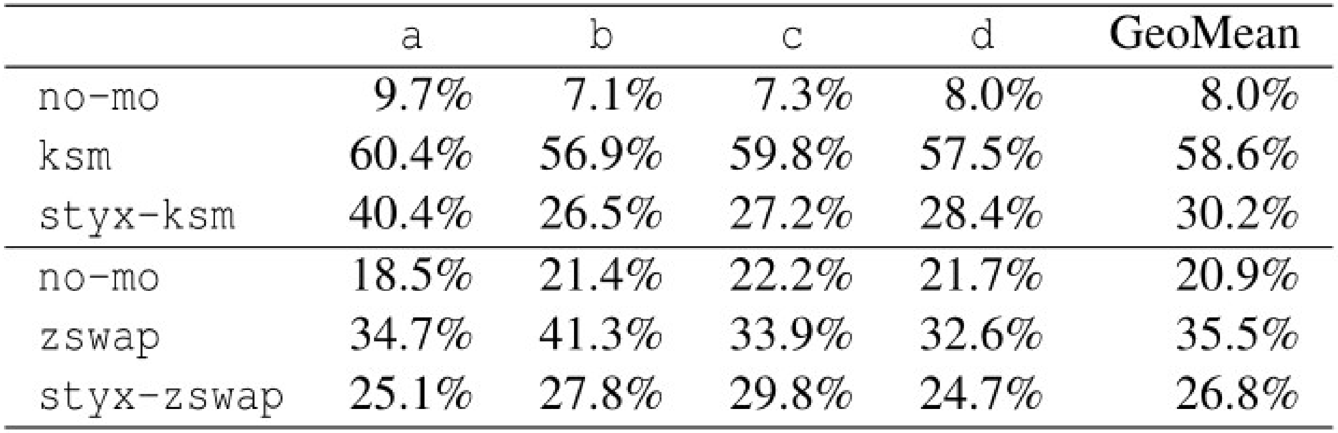
# Evaluation



(a) p99 latency

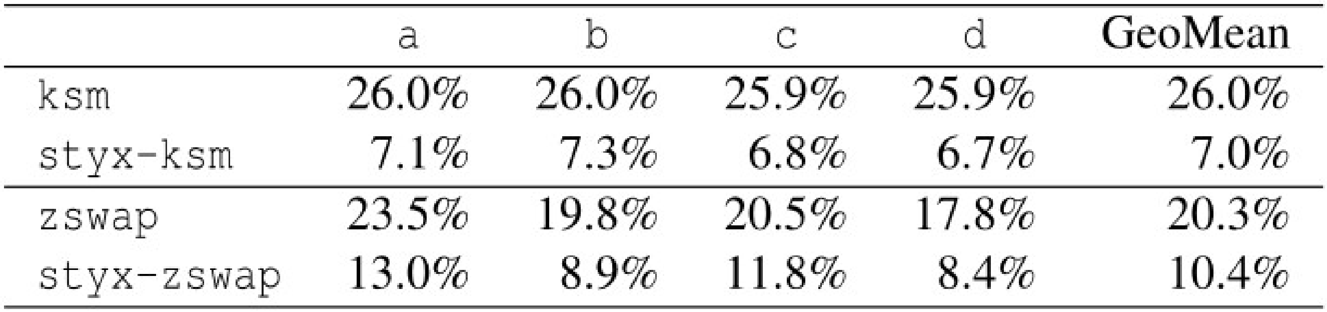
(b) Average latency

# Evaluation



| | a | b | c | d | GeoMean |
|---|---|---|---|---|---|
| no-mo | 9.7% | 7.1% | 7.3% | 8.0% | 8.0% |
| ksm | 60.4% | 56.9% | 59.8% | 57.5% | 58.6% |
| styx-ksm | 40.4% | 26.5% | 27.2% | 28.4% | 30.2% |
| no-mo | 18.5% | 21.4% | 22.2% | 21.7% | 20.9% |
| zswap | 34.7% | 41.3% | 33.9% | 32.6% | 35.5% |
| styx-zswap | 25.1% | 27.8% | 29.8% | 24.7% | 26.8% |

LLC miss ratio under different configuration



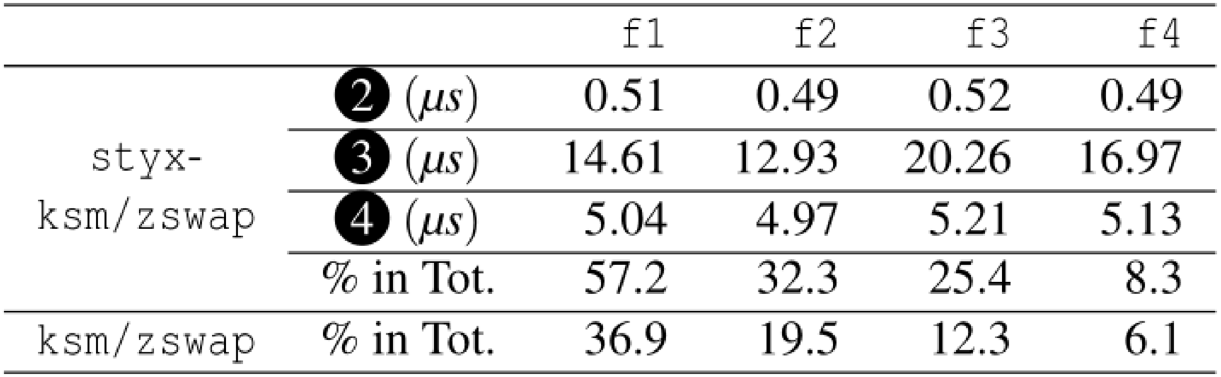
| | a | b | c | d | GeoMean |
|---|---|---|---|---|---|
| ksm | 26.0% | 26.0% | 25.9% | 25.9% | 26.0% |
| styx-ksm | 7.1% | 7.3% | 6.8% | 6.7% | 7.0% |
| zswap | 23.5% | 19.8% | 20.5% | 17.8% | 20.3% |
| styx-zswap | 13.0% | 8.9% | 11.8% | 8.4% | 10.4% |

cpu utilization under different configuration

# Evaluation

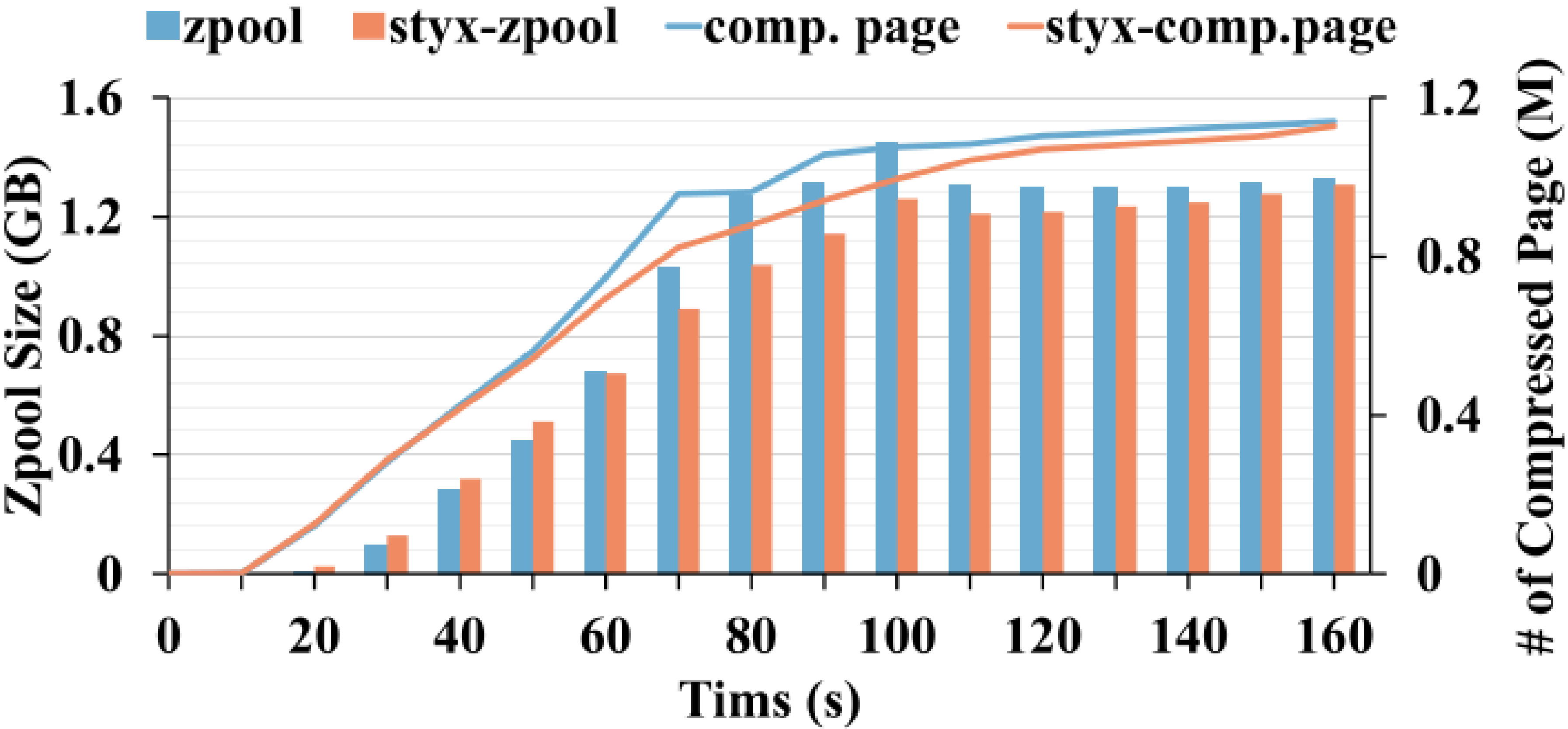
Time breakdown of styx offloaded kernel feature.

- f1: comparision of ksm
- f2: checksum of ksm
- f3: compress of zswap
- f4: decompress of zswap



| | | f1 | f2 | f3 | f4 |
|---|---|---|---|---|---|
| styx-ksm/zswap | ❷ ($\mu s$) | 0.51 | 0.49 | 0.52 | 0.49 |
| | ❸ ($\mu s$) | 14.61 | 12.93 | 20.26 | 16.97 |
| | ❹ ($\mu s$) | 5.04 | 4.97 | 5.21 | 5.13 |
| | % in Tot. | 57.2 | 32.3 | 25.4 | 8.3 |
| ksm/zswap | % in Tot. | 36.9 | 19.5 | 12.3 | 6.1 |

# Evaluation


zpool
styx-zpool
comp. page
styx-comp.page
Zpool Size (GB)
1.6
1.2
0.8
0.4
0
# of Compressed Page (M)
1.2
0.8
0.4
0
0
20
40
60
80
100
120
140
160
Tims (s)

# Impact on SNIC application

Under maximum 25Gbps network bandwidth:

- running regular expression matching (rem) on SNIC
- SNIC application needs at most 5 cores at a package size of 128B, and need only 1 core at a package size of 1024B
- STYX utilizes only ~30% of a core when running compression of zswap
- STYX has little impact on SNIC application(13.83us → 13.85us)