eBPF Qdisc:
A Generic Building Block for Traffic Control

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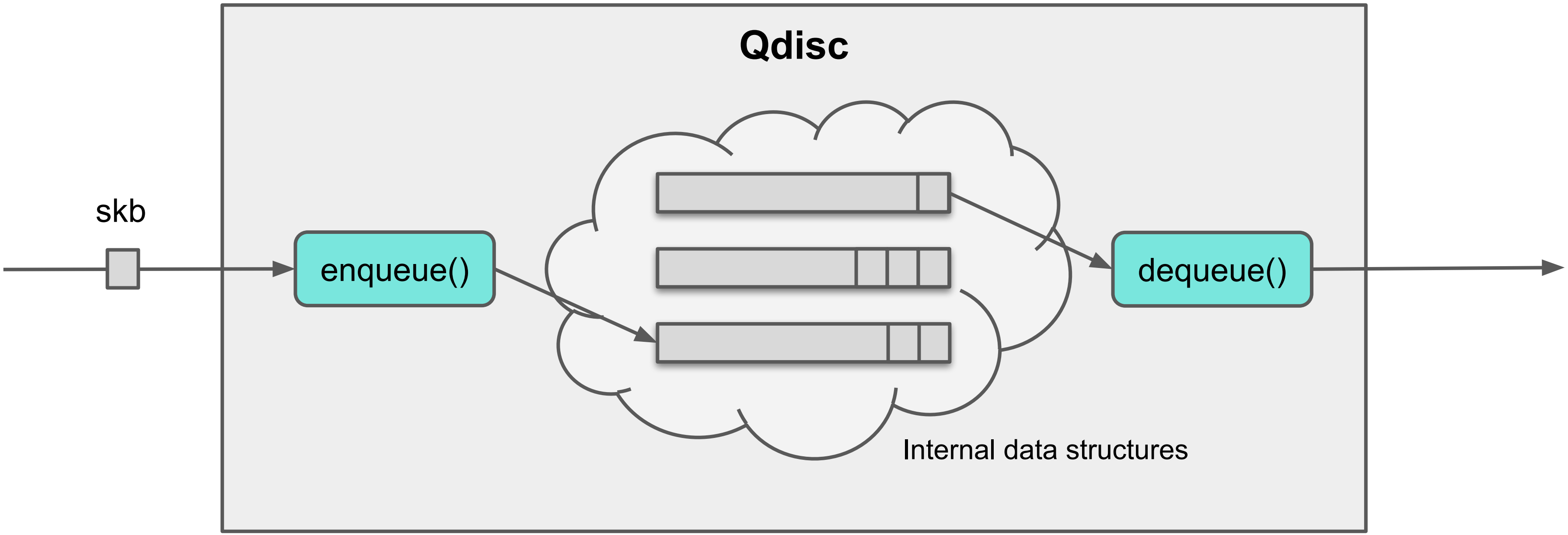
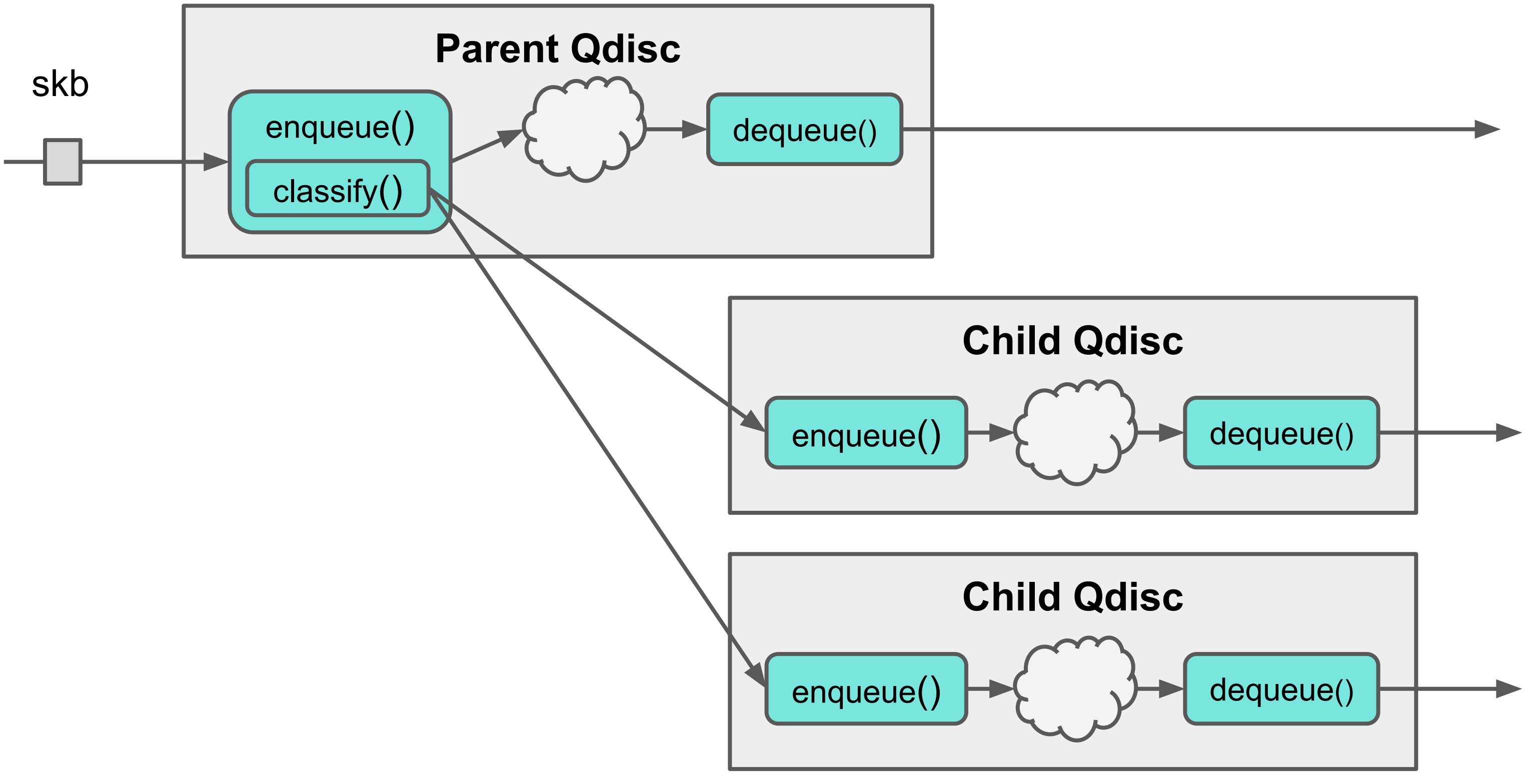
Packet scheduling in the Linux kernel



Classful Qdisc



Motivation

Qdiscs have fixed functionalities

Choosing the right Qdiscs and the combination are hard

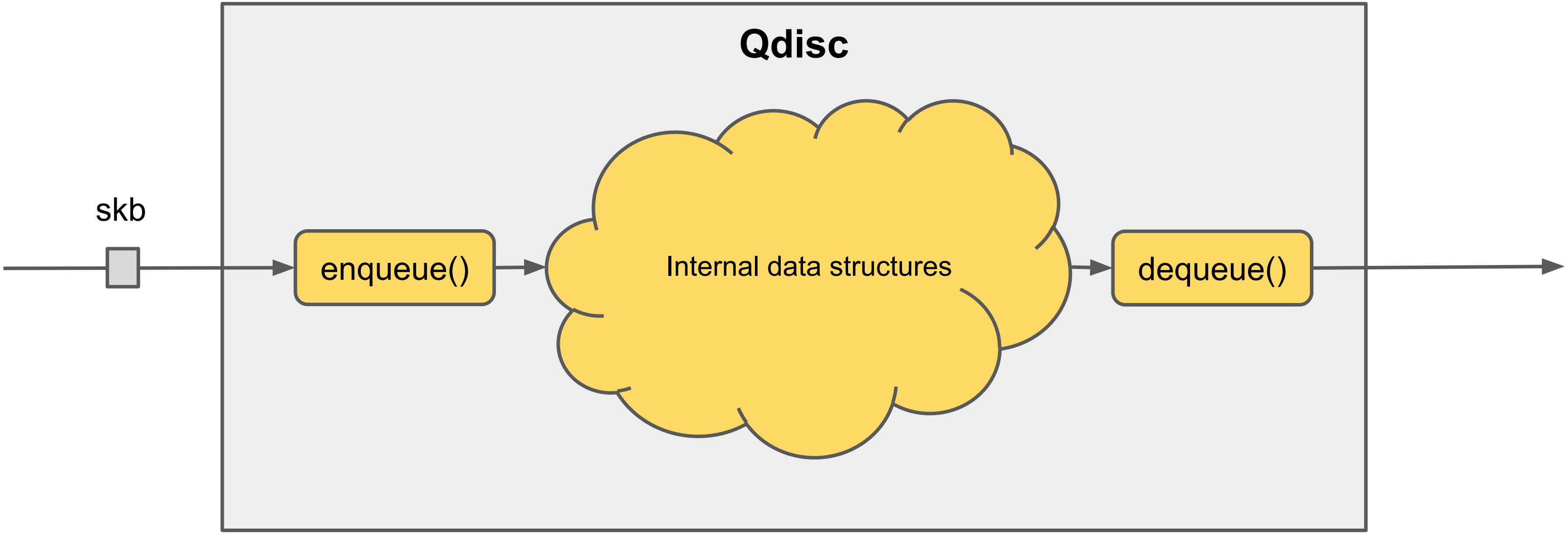
  fq, fq-codel, sfq, cake, choke, htb, hfsc, ...

Programmable packet scheduler designs

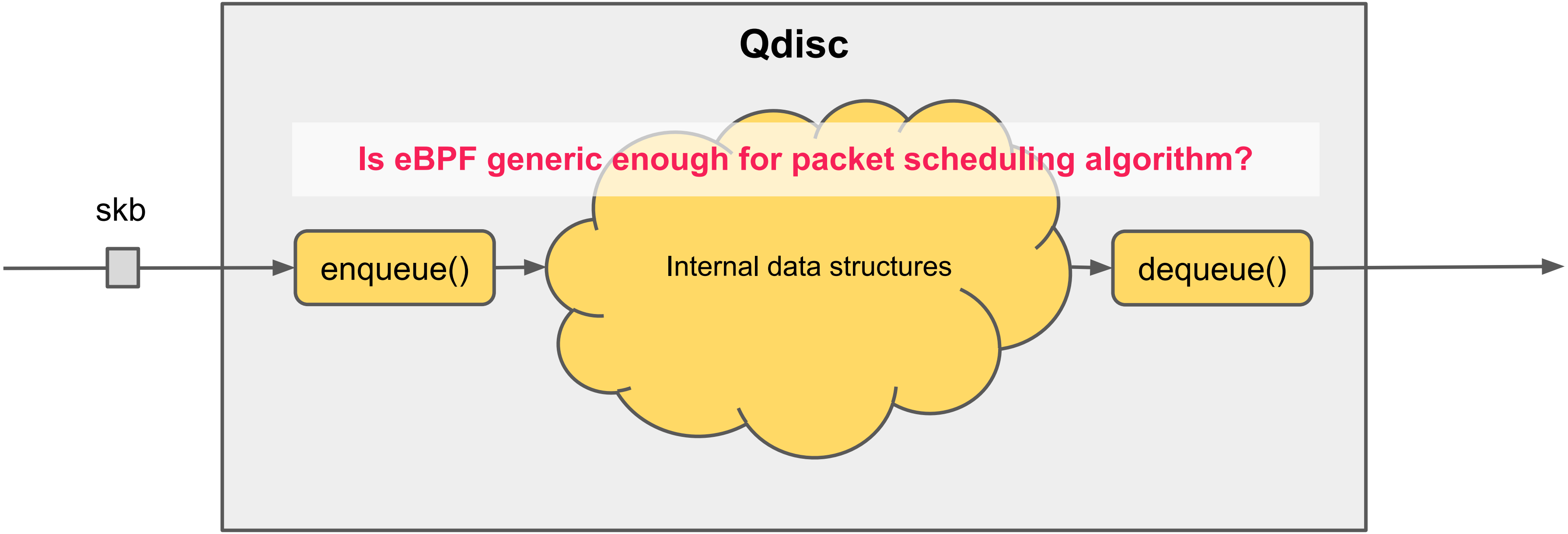
Pushed in first out (PIFO)

Eiffel

Idea: eBPF Qdisc



Idea: eBPF Qdisc



Is eBPF generic enough for packet scheduling algorithm?

New features in eBPF enable more generic programming

- Allocated objects, BPF linked lists
- BPF rbtree
- Shared allocated object ownership

Allocated objects

[PATCH bpf-next v6 00/26] Allocated objects, BPF linked lists - Kumar Kartikeya Dwivedi

```
void prog(void)
{
    struct foo *f;

    f = bpf_obj_new(typeof(*f));
    if (!f)
        return;

    bpf_obj_drop(f);
}
```

BPF linked lists

[PATCH bpf-next v6 00/26] Allocated objects, BPF linked lists - Kumar Kartikeya Dwivedi

```
void prog(void)
{
    struct foo *f;

    f = bpf_obj_new(typeof(*f));
    if (!f)
        return;

    bpf_list_push_front(head, &f->list);
    ...
```

Kfuncs: bpf_list_push/pop_front/back

BPF rbtree

[PATCH v5 bpf-next 0/9] BPF rbtree next-gen datastructure - Dave Marchevsky

```
static bool less(struct bpf_rb_node *a, struct bpf_rb_node *b)
{
    struct foo *foo_a = container_of(a, struct foo, node);
    struct foo *foo_a = container_of(a, struct foo, node);
    return foo_a->val < foo_b->val;
}

void prog(void)
{
    ...
    bpf_rbtree_add(head, &f->node, less);
    ...
```

Kfuncs: bpf_rbtree_add, bpf_rbtree_first, bpf_rbtree_remove

Shared allocated object ownership

[PATCH v2 bpf-next 0/9] Shared ownership for local kptrs - Dave Marchevsky

```
void prog(void)
{
    struct foo *f;

    f = bpf_obj_new(typeof(*f));
    if (!f)
        return;

    bpf_list_push_front(head, &f->list);
    bpf_rbtree_add(head, &f->node, less);
    ...
```

Design

- Programmability
  - Push-In-First-Out has serious limitations
  - Provide a mechanism, not a policy
  - Not enforce or imply any data structure

Design

- Flexibility and usability
  - Easy to use, we are not implementing a kernel module with eBPF
  - Focus on the core parts: enqueue and dequeue
  - It must work well with other TC components
    - Support TC filters and actions attached
    - Fit into any TC hierarchy

Design

struct_ops vs sch_bpf

struct Qdisc_class_ops {
select_queue, graft, leaf, qlen_notify, find,
change, delete, walk, tcf_block, bind_tcf,
unbind_tcf, dump, dump_stats
}

struct Qdisc_ops {
enqueue, dequeue, peek, init, reset,
destroy, change, attach,
change_tx_queue_len,
change_real_num_tx, dump, dump_stats,
ingress_block_set, egress_block_set,
ingress_block_get, egress_block_get
}

enqueue, dequeue

Design

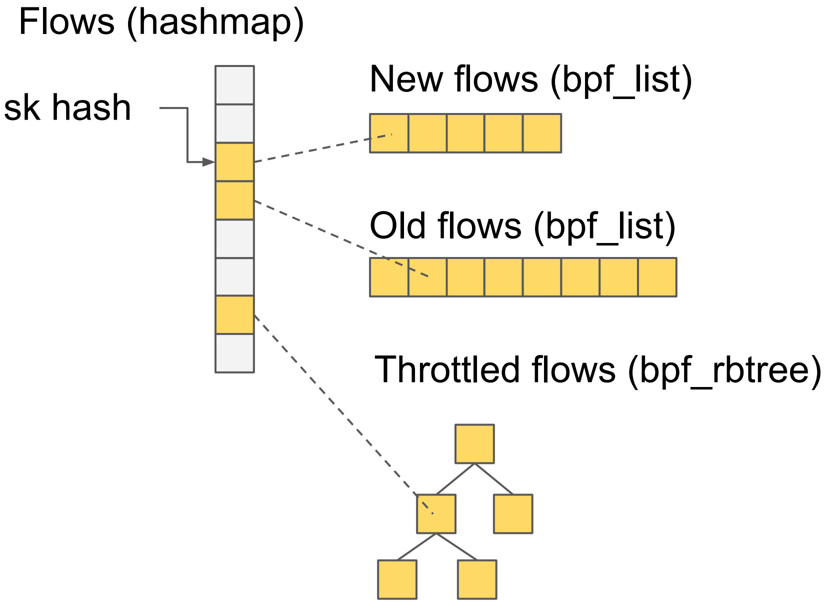
- Manage skb lifetime with kptr
- Reusing tc filters is possible through bpf_skb_tc_classify()
  - Like TC shared filter blocks
  - Some TC filters are complicated, e.g. cls_flower
- ABI compatibility

eBPF call context

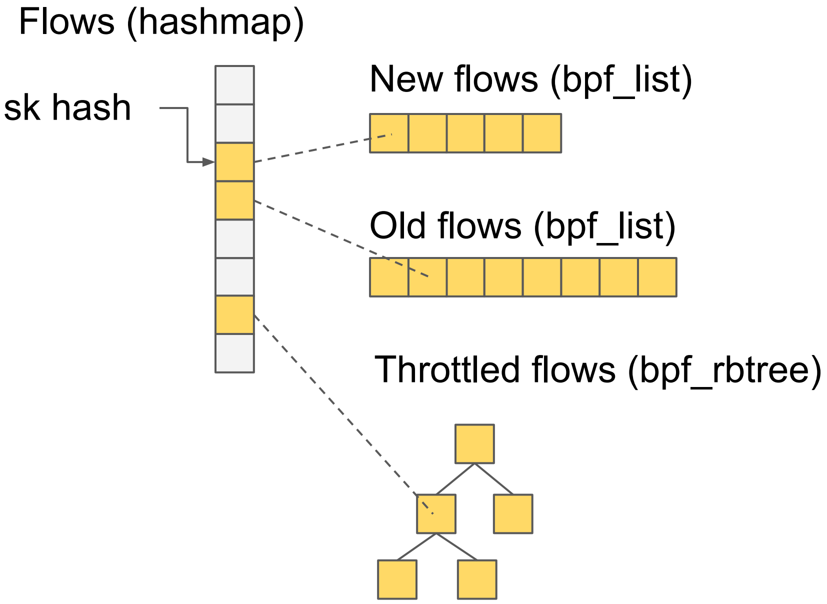
```
struct sch_bpf_ctx {
    struct sk_buff *skb;
    __u32 classid;
    __u64 expire;
    __u64 delta_ns;
}
```

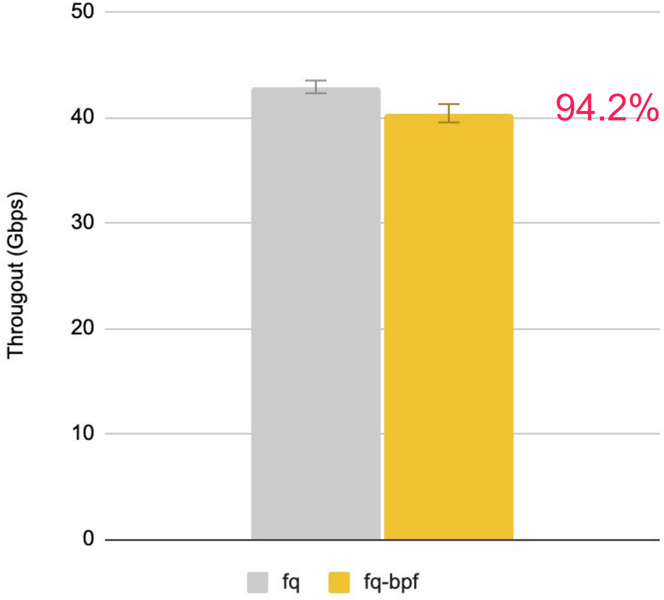
Program	Input	Output
enqueue	ctx->skb ctx->classid	SCH_BPF_THROTTLE: delay, delta_ns SCH_BPF_QUEUED SCH_BPF_DROP SCH_BPF_CN SCH_BPF_PASS: classid
dequeue	ctx->classid	SCH_BPF_THROTTLE: delay, delta_ns SCH_BPF_DEQUEUED: skb SCH_BPF_DROP SCH_BPF_CN SCH_BPF_PASS: classid

We can implement a sophisticated Qidsc using eBPF



We can implement a sophisticated Qidsc using eBPF

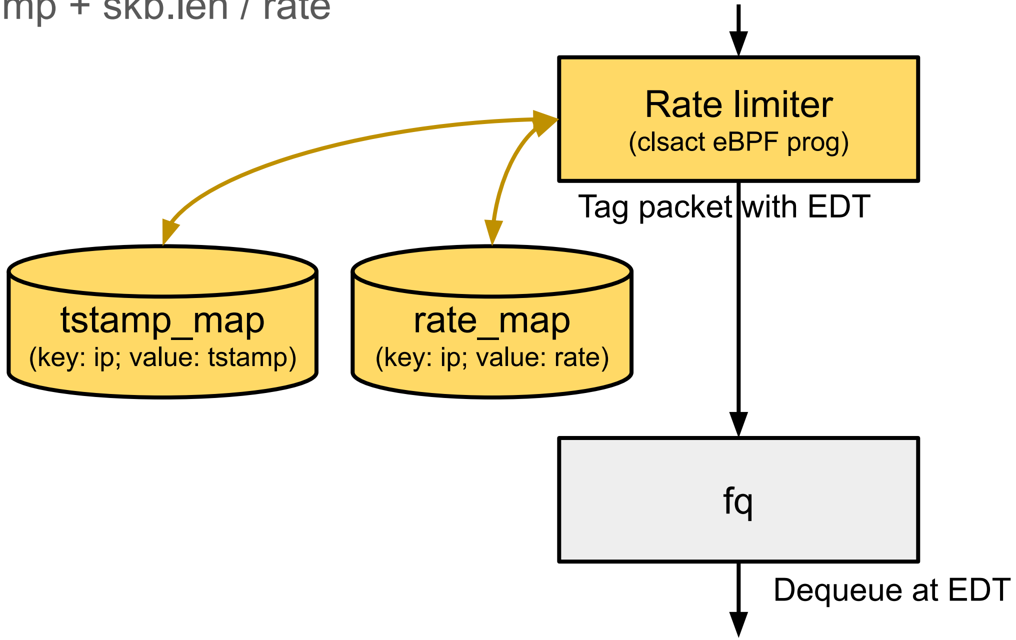




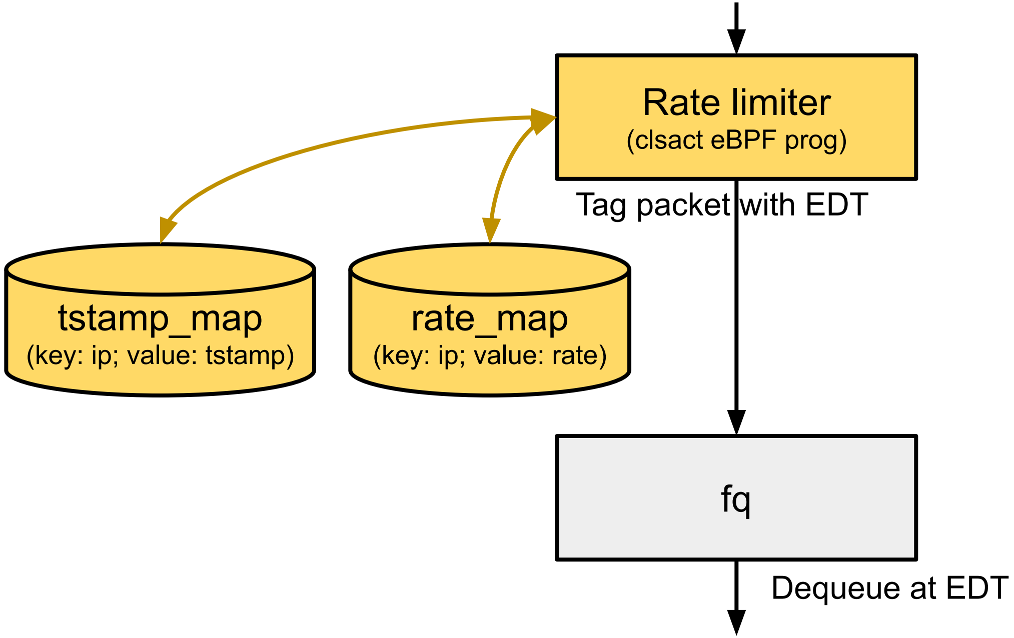
Two Use Cases

Use case 1: EDT + fq

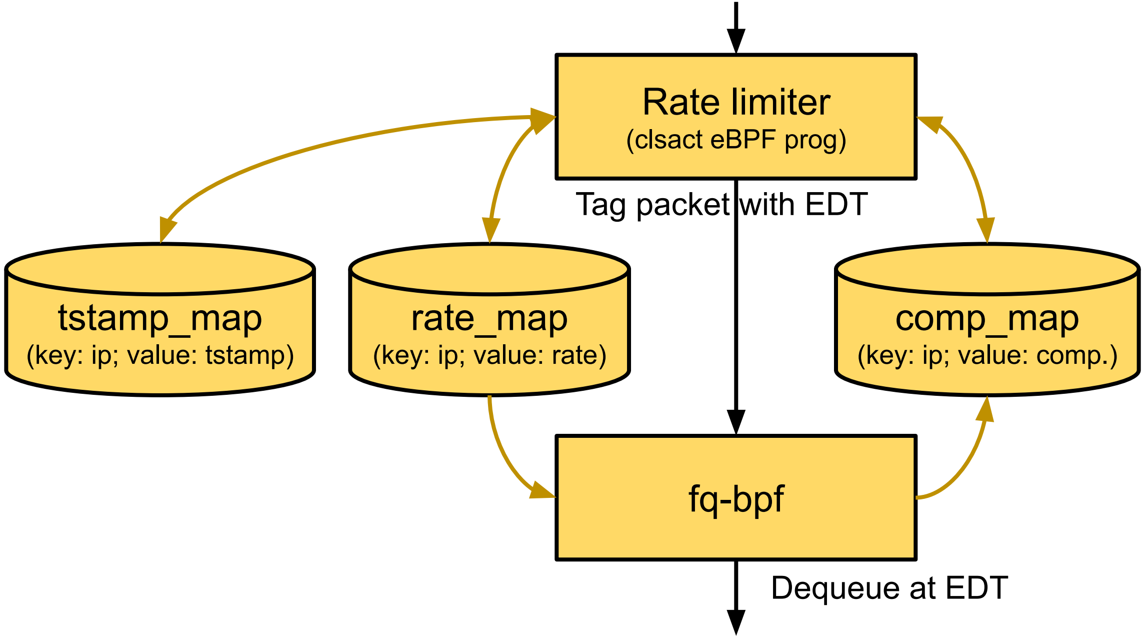
skb.tstamp = tstamp + skb.len / rate



Throughput loss as rate limiter is not aware of skb drops



Easy communication across components

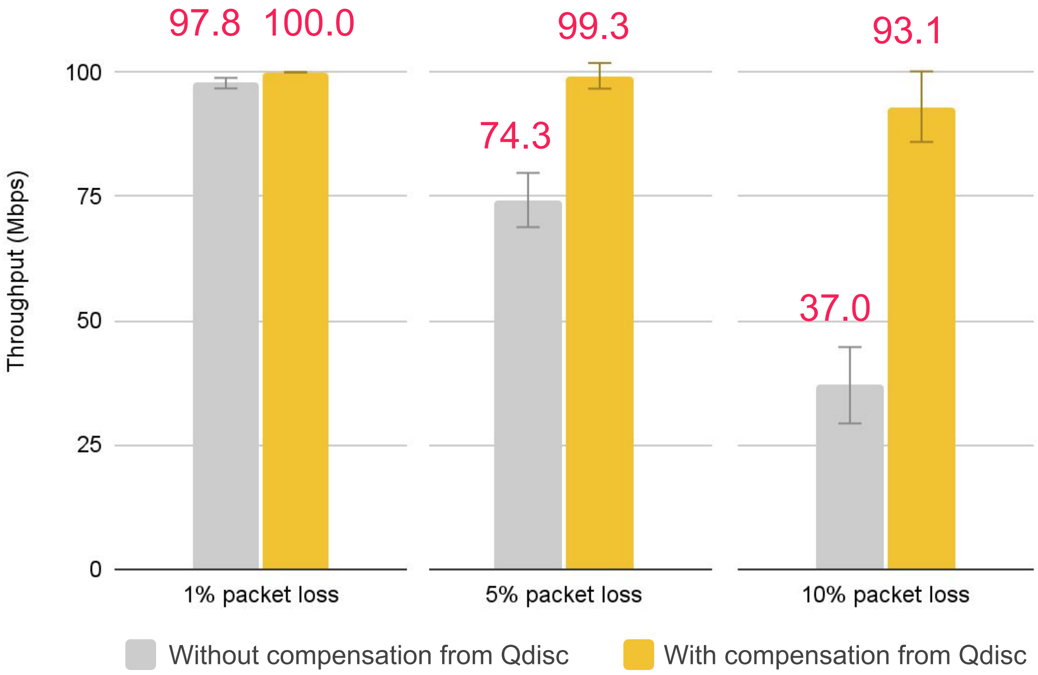


Adjust timestamp in rate limiter based on Qdisc skb-drops

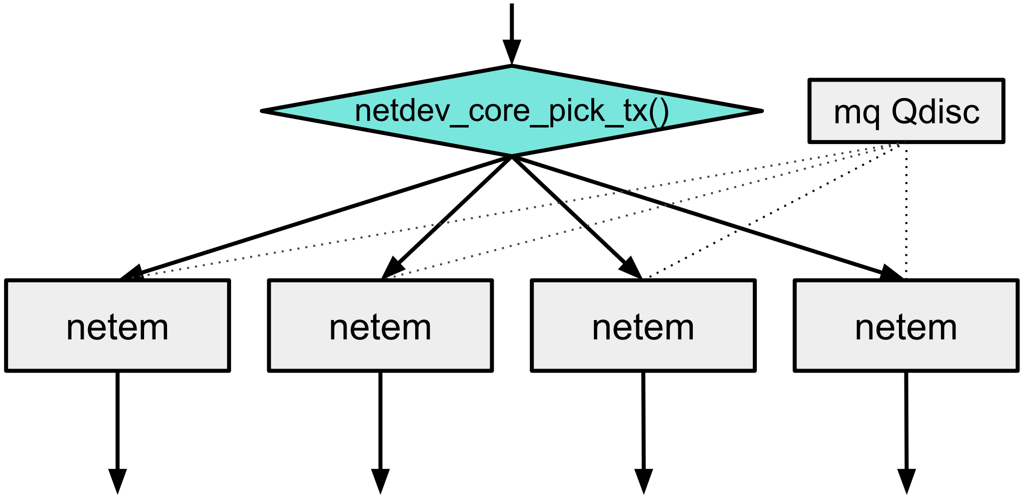
```
comp_ns = __sync_lock_test_and_set(comp, 0);
tstamp_comp = *tstamp - comp_ns;
if (tstamp_comp < now) {
    tstamp_new = tstamp_comp + delay_ns;
    if (tstamp_new < now) {
        __sync_fetch_and_add(comp, now - tstamp_new);
        __sync_lock_test_and_set(tstamp, now);
    } else {
        __sync_fetch_and_add(tstamp, delay_ns - comp_ns);
    }
    skb->tstamp = now;
    return TC_ACT_OK;
}

skb->tstamp = tstamp_comp;
__sync_fetch_and_add(tstamp, delay_ns - comp_ns);
return TC_ACT_OK;
```

Throughput drop reduced

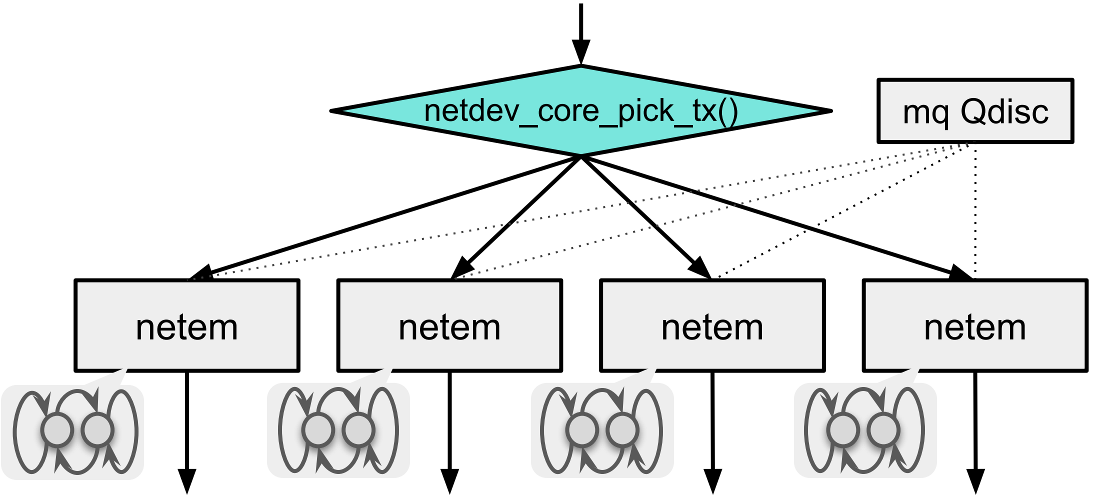
EDT: 100 Mbps



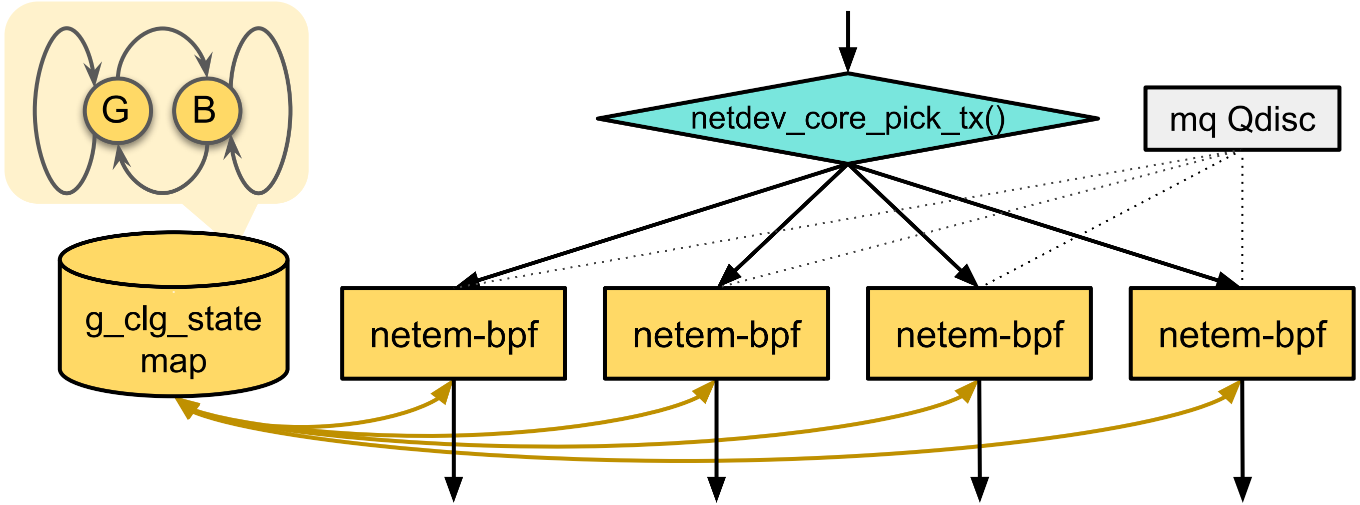
Use case 2: mq + netem



Discrepancy in network behavior caused by independent state machines

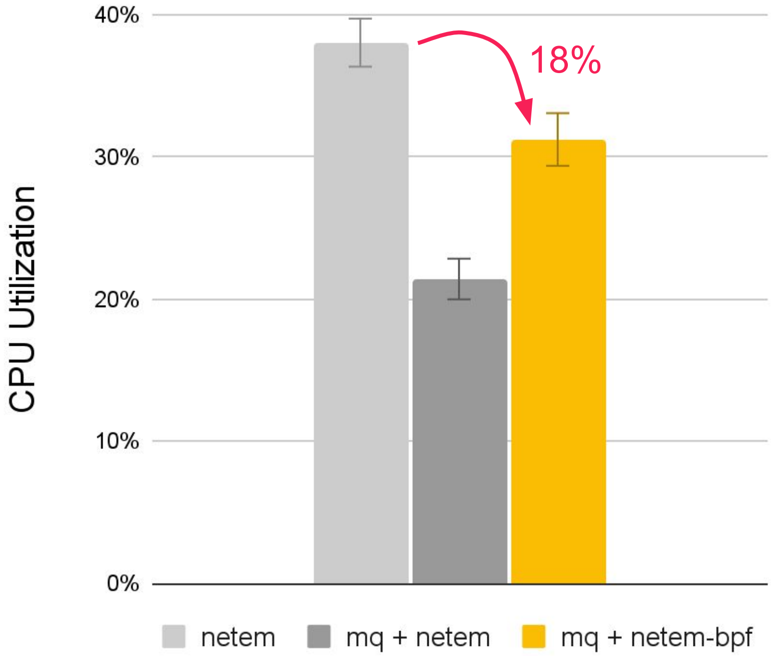


Collaboration between Qdiscs



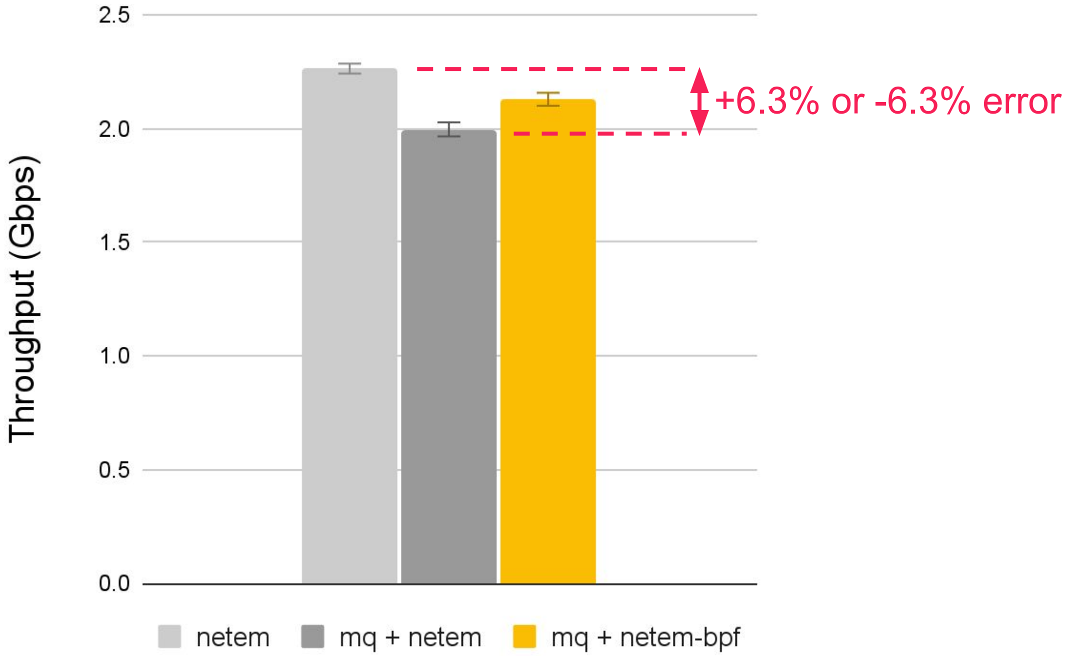
mq reduces contention on Qdisc locks

netem: loss gemodel 5% 95% 70% 0.1%
mq: 4 tx queues (virtio-net)
iperf3: 64 parallel flows



More accurate network behavior

netem: loss gemodel 5% 95% 70% 0.1%
mq: 4 tx queues (virtio-net)
iperf3: 64 parallel flows



Basic statistics

```
$ tc -s -d qdisc

qdisc mq 1: dev ens5 root
 Sent 16492097988 bytes 10895950 pkt (dropped 126999, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0
qdisc bpf 802: dev ens5 parent 1:2 [Unknown qdisc, optlen=96]
 Sent 2388137376 bytes 1578056 pkt (dropped 19220, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0
qdisc bpf 804: dev ens5 parent 1:4 [Unknown qdisc, optlen=96]
 Sent 534484773 bytes 353129 pkt (dropped 4661, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0
qdisc bpf 801: dev ens5 parent 1:1 [Unknown qdisc, optlen=96]
 Sent 12885633183 bytes 8512929 pkt (dropped 97278, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0
qdisc bpf 803: dev ens5 parent 1:3 [Unknown qdisc, optlen=96]
 Sent 683842656 bytes 451836 pkt (dropped 5840, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0
```

Things to be addressed

Storing kptr in local kptr

Egress only right now

Summary

- Recent eBPF developments make eBPF Qdisc possible as a generic and easy-to-use packet scheduler
- Using eBPF Qdisc with mq to avoid contention on the root Qdisc lock while being able to coordinate between queues
- eBPF Qdisc unlocks opportunities for new applications and optimizations

Sample code: https://github.com/ameryhung/ebpf-qdisc-examples