# A programmable Qdisc with eBPF

Cong Wang
xiyou.wangcong@gmail.com

# Agenda

- What is a packet scheduler
- A quick summary of existing Qdisc’s
- Programmable Qdisc’s
- eBPF quick overview
- Prototypes of sch_bpf

# Packet scheduling

- Ordering packets
- Traffic shaping/policing
- Flow classification and isolation
- Fairness
- Latency control

# Qdisc overview

- FIFO: pfifo, bfifo, pfifo_fast
- Fair queueing: fq, sfq, qfq, drr
- Traffic shaper: tbf, htb, hfsc
- AQM: choke, codel, pie
- Multiqueue: mq, mqprio
- And more...

# Why programmable?

- One qdisc for each algorithm
- Choosing qdisc’s is not easy
- Much more flexible
- Safer, easier to port and update via eBPF (CO-RE)

# Push-In-First-Out

- Enqueue in arbitrary position, dequeue from head
- Rank based priority queue, O(logN)
- Relative ordering with scheduling trees
- No arbitrary reordering

# Eiffel

- FFS-based priority queue
- On-dequeue scheduling
- Per-flow ranking and scheduling
- Arbitrary traffic shaping on any node

# eBPF overview

- Map based data structures
- Array map
- Queue/stack maps
- Map in map
- One or multiple programs for each attach point
- cls_bpf, act_bpf are already available

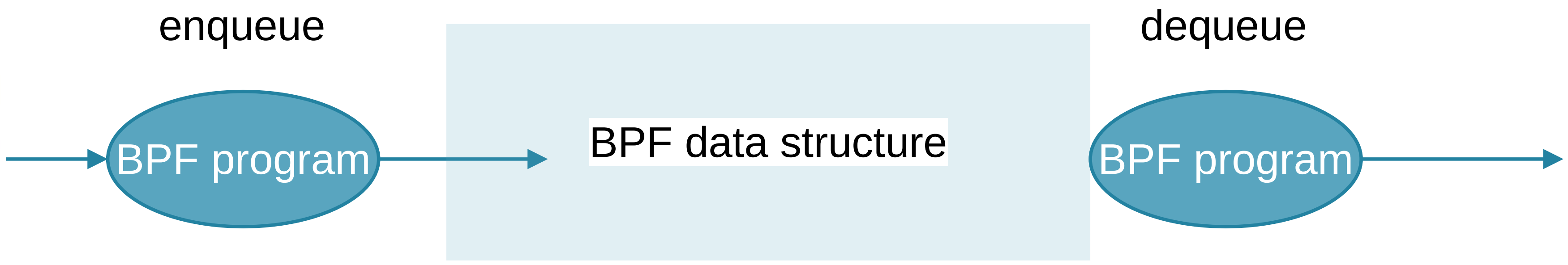
# Why sch_bpf is harder?

- At least two eBPF programs: enqueue() and dequeue()
- Work together via a shared data structure
- dequeue() is essentially harder than enqueue()
- Who owns the data structure? Kernel or user?
- How flexible is it?
- Interaction with TC filters and actions
- Hierarchy

# Design considerations

- Flexibility vs. Usability
- Kernel vs. User
- Efficiency
- Fits into existing TC infrastructure

# A lazy prototype



```
struct bpf_map_def SEC("maps") queue = {...};
SEC(“sch_bpf/enqueue”)
int enqueue(struct __sk_buff *skb)
{
  if (bpf_map_push_elem(&queue, skb, 0))
    return DROP;
  return SUCCESS;
}
```

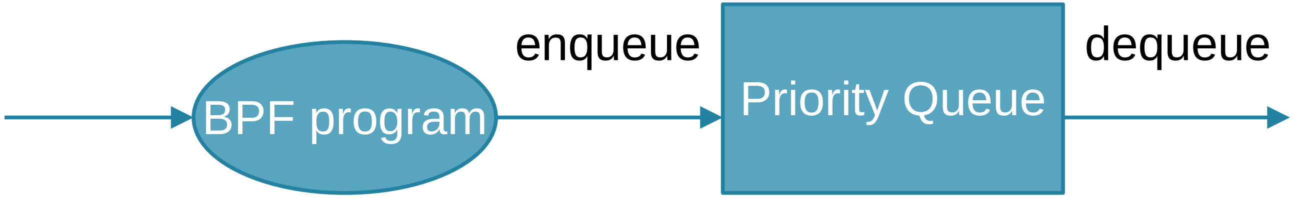
```
SEC(“sch_bpf/dequeue”)
int dequeue(struct sch_ctx *ctx)
{
  void *skb;
  if (bpf_map_pop_elem(&queue, &skb))
    return NONE;
  ctx->skb = skb;
  return SUCCESS;
}
```

# Problems

- Too flexible? Packets could be held infinitely.
- Hard to fit in Qdisc APIs: ->init(), ->peek(), ->reset()
- Multiple flows, map-in-map and map creation
- skb ownership

# Second prototype

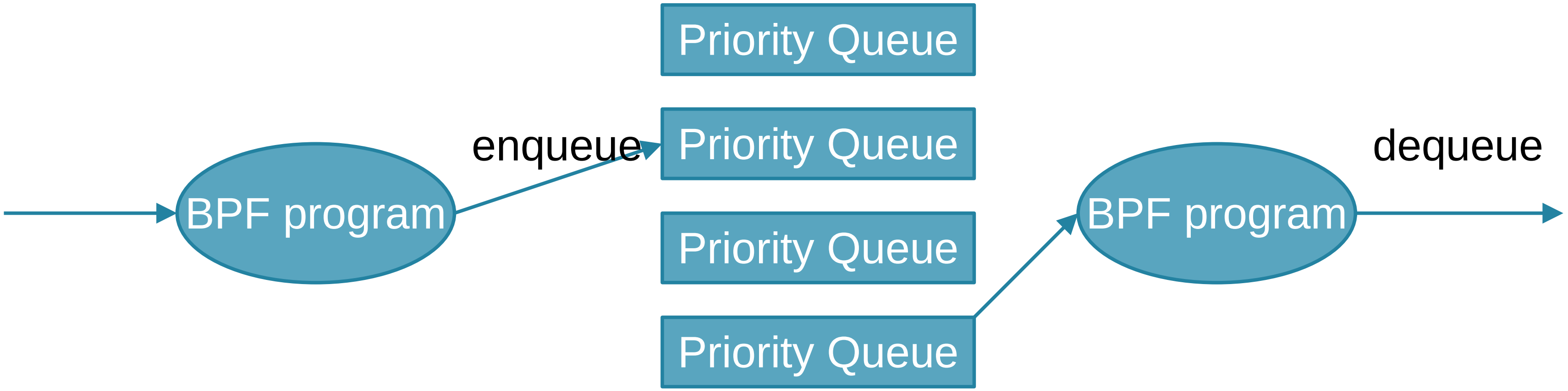
- Based on PIFO, a priority queue owned by kernel
- Invisible from eBPF program
- Enqueue(): calculate the rank, decide whether to drop
- Dequeue(): nothing


BPF program
enqueue
Priority Queue
dequeue

```
int counter;
SEC(“sch_bpf_enqueue”)
int enqueue(struct sch_ctx *ctx)
{
  if (ctx->total_packets > 1000)
    return DROP;
  ctx->skb->tc_rank = counter;
  counter++;
  return SUCCESS;
}
```

# Third prototype

- Multiple priority queues owned by kernel
- Map each queue to a flow/class
- Invisible from eBPF programs
- Enqueue(): classify packet to a queue, calculate rank within the queue
- Dequeue(): decide how many packets to dequeue from which queues


Priority Queue
enqueue
Priority Queue
dequeue
BPF program
BPF program
Priority Queue
Priority Queue

# TC cmdline

- tc qdisc add dev X root handle 1: bpf flows N enqueue obj bpf.o sec enqueue dequeue obj bpf.o sec dequeue
- tc filter add dev X parent 1:0 […] flowid 1:Y
- tc class add dev X parent 1:0 classid 1:1 bpf rate 10Mbit

```
int counter;
SEC("sch_bpf/enqueue")
int enqueue(struct sch_ctx *ctx)
{
  int classid;
  if (ctx->total_packets > 1000)
    return DROP;
  classid = bpf_tc_classify(ctx); // Wrapper for tcf_classify()
  ctx->skb->tc_classid = classid;
  ctx->skb->tc_rank = classid + counter;
  counter++;
  return SUCCESS;
}
```

```
int  current;
int quota = QUANTUM;
SEC("sch_bpf/dequeue")
int dequeue(struct sch_ctx *ctx)
{
  quota = quota - ctx->skb->len;
  if (quota <= 0) {
    quota = quota + QUANTUM;
    return SCH_BPF_REQUEUE | SCH_BPF_DONE;
  } else
    return SCH_BPF_OK | SCH_BPF_CONTINUE;
}
```

```
while (1) {
  ctx.flow = prio_dequeue(&q->flows);
  if (!ctx.flow)
    break;
  ctx.skb = prio_dequeue(&ctx.flow->queue);
  ret = BPF_PROG_RUN(&prog->filter, &ctx);
  if (ret & mask == SCH_BPF_DROP)
    kfree_skb(ctx.skb);
  else if (ret &mask == SCH_BPF_REQUEUE)
    prio_enqueue(&ctx.flow->queue, ctx.skb);
  else
    dev_hard_start_xmit(ctx.skb, dev, ...);

  if (ret & mask == SCH_BPF_DONE)
    break;
  if (!prio_empty(&ctx.flow->queue))
    prio_enqueue(&q->flows, ctx.flow);
}
```

# Problems

- sch_ctx becomes complicated
- dequeue() is stateful, harder to implement. Use multi-prog?
- O(MlogN)
- Need to provide per-flow information?
- Need arbitrary flow/packet access?
- Would eBPF verifier be happy?

Ideas? Questions?

# References


- http://web.mit.edu/pifo/pifo-sigcomm.pdf
- https://www.usenix.org/system/files/nsdi19spring_saeed_prepub.pdf
- https://eprints.networks.imdea.org/1654/1/icnp_17_final.pdf
- https://blogs.oracle.com/linux/notes-on-bpf-3