Overview of BPF networking hooks

+ **User experience in Meta**

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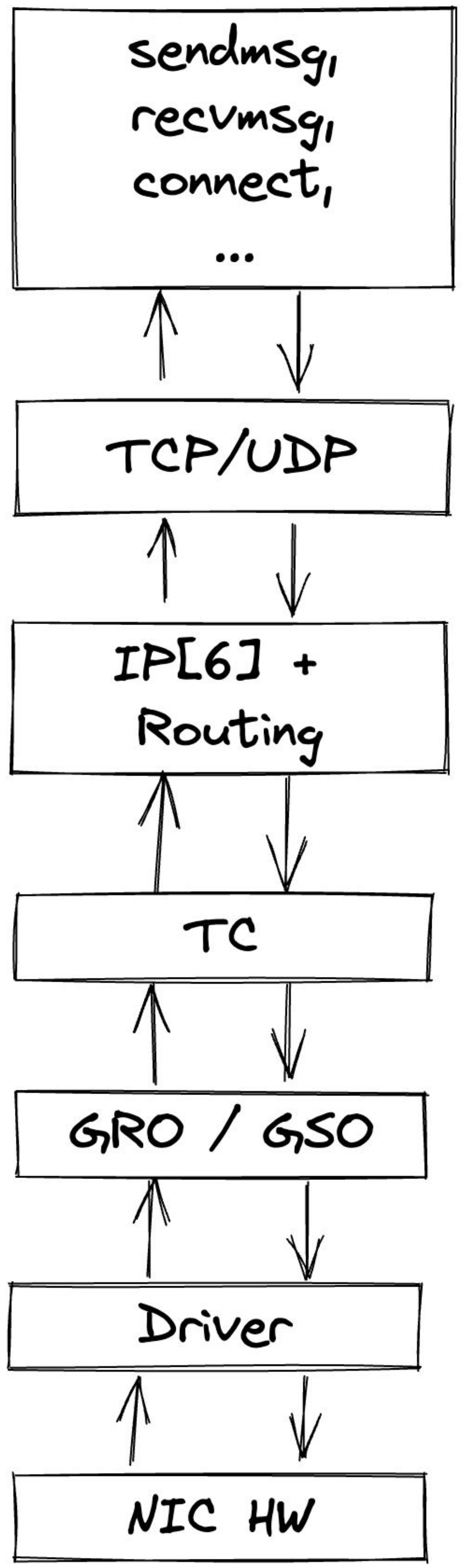
Linux network stack

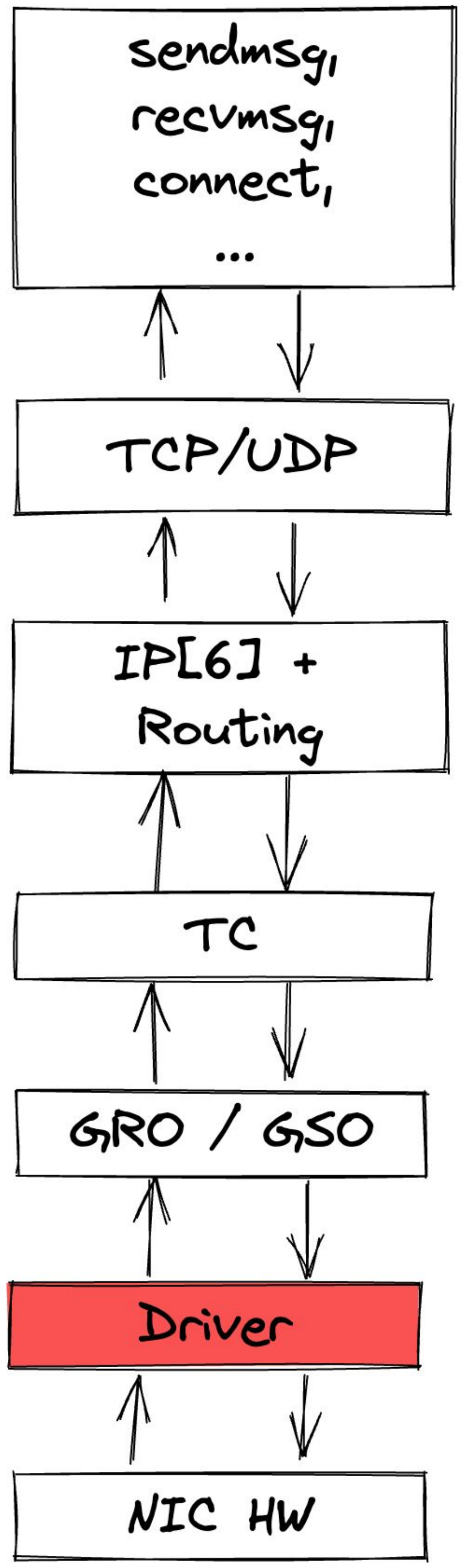
(super high level)



SEC(“xdp”)

Where is it run ?

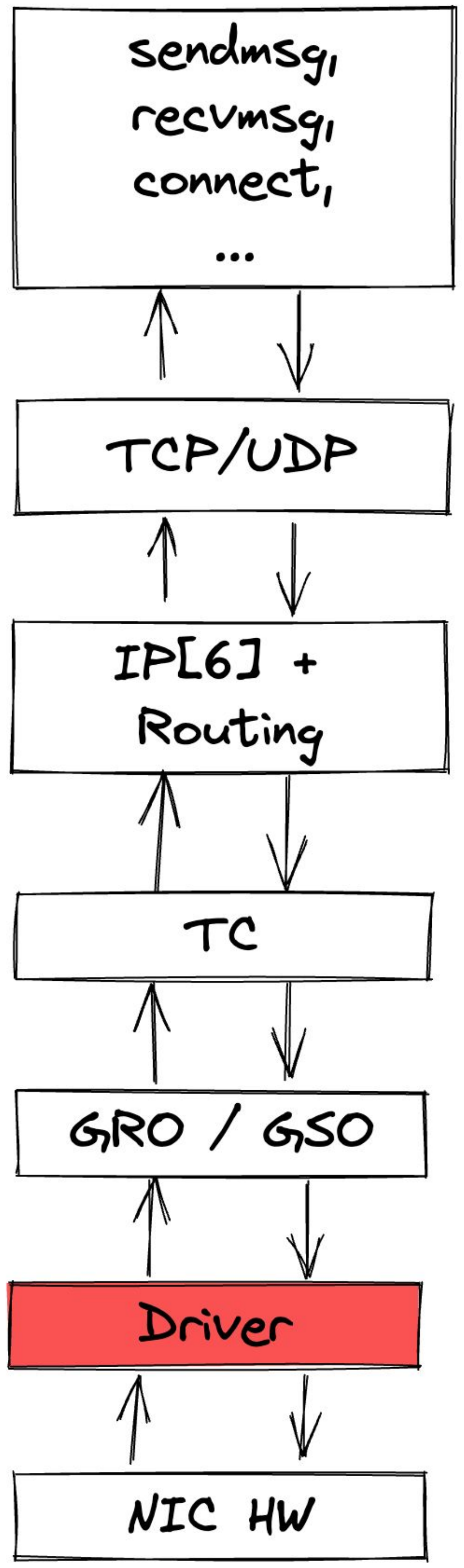
- Running at driver (ingress)
- Before skb creation. Speed!



SEC("xdp")

Header handling

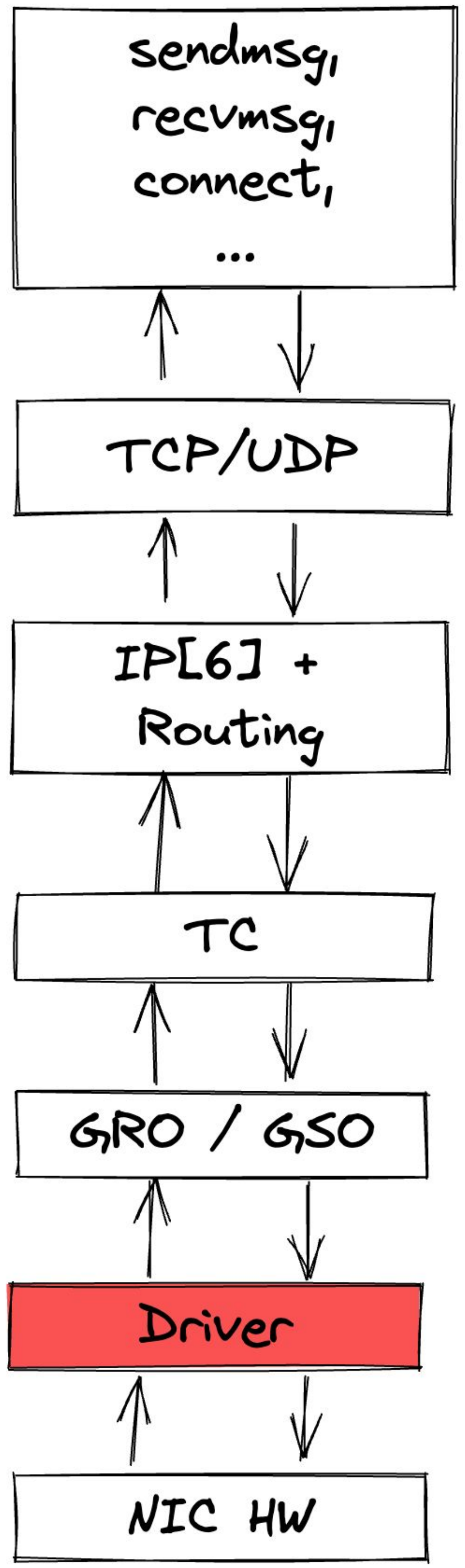
- [xdp->data, xdp->data_end)
- Multi-buffer: bpf_xdp_{load,store}_bytes()
- encap or decap: bpf_xdp_adjust_{head,tail}



SEC("xdp")

Actions on the packet (xdp_md)

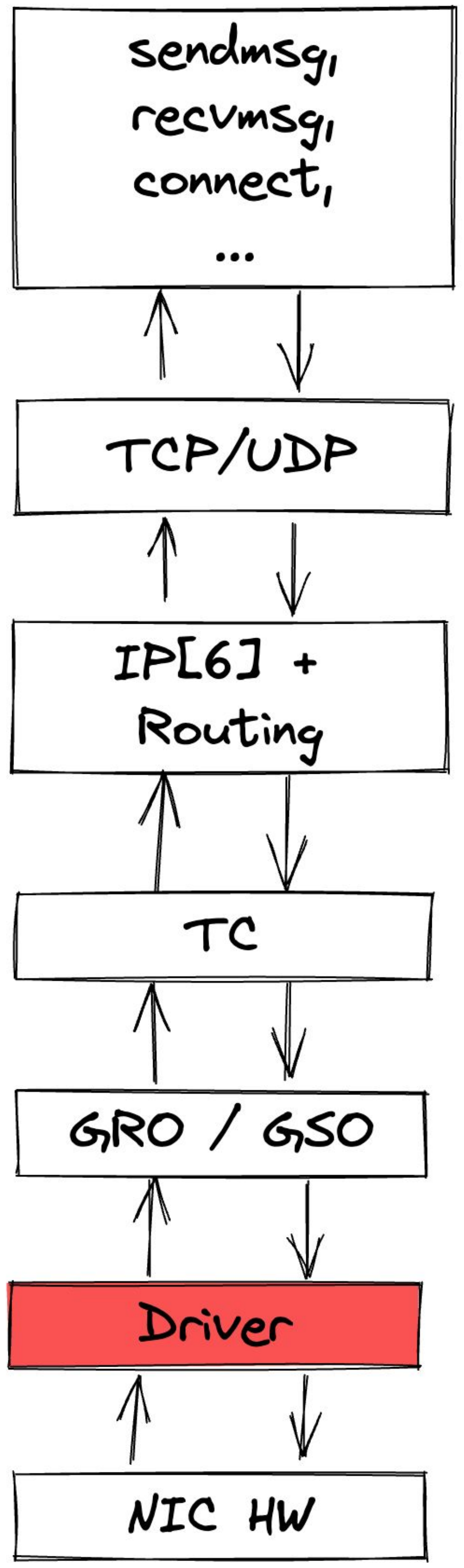
- XDP_PASS to pass up to the kernel stack
- XDP_TX to send it out at the same interface
- bpf_xdp_redirect() to send out at a different interface or cpu
  - devmap and cpumap



SEC("xdp")

Where is the sk ?

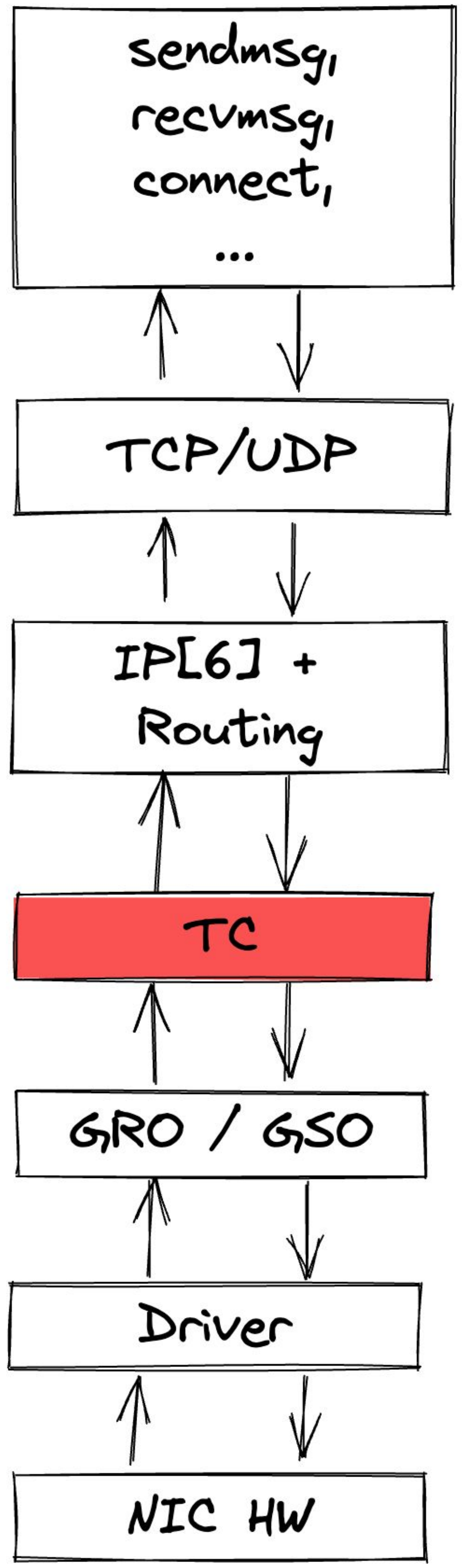
- Routing is not done yet. No sk.
- bpf_sk[c]_lookup_{tcp,udp}
  - TCP SYN-ACK reply with syn-cookie



SEC(“tc”)

Where is it run ?

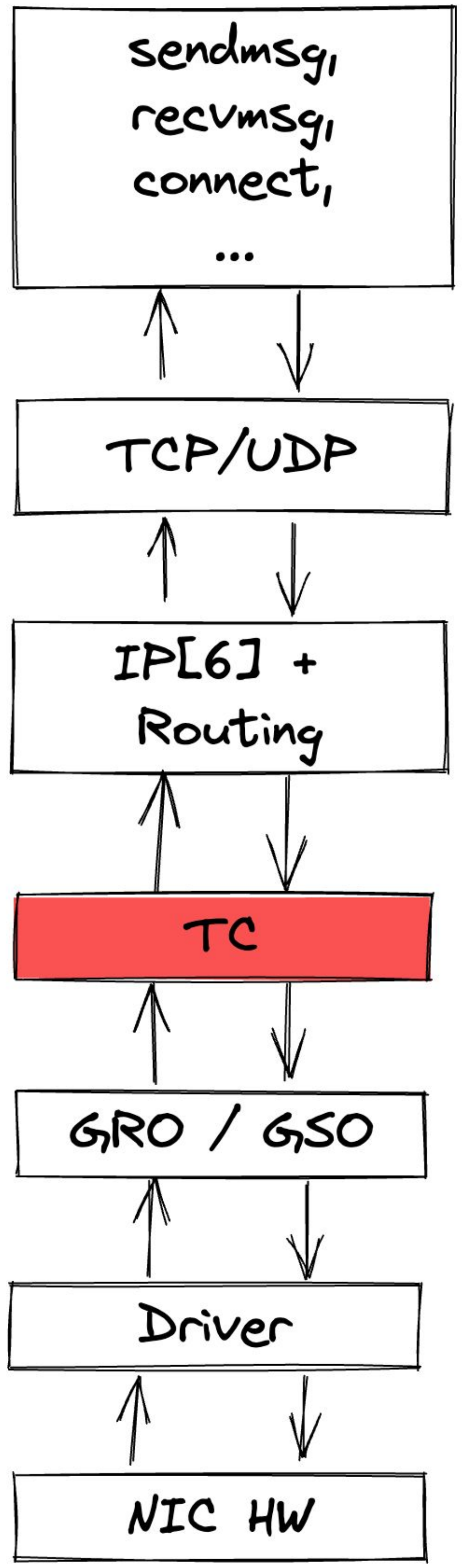
- tc ingress (after gro) or
- tc egress (before gso)



SEC(“tc”)

Header handling

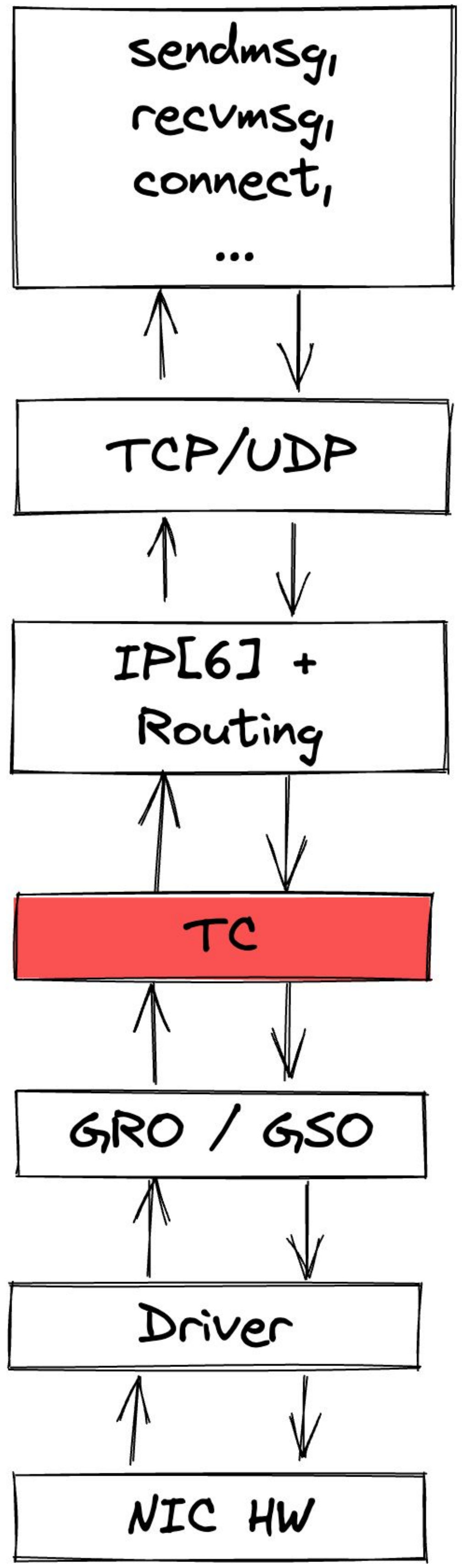
- Directly through skb->[data, data_end)
- bpf_skb_pull_data() and bpf_skb_{load,store}_bytes() for the non-linear part
- encap and decap: bpf_skb_adjust_room()



SEC(“tc”)

With skb, there are more, eg.

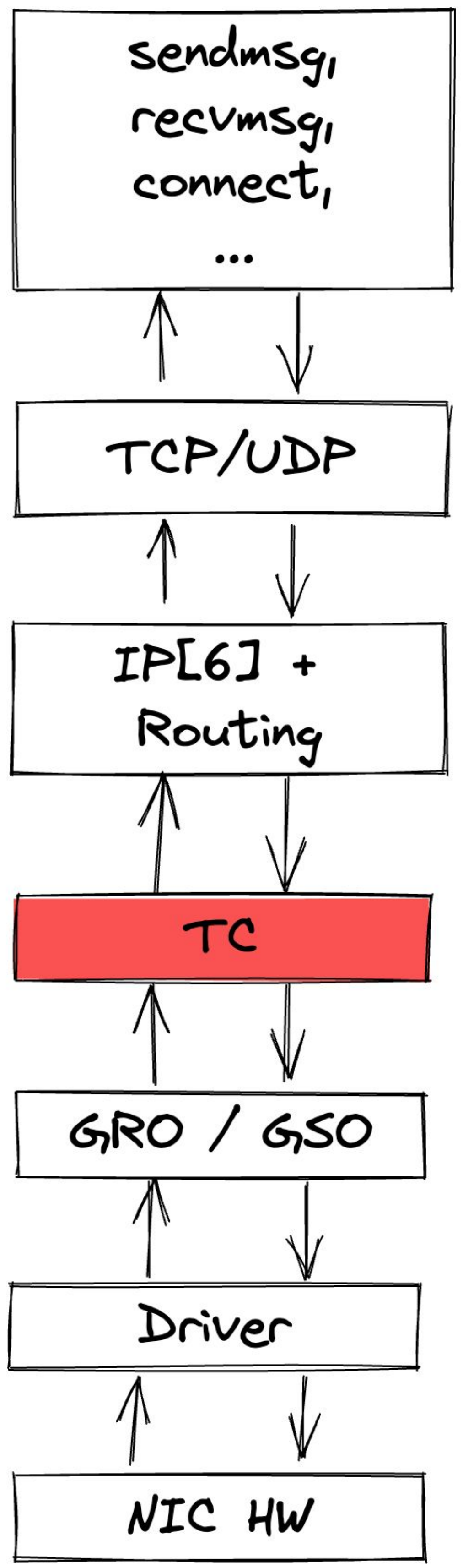
- skb->hwtstamp for ingress
- skb->protocol
- …etc



SEC("tc")

Action on skb

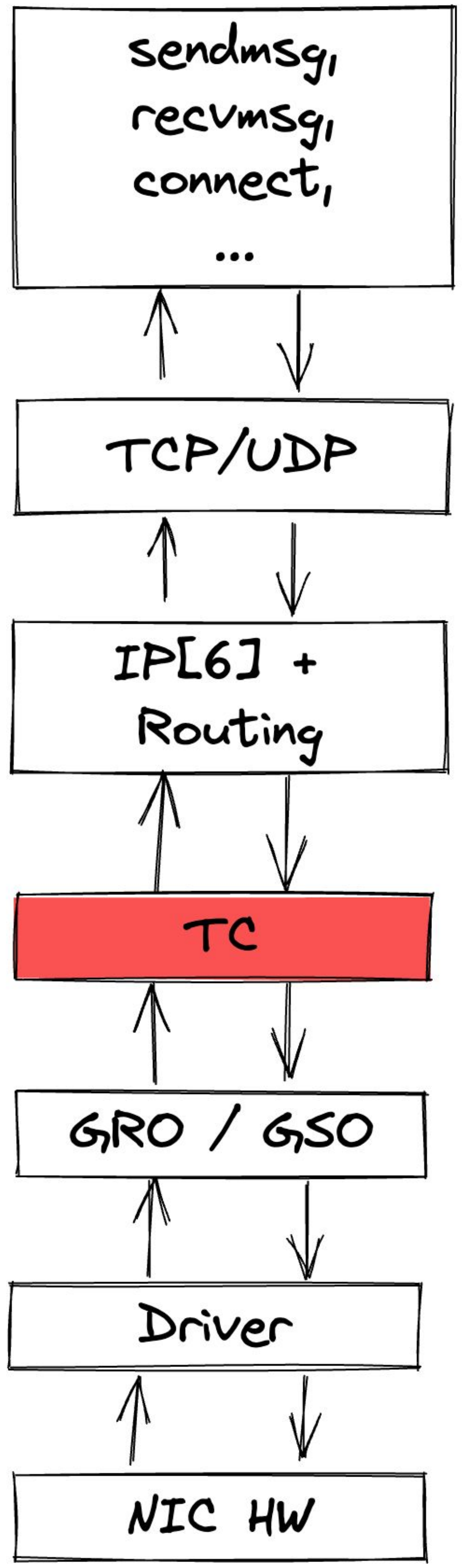
- TC_ACT_OK
- TC_ACT_SHOT
- TC_ACT_REDIRECT + bpf_redirect*()
  - eg. fast path to redirect packets between phy-eth to container veth
- At egress, set the skb->tstamp (EDT) + fq
  - Bandwidth shaping. Flexible and fast.



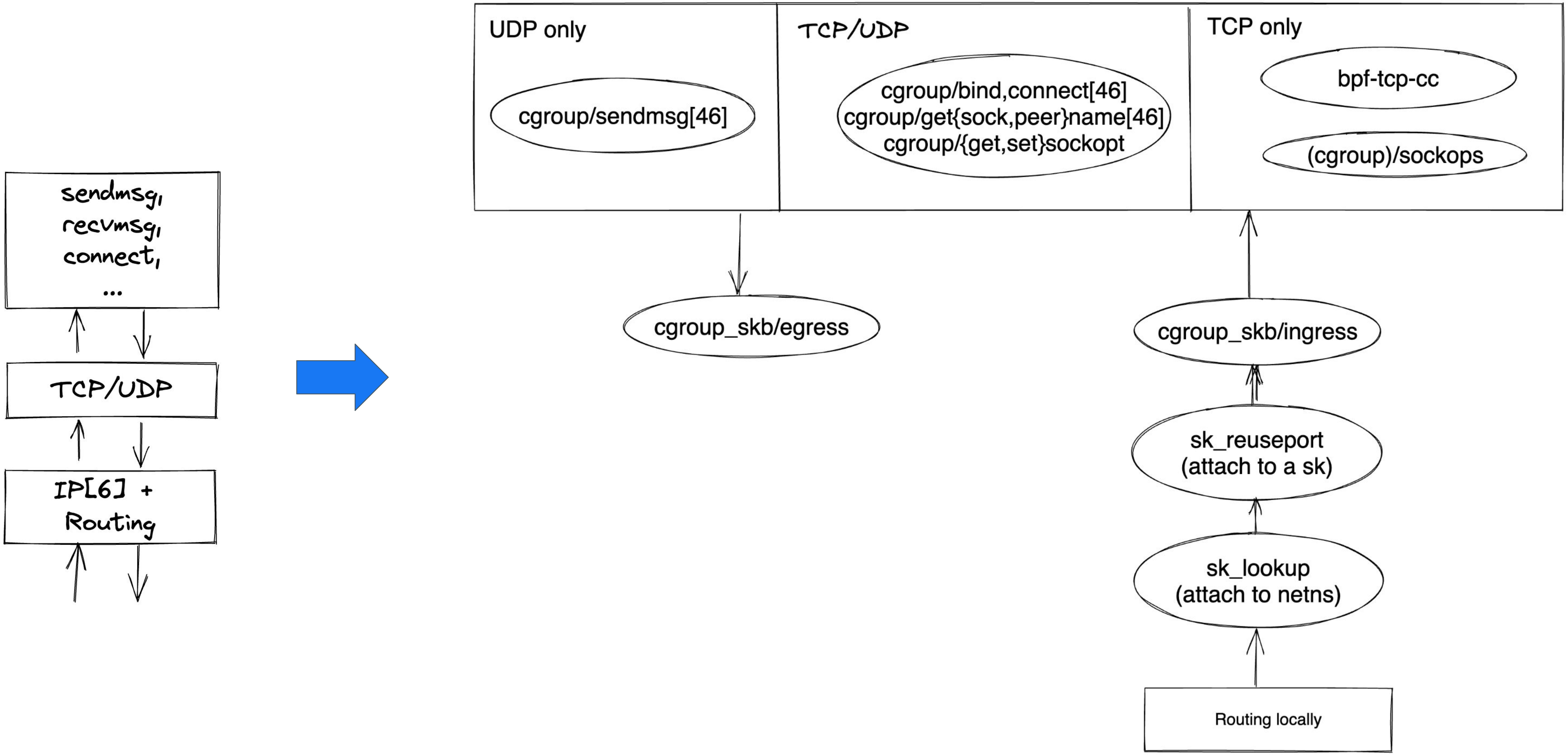
SEC(“tc”)

Where is the sk ?

- Ingress
  - No (routing is not done).
  - bpf_sk_lookup*(). With bpf_sk_assign(), earlier demux.
- Egress
  - skb->sk

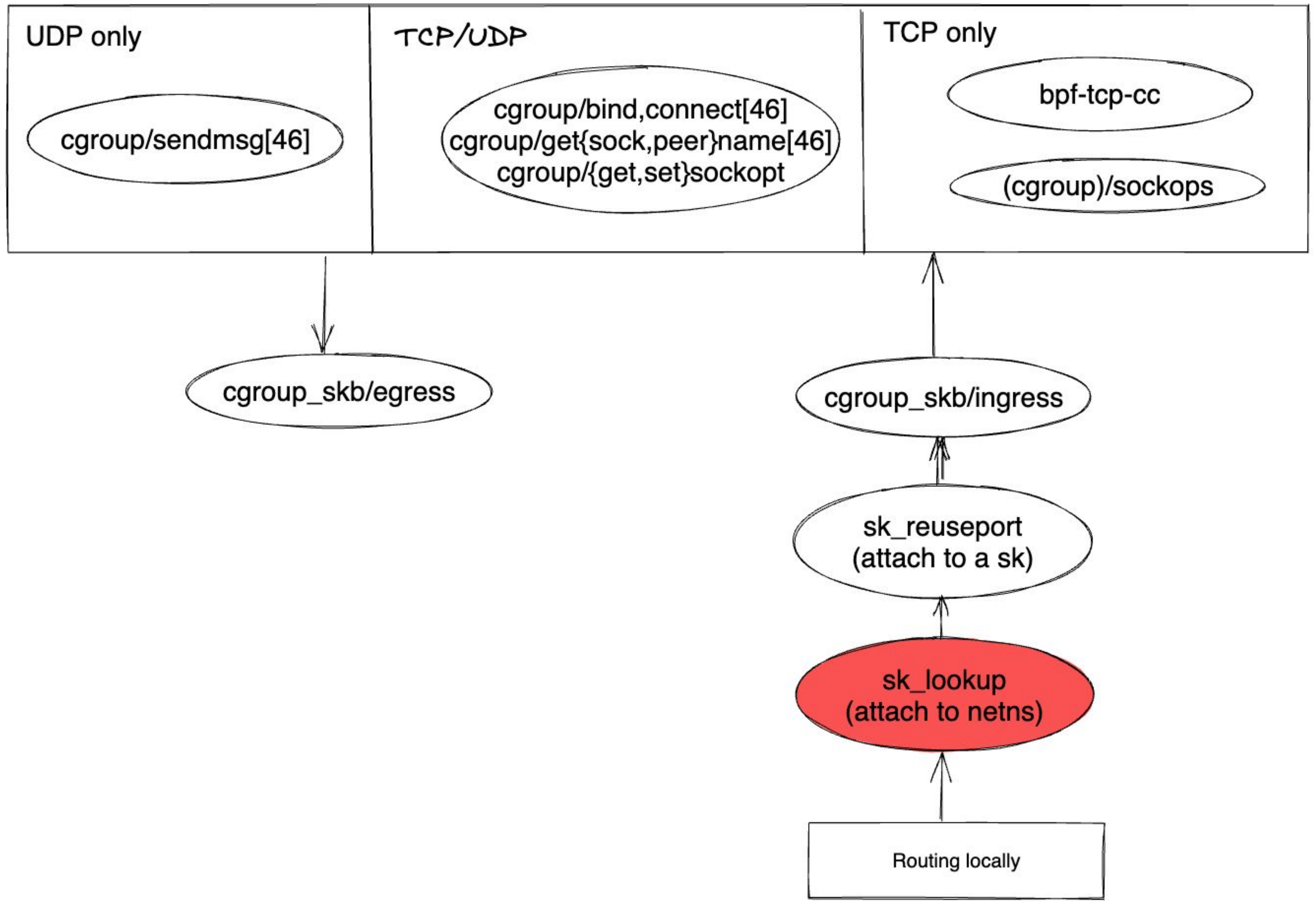


IP[46] and TCP/UDP



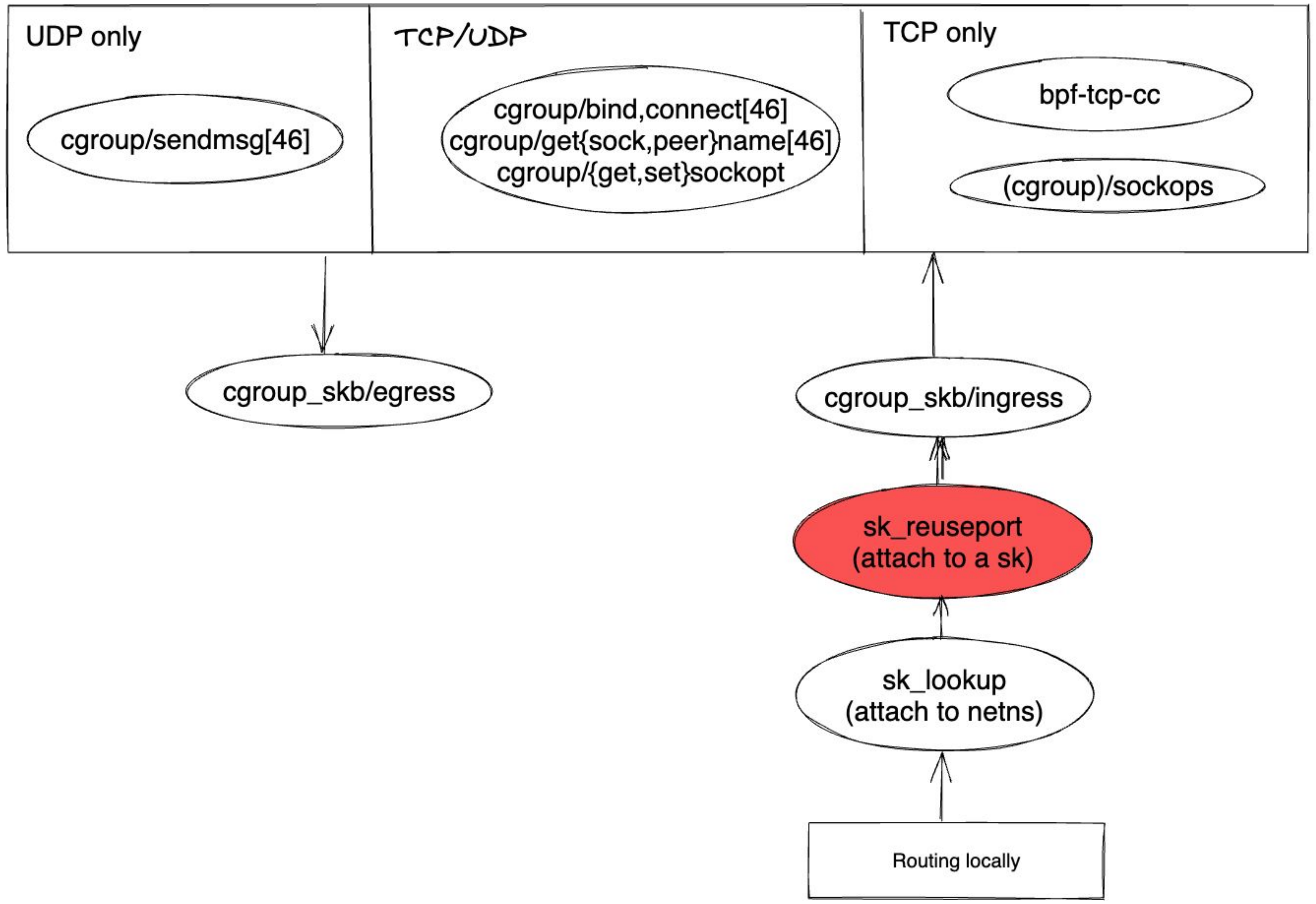
SEC("sk_lookup"), a netns hook

- SEC("sk_lookup") bpf prog can pick a sk different from the skb's ip/port
- TCP: A listening socket
- UDP: Any sk that is ready to receive packet
- skb is available. Read only.



SEC("sk_reuseport"), attach to sk

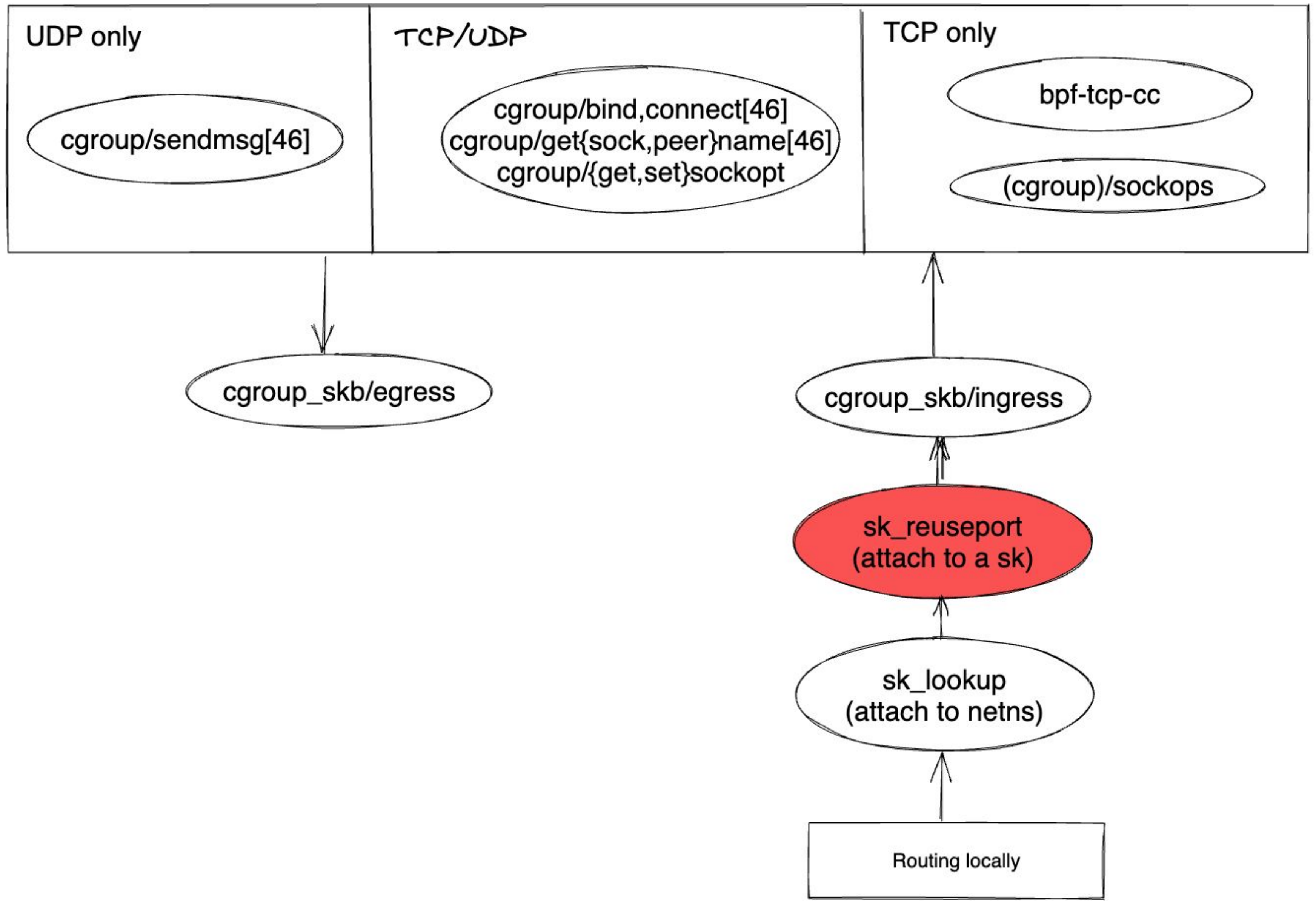
- Reuseport sk(s) is a group of sockets bind()-ed to the same IP[6] and port
- By default, kernel picks one by hash



SEC("sk_reuseport")

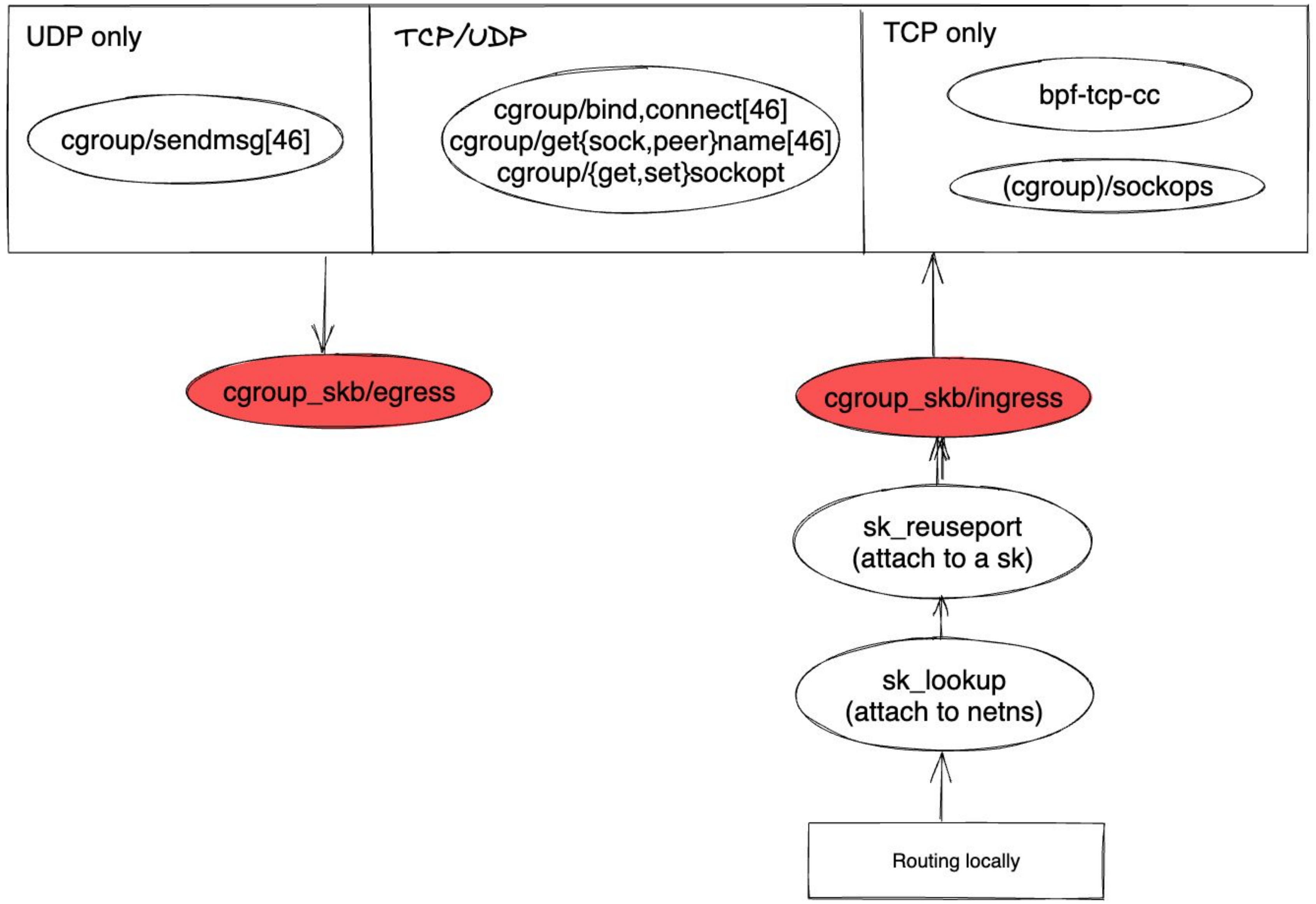
SEC("sk_reuseport") bpf prog can :

- Pick the sk by numa node
- Avoid picking the sk that its process is exiting. eg. process restart.
- Even migrate the not-yet accepted TCP sk from a closing listen sk to another sk
- Connection-ID in QUIC
- skb is available. Read only.



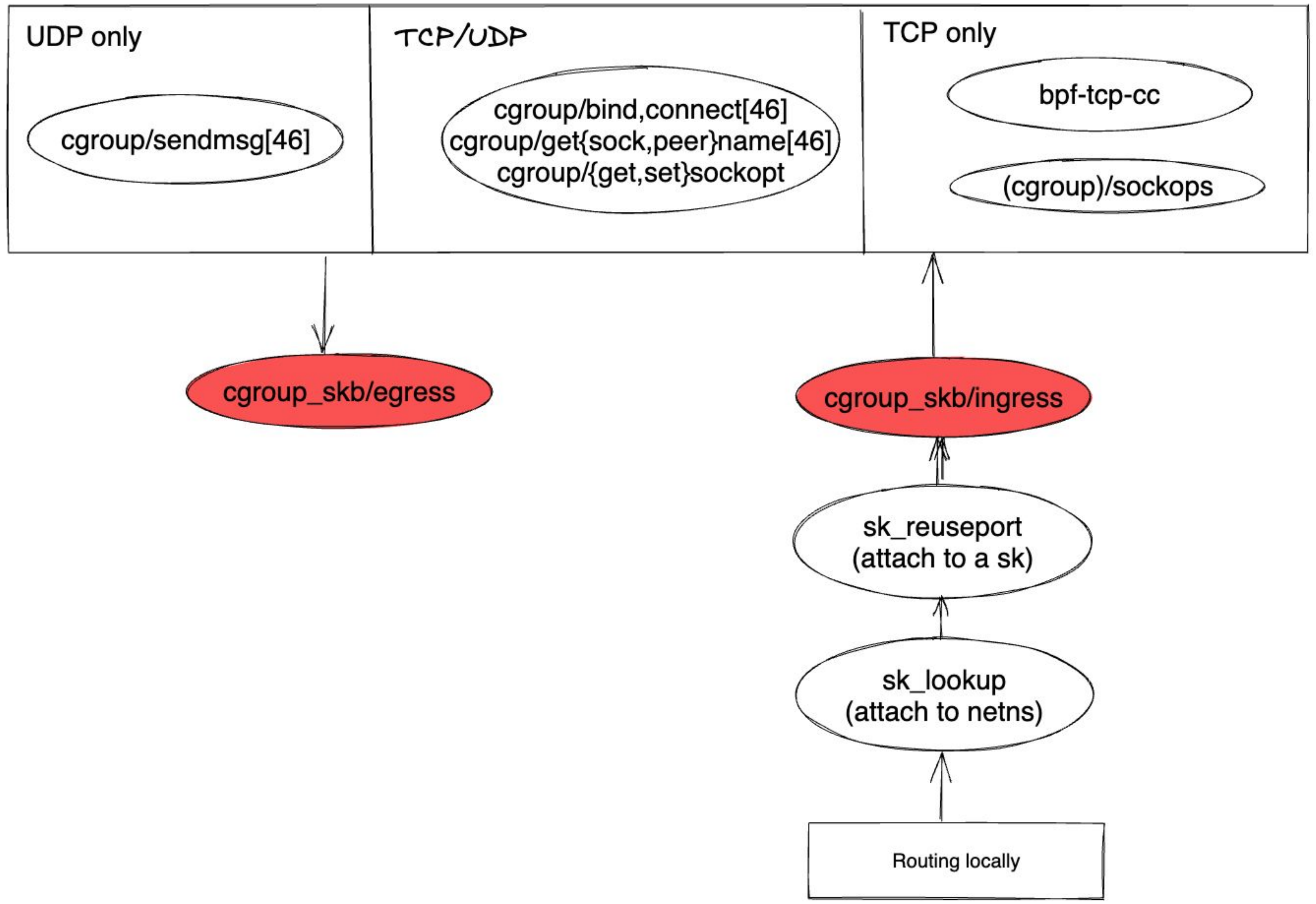
SEC("cgroup/{ingress,egress}")

- IPv6 and IPv4 skb only
- skb is available. Read only.
- sk is available. skb->sk



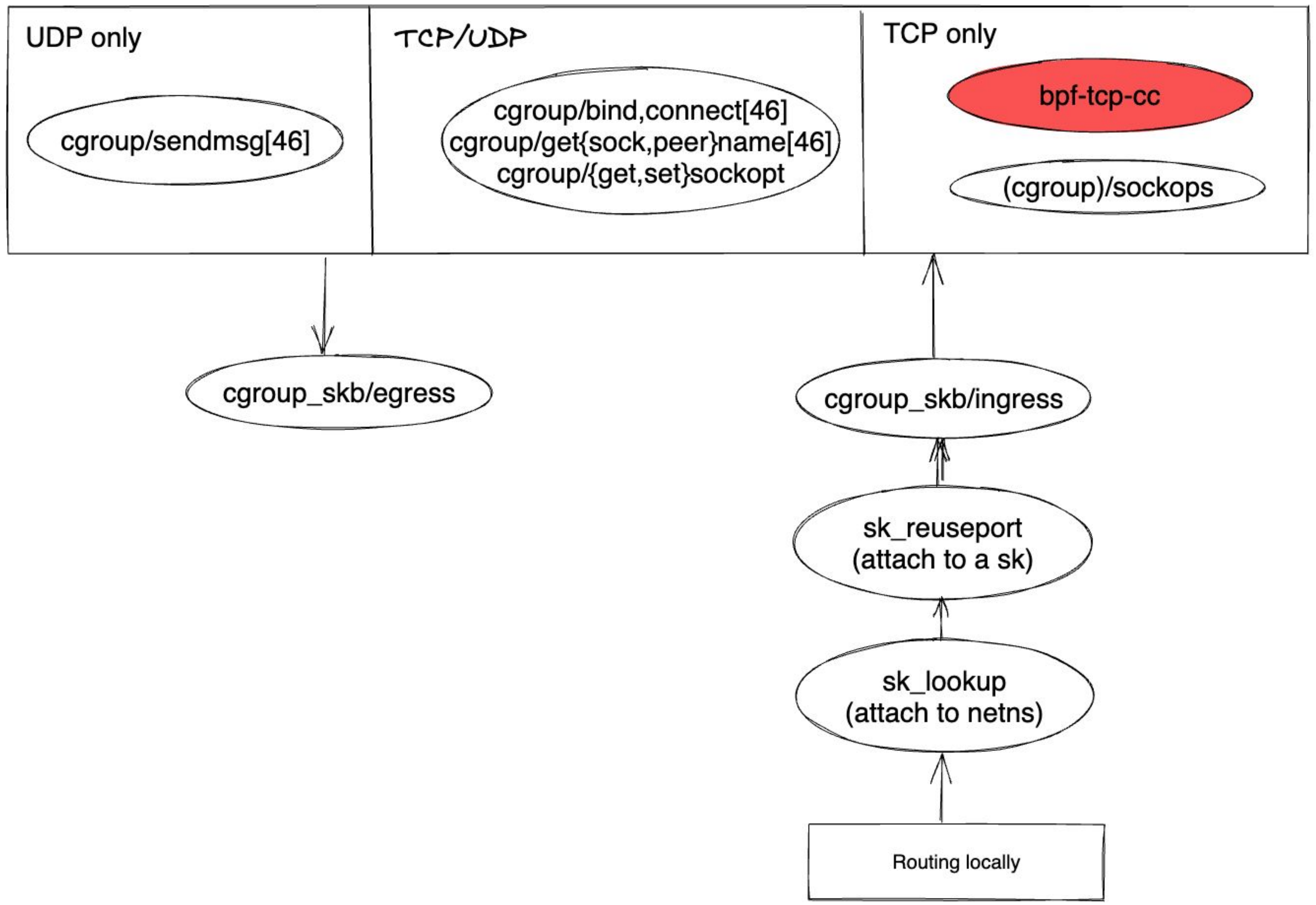
SEC("cgroup/{ingress,egress}")

- Ingress
  - Reject packets based on container policy
- Egress
  - Set the delivery time (EDT) in skb->tstamp (+ fq) to limit bandwidth usage per cgroup
  - Return NET_XMIT_{DROP, CN} to signal the tcp stack to tcp_enter_cwr()



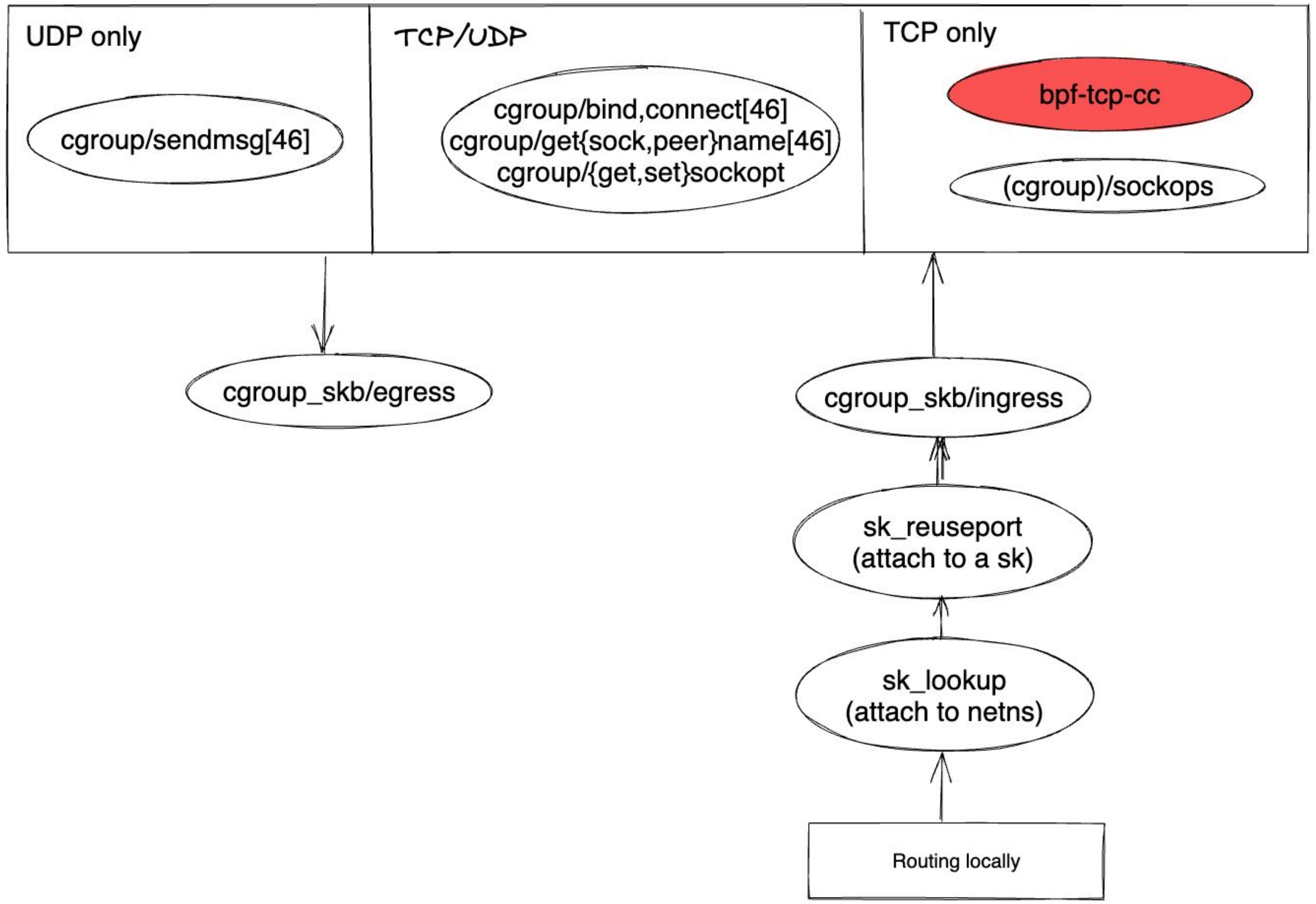
SEC(".struct_ops") aka bpf-tcp-cc

- A TCP CC (congestion control) fully implemented in BPF
- Enable congestion control experts to test ideas and collect data faster in production



SEC(".struct_ops") aka bpf-tcp-cc

- We have >=2 bpf-tcp-cc in production
  - One is for background bulk traffic and saving $$$ by not over provisioning bandwidth.
  - One is bpf_dctcp that has different ongoing experiments
  - Ideas on using one-way-delay is also brewing

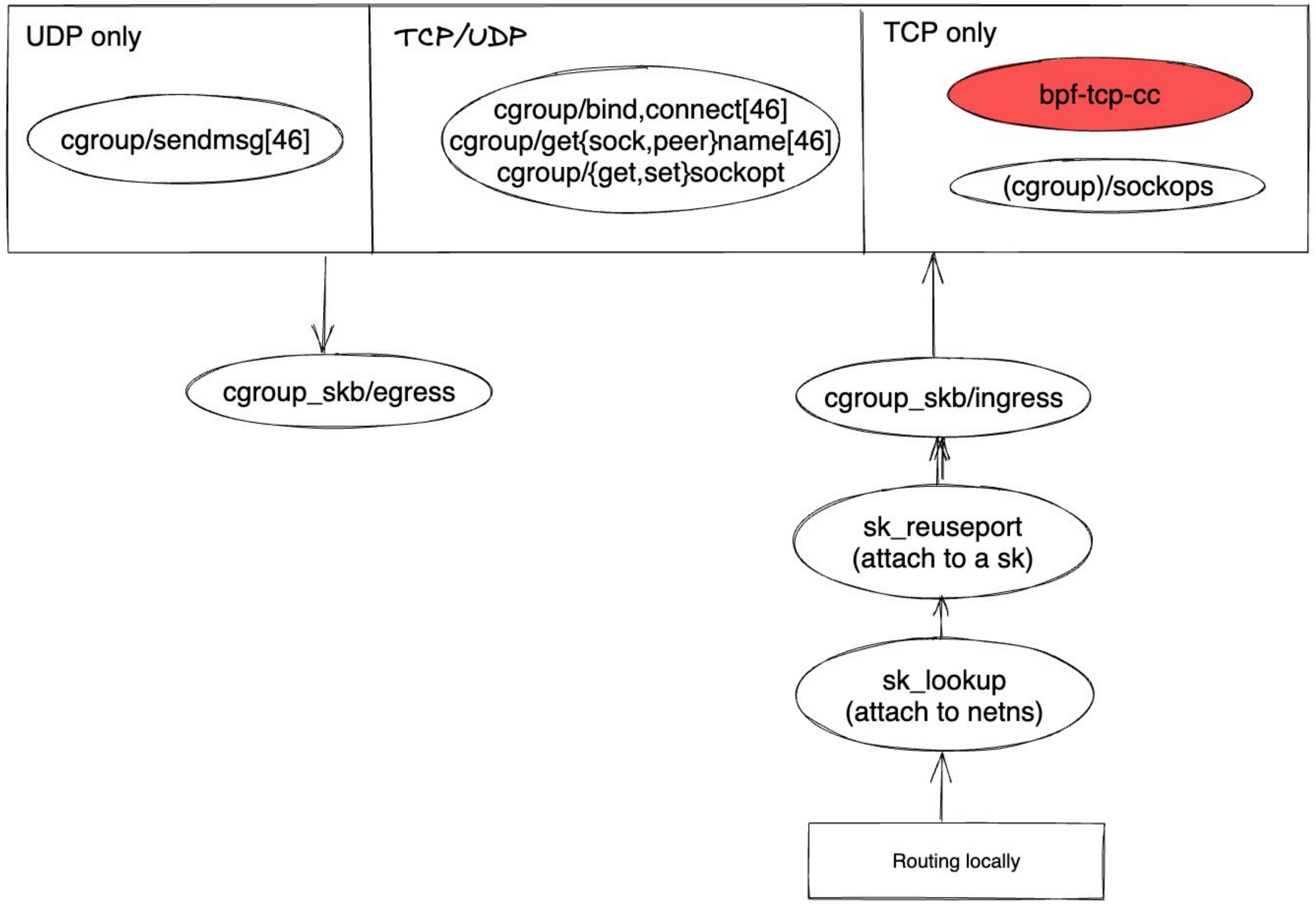


SEC(".struct_ops") aka bpf-tcp-cc

bpf-tcp-iter +

bpf_setsockopt(TCP_CONGESTION)

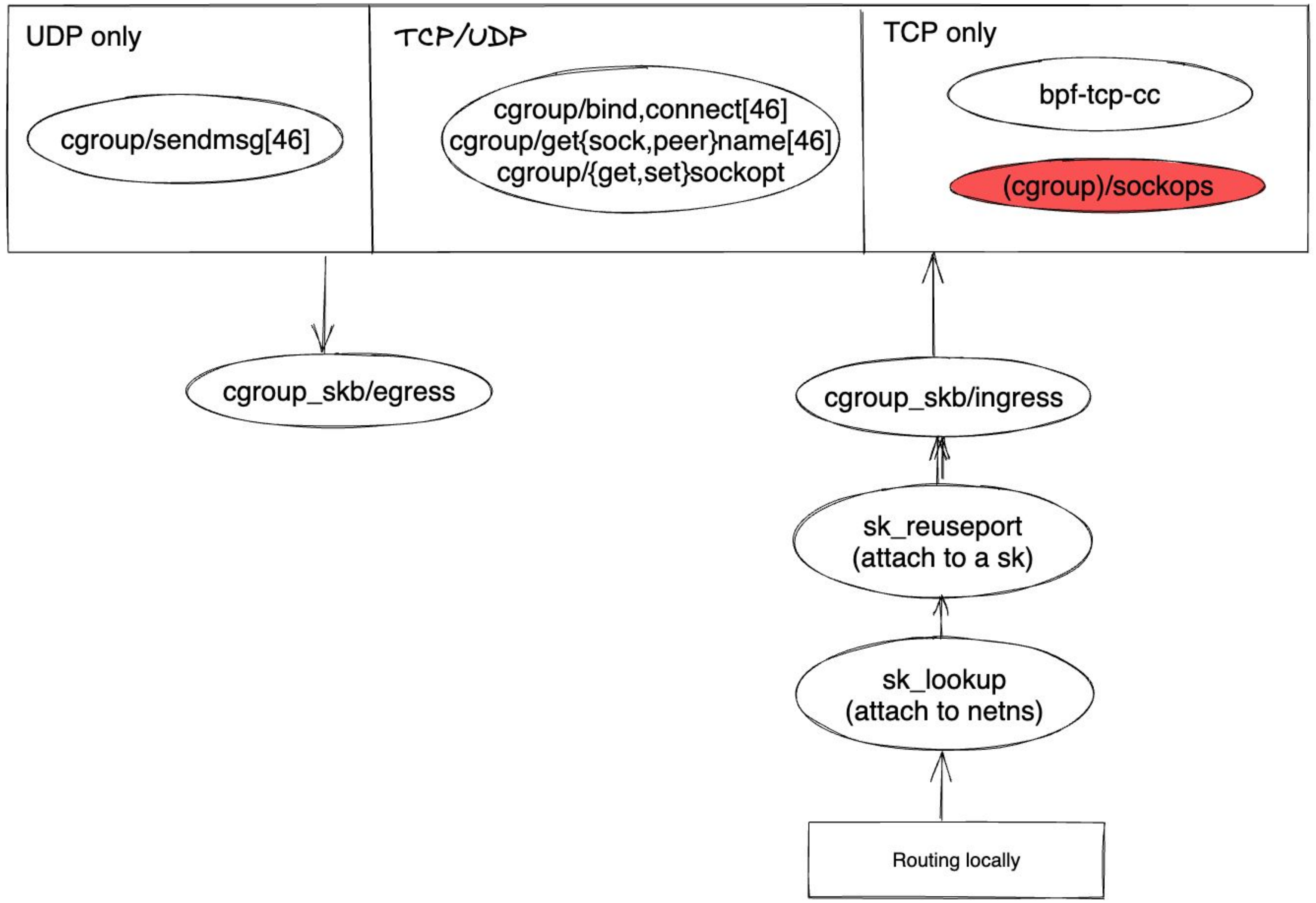
- Retire old cc faster on the long-lived connection



SEC("sockops")

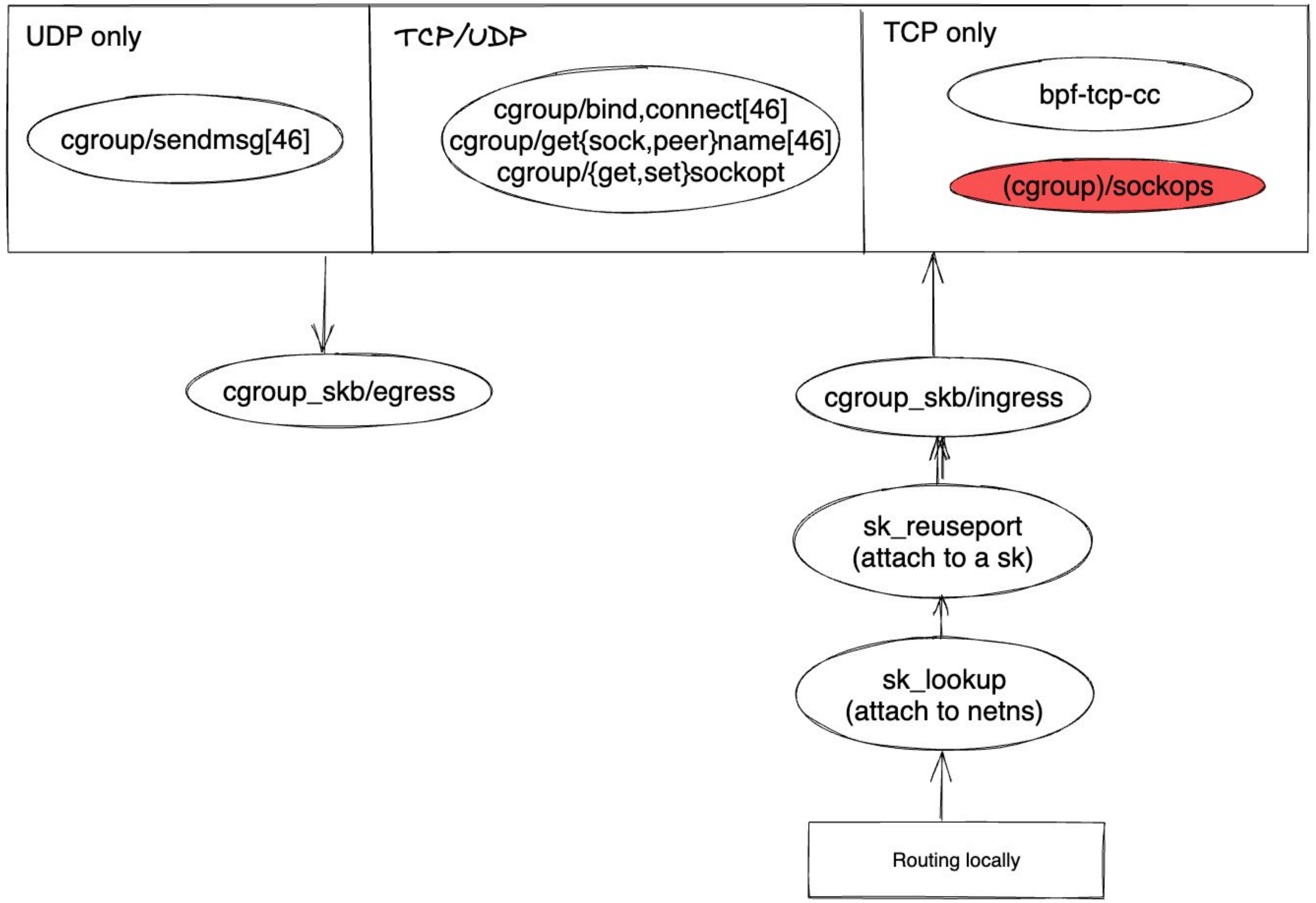
One logical bpf hook but different callbacks:

- BPF_SOCK_OPS_TCP_LISTEN_CB
- BPF_SOCK_OPS_TCP_CONNECT_CB
- BPF_SOCK_OPS_ACTIVE_ESTABLISHED_CB
- BPF_SOCK_OPS_PASSIVE_ESTABLISHED_CB
  - bpf_setsockopt(TCP_CONGESTION) based on peer address
  - Fallback to cubic, bbr, or others instead of the default reno if ECN is not supported



SEC("sockops"), contd

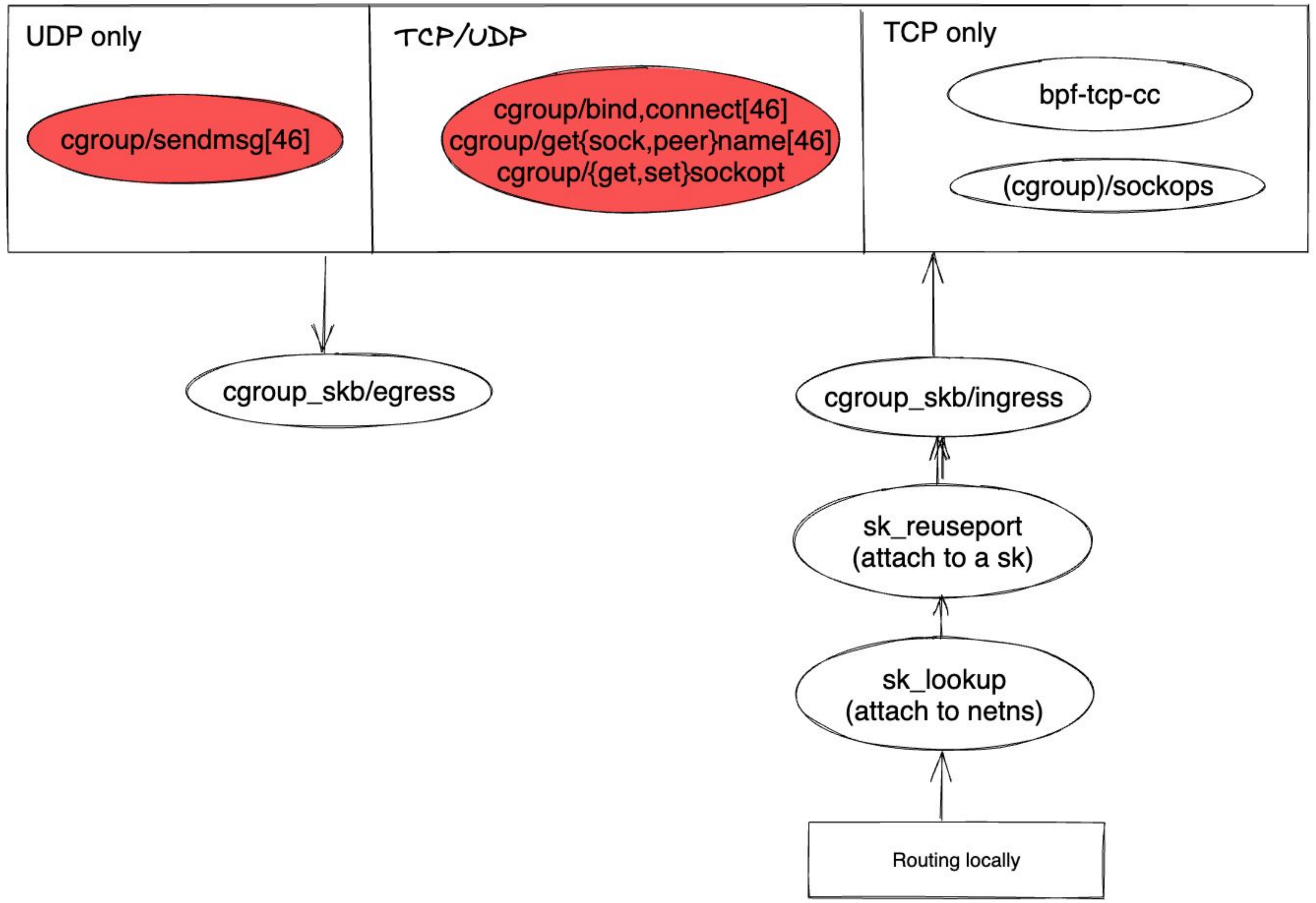
- BPF_SOCK_OPS_TIMEOUT_INIT
  - Configure initial RTO for SYN and SYN-ACK
- BPF_SOCK_OPS_*_HDR_OPT_CB
  - Read and write tcp header option
  - Add server id in SYN (similar to the connection-id in QUIC)
  - Add max delay ack + bpf_setsockopt(TCP_BPF_DELACK_MAX or TCP_BPF_RTO_MIN)



SEC(“cgroup/bind,connect,sendmsg…”)

cgroup bpf hooks at the syscall code path

- Bind, connect[46], sendmsg[46], get{sock,peer}name[46]
  - Change the local or remote address
- {set,get}sockopt()
  - Do extra setsockopt
    - userspace setsockopt(IPV6_TCLASS, background_dscp) and the bpf prog does bpf_setsockopt(TCP_CONGESTION, background_cc).
  - Userspace invent new sockopt, supported by the bpf sk storage
- The recent bpf lsm cgroup hooks (by Stanislav Fomichev) enabled more syscall code path



Common Q#1 (Where is a sk helper) ?

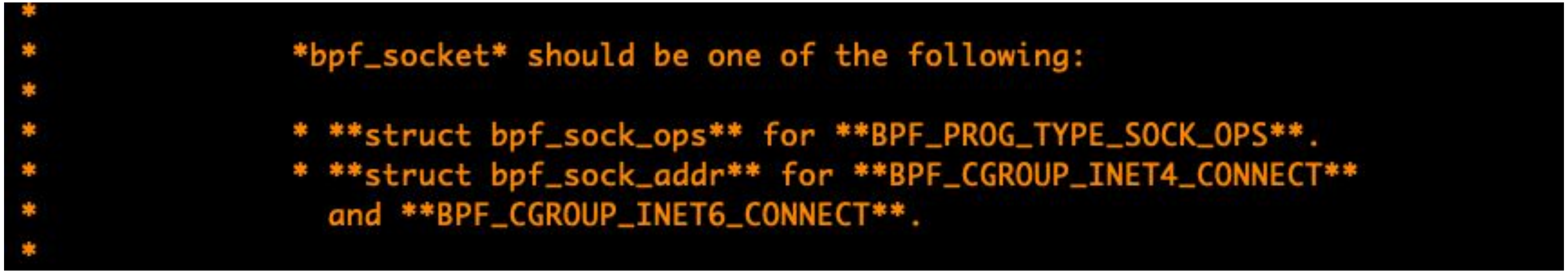
Q: The bpf prog has a sk. Why a sk bpf helper is not available ?

- A cgroup prog SEC(“sockops”). Where is bpf_sk_cgroup_id() ?
- SEC(“tc”) can call bpf_get_socket_cookie(skb)
  - but cannot do “sk = bpf_sk_lookup_tcp();” and then “bpf_get_socket_cookie(sk);”

Common Q2 (Pass ctx or sk ptr to a helper) ?

Q: When calling a “sk” helper, should ctx be passed or sk be passed ?

eg. long bpf_setsockopt(**void** *bpf_socket, ….) and the comments:



```
 *
 *              *bpf_socket* should be one of the following:
 *
 *              * **struct bpf_sock_ops** for **BPF_PROG_TYPE_SOCK_OPS**.
 *              * **struct bpf_sock_addr** for **BPF_CGROUP_INET4_CONNECT**
 *                and **BPF_CGROUP_INET6_CONNECT**.
 *
```

- The same for bpf_get_socket_cookie. bpf.h has:
  - bpf_get_socket_cookie(struct bpf_sock_addr *ctx)
  - bpf_get_socket_cookie(struct bpf_sock_ops *ctx)
  - bpf_get_socket_cookie(struct sock *sk)
  - However, there is always ctx->sk for both bpf_sock_addr and bpf_sock_ops case.

Common Q3 (cgroup storage)

Q: If the SEC(“tc”) prog can access the cgroup (skb->sk), can it access the bpf cgroup storage?

A: No. The tc prog is not a cgroup prog.

Q: Why sk, task, and inode storage is not limited by prog types? Even tracing bpf prog can use it.

A: …

Q: A bpf prog can access multiple sk storage map. Why a cgroup bpf prog can only access one cgroup storage map?

A: …

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