Optimizing `sk_msg` for Socket Map

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What is `sk_msg`?

- `sk_msg` is a kernel data structure for socket layer messaging
- Similar to the traditional `sk_buff` but much simpler
- A core component of the socket map infrastructure
- Exposed directly to (some) eBPF socket map programs

Socket Map and `sk_msg`

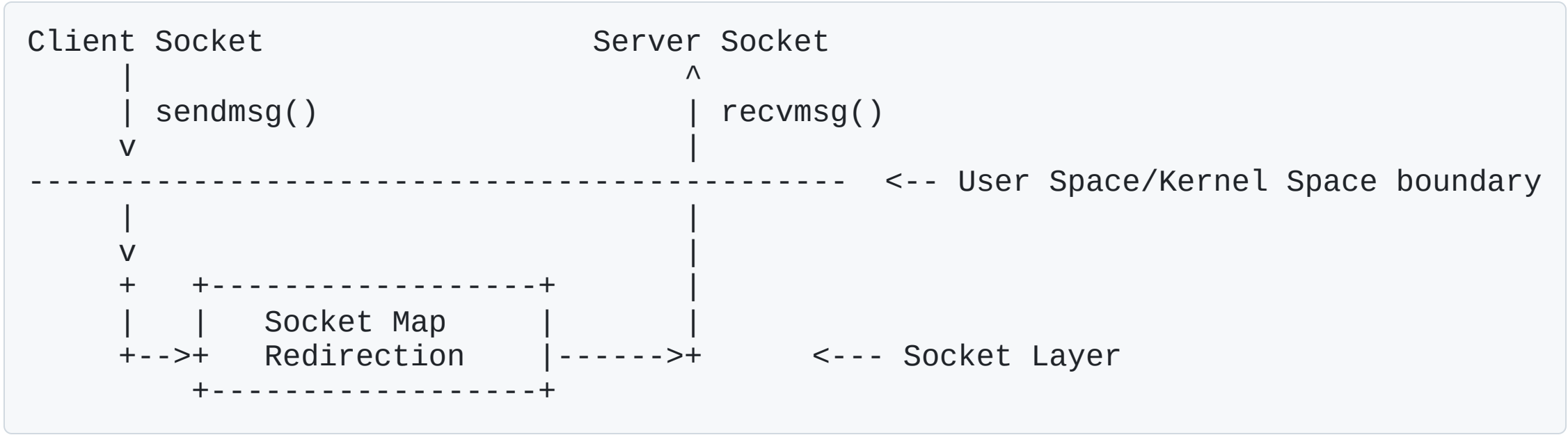
- Socket map: eBPF map type that stores socket references
- `sk_msg` works with sockmap to:
  - Intercept messages at socket layer
  - Apply eBPF programs for verdict decisions
  - Redirect messages between sockets
- Used extensively in socket-level policying and redirection

Data Path Overview

In order of complexity:

- TX -> RX: `sk_msg` -> `sk_msg`
- RX -> RX: `sk_buff` -> `sk_msg`
- TX -> TX: `sk_msg` -> `sk_buff`
- RX -> TX: `sk_buff` -> `sk_msg` -> `msghdr` -> `sk_buff`

Use Case: TCP Stack Bypassing



- A very elegant and simple optimization
- Remember TCP friends?

Use Case: Cilium enable-sockops

- `enable-sockops` is a Cilium feature that leverages sockops to bypass TCP stack
- It is removed in Cilium v1.14 and later
- It hijacks *all* the local TCP sockets and splices the data in between the sockets
- Including loopback TCP sockets, sockets between containers on the same host

Performance Issue #1

- Small messages perform worse than traditional TCP!
  - TCP has sophisticated batching, e.g. `release_sock()`
  - TCP protocol itself supports batching (e.g. Nagle's algorithm)
  - `sk_data_ready()` is batched by `sk->sk_rcvlowat`
  - `sk_buff` is highly optimized by network developers for decades
  - `sk_msg` is a simple structure, with no batching mechanism (as of now)
  - `lock_sock()` is really a performance killer

Performance Issue #2

- Data copying on the redirection path:
  - Ingress (relatively okay):
    - `tcp_bpf_recvmsg()` takes `sk_msg`
    - `sk_psock_skb_ingress_enqueue()` moves data from `sk_buff` to `sk_msg`
  - Egress (bad):
    - `->sendmsg()` moves data from `sk_buff` to `struct msghdr`
    - `->sendmsg()` copies data from `struct msghdr` to a TX `sk_buff` again
    - It is not trivial to reuse `sk_buff` from RX for TX

Batching Ingress `sk_msg`

- Excellent work by Zijian Zhang
- Introduces a kworker-based message corking mechanism
- Adds a backlog queue to accumulate messages before delivery
- Intelligent notification based on buffer fullness, message size etc.
- Significantly improves throughput by reducing wake-ups and lock contention

What About Egress?

- Egress is very different from ingress
  - `->sendmsg()` is invoked directly but also serves `sendmsg()` syscall
  - But TCP `->sendmsg()` itself could coalesce packets
  - Reuse TCP Nagle's algorithm for free

RX and TX Contexts

- Networking RX is typically in softirq context (unless in `ksoftirqd`)
- Networking TX is typically in process context, nearly synchronous with `sendmsg()`
- `skb->data` is already past all headers at the point of `->sk_data_ready()`
- `struct sk_buff` has a layer-specific control buffer `skb->cb[]`
- And `skb->dst`, `skb->sk`, `skb->mark`, etc.

Idea: Scrub `sk_buff` and Replace `->sendmsg()`

- Scrub RX `sk_buff` properly and place it directly to `sk->sk_write_queue`
  - We already have `skb_scrub_packet()`
  - Replace `->sendmsg()` with direct skb queueing
  - Eliminate the data copying

Idea: Lockless Socket Accounting

- Socket accounting functions on receive side:
  - `sk_mem_charge()` / `sk_mem_uncharge()`
  - `atomic_add()` / `atomic_sub()` on `sk->sk_rmem_alloc`
  - `__sk_rmem_schedule()` for memory reservation
  - Those counters are atomic anyway
  - `__sk_mem_raise_allocated()` is a monster
- This is possible in this simple case
- Need to satisfy `inet_sock_destruct()`

Idea: Get rid of `psock->work`

- This is essentially hard due to atomic context
  - RX softirq context and `bh_lock_sock()`
- `lock_sock()` itself is blocking too (shrug)
- Potentially there are more blocking operations along the path

Idea: One `__sk_buff` to Rule Them All

- Ideally, no more `sk_msg` on all the data path
- Too late to change some eBPF socket map programs due to compatibility
- But we can always introduce new programs
- Apply "message" verdicts to `__sk_buff` instead

Idea: Implement struct proto with struct_ops

- Socket map rebuilds `struct proto` anyway
- Since we already (always) replace `->recvmsg()`, why not others?
- Goal: User-defined AF_INET socket operations
  - TCP sockets from userspace, your own logic in kernel space
  - Possibly replace those TCP sockops, for non-TCP sockets

Thank You!

Questions?

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