Optimizing Envoy's Network Stack with Kmap

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1 Introduction

The development of the microservice and servicemesh has brought the sidecar container to the forefront of distributed services. These sidecares provide shared features among services deployed on the servicemesh. However, these sidecars are often interjected in a service-agnostic way by modifying iptables to redirect network communication through the sidecars. This process can introduce significant latency to responses. Istio has benchmarked Envoy to add between 5-10ms to response latencies on average for small to medium sized meshes (<=16 concurrent connections) [1]. We focus on the Envoy [3] sidecar used by the Istio [6] servicemesh.

We present Kmap as an alternative library loaded via LD_PRELOAD using shared memory to optimize data communication between processes. Our work focuses on two key aspects:

1. Building an efficient data path between Envoy and services
2. Developing a robust API which mirrors classic POSIX sockets, which most common languages and tools use for interacting with the kernel stacks

Our initial prototype explores challenges and design paths for the development of Kmap. We highlight challenges for implementing Kmap for production network systems. Then, we present our prototype working on sample C/C++ webservers.

2 Background

Recent shifts to microservice architectures and the resulting servicemesh have prioritized development and deployment efficency over performance. Microservices deployed on a servicemesh (i.e. Istio [6]) use proxies which are co-located with microservices. These proxies intercept and control networking communication between services. The proxies are relatively lightweight, but use the networking stack for communication with the co-located service (Figure-3). They do this to preserve a common interface for services– the networking stack. Istio uses Envoy [3] which is the tool we focus on here for Kmap.

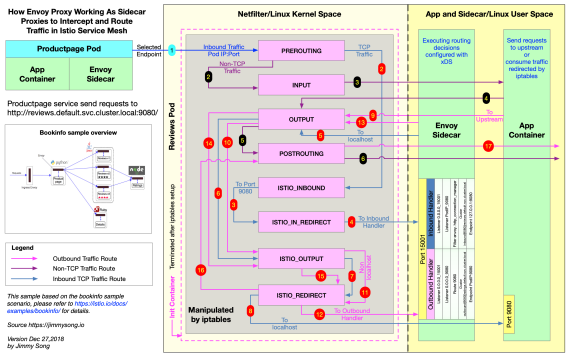

Figure 1: Envoy Network Stack [9]

3 Kmap

Our design for Kmap focus on avoiding costly, unnecessary invocations of the network stack. These network calls involve copying of bytes between two processes and kernel context switches. Avoiding the extraneous copying and reducing the frequency of context switches should greatly improve data transfer speed. Envoy prides itself on being application agnostic, which leads to the helpful ability to auto-inject Envoy into microservices. However, this abstraction results in unnecessary invocations of the network stack. In Figure-3 we highlight in red all the calls to the network stack for the path of a single request. Then, in Figure-2 we show the reduction in those calls by using Kmap instead of the network stack for local data transfer.

Kmap works by using LD_PRELOAD to load Kmap before libc regular calls. Kmap contains several functions which match the signature of libc network calls and thus when applications invoke those calls, Kmap's version of those functions

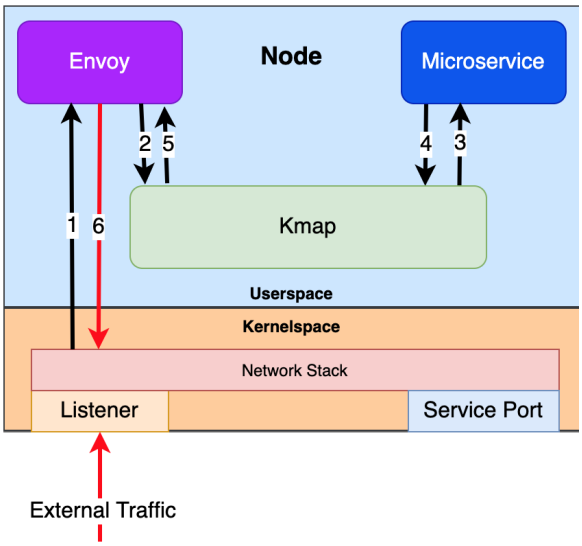

Figure 2: Kmap

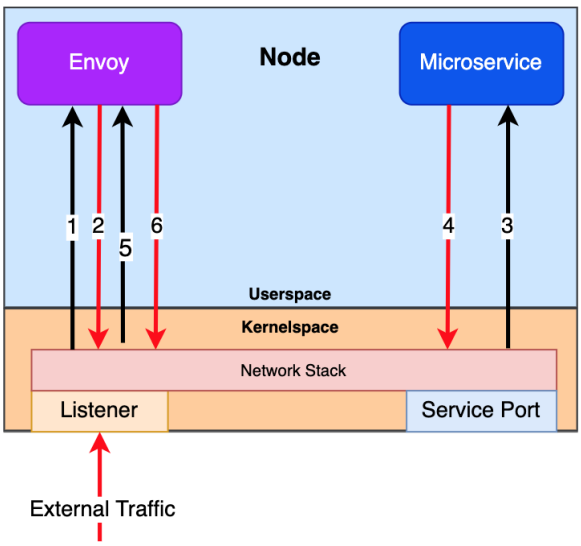

Figure 3: No Kmap Envoy Network Stack

is invoked instead of libc. Using the Kmap functions, Envoy and the microservice call read and write passing data through userspace rather than passing the data into the network stack, using shared buffers to efficiently transfer the data. Thus, we must load the shared library for both the Envoy sidecar and the microservices. The two critical challenges to realizing Kmap are:

1. Building a robust, efficient shared buffer system that's *faster* than the network stack

2. Determining in a microservice-agnostic way which POSIX network calls should be preloaded by Kmap

3.1 Intercepting Network Calls

Direct libc Modification: One method of implementing Kmap would be to modify libc in environment for Envoy and the service. This option, however, would require extensive infrastructure modification to ensuring Envoy and the service each boot with the proper libc version (compiled for them). Further, the library change would effect any other process running the in the same environment (container or system) and thus Kmap would have to handle calls from neither Envoy or the service.

LD_PRELOAD: The Linux LD_PRELOAD command [7] allows users to preload particular libraries ahead of the conventional linker and loader. This enables users to load symbols before classic libraries (e.g. libc, syscalls). Commonly this is referred to as the "LD_PRELOAD trick" [2]. The LD_PRELOAD command modifies the linking process of the particular process it is attached to, requiring no modification of the default library and not interfering with any other process.

For Kmap, we use LD_PRELOAD to load the Kmap libraries before conventional libraries such as libc. Inside each Kmap library we use *dlsym* to load the "real" libc functions we wrap. Thus, we can use libc functions in Kmap, passing through most calls, while intercepting and adjusting only the subset relevant to Kmap. From a maintainability perspective, this allows libc and Kmap to evolve independently while remaining compatible.

3.2 Pipe options

Here, we outline potential methods for implementing the buffer Kmap uses to pass data between Envoy and the microservice.

Named Pipes: Named pipes, (FIFO) are blocking, unidirectional I/O buffers for passing data between two processes. The pipe must be opened for both reading and writing before being written two. Named pipes are traditionally slow, only offering slight speed advantages over TCP [5]. Further, they are un-directional which makes them less accessible or interchangeable compared to TCP.

Unnamed Pipes: Unnamed pipes are slightly faster than Named pipes, but are created per-process. They traditionally are used when a process forks, as they both will share a reference to the pipe. This makes them particularly tricky to implement across two independent processes and thus unhelpful for Kmap.

Shared Memory: Shared memory is a robust API which allows processes to share use of a memory region (*schm_open*). This requires mapping the same underlying memory region into the virtual memory of each process (*mmap*). Shared memory is concretely faster than pipes and the primary API Kmap uses for communicating information. Shared memory has

been benchmarked to be 170 times faster than TCP sockets for communicating information between processes [5]. However, shared memory does not directly provide a buffer interface like TCP, ans so Kmap must implement that as part of its library.

3.3 Dual Pipes

Since Kmap mirrors the network stack for two unique clients, Envoy and the service, we must implement two circular buffers. These buffers are unidirectional, providing read/write direction for each service. A core function of the POSIX network stack is blocking write and reads using syscalls like *select* and *epoll*. As such, we use have dedicated synchronization for each buffer using pthread mutexes and conditional variables. We display these aspects of Kmap in Figure-4

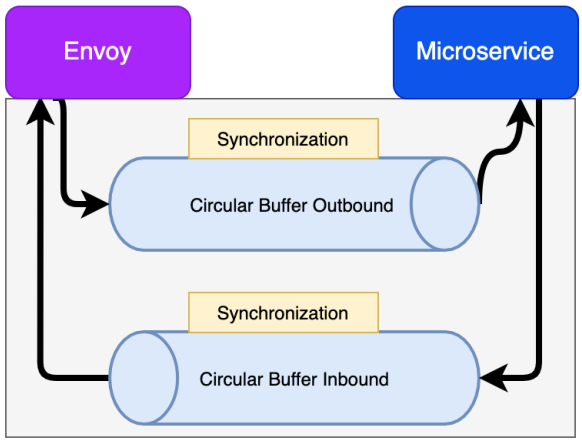

Figure 4: Kmap Design

3.4 When to apply Kmap

The network stack has a very well defined, robust API commonly called POSIX sockets. A particular challenge for Kmap is pre-loading in front of these network calls and knowing when to pass through the call, or when to route to the local buffer. Since Kmap is designing primarily for Envoy, we use information about how it communicates with microservices to determine which file descriptors should use Kmap. The Envoy codebase uses unique handlers for different requests (e.g. gRPC, TCP, HTTP 2, HTTP 3, QUIC) and as such Kmap will have to adjust it's structure to match the protocol in use. For now the focus of our Kmap prototype, discussed in Section-4 is Envoy's HTTP stack. We do not view Kmap as generalizable to other Envoy paths or other tools (e.g. Linkerd) without thorough inspections of the pathways. It is likely for Kmap to generalize it would require the tool and path as part of its compilation process.

4 Prototype

Here, we discuss our current prototype, challenges, and target applications. Currently we compile a single shared object ({envoy,service}.so) for each side using compiler flags. It is imperative we intercept syscalls on each side, and as such we must know which side of communication the library is running on to determine which network calls to intercept. Our library is written in C and is approximately 800 LOC.

4.1 Kmap Buffer

Our implementation of Kmap uses *shm_open* and *mmap* to map shared buffers across the two processes. The buffer structs container a data buffer, head/tail integers, and pthread mutexes and conditional variables for synchronizing access. We implemented write/read, and write(v)/read(v) APIs for the buffers since Envoy uses iovec structures for reading and writing.

Function	Envoy	Service
connect	X	
accept		X
write	X	X
read	X	X
writev	X	
readv	X	

Table 1: Libc Functions Preloaded (Tiny C Webserver)

4.2 Kmap Network Calls

The most challenging of Kmap's design is properly intercepting and replicating the behavior of network system calls. This aspect is especially challenging because Envoy uses unique handlers for request types (UDP, TCP, HTTP{1,2,3}, gRPC, Quic). Further, the service itself may use the network stack in obtuse ways. Our investigation of Flask [4] has revealed a number of idiosyncrasies with how Flask uses the network stack. To make Kmap generalizable, you would truly have to intercept very single network call (or possible network related). This task is enourmous. For our prototype we have focused on HTTP. In Table-**??**, we show the calls on each side we intend to link to use Kmap for flask. Currently our prototype is geared for the tiny C server (Table-1).

4.3 Kmap Status

We have found tracing the call paths and stack for the networking calls of the C web server and flask tremendously difficult. As of now we do not have a functional prototype for results.

5 Related Work

NetKernel: [8] This work focuses on moving optimizing the network stack by moving it out of the kernel. The impetus was in the VM-age, riping the kernel out of the VM itself provides more control and optimization for users. Their improvements include shared memory. In their work (Section 4.1) they discuss the use of LD_PRELOAD for transport socket redirection. For their usecase, LD_PRELOAD was not robust enough and required too many mappings. However, we see that for Kmap the transport socket redirection should be sufficient.

Slim (OS): [10] SlimOS addresses performance challenges within the container network stack. Similar to Kmap, they attempt to avoid traveling the virtualized network stack and directly preceding through the host network interface. They work works at a lower abstraction level than Kmap but employs a similar principal. SlimOS dynamically links its user-space library onto of containers using LD_PRELOAD on unmodified application binaries.

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