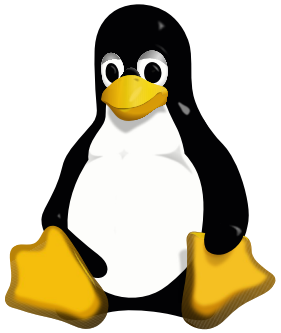
Joyride: Rethinking Linux's Network Stack Design

Yanlin Du, Ruslan Nikolaev
The Pennsylvania State University
KISV '25, Seoul, Republic of Korea

PennState

The Growing Network Performance Gap



200-800 Gbps NICs

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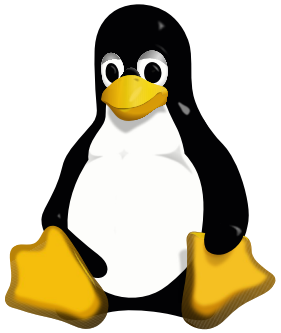
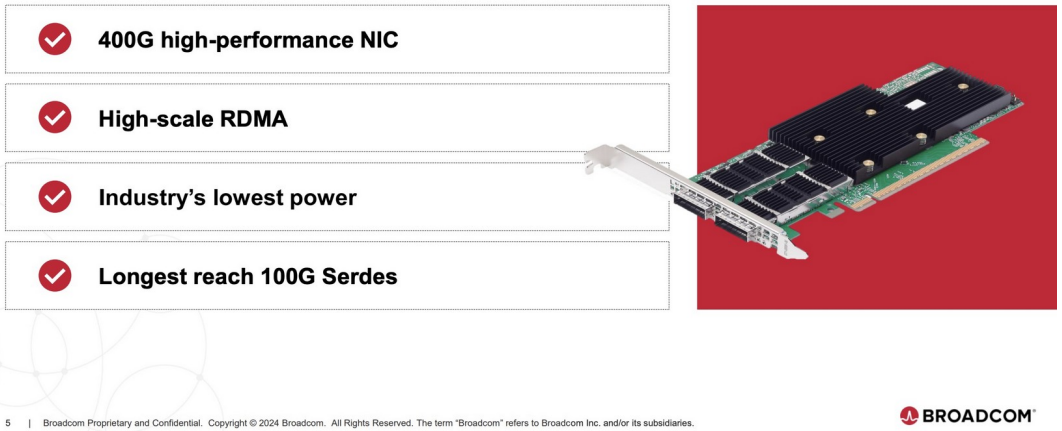


200-800 Gbps NICs

Introducing
The Broadcom
400GbE RDMA NIC



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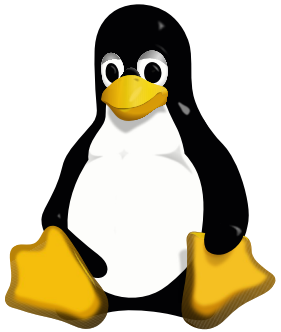

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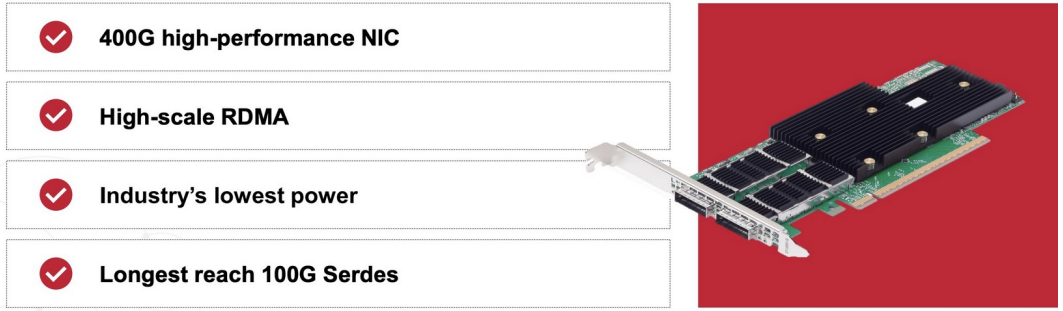

Intel E830 Launch Slide

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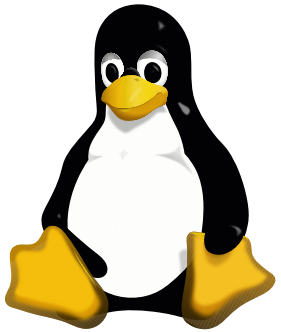

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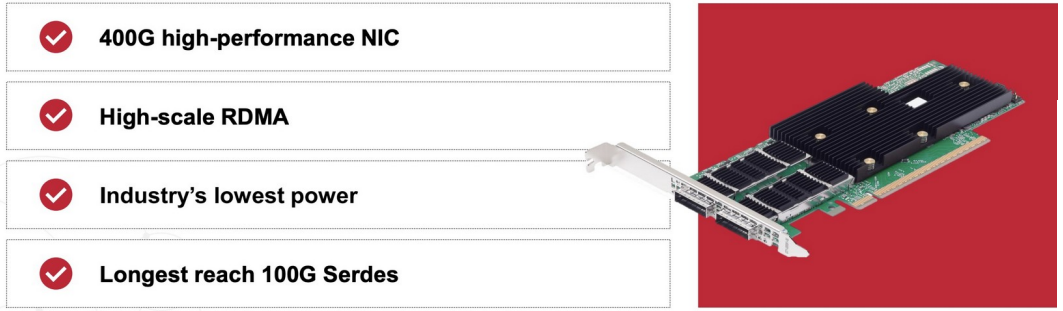

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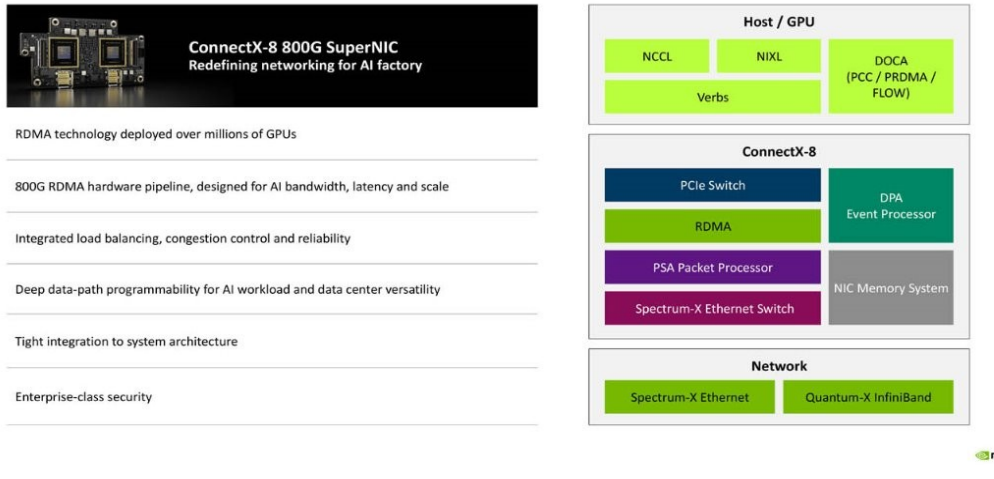

NVIDIA ConnectX 8 At Hot Chips 2025 Page 03

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Network hardware
10 Gbps → 25 Gbps → 50 Gbps → 100 Gbps → 200 Gbps → 400 Gbps → 800 Gbps

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At 100 Gbps with 1500-byte MTU

- 8+ million packets per second

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Kernel processing, not hardware, is now the bottleneck

Limitations of Existing Solutions

Kernel Improvements:

BIG TCP => Bigger TCP window => Enable larger segments, fewer packets to process.
Generic Receive Offload (GRO) / Generic Segmentation Offload (GSO) => Packet coalescing to reduce per-packet overhead
Performance gains are incremental

Kernel-Bypass Solutions:

IX [OSDI'14], TAS [EuroSys'19], Junction [NSDI'24], F-stack, among others

The Fundamental Gap:

No existing system provides a transparent kernel bypass for unmodified applications on standard Linux

Kernel Bypass: IX [OSDI'14]

- An independent TCP implementation that uses DPDK code partially
- **Pros:** Scalable performance, reducing lock overheads
- **Cons:**
  - No POSIX compatibility, custom interfaces
  - No support of numerous TCP extensions
  - Packet delivery reliability issues
  - Not being actively developed, not tested with modern NICs

Kernel Bypass: TAS [EuroSys'19]

- A more recent effort that runs on top of DPDK
- **Pros:**
  - Scalable and CPU efficient stack
  - TAS tries to optimize performance for datacenter applications which helps to reduce costs => faster than IX
- **Cons:**
  - No POSIX compatibility
  - Like IX, does not provide full TCP stack that can replace Linux's TCP
  - Not being updated recently, uses an older DPDK version
  - Data-center specific assumptions: no IP fragmentation, reliable in order delivery, rare timeouts

Kernel Bypass: RDMA

- Enables direct memory-to-memory communication between machines, bypassing the CPU and kernel
- **Pros:**
  - Very low-latency and high-throughput communication
  - Zero-copy data transfer, reducing CPU overhead
  - Offloads tasks to specialized NICs
- **Cons:**
  - Specialized NIC is required => not a suitable general-purpose replacement
  - No TCP/POSIX support

Kernel Bypass: Junction [NSDI'24]

- A datacenter OS with a specific focus on Mellanox/NVIDIA NICs
- **Pros:**
  - Very good performance and scalability
  - Unmodified applications (mostly)
- **Cons:**
  - Cannot replace Linux's standard stack
  - Great performance but unclear how that works outside of Mellanox/NVIDIA NICs
  - These NICs still typically depend on a kernel-level driver

Kernel Bypass: F-Stack

- Uses FreeBSD code to build TCP on top of DPDK
- **Pros:**
  - Good-quality code due to BSD-based TCP implementation
  - Support various TCP extensions
  - POSIX compatibility (but only partial due to lack of multithreading)
- **Cons:**
  - No support for multithreading
  - Limited LibC integration
  - No NIC sharing across different programs

Joyride's Vision

A Microkernel-Inspired Network Architecture

- **User-Space TCP/IP Processing**
  FreeBSD's mature stack + kernel-bypass (DPDK) performance
- **Separate TCP stack instance for each application**
- **Transparent Application Support**
  Modified LibC will integrate network-syscall replacements
- **System-Wide Deployment**
  One service for all apps, no per-application network configuration

Joyride's Architecture

PennState

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- App 1
  High-performance network path via Joyride

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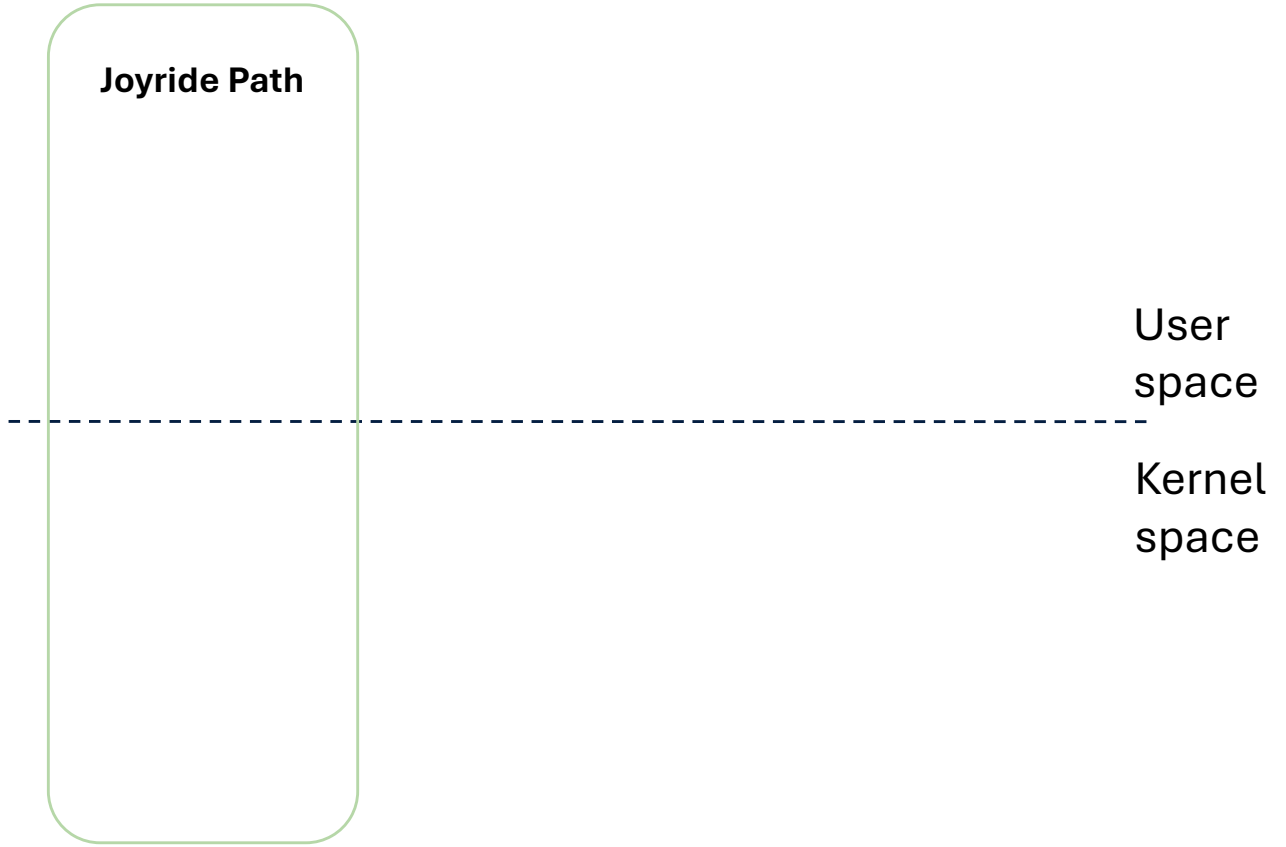

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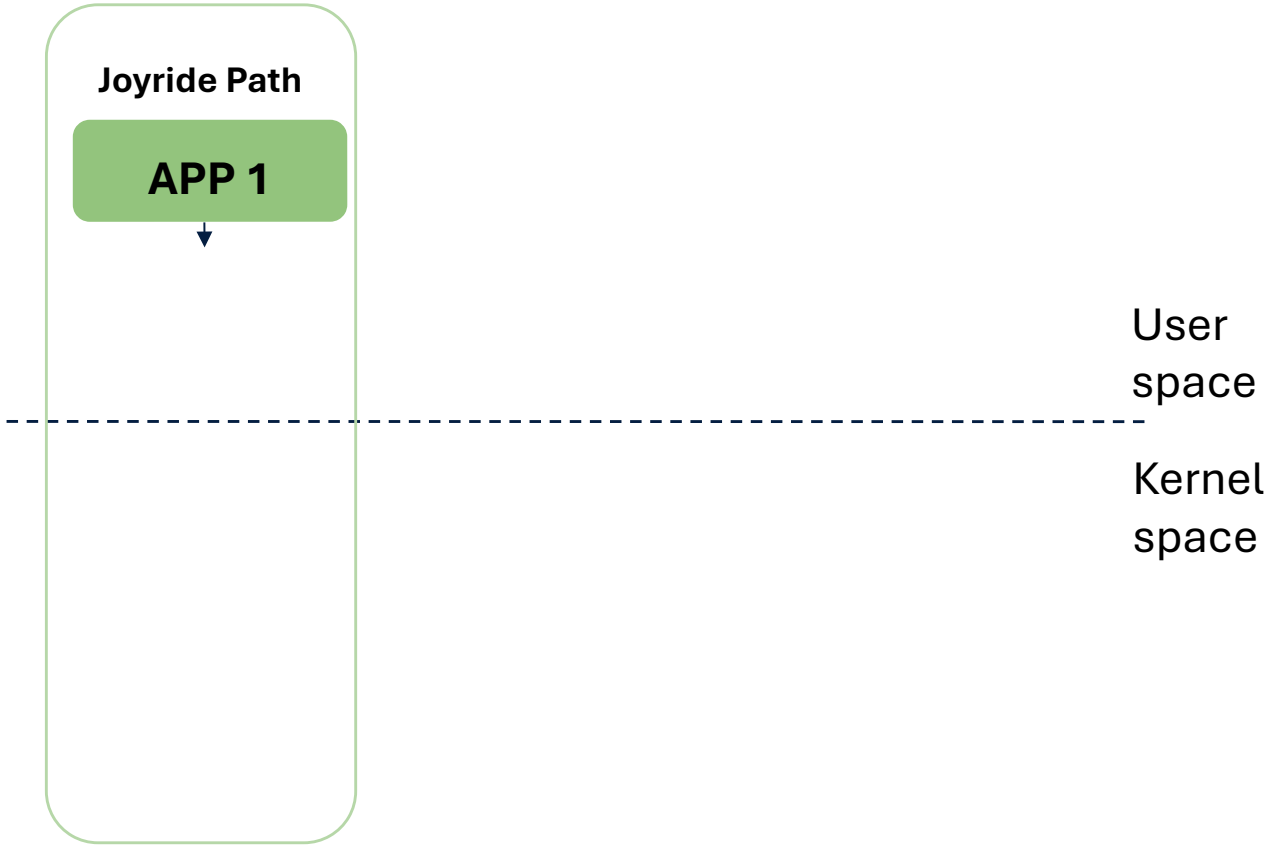

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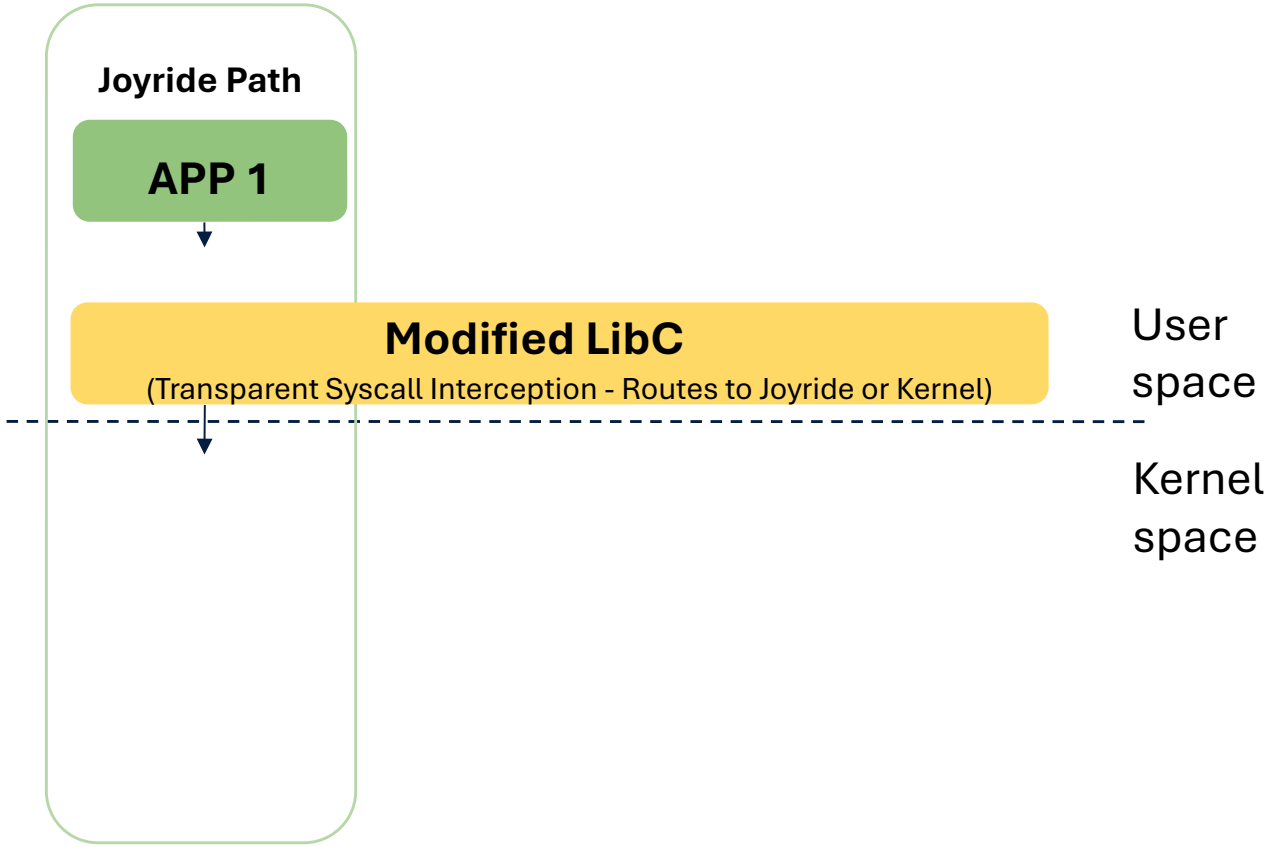

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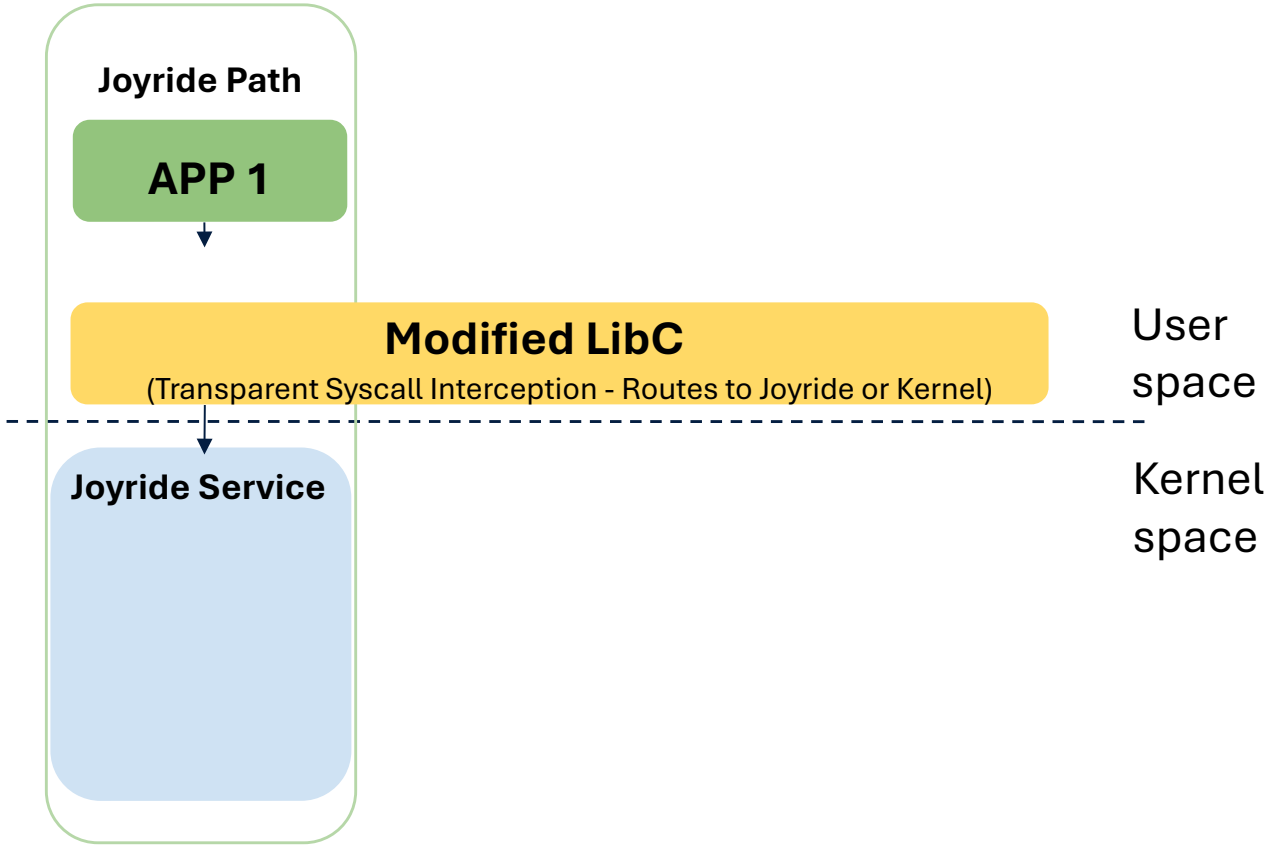

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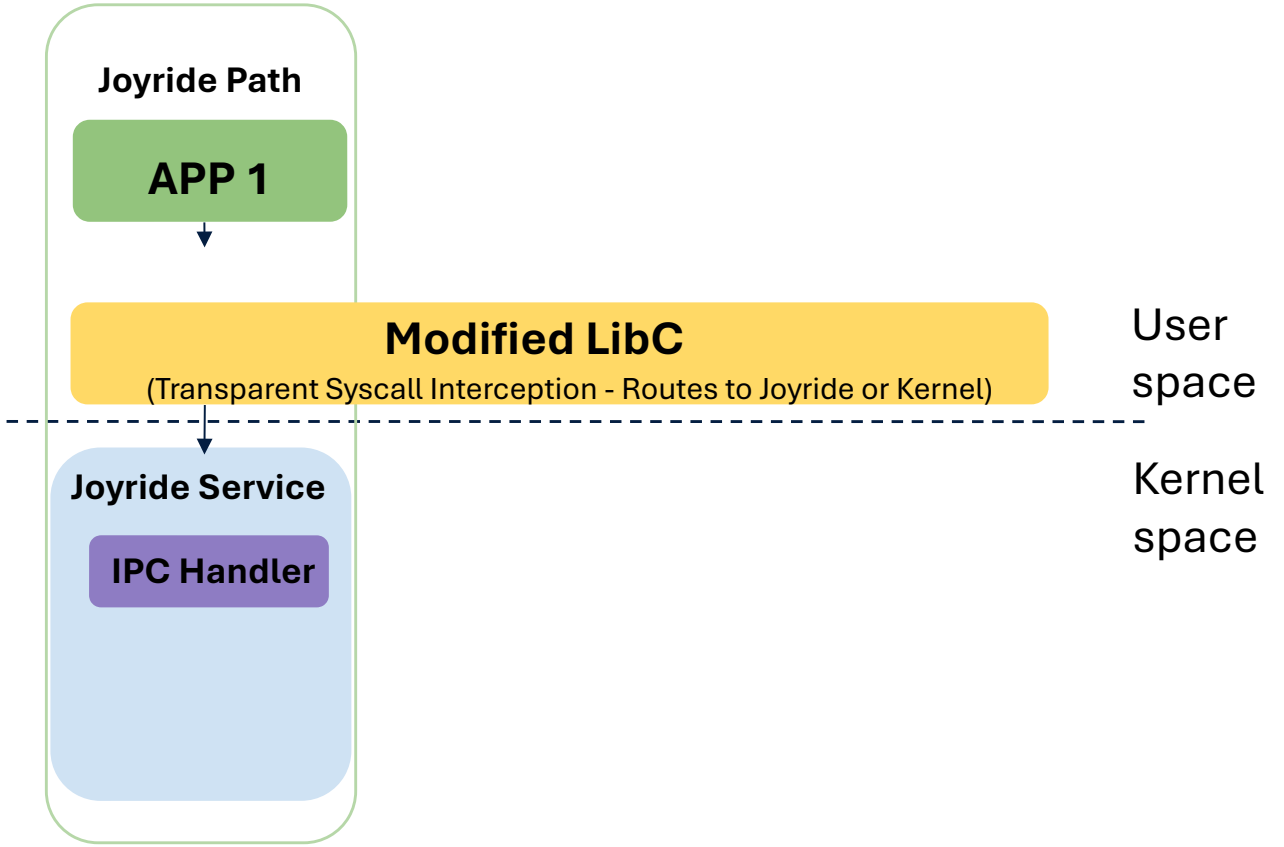

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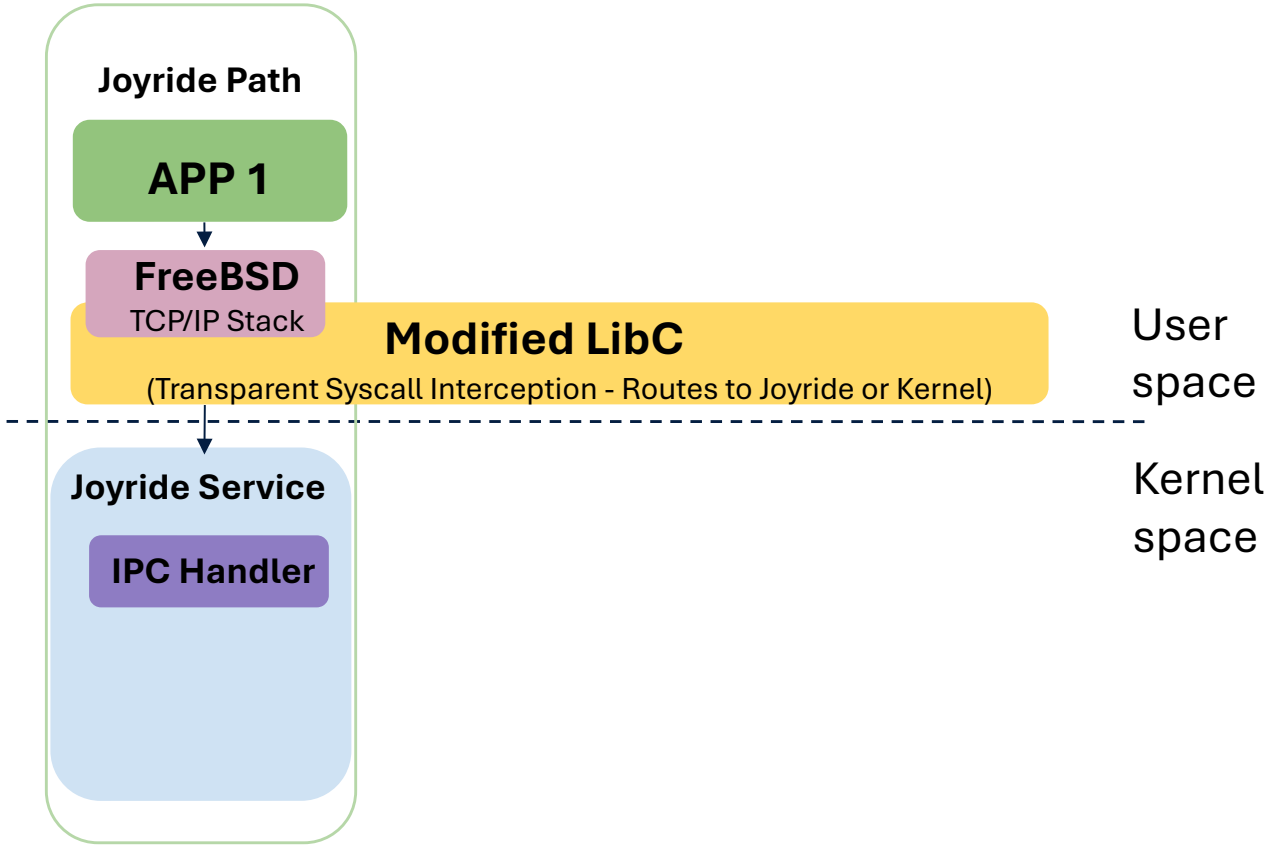

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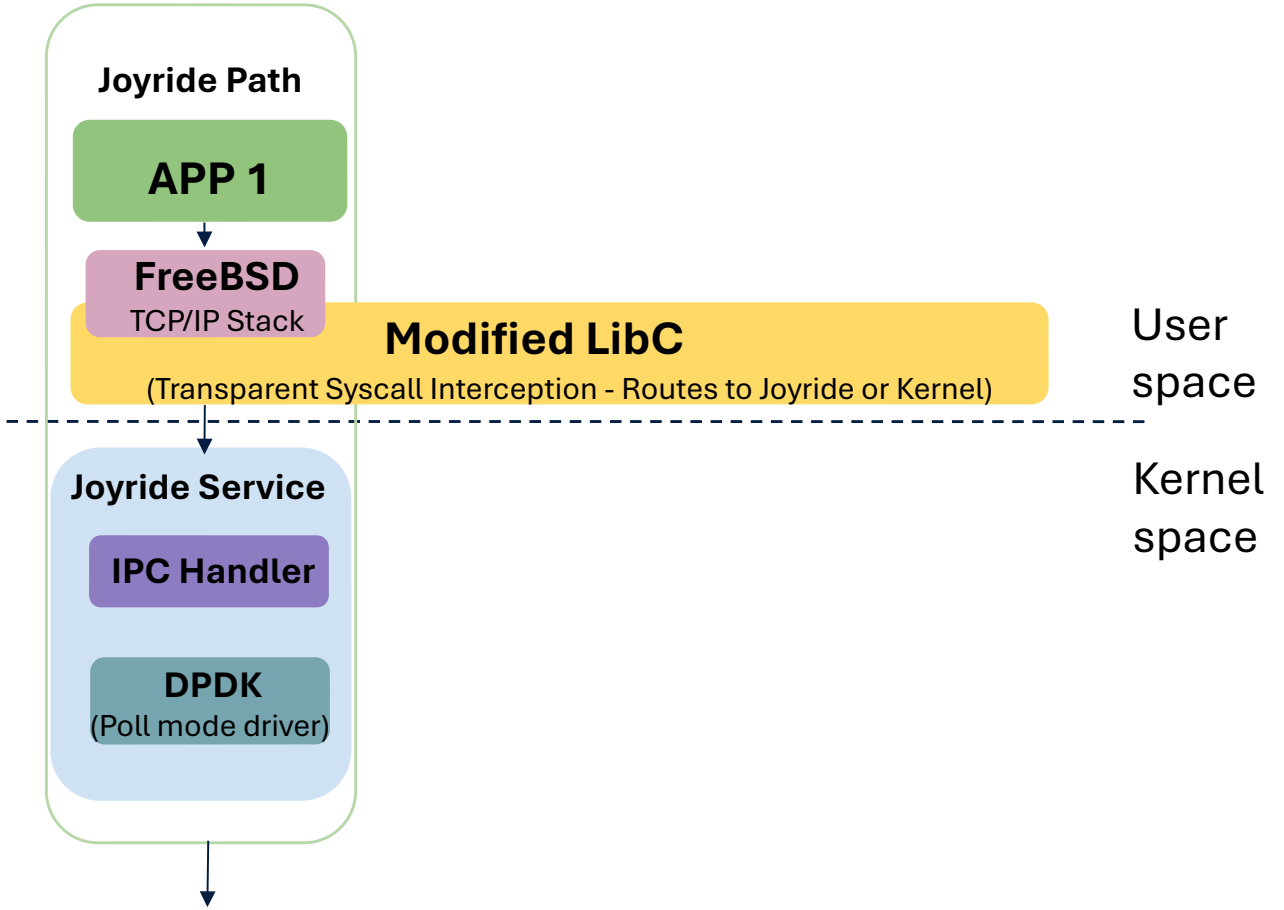

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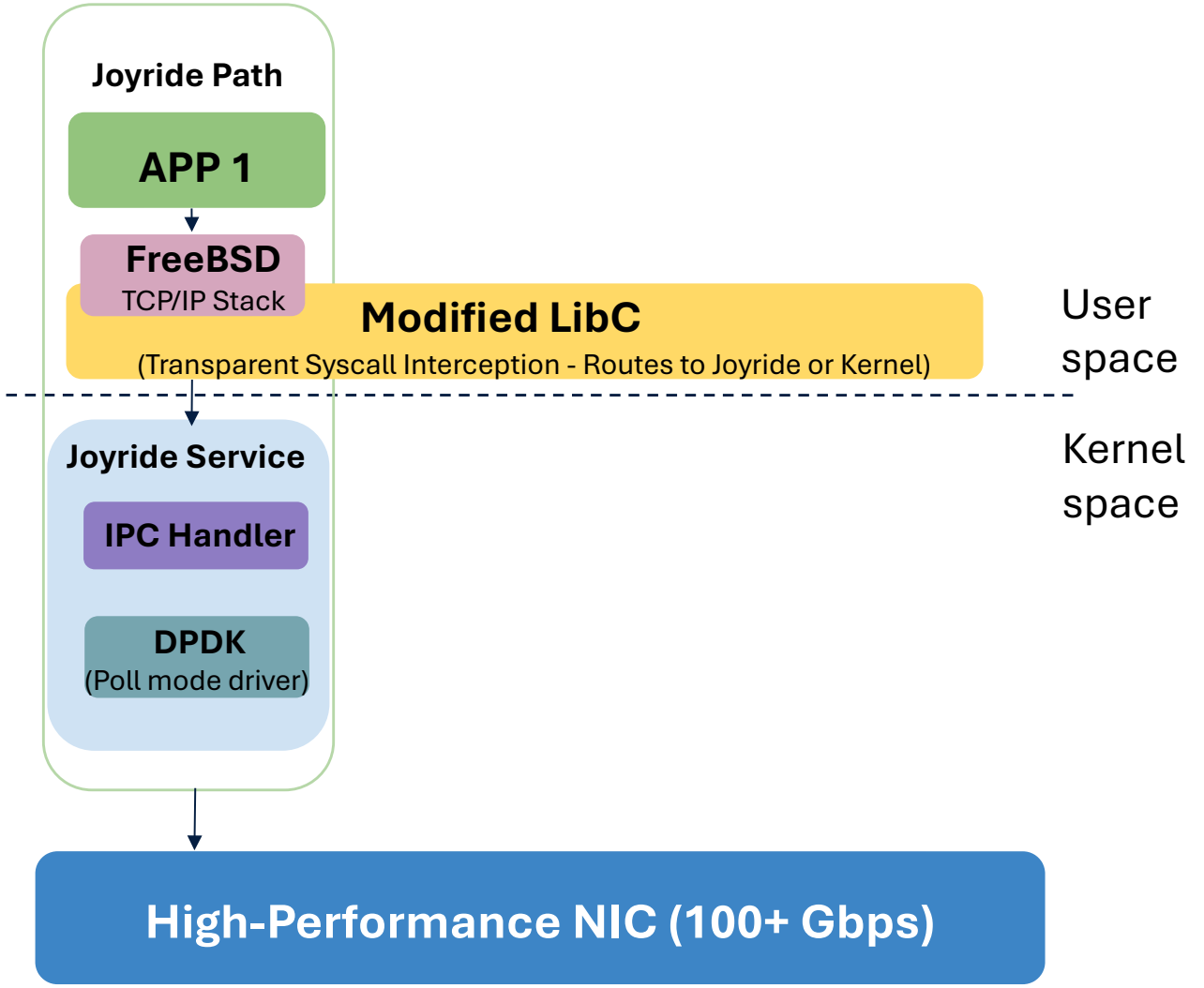

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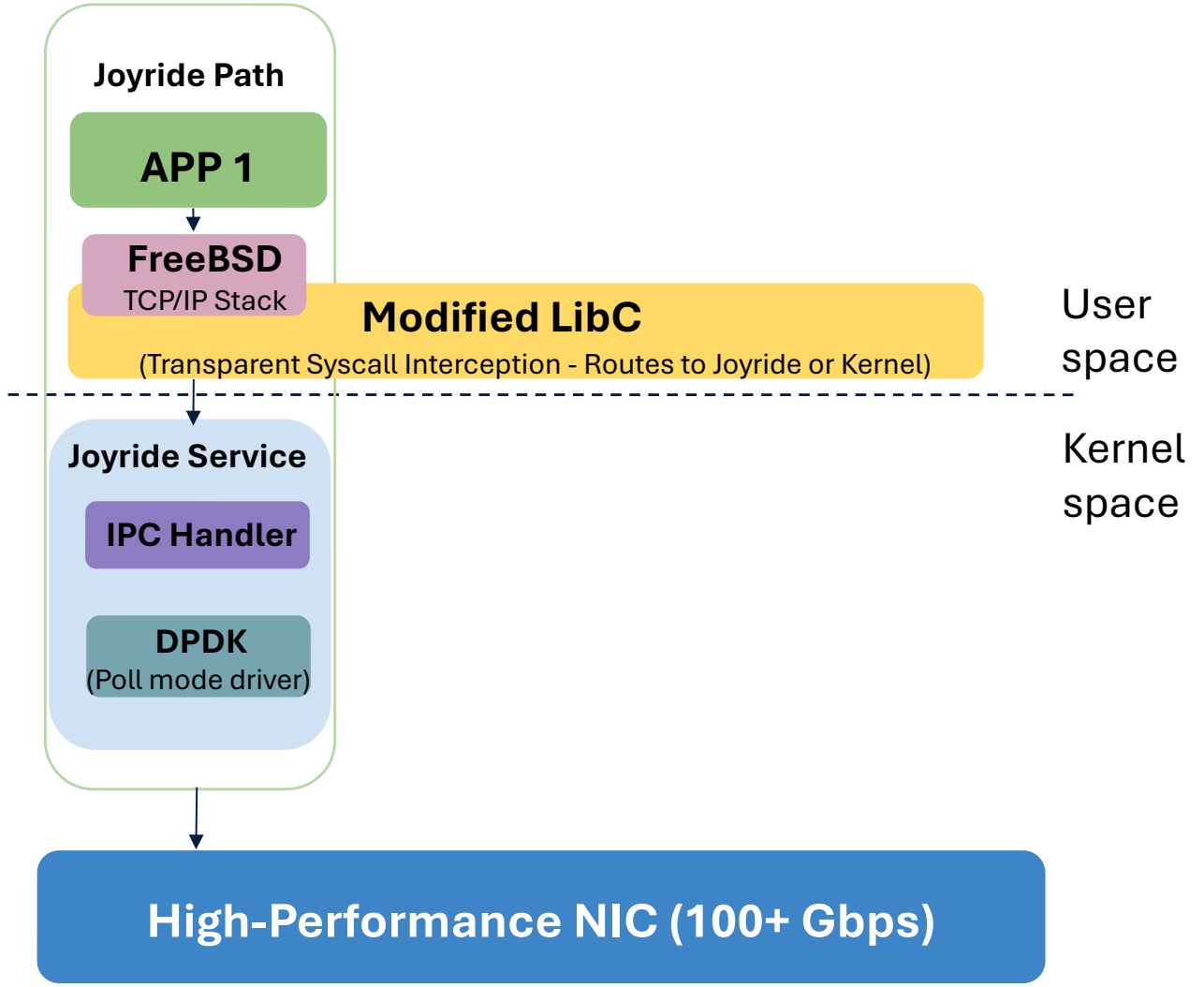

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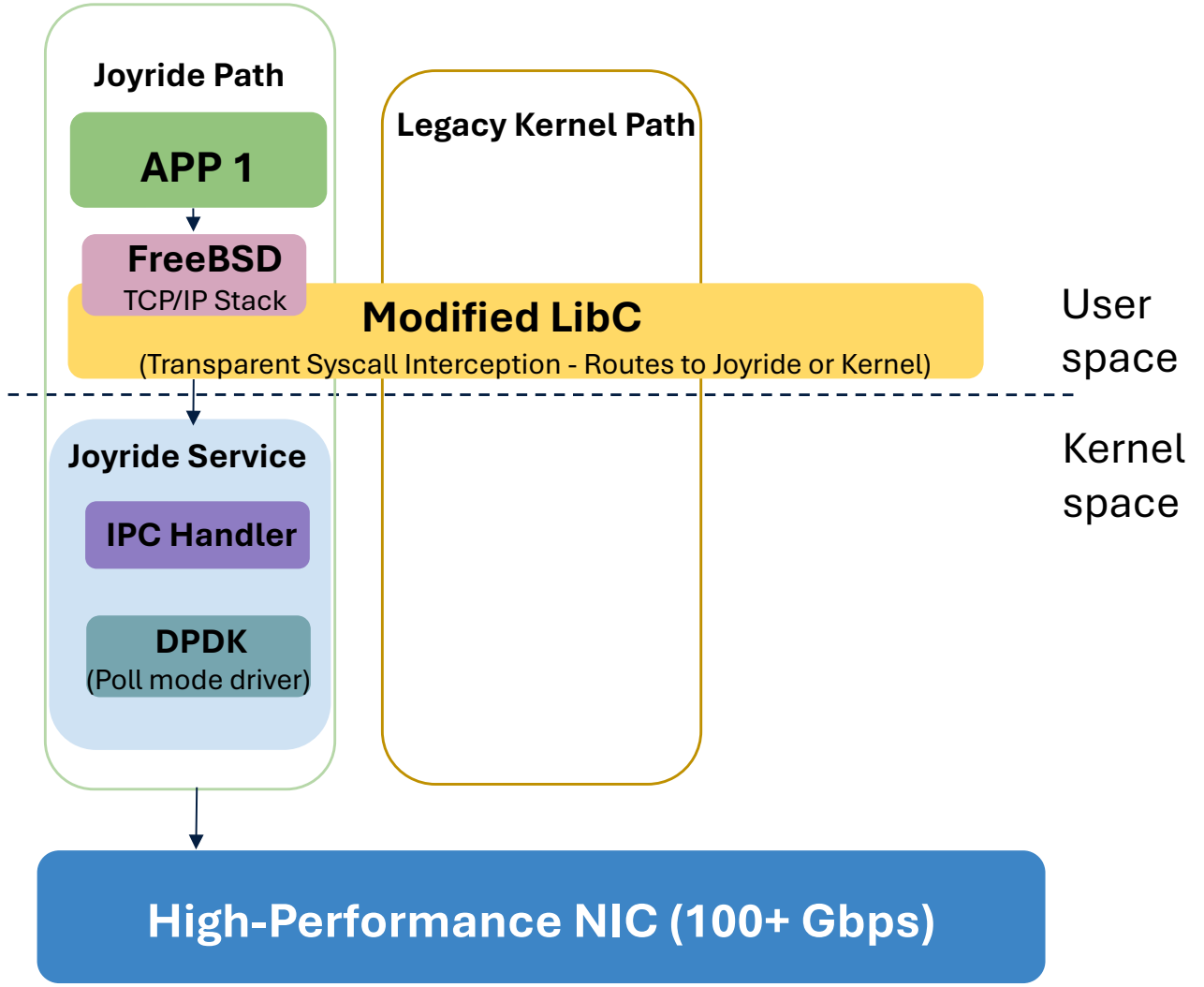

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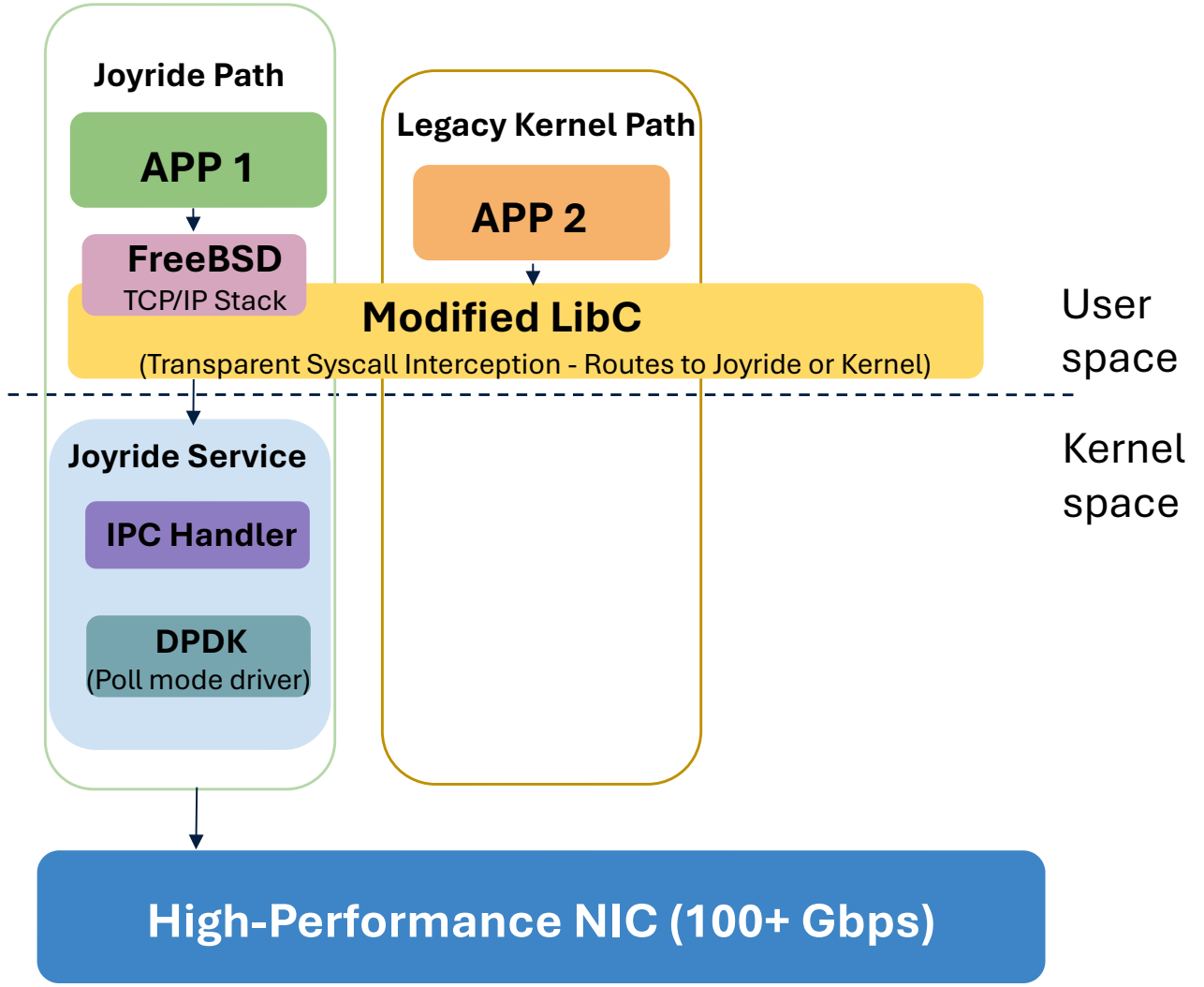

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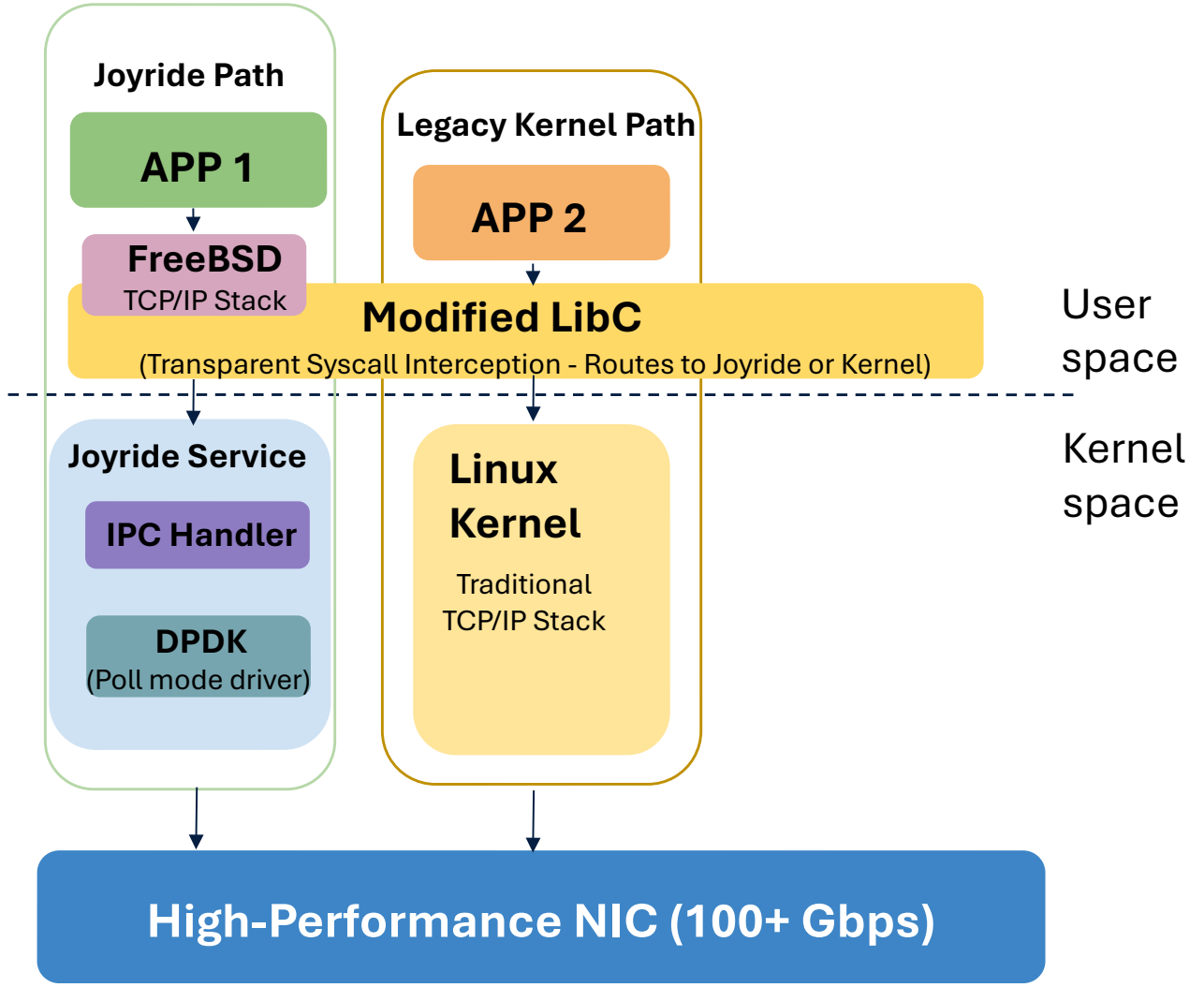

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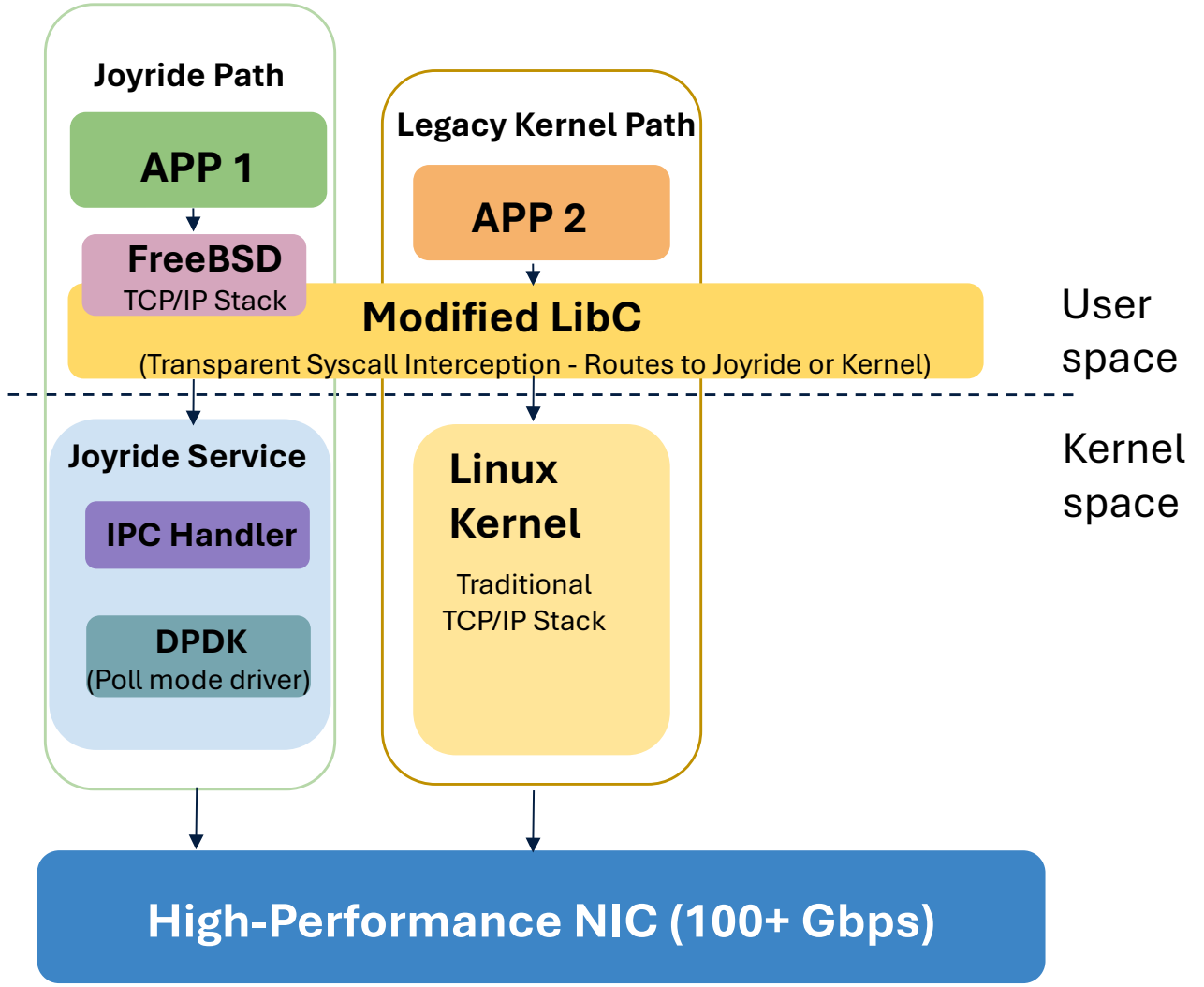

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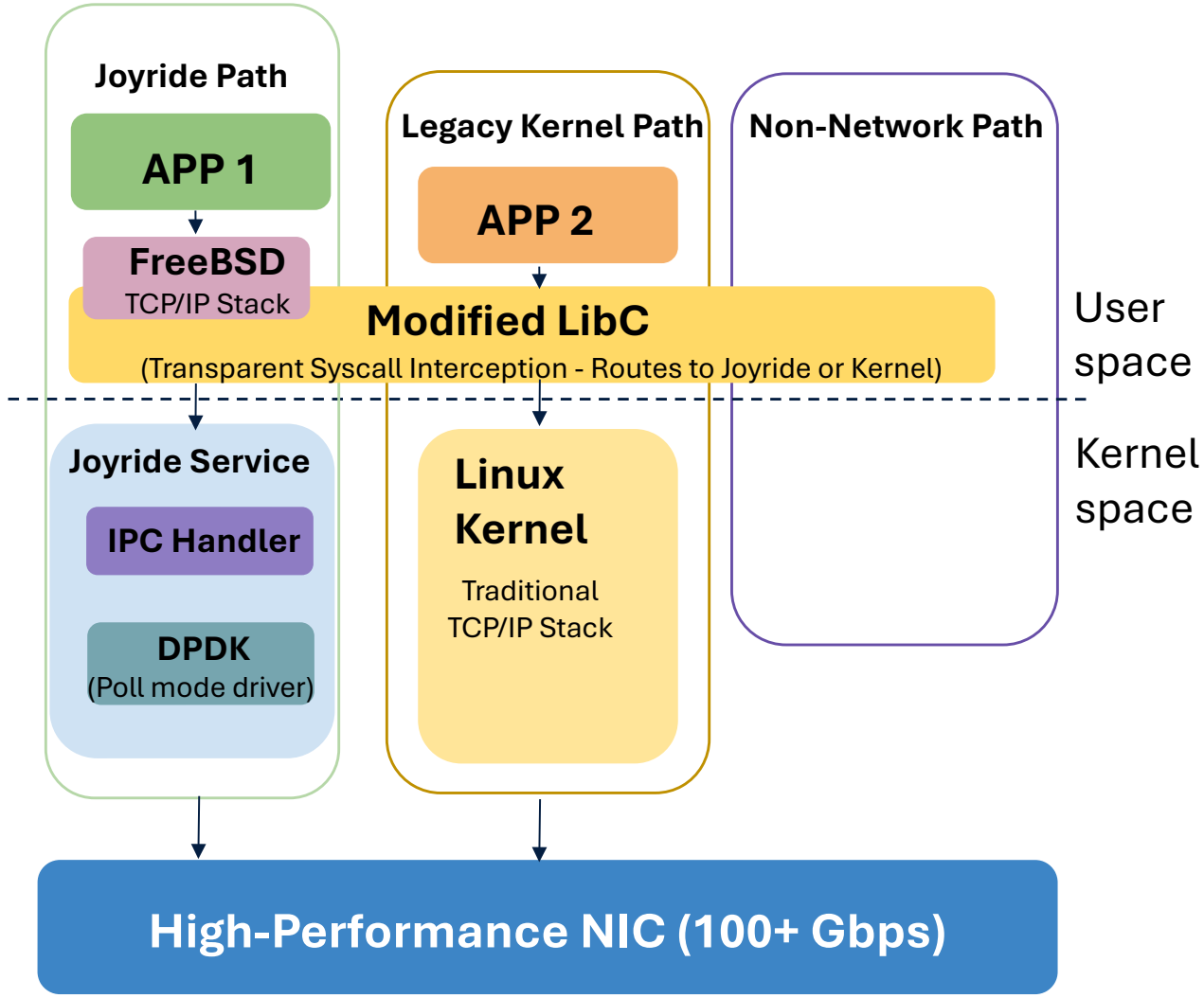

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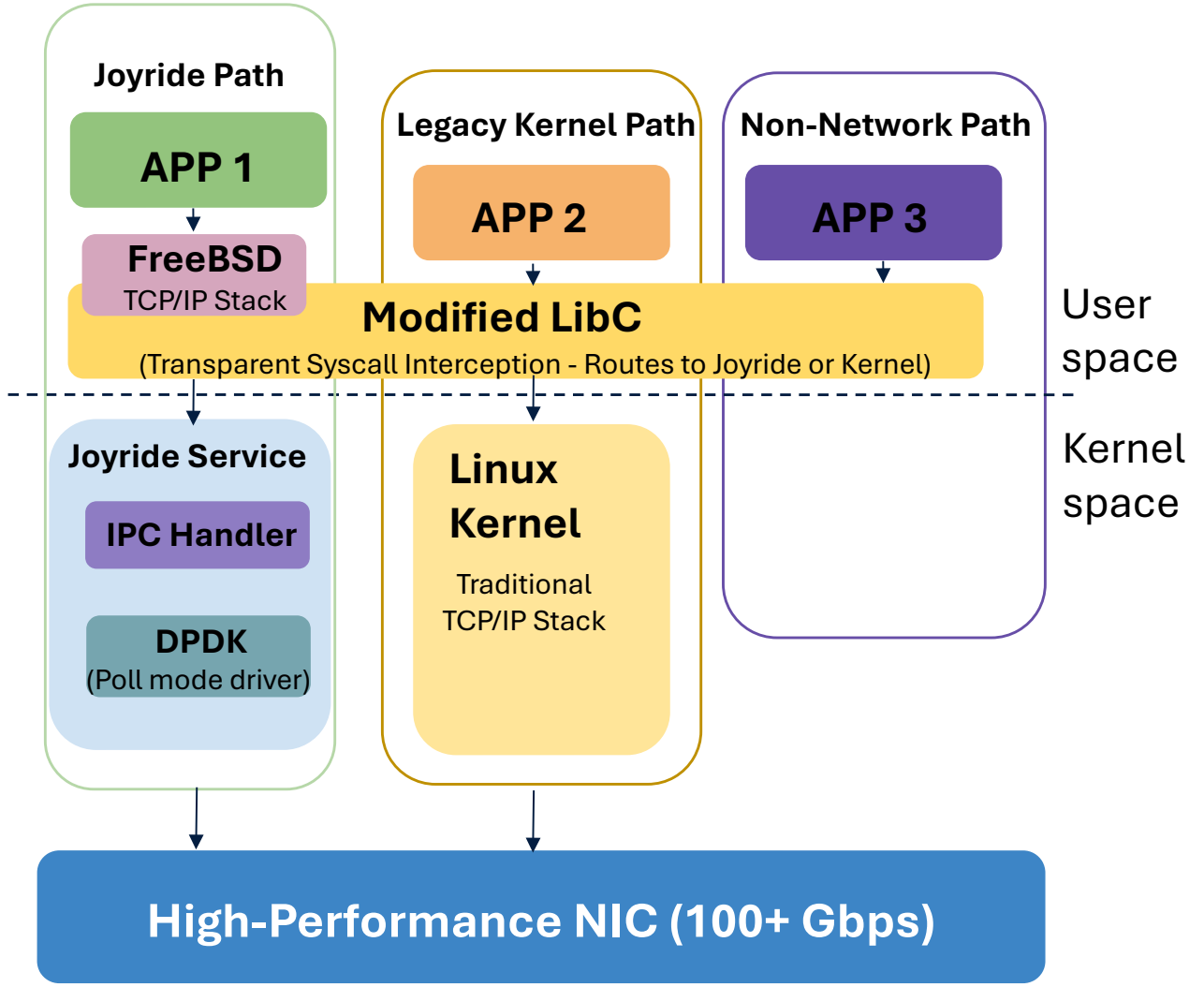

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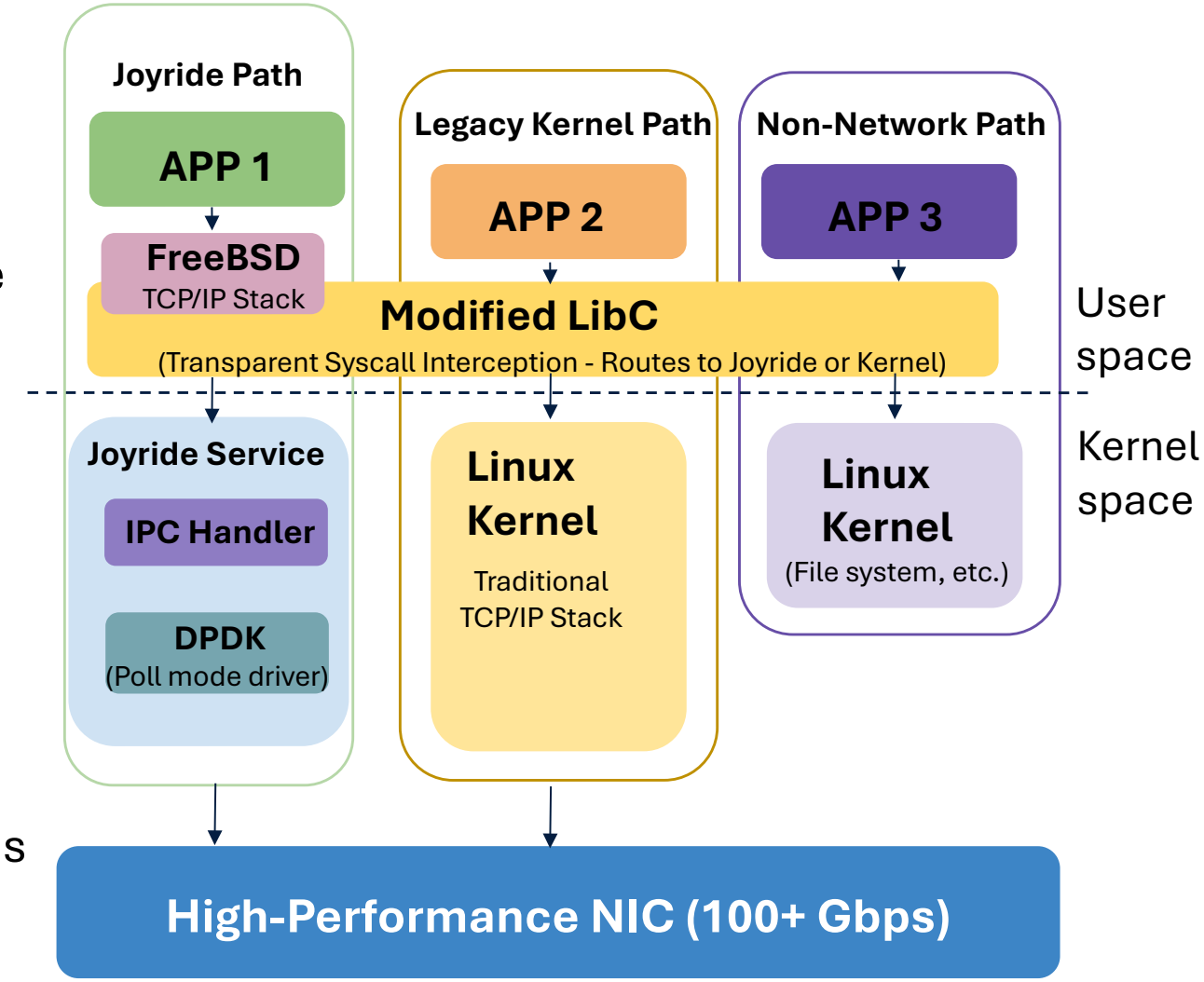

Single NIC shared transparently across all paths using SR-IOV and VF (Virtual Functions)

Potentially multiple isolated Joyride Services

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- Potentially a **hybrid** architecture for high-demanding applications, LibrettOS [VEE'20]

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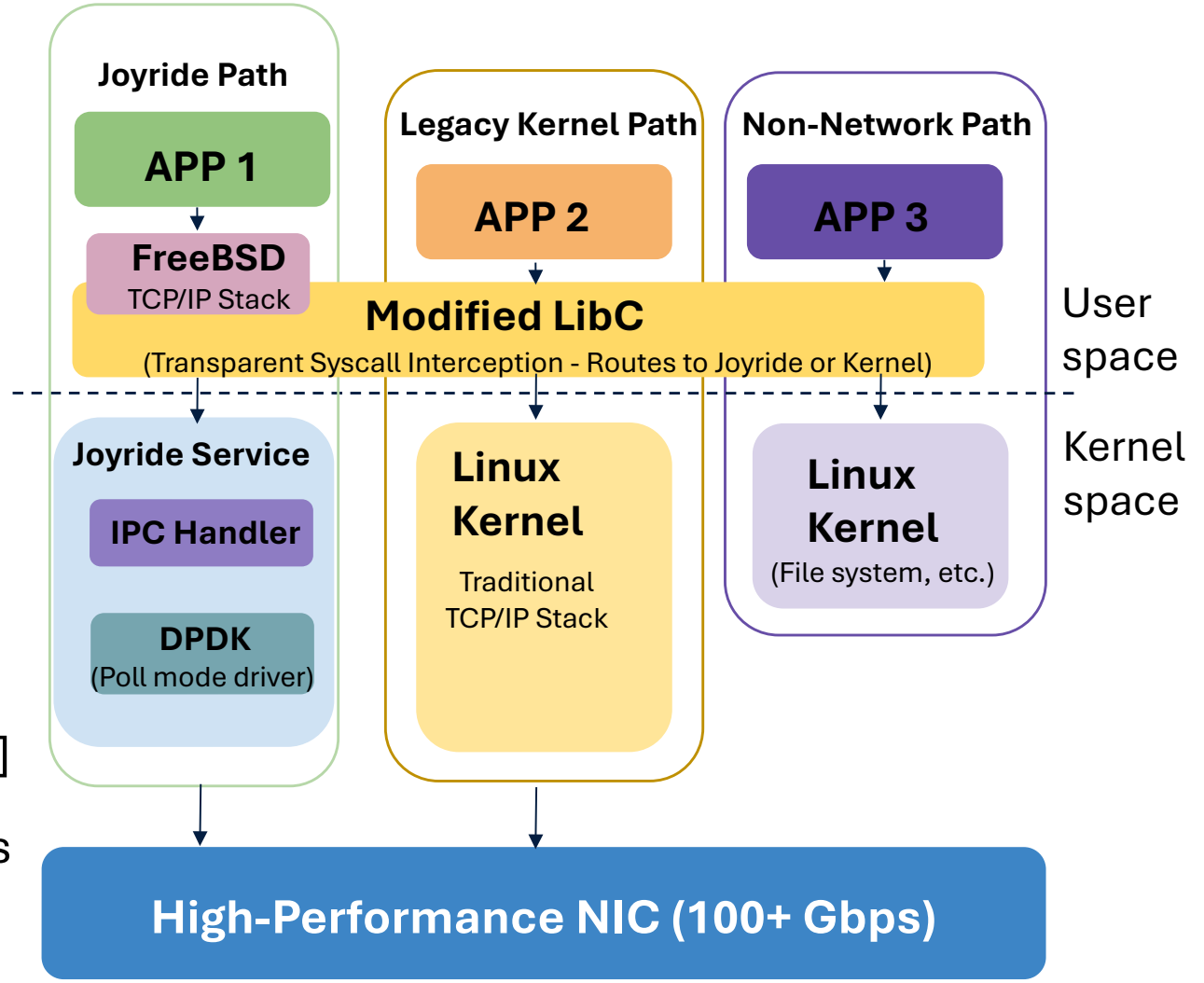

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- **Performance:**
  Will use fast inter-process communication mechanisms based on shared memory and scalable data structures

Preliminary Results: Experimental Setup

Hardware:
AMD EPYC 9005 series (both client and server)
Intel E810 100 Gbps NICs

System:
Ubuntu 22.04
Linux kernel 6.2

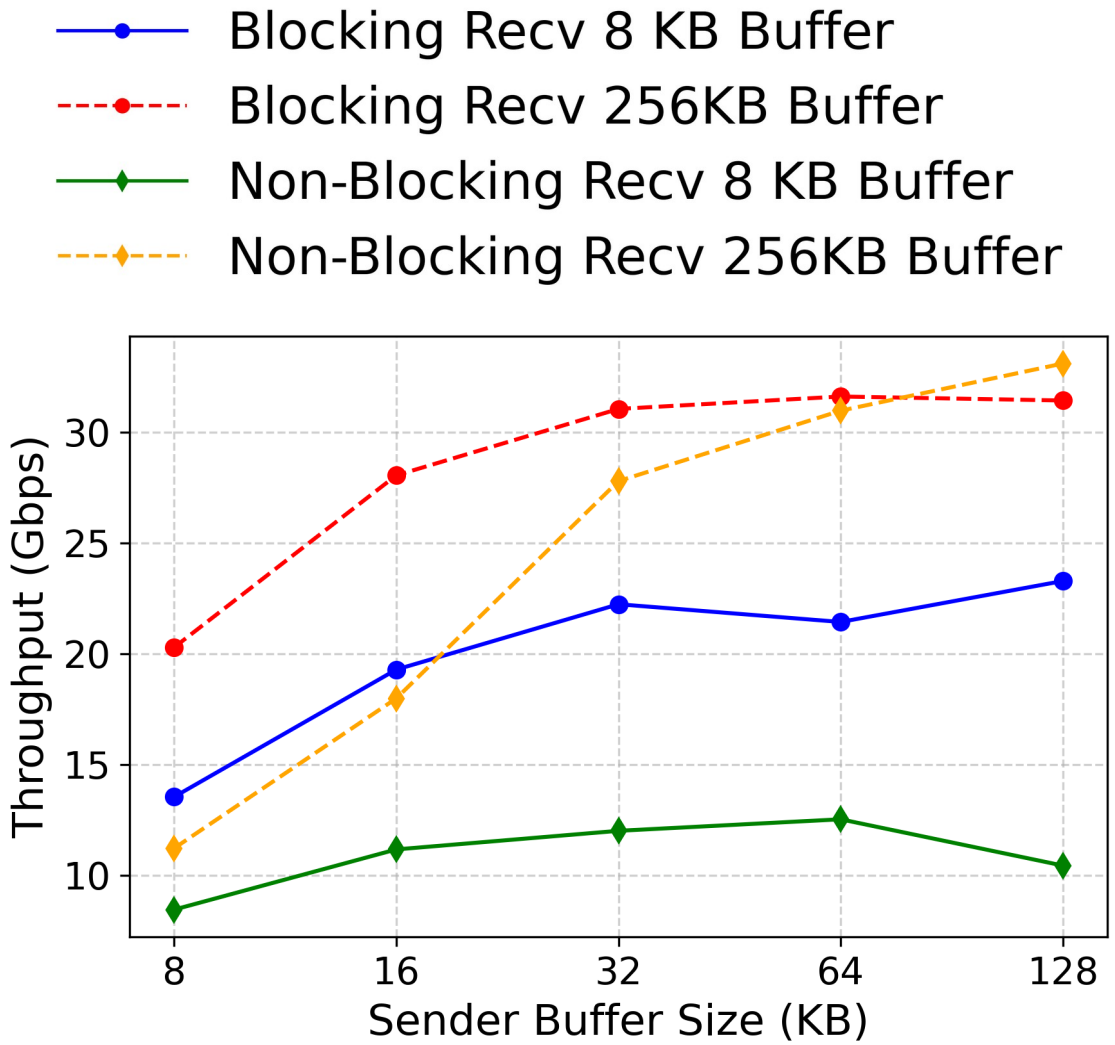
Benchmark: ttcp (Linux), a built-in throughput test (DPDK)
Standard ttcp version for blocking socket tests
Custom non-blocking ttcp variant implemented for comparison

(Note: the original ttcp tool did not support the non-blocking mode, we implemented our own ttcp variant to test performance under the non-blocking mode)

Preliminary Results

Single-Process Throughput vs. Buffer Size (Linux):

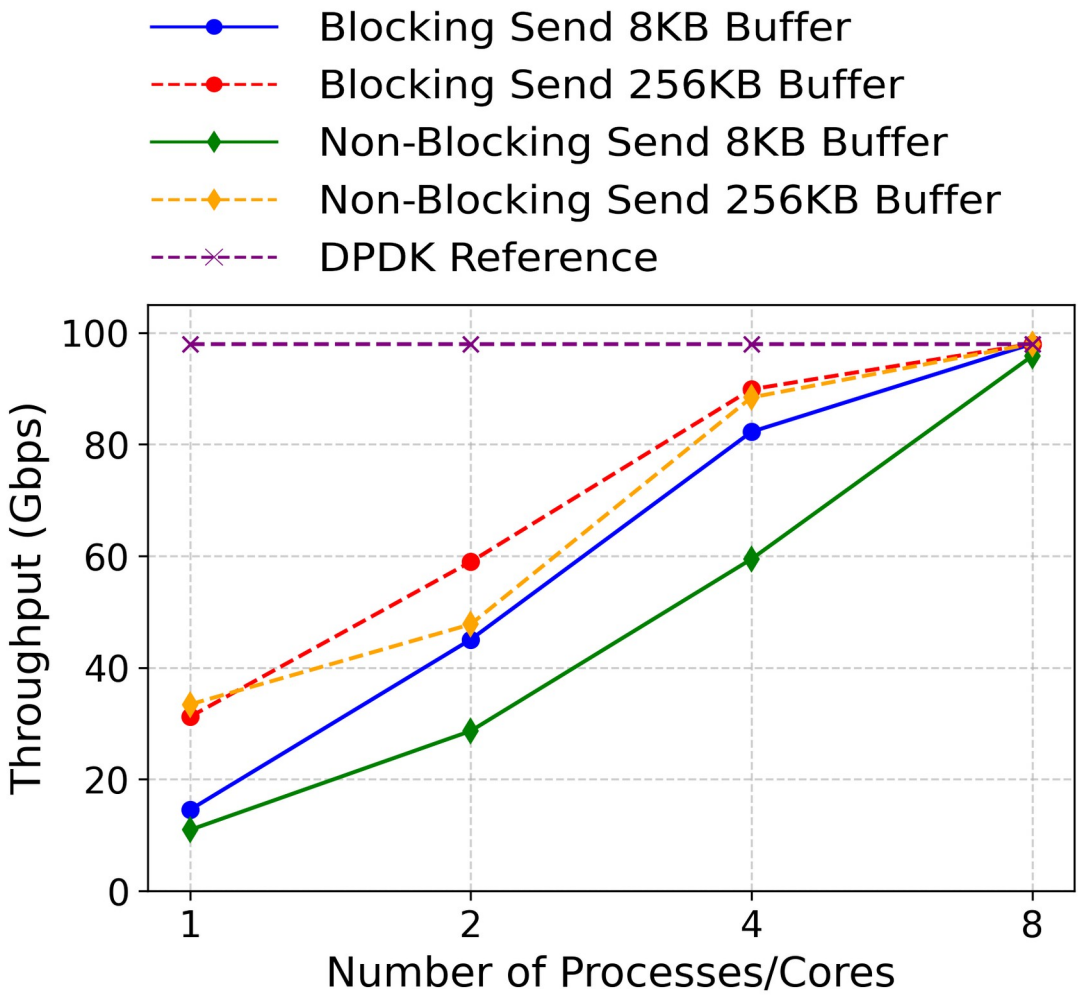
- Performance is greatly affected by buffer size and whether it is blocking vs. non-blocking
- Both implementations plateau far below link capacity



Preliminary Results

Aggregate Network Throughput:

- 4-8 cores saturate the link in Linux vs. just 1 core with DPDK
- Linux's network stack and mode switches have a visible performance overhead
- Buffer-size increases help but provide only a sublinear improvement
- Linux's non-blocking version is not helping much to reduce the overhead



Future Work

- **Design a New TCP Stack and User-Space Server:**
  Port the most recent FreeBSD TCP/IP code to run over DPDK
  Avoid shortcuts made in F-stack

- **LibC Replacement and Integration Layer:**
  Complete POSIX socket API coverage with poll/select/epoll/etc

- **Real-Life Tests:**
  Web servers (Nginx, Apache)
  Databases (PostgreSQL, Redis)

Thank you!

Q&A?

Yanlin Du
duyanlin@psu.edu

Ruslan Nikolaev
rnikola@psu.edu

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