Design, Implementation and Evaluation of a High Performance I/O Subsystem in Linux

Pramodh Mallipatna
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Thesis Committee: Dr. Douglas Niehaus, Chair
Dr. Joseph B. Evans
Dr. Gary Minden

Presentation Outline

- Motivation
- Related Efforts
- Implementation of FlexIO
  - Disk-Disk I/O
  - Disk-Network I/O
  - Network-Network I/O
  - WildForce I/O
- Evaluation
- Conclusions & Future Work

Motivation

- Problem Statement
  - Modern systems use faster CPUs, hardware and more main memory
  - Fast I/O applications
    - E.g. Streaming audio, video and some customized applications
  - Possible bottle-necks for fast I/O applications
    - Software I/O operations
    - conventional software I/O APIs
      - Data flow crosses address space boundaries
      - Multiple data copies during I/O
- Approach
  - Re-design of the I/O subsystem
- Our focus
  - Minimize the copy operations
  - Let the data flow remain in the kernel

Related Efforts

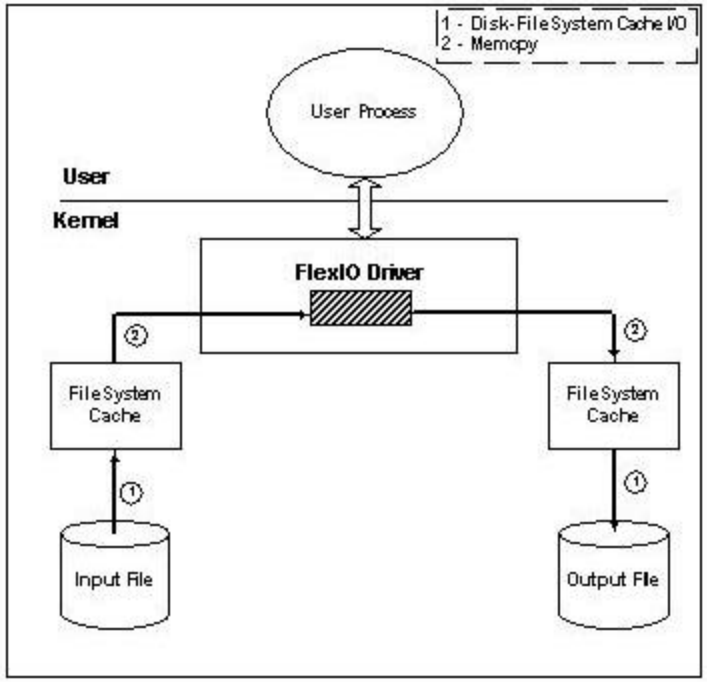
- The Hardware Approach
  - Using ASICs, FPGAs etc.
    - ASICs for Packet Forwarding, Buffer Management
- Direct Memory Access (DMA)
  - Data transfer without the involvement of CPUs
    - High speed devices - Hard disk controllers, Ethernet and ATM cards
- Efficient management of Caches
  - LRU/LFU, Second chance algorithm
    - Early Eviction LRU, an adaptive page replacement algorithm

Implementation (FlexIO)

- FlexIO - A pseudo device driver for high performance I/O in the kernel
- Features
  - Built into the kernel or a Linux loadable module
  - Enables user processes to describe and control data flows among kernel components
  - Currently supports
    - Disk-Disk I/O (Ext2 files and Raw Partitions)
    - Disk-Network I/O (Ethernet and ATM networks)
    - Network-Network I/O
    - WildForce I/O
  - Supports Memory Mapped I/O

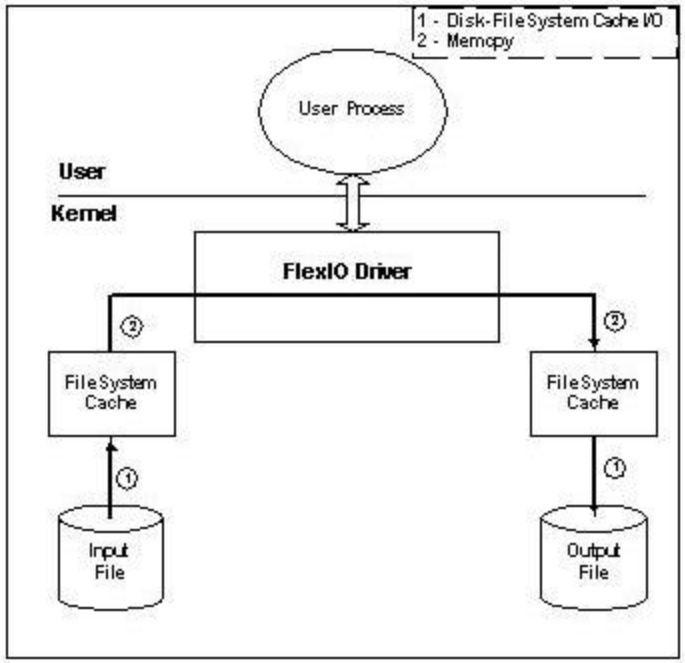
Disk-Disk I/O using FlexIO

- Data flow remains in the kernel
- Supports I/O between
  - Ext2 files
    - I/O using kernel buffers
    - I/O at the Buffer Cache level
    - Memory Mapped I/O
  - Raw Partitions

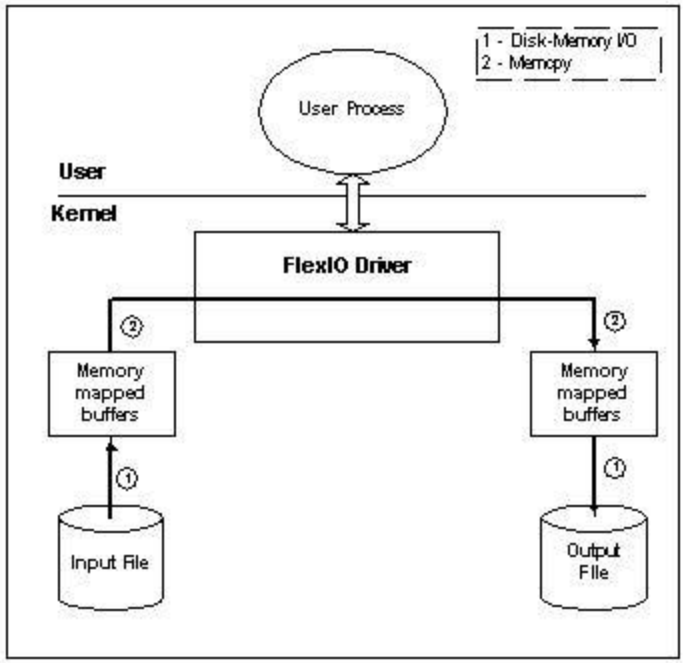


I/O Using kernel buffers

Disk-Disk I/O using FlexIO...



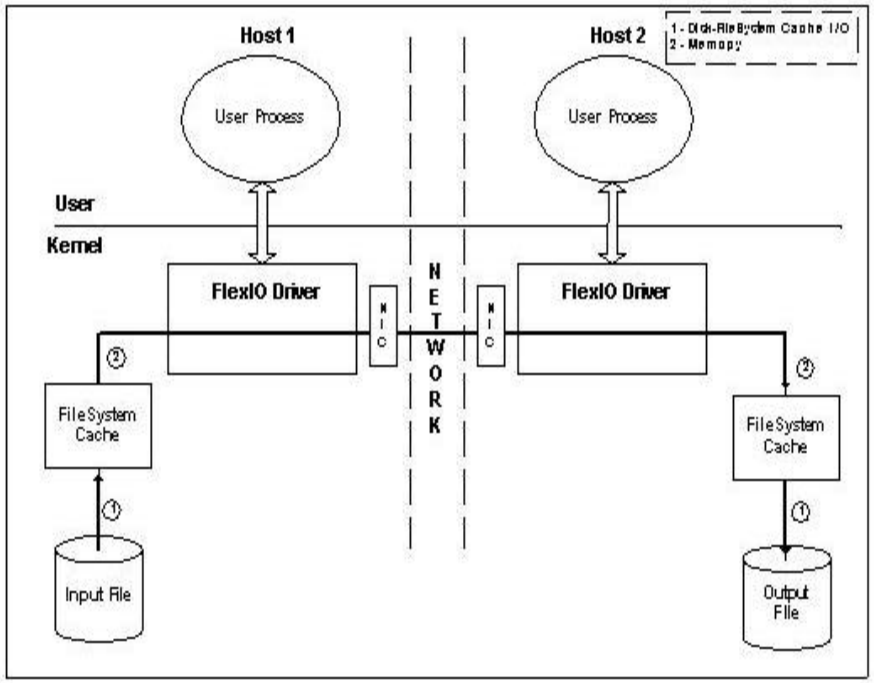
I/O at the Buffer Cache level



Memory Mapped I/O

Disk-Network I/O using FlexIO

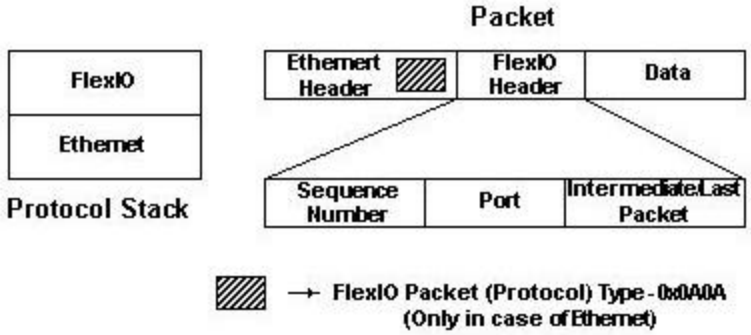
- Data flow remains in the kernel
- Supports Ethernet and ATM
- Runs directly over Link layer
- No error correction incorporated - Lost packets are lost - We do not lose any



Disk-Network I/O using FlexIO

Disk-Network I/O using FlexIO...

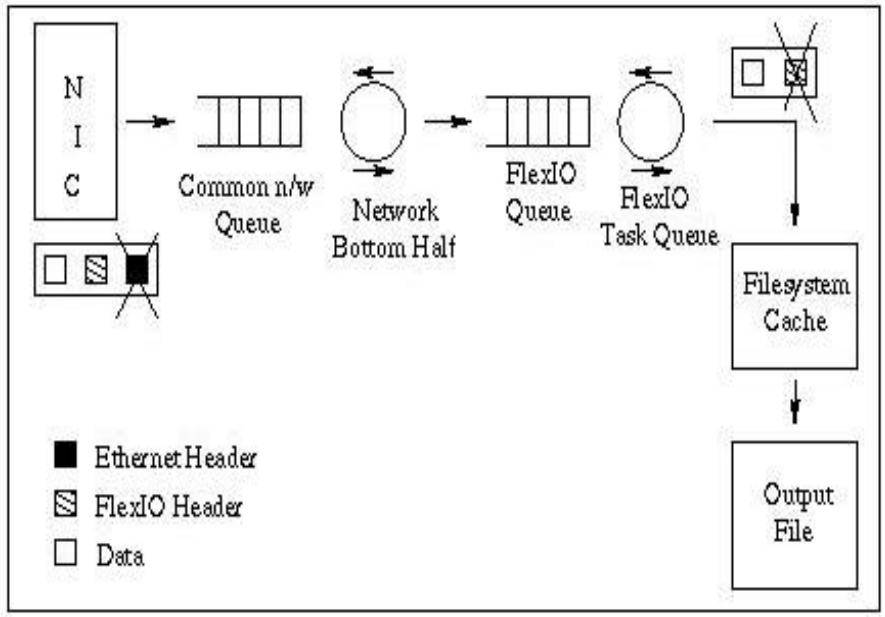
- Own protocol type defined
- Protocol Type - 0x0A0A
- FlexIO header
  - Port
  - Packet Information



FlexIO Packet and Protocol Type

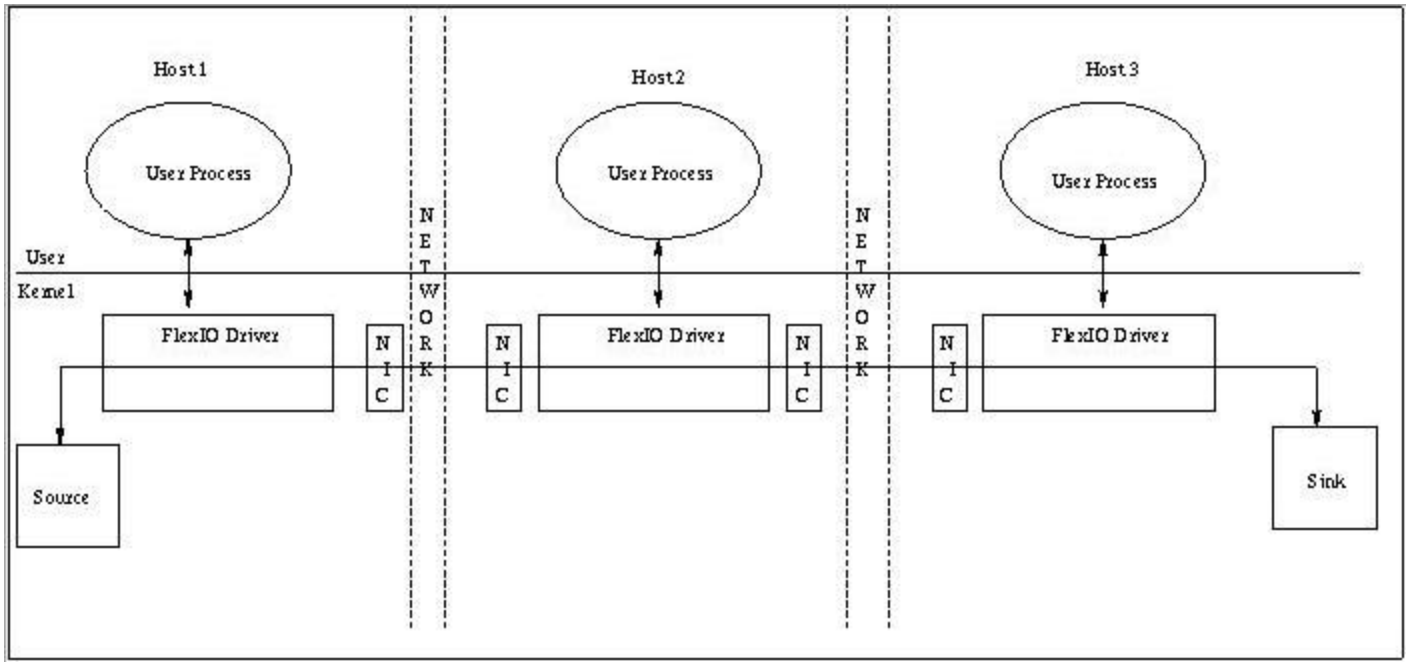
Disk-Network I/O using FlexIO...

- Network Bottom-Half hands the packet to FlexIO
- FlexIO Queue at the receiver
- FlexIO Task Queue to service the queue
  - Identifies flow specific information
  - Writes the data to the disk



Receiver Implementation

Network-Network I/O using FlexIO



Network I/O between three hosts with the intermediate host just forwarding the packets

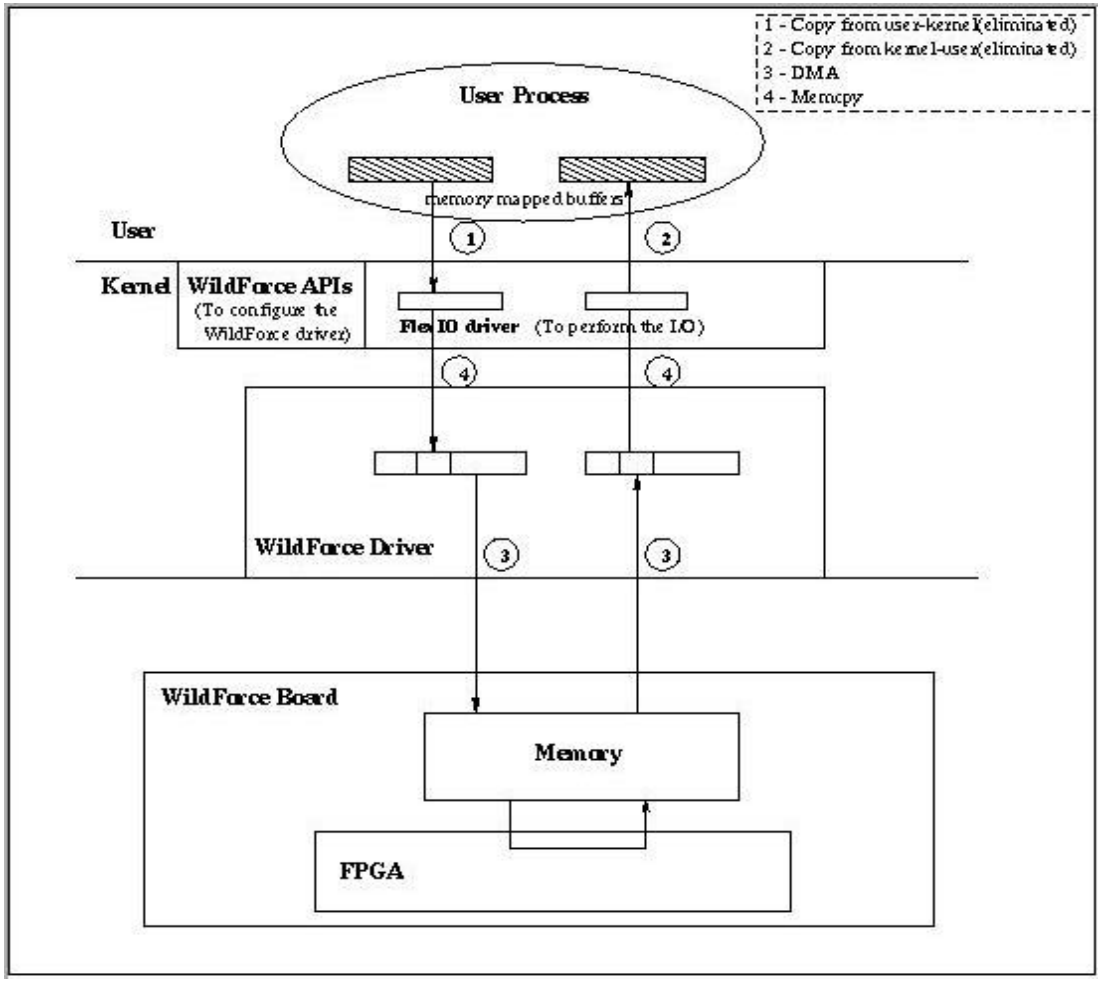
- End hosts - Same functionality as before
- Intermediate hosts - Forward the packets

WildForce I/O using FlexIO

- WildForce
  - PCI card housing FPGAs
  - Has on-board memory
  - Used for digital data processing
  - Device driver and user level APIs to interact with the board
  - No access to the driver source
- I/O using FlexIO
  - Accesses Character Device Table using WildForce Major number
  - WildForce configuration still done using WildForce user level APIs
  - Data flow remains in the kernel
  - Supports Memory Mapping user and kernel memory segments

WildForce I/O using FlexIO...

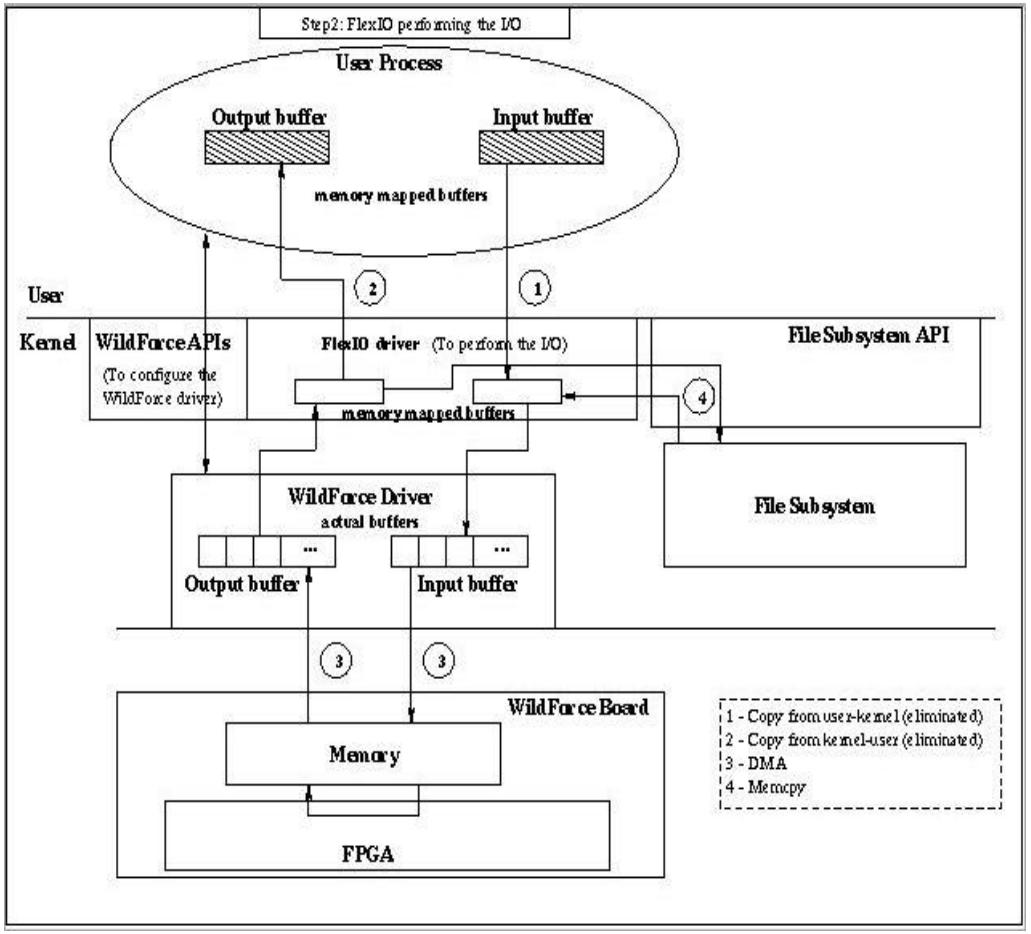
- Maps user buffers to kernel space
- Calls WildForce driver's entry points
- WildForce driver still copies data across address spaces



Description of a simple WildForce I/O using FlexIO

WildForce I/O using FlexIO...

- Input and Output data are stored in files
- File descriptors passed to FlexIO
- Performs I/O in the kernel



Description of a File-WildForce I/O using FlexIO

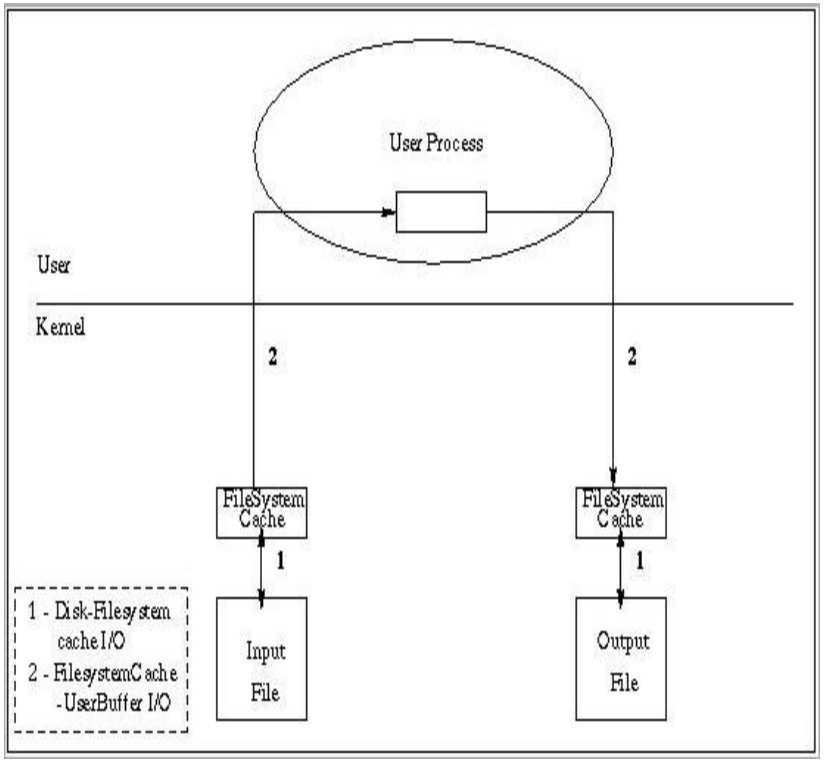
Evaluation of FlexIO

- FlexIO driver was tested by
  - Transferring various sets of data using FlexIO
    - Disk-Disk I/O
    - Disk-Network I/O
    - Network-Network I/O
    - WildForce I/O
  - Compared with conventional I/O mechanisms
    - File System and Socket APIs for Disk and Network I/O
    - WildForce user level APIs for WildForce I/O

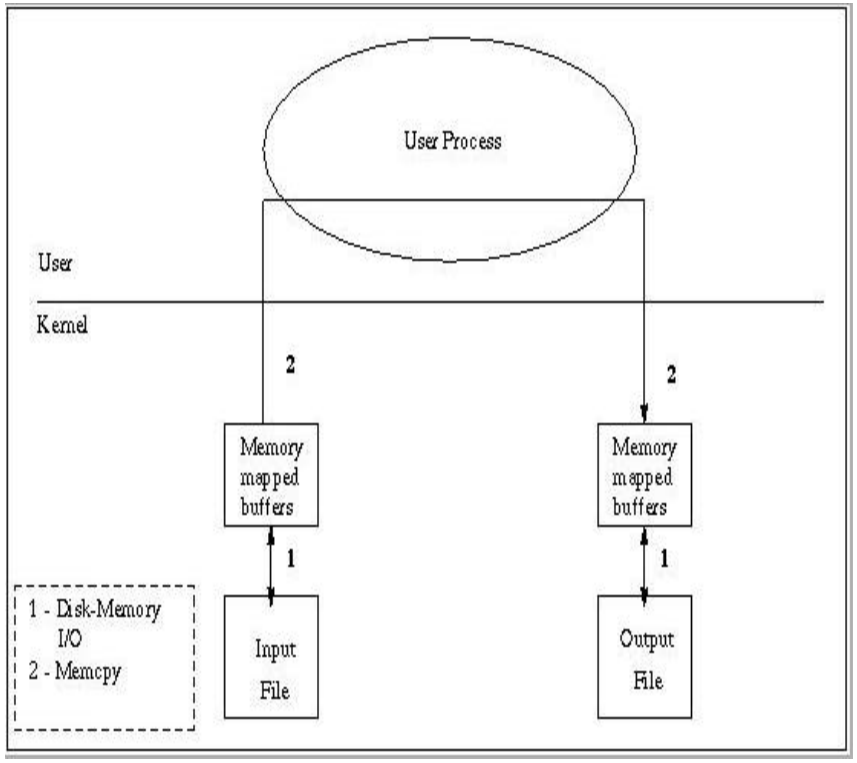
Disk-Disk I/O Evaluation

- FlexIO compared with a user process, both doing Disk-Disk I/O between
  - Ext2 files on same and different partitions of an IDE disk
  - Ext2 files on same and different partitions of a SCSI disk
- I/O using FlexIO
  - Using a kernel buffer
  - I/O at the Buffer Cache level
  - Memory Mapped I/O
- User Process I/O
  - Using a user buffer
  - Memory Mapped I/O

Disk-Disk I/O Evaluation...

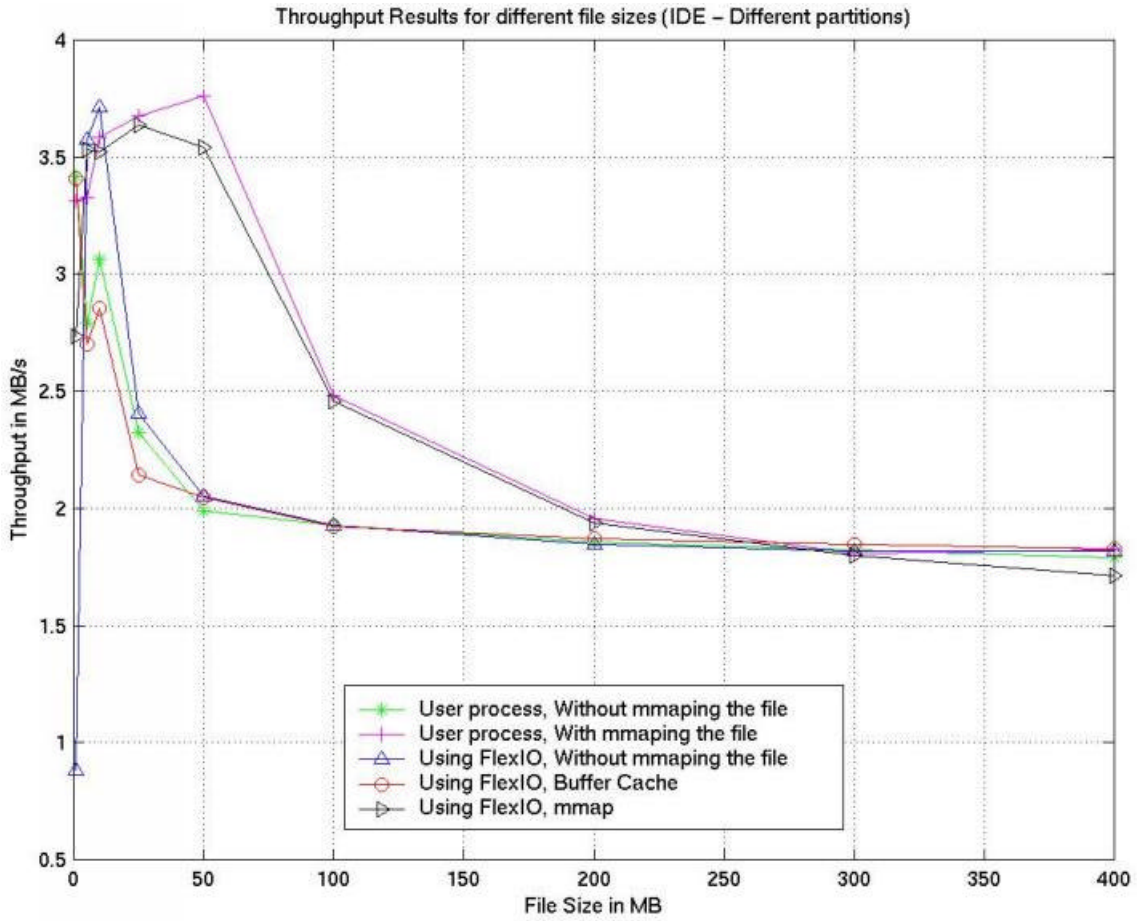


User process performing Disk-Disk I/O using intermediate buffers



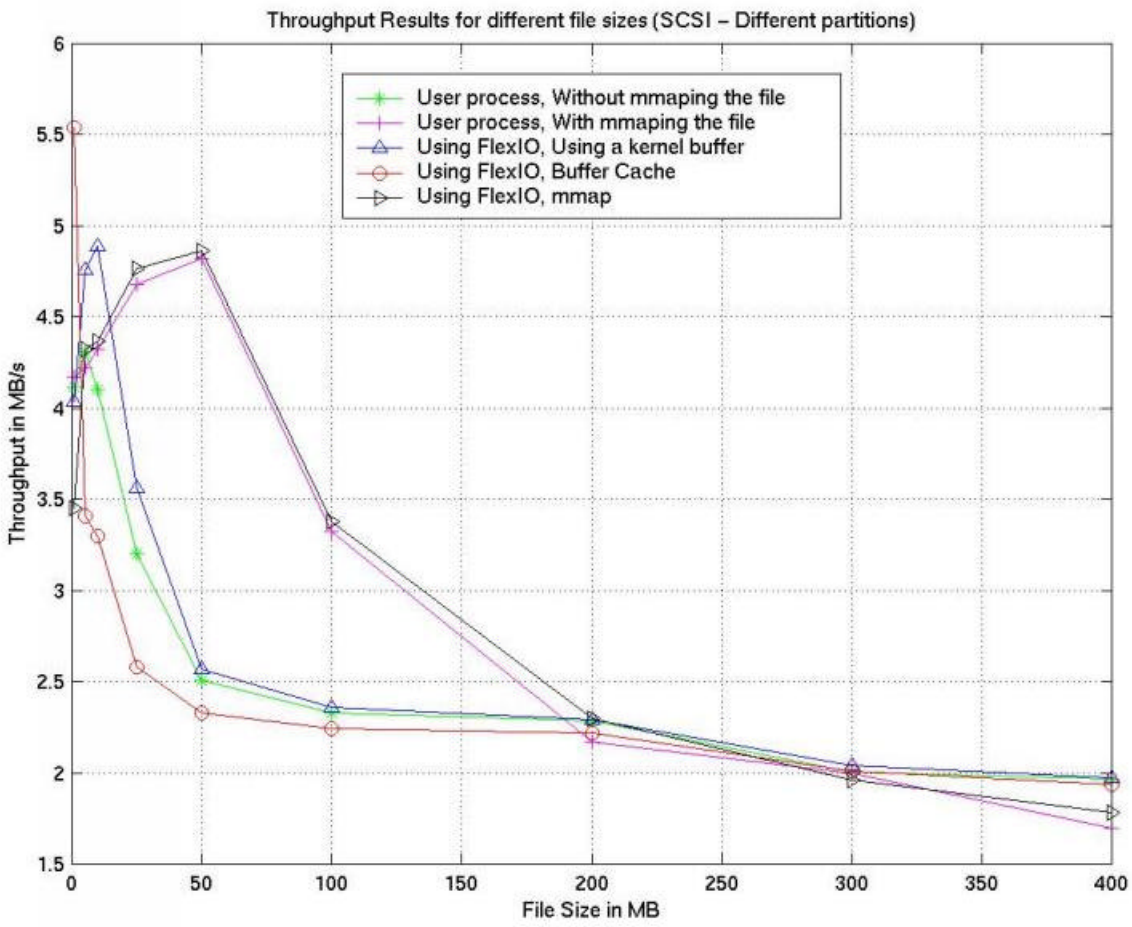
User process performing Disk-Disk I/O Memory Mapping the files

Disk-Disk I/O Results



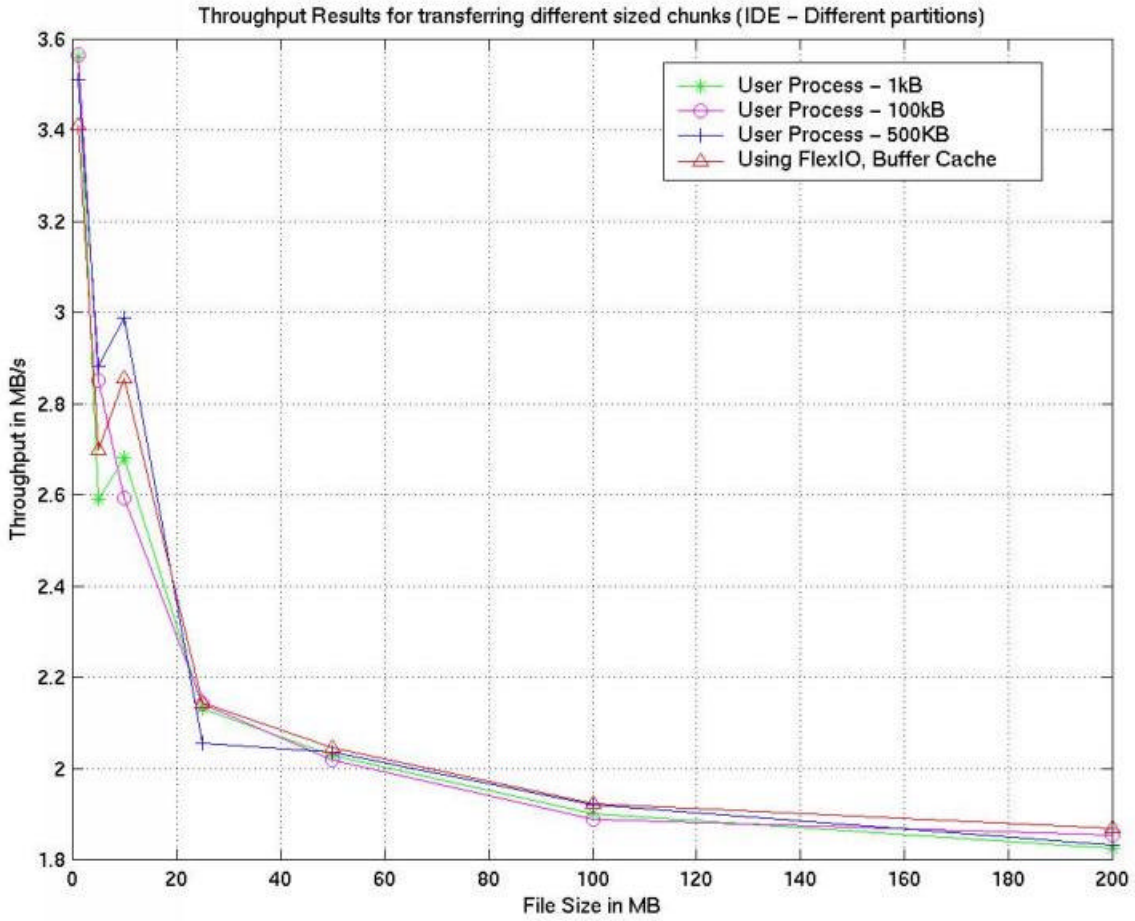
Memory Mapping the files improves the throughput for files as large as 200MB

Disk-Disk I/O Results...



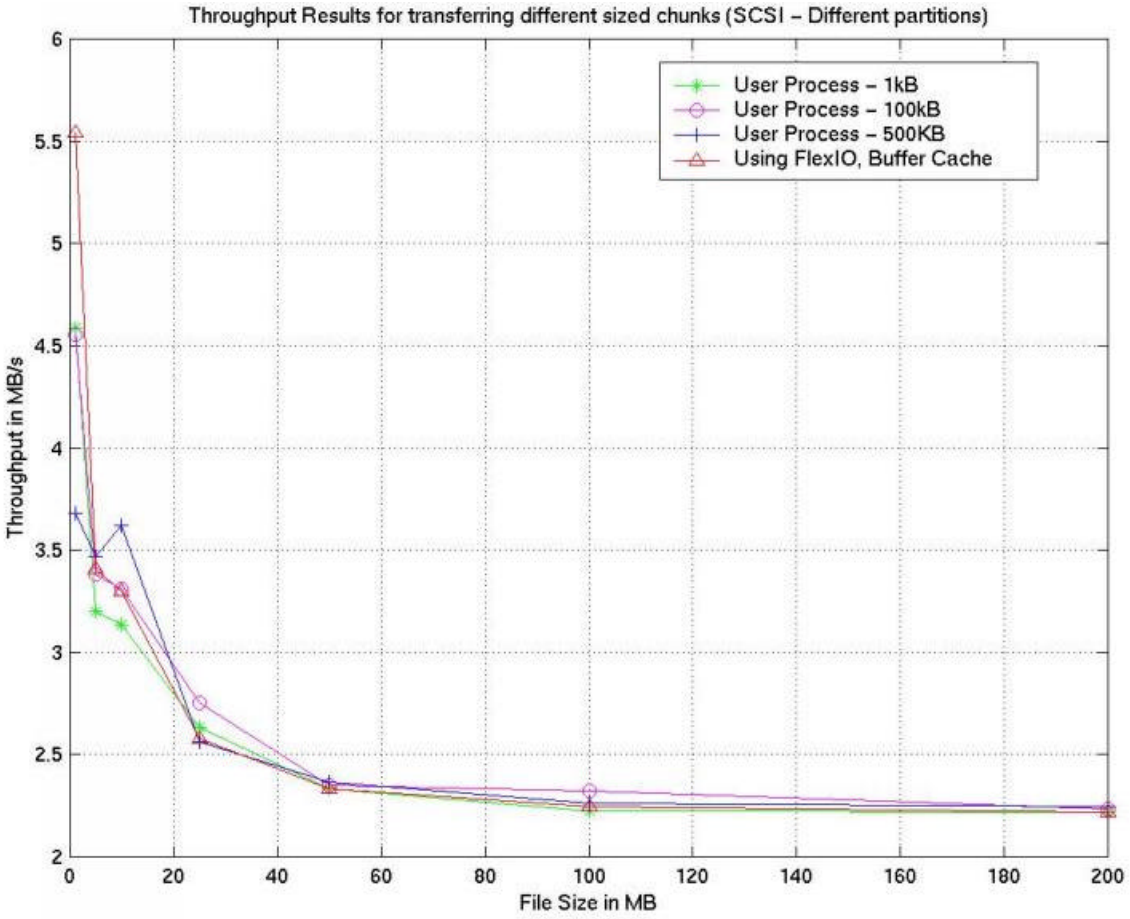
Throughput for SCSI is more than IDE

Disk-Disk I/O Results...



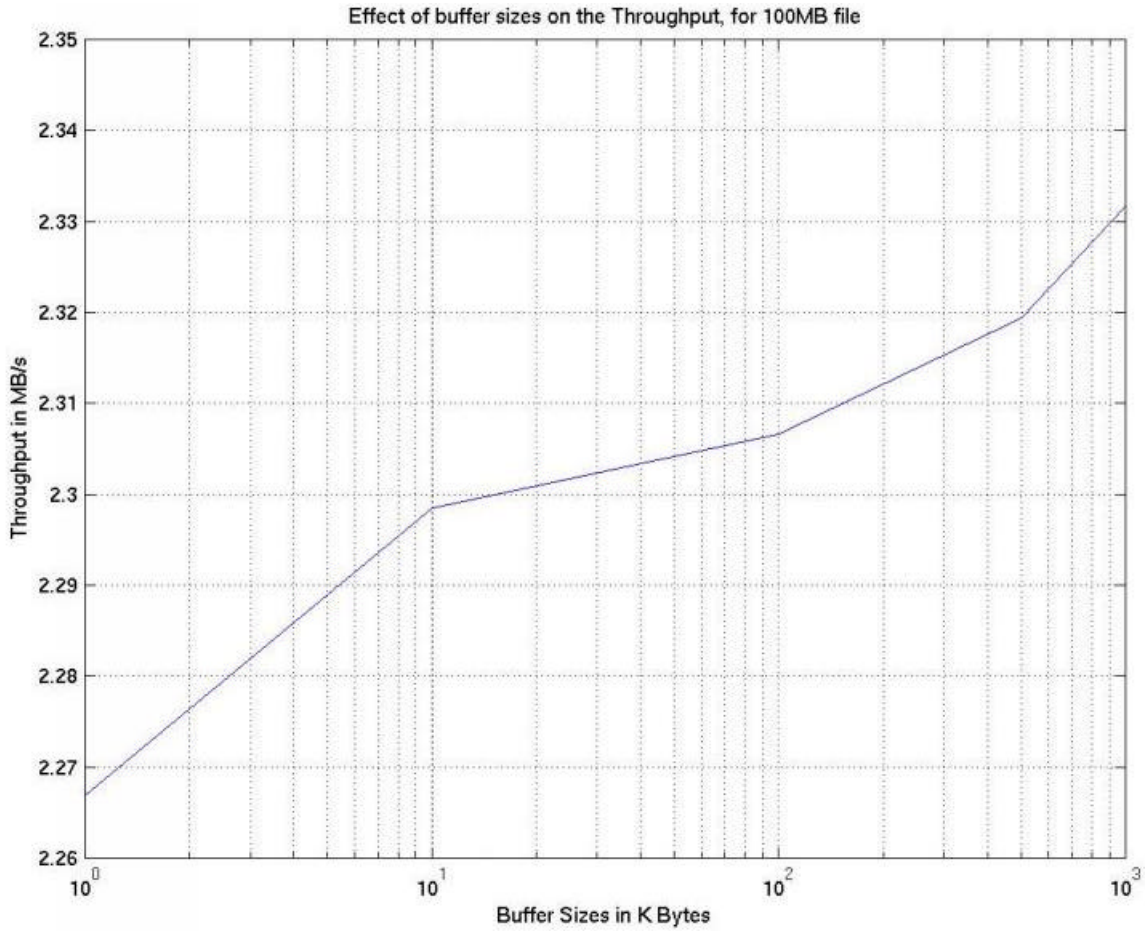
Throughput of I/O between same and different partitions is almost the same

Disk-Disk I/O Results...



FlexIO offers the same performance as that of File System APIs

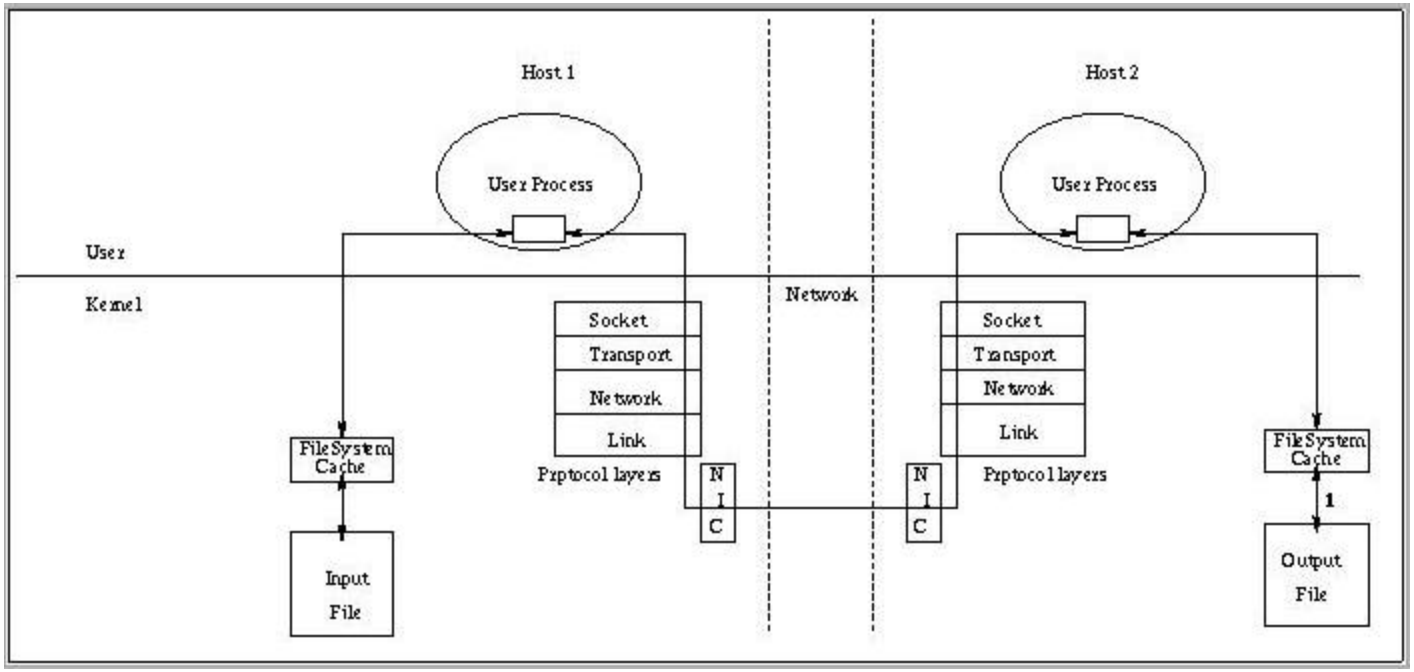
Disk-Disk I/O Results...



Buffer size has small effect on the throughput

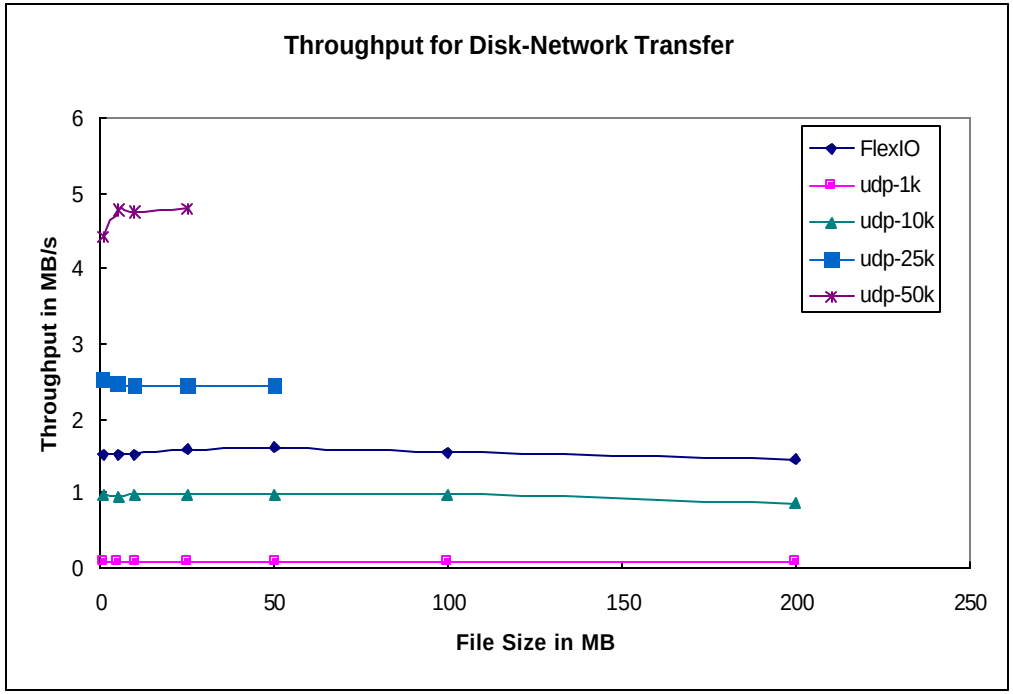
Disk-Network I/O Evaluation

- FlexIO compared with a user process using UDP sockets



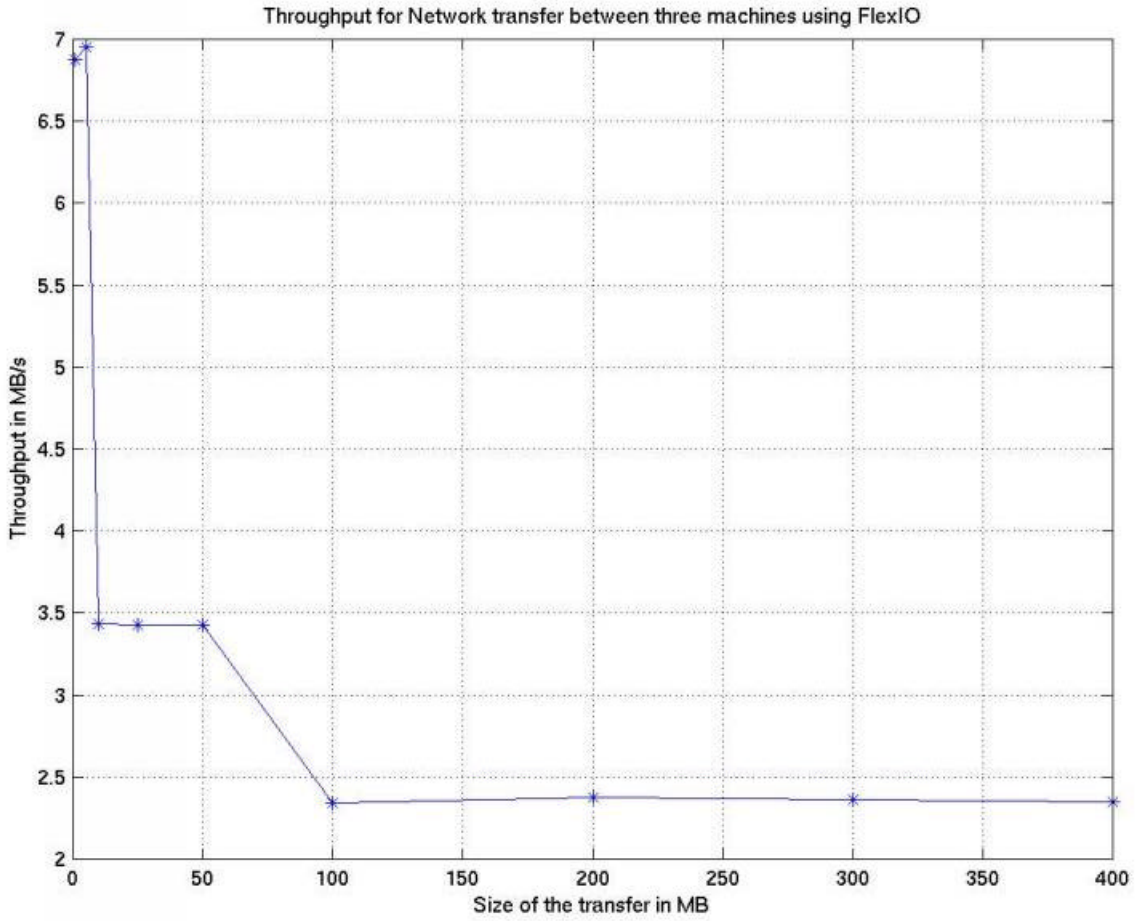
Disk-Network I/O Results

- UDP offers better throughput for small file transfers - with larger send and receive buffers
- Unable to transfer large files at high rates
- FlexIO offers better sustained throughput than UDP for large files



Throughput of Disk-Network I/O

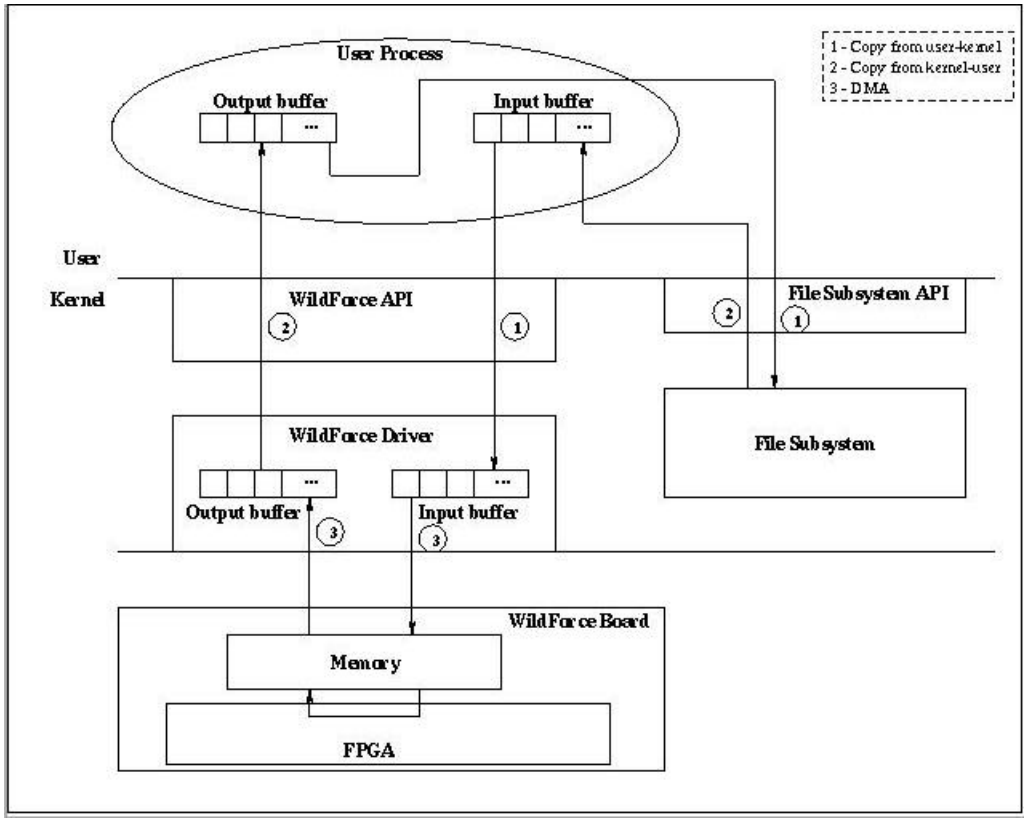
Network-Network I/O Results



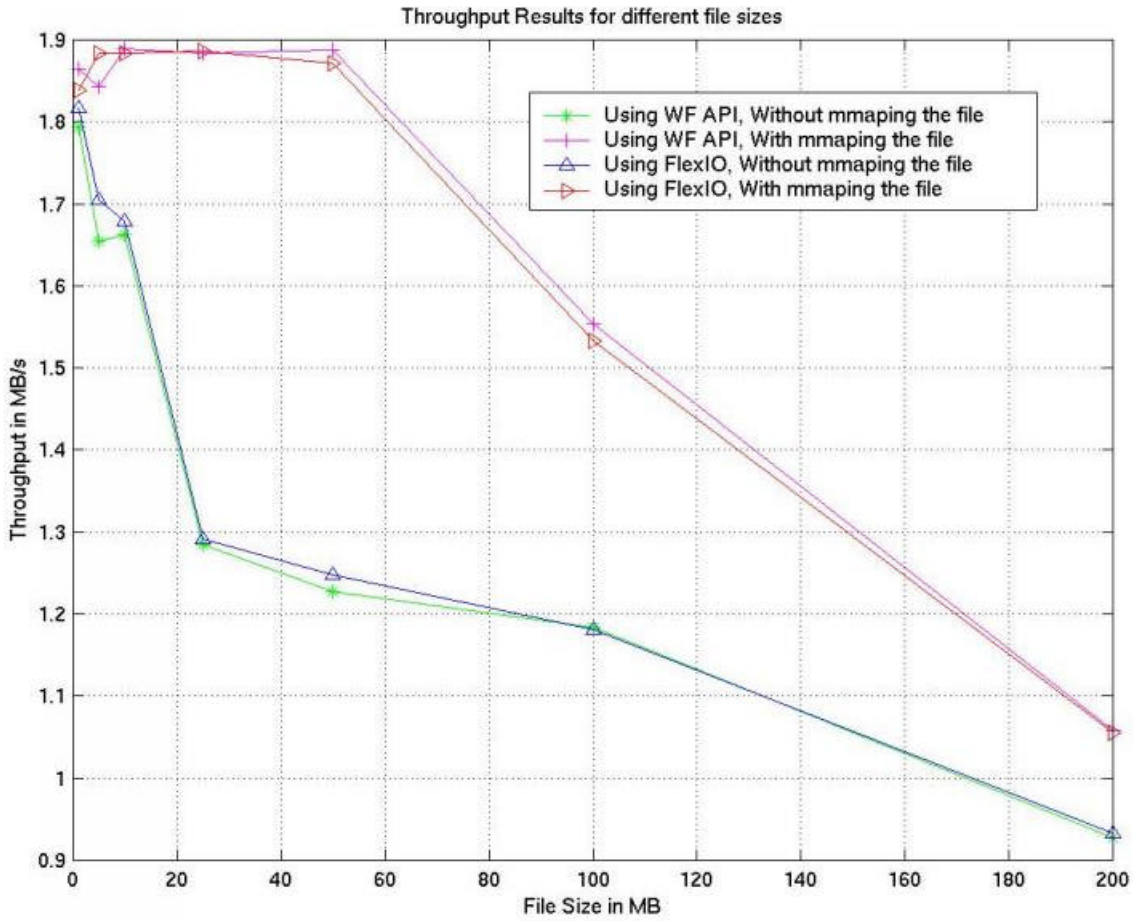
FlexIO offers about 2.3MB/s for transferring 400MB

WildForce I/O Evaluation

- FlexIO compared with a user process using WildForce APIs for I/O
- Used to perform I/O for SAR processing



WildForce I/O Results



FlexIO offers the same performance as that of WildForce APIs

Conclusions

- Conventional I/O APIs are not suited for all kinds of applications
- I/O flow need not always cross address space boundaries
- FlexIO
  - Lets user processes define and control data flows in the kernel
  - Memory Mapped I/O supported
  - Supports
    - Disk-Disk I/O
    - Disk-Network I/O
    - Network-Network I/O
    - WildForce I/O
  - Disk-Disk I/O: Offers the same performance as that of File System APIs
  - Disk-Network I/O and Network-Network I/O: Offers higher throughput than UDP based transfers
  - WildForce I/O: Offers the same performance as that of WildForce APIs

Conclusions...

- Framework for
  - generalized high performance I/O subsystem
  - Assembling data flow for computations across sets of machines
- Demonstrates how I/O among dissimilar input and output entities can be controlled from within the kernel
  - E.g. Disk-Network I/O, File-WildForce I/O, Network-WildForce I/O

Future Work

- Streaming real-time audio and video data
- Use of Memory Mapping functionality for WildForce I/O
- Integration with the higher layer network protocols
- Flow control in FlexIO
- Testing the driver under real-time