A Guide to Today's Class

- Quick Ethernet Overview
- Basic Data Structures
- Break
- Device Startup and Initialization
- Break
- Packet Reception
- Packet Transmission
- Break
- Device Control
- Special Features

Introduction

- Networking begins and ends and the driver layer
- A day in the life of a packet
- Look into many code files in the kernel
- We will use FreeBSD 7.2 (STABLE) as our reference

Device Driver Section Intro

- Lowest level of code in the kernel
- Deal directly with the hardware
- Use a well defined API when interfacing to the kernel
- Are rarely written from scratch
- We will only describe Ethernet drivers in this class

Network Layering

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

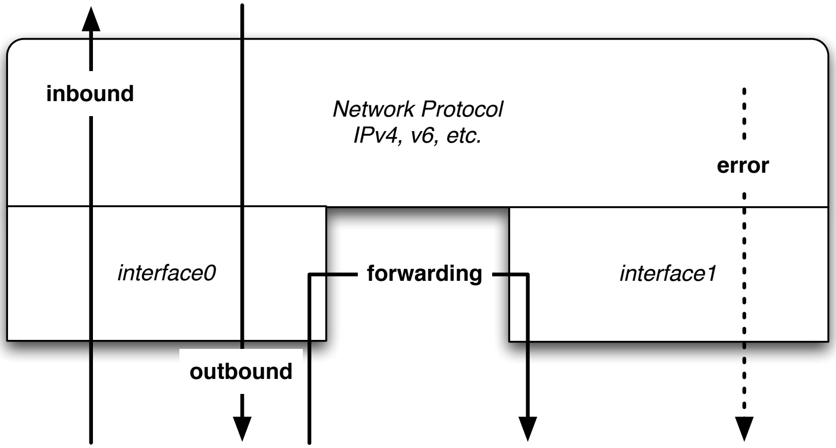
Network Layering

- Application (All)
- Presentation (Protocols)
- Session (Should)
- Transport (Transport)
- Network (Network)
- Data Link (Data)
- Physical (Properly)

The Four Paths

- Packets traverse four possible paths in the network code
- Inbound (for this host)
- Outbound (from this host)
- Forwarding (between two interfaces on this host)
- Error

Four Paths Through The Stack



Ethernet Overview

- Data Link Layer Protocol
- The most common form of wired networking
- Available in many speeds, now up to 10Gbps
- A simple header followed by data

Ethernet Packet and Encapsulation

Dest	Source	Type	IP Header	TCP Header	Data ...

Memory for Packets

- Packets need to be stored for reception and transmission
- The basic packet memory stuctures are the `mbuf` and `cluster`
- `mbuf` structures have several types and purposes
- Clusters hold only data
- History dictates that `mbuf`s are named `m`
- In the kernel we will see many pointers to `mbuf`s

Types of mbufs

- Wholly contained
- Packet Header
- Using a cluster

Welcome to SMP

- FreeBSD is a multi-threaded, re-entrant kernel
- Only way to scale on multicore and multi-processor systems
- Kernel is full of cooperating tasks
- Inter process synchronization is *required*

Kernel Synchronization Primitives

- Spin Locks
- Mutexes
- Reader/Writer Locks
- Shared/Exclusive Locks
- Drivers use mostly spin locks or mutexes
  - See locking(9) for more information

Ethernet Drivers, an Overview

- Implemented in the kernel
  - May be kernel loadable modules (KLD)
- Responsible for getting packets into and out of the system
- Follow a well known set of Kernel APIs
- May drop packets

Introducing, the Intel Gigabit Ethernet Driver

- Supports modern Intel ethernet hardware
- Parts available on motherboards and PCI cards
- A typical example of a modern Ethernet chip
- Driver is well written and maintained by an Intel developer
- A good example to start with
- Data book available at intel.com
- Referred to as igb for short
    - The em driver is the previous incarnation

IGB Features

- Various types of media support
- MSI-X Interrupts
- Jumbo Frames
- Adaptive Interrupt Modulation
- IEEE-1588 (some chips only)

Code Overview

- All FreeBSD device drivers are kept in /usr/src/sys/dev
- The IGB driver resides in /usr/src/sys/dev/e1000/if_igb.[ch]
- Other supporting files also exist but will not be necssary for this class
- The main data structures are in the header file and the main body of the driver is in if_igb.c
- Generic code to support all network drivers is in the /usr/src/sys/net* directories

Network Driver Data Structures

- There are two main data-structures in every network driver
  - `ifnet` and `adapter`
- The `ifnet` structure is used to hook the device into the network protocols
- The `adapter` structure is private to the device.
  - The `adapter` structure is often called the `softc`

Objects in C and the BSD Kernels

- Since the early days of the BSDs many kernel data structures have contained both data and function pointers
- A clever and cheap way to get the benefits of object orientation without paying for unwanted features
- Function pointers in structures are used throughout the kernel, not just in the network devices.
- No need to be alarmed

ifnet Overview

- The main interface between the driver and the kernel
- Contains data and functions that are generic to *all* network devices
- Each device instance *must* have at least one `ifnet`

adapter

- Contains device specific data
  - Hardware registers
  - Device control functions
  - Pointers to packet rings
  - Interrupt vectors
  - Statistics
- Always points back to the `ifnet` structure

IGB adapter structure

Break

- Please take a 10 minute break

Relevant APIs

- `igb_attach()`
- `igb_ioctl()`
- `igb_msix_rx()`
- `igb_msix_tx()`
- `igb_msix_link()`

attach()

- Each device driver *must* have a way to connect to the kernel
- The `igb_attach` routine is used to activate a device
- Setup sysctl variables
- Allocate memory
- Set up device registers
- Hook function pointers into place
- Start the device running

Setup Control Variables

- Kenel code can expose controls via sysctl
- Tunables are like sysctls but can only be set at boot
- Used mostly to communicate integers into and out of the kernel
- Also support more complex data structures

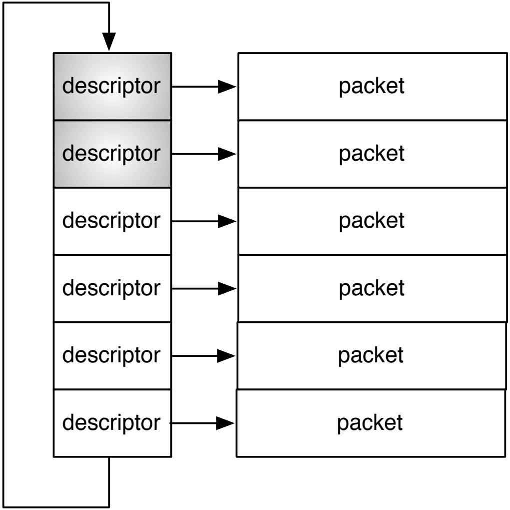
Tunables

sysctls

Rings of Packets

- CPU and device share a ring of packet descriptors
- Each descriptor points to a packet buffer
- Used for transmission and reception
- Allows decoupling of the CPU and the device

Packet Ring Structures



Tx Ring Allocation

Allocate Receive Ring

Set Device Registers

Hook in function pointers

Set device capabilities and Media Type

Add Media Types

Start the device

Break

- Please enjoy a 15 minute break

rx()

- Interrupt processing
- Work deferral
- Handling basic errors
- Passing packets into the kernel

Message Signalled Interrupts (MSI/X)

- Old style interrupts required raising a line on a chip
- Old style interrupt routine had to be all things to all people
- MSI allows for different functions to be assigned to different channels
- The IGB driver has one channel per receive or transmit queue and a single interrupt for link state changes

Receive Interrupt

Recieving a Frame

Recieving a Frame (End of Packet)

Passing in the Packet

tx()

- Packets from above
- Work deferral
- Error handling

Protocols Pass Packets Down

- `ip_output()`
- `ether_output()`
- `ether_output_frame()`
- `IFQ_HANDOFF()/IFQ_HANDOFF_ADJ()`

Handing a Packet Off

A word about queues

- Queues of packets are used throughout the networking stack
- Prevent overuse of resources
- Allow for work deferral
- A good way to connect lightly related modules
- Allow the administrator to tune the system

The IGB start routine

Draining the Queue

Watchdogs and Drivers

- Hardware is not as perfect as software
- One failure mode is freezing up
- Watchdog routines can be quite harsh
- Continuously resetting a device is *not* the best way to fix it
- Reading `igb_watchdog` is left to the reader

Cleaning up first

Checksum Offloading

- Many protocols required a packet checksum calculation
- Math is hard, and also expensive
- Many 1Gig chips can calculate the checksum in hardware
- For 10Gig this is *required* to operate at full speed
- A layering violation in the stack

Checksum Offload Code

Setup the Transmit Descriptors

Really transmit the packet

Break

- Please enjoy a 10 minute break

Controlling the Device

- Devices need to be controlled
- Setting network layer addresses
- Bringing the interface up and down
- Retrieving the device state
- The `ioctl` routine is the conduit for control messages and data

Data in/data out

The Big Switch

Setting the MTU

Special Features

- Multicast
- Interrupt Moderation
- Checksumming

Multicast

- One to many transmission
- Mostly handled by hardware
- Table size is important for performance

Interrupt Moderation

- System can easily be overwhelmed by interrupts
- Different types of traffic have different needs
  - Low Latency
  - Average Latency
  - Bulk Transmission

Checksumming

- Difficult to get line rate TCP without hardware help
- Leads to a layering violation
- TCP *must* be aware of hardware checksumming abilities

Section Summary

- All networking device drivers have similar structure
- The hardware details *should* be hidden
- Drivers are rarely written from scratch
    - Copy when write

Questions?