Network Bandwidth Isolation

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Outline

- Part I: Overview
- Part II: Identifying Packets
- Part III: Packet Scheduling
- Part IV: Interesting Problems

Part I

Overview

Motivation

Fairness

- Wish to ensure that each domain received a fair share of network-related resources
  - As defined by the administrator
- Guard against malicious domains
- Guard against domains that have been infected by a virus

Assumptions

Frame for discussion

- Xen — Though this ought to be applicable to KVM
- Network is bridged in dom0
- Dom0 is running Linux
- Only discuss transmit path

Network-Related Resources

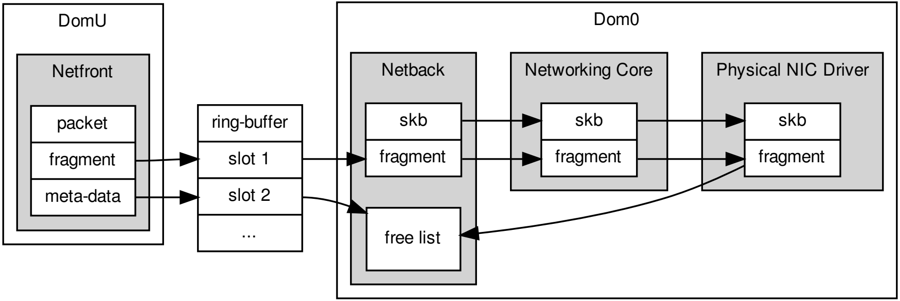
- NIC Bandwidth
    - How fast packets are being transmitted and received by domUs
- Dom0 CPU
    - How fast packets are being transmitted and received by domUs
- Dom0 Kernel memory
    - How many packets are held in the kernel

Packet Scheduling

- Prioritise packets based on domain
  - NIC Bandwidth
  - Dom0 CPU
- Drop packets if a domain has too many enqueued
  - Dom0 Kernel memory usage

Netback/Netfront Flow Control

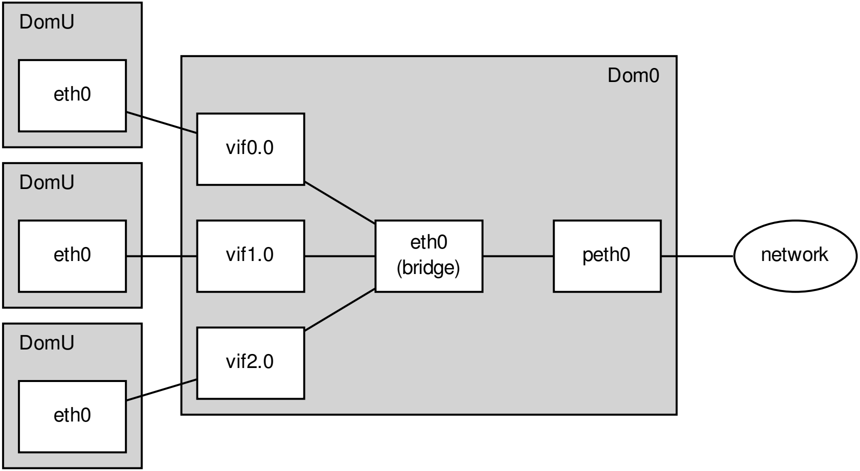
- End-to-end flow control from netfront until a packet is transmitted by the destination interface
- Allows packet scheduling to control network-related resource usage
  - dom0 CPU
  - dom0 Kernel memory



Part II

Identifying Packets

Bridged Xen Network



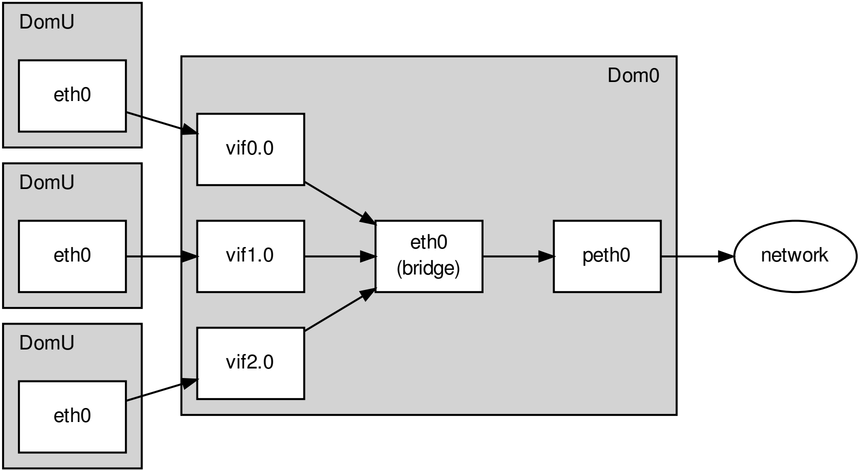
Three domUs bridged to a single physical interface

Tools of the trade

`iptables`

- Can mark packets passing through interfaces
- Keys can include source MAC address and interface

DomU Transmit: Identifying Packets



- Match the interface from which packets enter eth0 (bridge)
- Identifies the source-domU

DomU Transmit: iptables Rules

Mark the packets according to which interface they arrive on

```
iptables -t mangle -A FORWARD -m physdev \
        --physdev-in vif2.0 -j MARK --set-mark 100
iptables -t mangle -A FORWARD -m physdev \
        --physdev-in vif3.0 -j MARK --set-mark 110
iptables -t mangle -A FORWARD -m physdev \
        --physdev-in vif5.0 -j MARK --set-mark 120
```

Part III

Packet Scheduling

Packet Scheduling

- Filter
    - Assign to a class
- Prioritise
    - Based on class assignment
    - May selectively delay packets
- Queue
    - For transmission after filtering or prioritisation
- Drop
    - If a queue becomes full

DomU Transmit Control

How many packets are held in the dom0 kernel

- Limited by the number of netback ring-buffer slots

$$p \leq n$$

where:	p:	transmit packets enqueued in dom0 for vif$N.M$
	n:	netback ring-buffer slots (default $= 256$)

DomU Transmit Control

How fast packets are transmitted

- Delaying packets in dom0 should be sufficient
- Dropping packets may actually be harmful
  - Holding onto packets actually slows down domU

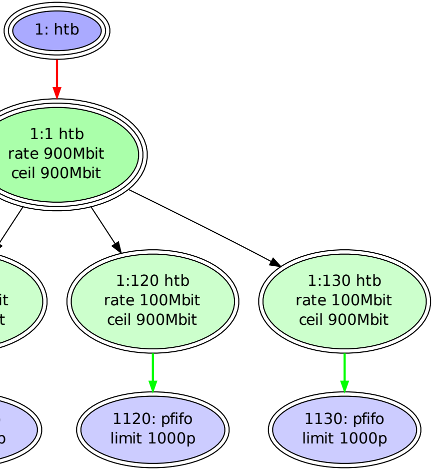
Borrowing

Allow classes exceed their rate if there is unused bandwidth

- *rate*: Maximum rate a class and its children are guaranteed
- *ceil*: Maximum rate at which a class can send, if its parent has bandwidth to spare

tc-htb(8) man page

DomU Transmit: Packet Scheduling Hierarchy



1: htb

1:1 htb
rate 900Mbit
ceil 900Mbit

1:100 htb
rate 500Mbit
ceil 900Mbit

1:110 htb
rate 100Mbit
ceil 900Mbit

1:120 htb
rate 100Mbit
ceil 900Mbit

1:130 htb
rate 100Mbit
ceil 900Mbit

1100: pfifo
limit 1000p

1110: pfifo
limit 1000p

1120: pfifo
limit 1000p

1130: pfifo
limit 1000p

Tools of the Trade

- `tc`
  - Used to configure traffic control
  - Configure filters
  - Configure packet scheduling

DomU Transmit: HTB Rules: Root and Inner Classes

Root Class

```
tc qdisc add dev peth0 root handle 1: htb default 130
```

Inner Class

- To allow Borrowing

```
tc class add dev peth0 parent 1: classid 1:1 htb \
    rate 900Mbit ceil 900Mbit
```

DomU Transmit: HTB Rules: Leaf Classes

Leaf Classes

- One per domain + default

```
tc class add dev peth0 parent 1:1 classid 1:100 htb \
    rate 500Mbit ceil 900Mbit
tc class add dev peth0 parent 1:1 classid 1:110 htb \
    rate 100Mbit ceil 900Mbit
tc class add dev peth0 parent 1:1 classid 1:120 htb \
    rate 100Mbit ceil 900Mbit
tc class add dev peth0 parent 1:1 classid 1:130 htb \
    rate 100Mbit ceil 900Mbit
```

DomU Transmit: FIFO Rules

Terminate each leaf class with a fifo

- The default is a PFIFO, made explicit by the following rules

```
tc qdisc add dev peth0 parent 1:100 handle 1100: \
    pfifo limit 1000
tc qdisc add dev peth0 parent 1:110 handle 1110: \
    pfifo limit 1000
tc qdisc add dev peth0 parent 1:120 handle 1120: \
    pfifo limit 1000
tc qdisc add dev peth0 parent 1:130 handle 1130: \
    pfifo limit 1000
```

DomU Transmit: Filter

Filter based on the fwmark set by `iptables`

- `handle` N is the fwmark match
- `flowid` X:Y is the class to assign the packet to match

```
tc filter add dev peth0 protocol ip parent 1: \
   handle 100 fw flowid 1:100
tc filter add dev peth0 protocol ip parent 1: \
   handle 110 fw flowid 1:110
tc filter add dev peth0 protocol ip parent 1: \
   handle 120 fw flowid 1:120
```

Part IV

Interesting Problems

Problem 1: UDP, VLANs and Lack of Flow Control

Problem

- VLAN devices do not support scatter-gather
- This means the that each skb needs to be linearised and thus cloned if they are trasmitted on a VLAN device
- Cloning results in the original fragments being released
- This breaks Xen's netfront/netback flow-control

Result

- A guess can flood dom0 with packets
- Very effective DoS attack on dom0 and other domUs

Problem 1: UDP, VLANs and Lack of Flow Control

Work-Around

- Use the credit scheduler to limit the rate of a domU's virtual interface to something close to the rate of the physical interface

```
vif = [ "mac=00:16:36:6c:81:ae,bridge=eth4.100,
         script=vif-bridge,rate=950Mb/s" ]
```

- Still uses quite a lot of dom0 CPU if domU sends a lot of packets
- But the DoS is mitigated

Problem 1: UDP, VLANs and Lack of Flow Control

Partial Solution

- scatter-gather enabled VLAN interfaces
- Problem is resolved for VLANS with supported physical devices
- Still a problem for any other device that doesn't support scatter-gather

Problem 1: UDP, VLANs and Lack of Flow Control

Patches

- Included in v2.6.26-rc4
  - "Propagate selected feature bits to VLAN devices" and;
  - "Use bitmask of feature flags instead of seperate feature bit" by Patrick McHardy.
  - "igb: allow vlan devices to use TSO and TCP CSUM offload" by Jeff Kirsher
- Patches for other drivers have also been merged

http://kerneltrap.org/mailarchive/linux-netdev/2008/5/21/1898674

http://kerneltrap.org/mailarchive/linux-netdev/2008/5/23/1922094

http://kerneltrap.org/mailarchive/linux-netdev/2008/6/5/2037984

Problem 2: Bonding and Lack of Queues

Problem

- The default queue on bond devices is no queue
  - This is because it is a software device, and generally queuing doesn't make sense on software devices
- qdiscs default the queue-length of their device

Result

- It was observed that netperf TCP_STREAM only achieves 45-50Mbit/s when controlled by a class with a ceiling of 450Mbit/s
- A 10x degredation!

Problem 2: Bonding and Lack of Queues

Solution 1a

- Set the queue length of the bonding device before adding qdiscs

```
ip link set txqueuelen 1000 dev bond0
```

Solution 1b

- Set the queue length of the qdisc explicitly

```
tc qdisc add dev bond0 parent 1:100 handle 1100: \
    pfifo limit 1000
```

Problem 3: TSO and Lack of Accounting Accuracy

Problem

- If a packet is significantly larger than the MTU of the class, is is accounted as being approximately the size of the MTU
- And the giants counter for the class is incremented
- In this case, the default MTU is 2047 bytes
- But TCP Segmentation Offload (TSO) packets can be much larger
  - 64kbytes
- By default Xen domUs will use TSO

Result

- The result similar to no bandwidth control of TCP

Problem 3: TSO and Lack of Accounting Accuracy

Details

- ceil_log is a logarithmic scaling value used when accounting the cost of a packet.

```
mtu  = 2047;                                          #default
cell_log = 0;
while (mtu >> cell_log) > 255)
    cell_log++;
```

Code has been simplified for the sake of brevity

Problem 3: TSO and Lack of Accounting Accuracy

Details

- `rtab` is a lookup table of packet costs

  ```
  for (i = 0; i < 256; i++) {
      size = (i + 1) << cell_log;
      rtab[i] = TIME_UNITS_PER_SEC * size / rate;
  }
  ```

- `rtab` is looked up using `packet_size >> cell_log` as the index
- Where the index is truncated to 255

Code has been simplified for the sake of brevity

Problem 3: TSO and Lack of Accounting Accuracy

Workaround 1

- Disable TSO in the guest
  - ...but the guest can re-enable it

```
# ethtool -k eth0 | grep "tcp segmentation offload"
tcp segmentation offload: on
# ethtool -K eth0 tso off
# ethtool -k eth0 | grep "tcp segmentation offload"
tcp segmentation offload: off
```

Problem 3: TSO and Lack of Accounting Accuracy

Workaround 2

- Set the MTU of classes to 40000
  - Large enough to give sufficient accuracy
  - Larger values will result in a loss of accuracy when accounting smaller packets

```
tc class add dev peth2 parent 1:1 classid 1:101 \
    rate 10Mbit ceil 950Mbit mtu 40000
```

http://kerneltrap.org/mailarchive/linux-netdev/2009/11/2/6259456

Problem 3: TSO and Lack of Accounting Accuracy

Solution

- Account for large packets
- Instead of truncating the index, use rtab values multiple times

  ```
  rtab[255] * (index >> 8) + rtab[index & 0xFF]
  ```

- "Make HTB scheduler work with TSO" by Ranjit Manomohan was included in 2.6.23-rc1

http://kerneltrap.org/mailarchive/linux-netdev/2007/12/11/488315

Conclusion

- Existing infrastructure can be used for network bandwidth control
- The key is to be able to identify packets
- And then design an appropriate class hierarchy
- But there are some subtle traps — testing is vital

Questions