Network Performance Improvement for FreeBSD Guest on Hyper-V

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Outline

• Introduction to Integration Service for FreeBSD (BIS)
• Our work on Hyper-V network driver (NetVSC or hn(4))
  • VMBus multi-channel
  • Checksum offload
  • TCP Segmentation Offload
  • Large Receive Offload
  • Virtual Receive Side Scaling
• Performance achievement
Integration Service for FreeBSD (BIS)

• Hyper-V presents synthetic devices to the guest OS
  • Synthetic devices seen by the guest OS are the same, regardless of the real hardware under Hyper-V

• Guest OS needs drivers for these synthetic devices
  • Just like an OS needs drivers for devices it sees when running on real hardware

• Integration Services == the drivers for the Hyper-V synthetic devices
  • They run in the guest OS so follow the device driver model for that guest OS
  • Also include some user-space daemons that interact with the drivers
Integration Service for FreeBSD - High Level Architecture

Windows Server
- Virtual Machine Management Services (VMMS)
- Virtual Machine Worker Process (VMWP)
- Virtual Infrastructure Driver (VID)
- Virtualization Service Provider (VSP)
- Drivers
- VMBus
- Windows Kernel

FreeBSD VM
- Daemon
- TCP/IP
- CAM
- ifnet
- StorVSC
- NetVSC(hn)
- Utilities
- VMBus
- FreeBSD Kernel

Hyper-V hypervisor
Hardware

User mode
Kernel mode
Networking data path in Hyper-V

Hyper-V virtual switch traffic and data path
Integration Service for FreeBSD - Evolution

• Ports available for FreeBSD 8.4, 9.1, 9.2 and 9.3.
• FreeBSD 10 has built-in BIS drivers.

**FreeBSD 10, 10.1**
- Lacking core support to enable I/O performance
- Supported on a “best effort” basis by Microsoft Customer Support

**FreeBSD 10.2**
- Enhance core functionality
  - VMBus multi-channel
  - CARP, CSUM offload, TSO
  - Storage sub-channel & Scatter/Gather List
  - KVP driver and daemon

**FreeBSD 10.3, 11-CURRENT**
- Enable network based FreeBSD workloads on Hyper-V & Azure
  - Enhance networking stability – 10.3
  - LRO – 10.3
  - vRSS – 11-CURRENT
NetVSC performance enhancement

• VMBus Multi-channel (10.2)
• Checksum Offload (10.2)
• TCP Segmentation Offload (10.2)
• Large Receive Offload (10.3)
• Virtual Receive Side Scaling (11-CURRENT)

• Test Environment
  • Windows Server 2012 R2 host: 32GB memory, 16 cores (2 sockets) with HT disabled (Intel Xeon CPU E5-2650 v2 @2.6GHz), Intel 10G 2P X520 NIC (82599).
  • FreeBSD guest: 8 vCPUs, 4GB memory.
  • Netperf is used.
VMBus multi-channel on SMP guest (10.2)

<table>
<thead>
<tr>
<th>Principle</th>
<th>VMBus Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Class ID and Instance ID: identify a device.</td>
<td>A pair of send/recv ring buffers (i.e. for NIC device: 1 Tx queue and 1 Rx queue) hypercall-based signaling (every channel has a vCPU bound to it).</td>
</tr>
</tbody>
</table>

**Improvement -1** Bind different channels to different vCPUs – 10.2

• In 10.1, all channels were bound to vCPU0 even on recent Hyper-V.

**Improvement -2** Enable multiple channels for performance-critical devices

• 1 NIC device can have multiple channels.
• This paves the way for the later vRSS support in 11-CURRENT.
CheckSum Offload (10.2)

**Principle**
Offload the csum calculation to the host.

- **On send**: the upper layer passes down mbufs with CSUM_IP/TCP/UDP flags; NetVSC hands over them to the backend VSP driver with the flags.
- **On recv**: NetVSP hands over packets with the flags to NetVSC; NetVSC pushes them to upper layer.

**Improvement**
Throughput improved by ~200Mbps

- Send and Recv: 2 Gbps -> 2.2 Gbps

**Other Problem**
Guest interrupt handler: 100% utilization of single CPU.

- Mainly because of protocol processing
  process incoming TCP segments or ACKs, wake up process (if necessary)
  send ACKs or send pending outgoing TCP segments.
TCP Segmentation Offload (10.2)

**Principle**

- Offload the segmentation work to Hyper-V host.
- It saves lots of CPU cycles on the send side.
- On send, the upper layer passes down mbuf chains (up to 64KB).
- NetVSC hands them over to the host with the TSO RNDIS header (RNDIS == Remote NDIS).

**Improvement**

- The Send throughput increases significantly.
  - 2.2 Gbps → 4.5~7 Gbps
  - Interrupt handler uses 60~80% of single CPU.
  - TSO is crucial for send performance, especially in guest.

**Other Problem**

Receive side?
## Large Receive Offload (10.3)

### Principle

<table>
<thead>
<tr>
<th>Aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Aggregate multi incoming TCP segments or ACKs from single stream into one mbuf chain</td>
</tr>
<tr>
<td>• Effectively reduceRecv protocol processing overhead</td>
</tr>
<tr>
<td>• <strong>Significantly reduce ACKs rate</strong></td>
</tr>
</tbody>
</table>

### Improvement

<table>
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<th>Recv throughput increases significantly.</th>
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<td>• 2.2 Gbps → 4.5~7.5 Gbps</td>
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Recv side: interrupt handler uses only 20~40% of single CPU.

### Other Problem

<table>
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<tr>
<th>It’s not always good to aggregate as many packets as possible</th>
</tr>
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<tbody>
<tr>
<td>• Throughput instability with many concurrent connections</td>
</tr>
<tr>
<td>• Small throughput jitter</td>
</tr>
</tbody>
</table>
Problem
Good to aggregate as many packets as possible?

- Pure-ACKs received: should be timely passed up to the upper layer.
  Data segments: aggregating too much can delay sending ACKs to the peer.

Solution
Enhance the LRO API

- Allow the driver to configure the per-connection limits of data length and the ACK count.
- By default, at most we aggregate 25*MTU data (for 1 queue) or 2 ACKs.

Improvement
BothRecv and Send throughputs increase again!

- **Recv:**
  - 4.5~7.5Gbps to 8~9.1Gbps (1 queue)
  - Interrupt handler uses 40~60% of single CPU.
- **Send:**
  - 4.5~7Gbps to 8~9.1Gbps (1 queue)
  - Interrupt handler uses 40~50% of single CPU (it was 60~80% with TSO only): receiving less ACKs.
Large Receive Offload (10.3) - 2

**Problem**  
Throughput instability with many concurrent connections

- Especially obvious for >64 connections per Rx ring.

**Solution**  
Enhance the LRO API

- The default 8 LRO entries per-Rx-ring are not enough.
- NetVSC allocates 128 entries by default.
  - tcp_lro_init_args()
Large Receive Offload (10.3) - 3

**Problem**
Small throughput jitter.
- LRO internal data structure is not efficient for entry removal & lookup

**Solution**
Optimize LRO internal data structure
- Fast entry removal: SLIST -> LIST
- Speed up LRO-entry lookup using hash table (not committed in 11-CURRENT yet)
Recap

How about the performance in 40Gb environment?
vRSS (11-CURRENT)

**Principle**

- Enable the host to efficiently distribute traffic to different guest vCPUs
- Multiple queues: each has its own bound vCPU.
- The same connection is handle by the same queue.
  - Reduce lock contention
  - Keep things more hot in CPU cache
- It’s crucial for really high-speed 40Gb NIC.
How we integrate vRSS in NetVSC

• On init:
  • Ask the host to create multiple channels (e.g. 8 vCPUS → 8 channels).
    • A channel consists of 1 TX queue & 1 RX queue.
  • Register the hash key/type/function & indirection table to the host.
    • Indirection table: hash values → channels

• On recv: we pass the hash value as flow_id, and the hash type, to the upper layer.

• On send: the same flow_id is used to choose the same channel.
How we integrate vRSS in NetVSC
Performance data with 10Gb NIC on local Hyper-V VM

FreeBSD on Hyper-V (10G)

Throughput (Gbps)

Connections

Disclaimer: this is not official performance data from Microsoft. The data could be different due to different test tools, environment, etc.
Performance data with 40Gb NIC on Azure G5 size VM

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To-Do list

• Investigate how hypervisor scheduling affects performance (NUMA?)
• Analyze the throughput & latency with >8K concurrent connections
• Integrate Hyper-V network driver with FreeBSD RSS framework
• More profiling on UDP and packet forwarding
• Try netmap with Hyper-V network driver
• SR-IOV? DPDK?
• And more...
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