Network Performance Improvement for FreeBSD Guest on Hyper-V

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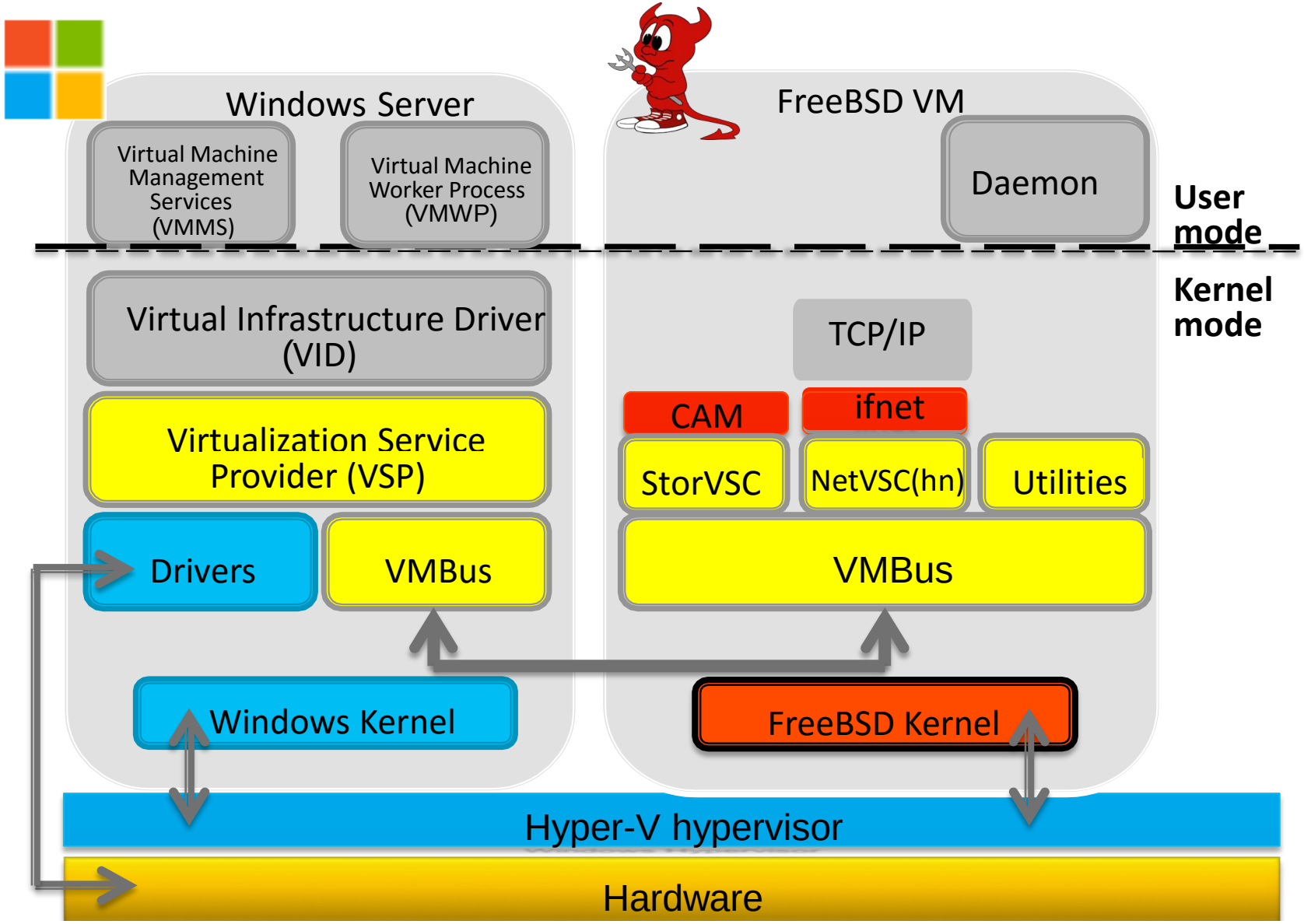
Outline

- 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

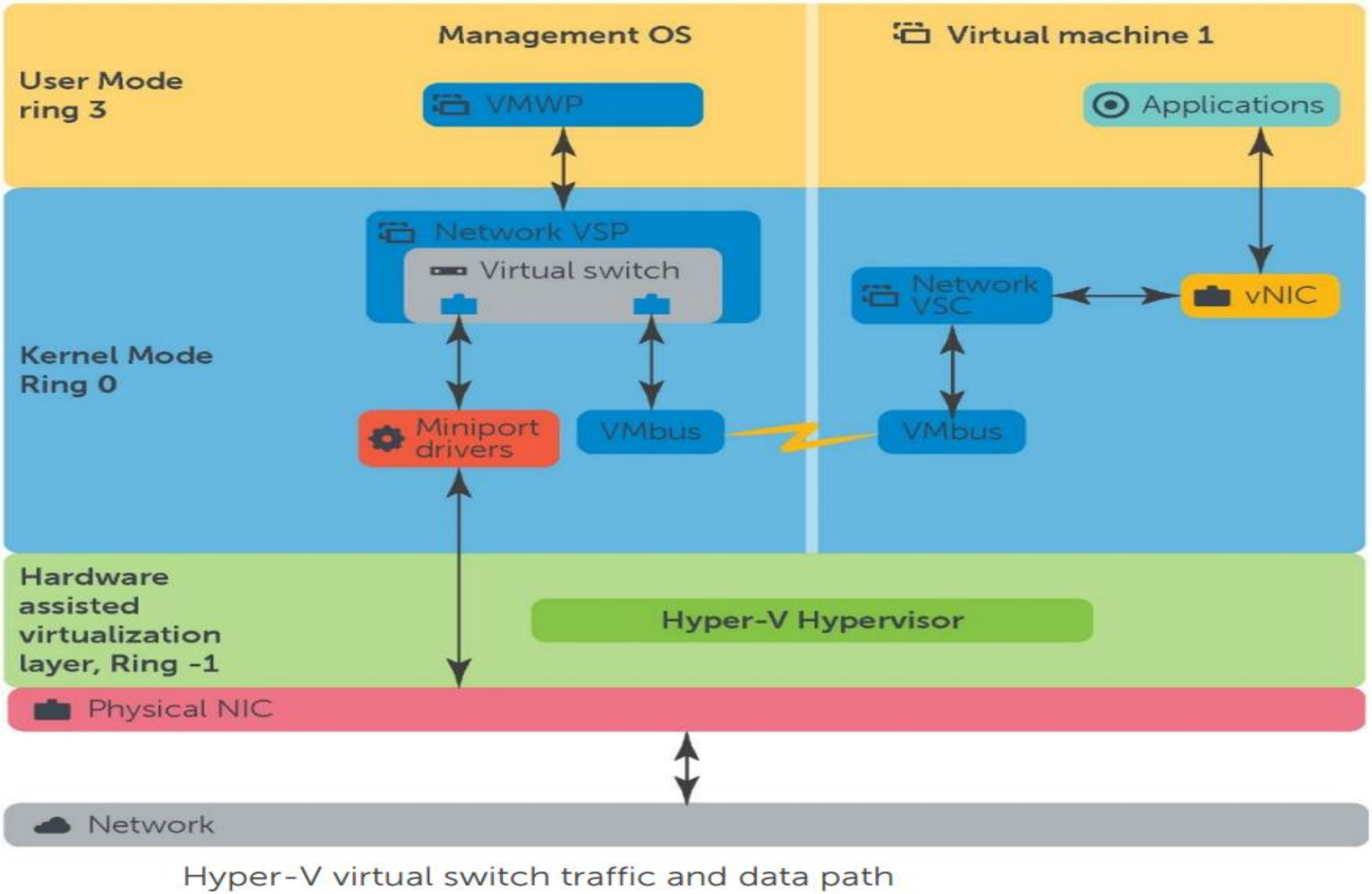
Integration Service for FreeBSD (BIS)

- 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



Networking data path in Hyper-V



Hyper-V virtual switch traffic and data path

The picture is from here.

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)

Principle — VMBus Channel

- Class ID and Instance ID: identify a device.
  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).

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 — Aggregation

- Aggregate multi incoming TCP segments or ACKs from single stream into one mbuf chain
- Effectively reduce Recv protocol processing overhead
- **Significantly reduce ACKs rate**

Improvement — **Recv** throughput increases significantly.

- 2.2 Gbps → 4.5~7.5 Gbps
  Recv side: interrupt handler uses only 20~40% of single CPU.

Other Problem

- It's not always good to aggregate as many packets as possible
- Throughput instability with many concurrent connections
- Small throughput jitter

Large Receive Offload (10.3) - 1

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 — Both Recv 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

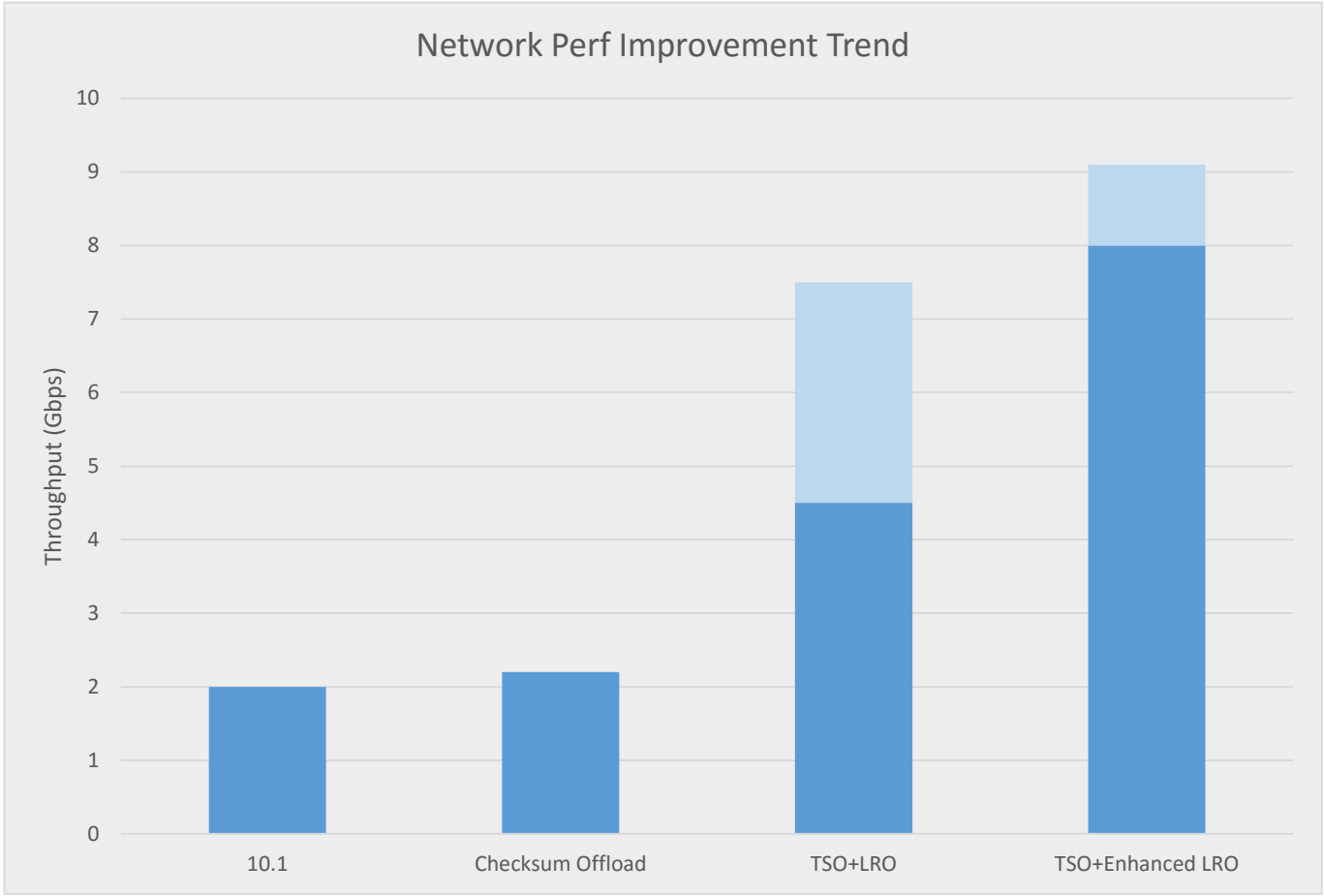
Problem Small throughput jitter.

- 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

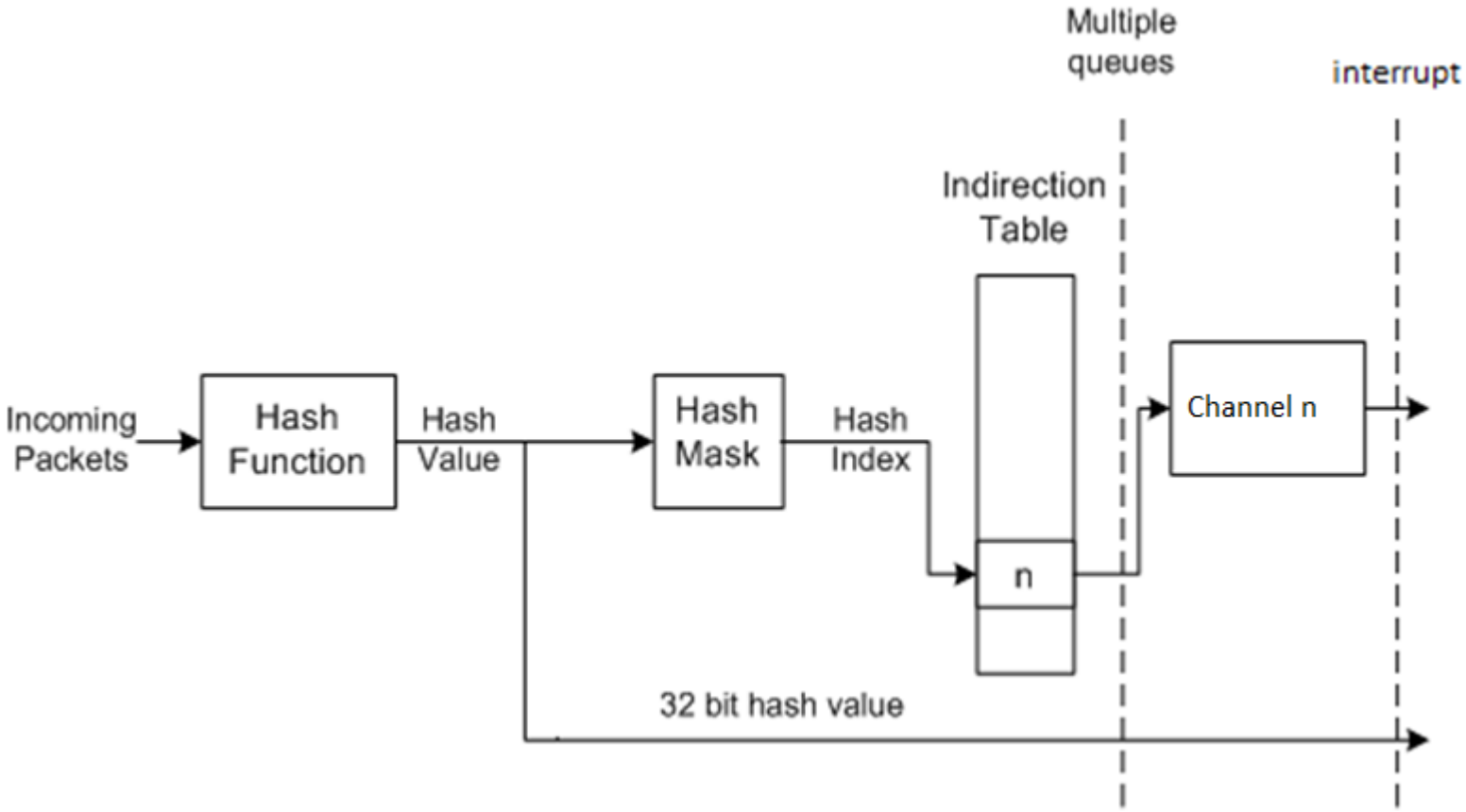
Virtual Receive Side Scaling

- 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.

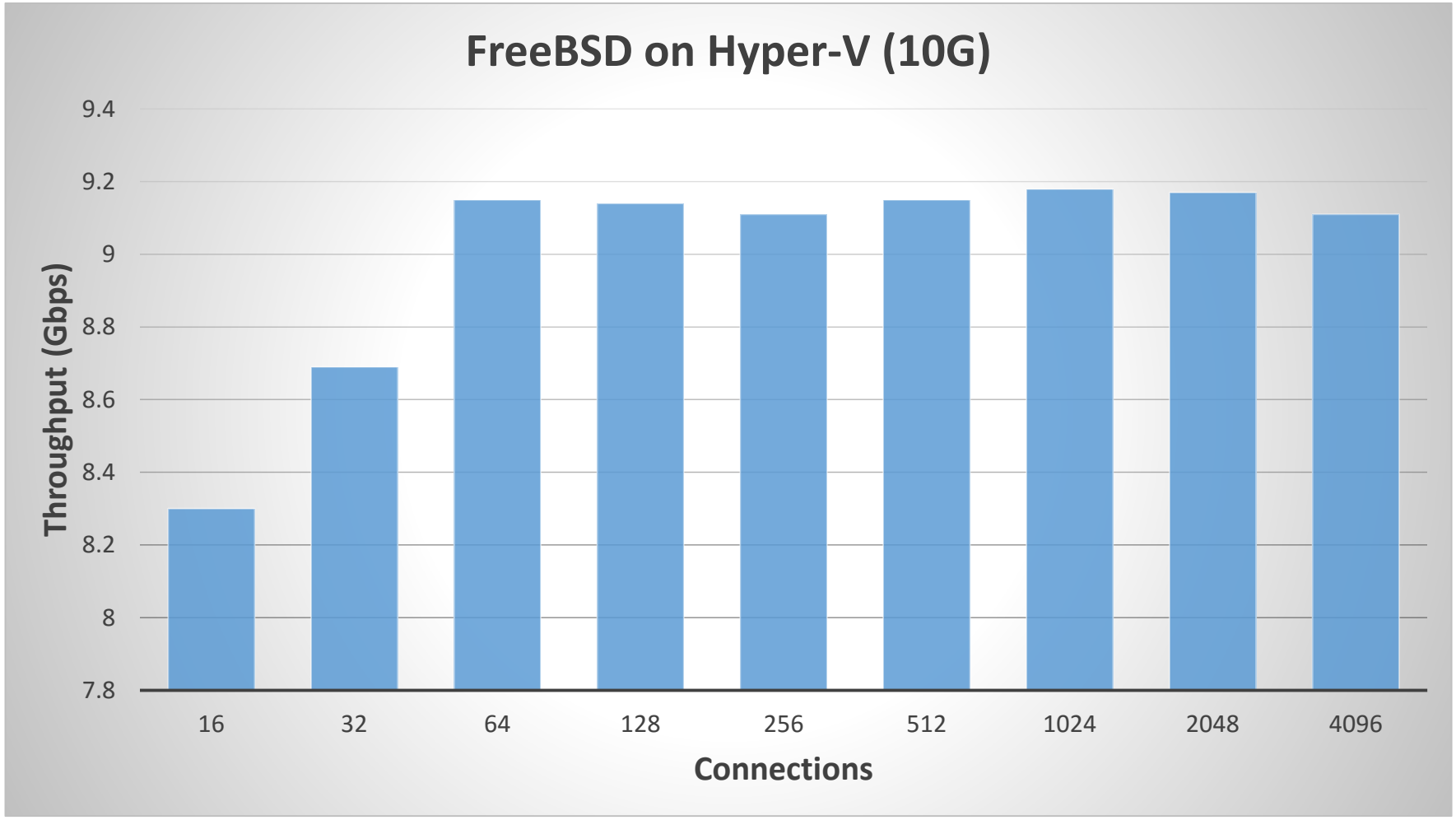
How we integrate vRSS in NetVSC

- 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

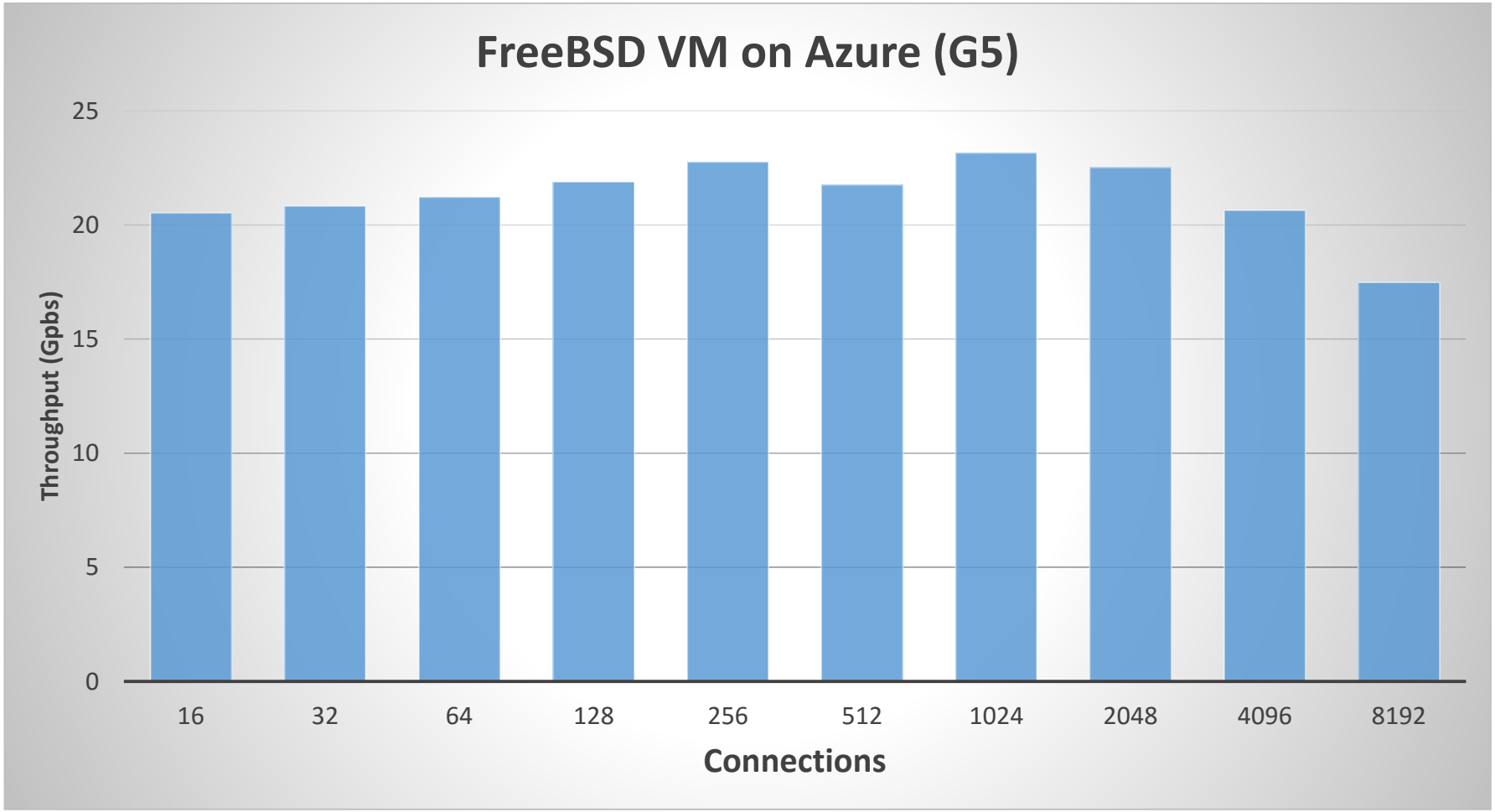


Performance data with 10Gb NIC on local Hyper-V VM



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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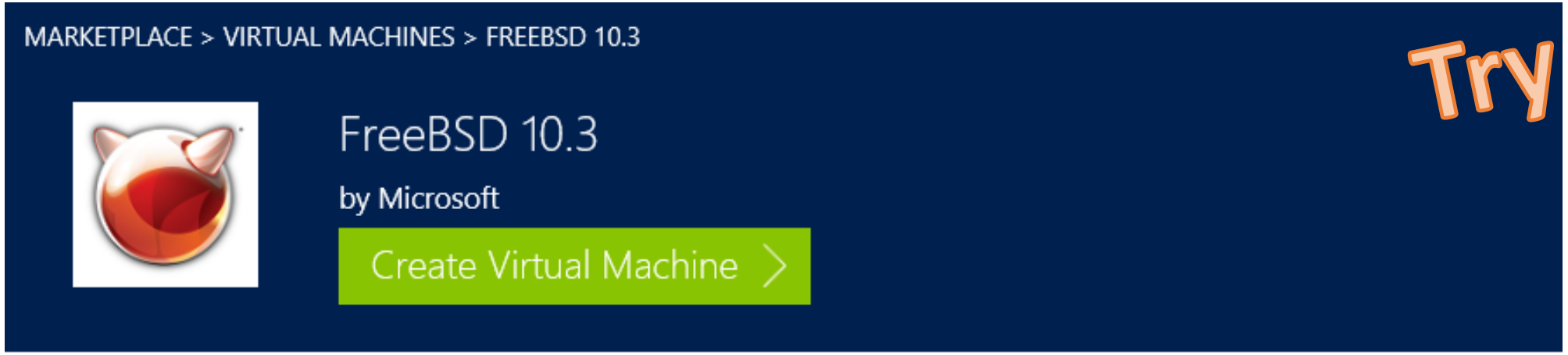
To-Do list

- 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…

FreeBSD is available on Azure Marketplace.



Try It !

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