I/O Scalability in Xen

Kevin Tian  kevin.tian@intel.com
Eddie Dong  eddie.dong@intel.com
Yang Zhang  yang.zhang@intel.com

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Agenda

Overview of I/O Scalability Issues

• Excessive Interrupts Hurt
• I/O NUMA Challenge

Proposals

• Soft interrupt throttling in Xen
• Interrupt-Less NAPI (ILNAPI)
• Host I/O NUMA
• Guest I/O NUMA
Retrospect...

2009 Xen Summit (Eddie Dong, ...)

Extending I/O Scalability in Xen

Covered topics

- VNIF: multiple TX/RX tasklets, notification frequency
- VT-d: vEOI optimization, vIntr delivery
- SR-IOV: adaptive interrupt coalescing (AIC)

Interrupt is the hotspot!
New Challenges Always Exist

Interrupt overhead is increasingly high

- One 10G Niantic NIC may incur 512k intr/s
  - 64 (VFs + PF) x 8000 intr/s
  - Similar for dom0 when multiple queues are used
- 40G NIC is coming

Prevalent NUMA architecture (even on 2-node low end server)

- The DMA distance to memory node matters (I/O NUMA)
- w/o I/O NUMA awareness, DMA accesses may be suboptimal

Need breakthrough in software architecture
Excessive Interrupts Hurt! (SR-IOV Rx Netperf)
Excessive Interrupts Hurt!

Bandwidth is not saturated with low interrupt rate!

CPU% increases fast with high interrupt rate!
Excessive Interrupts Hurt! (Cont.)

Excessive VM-exits (7vm as example)

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>External Interrupts</td>
<td>35k/s</td>
</tr>
<tr>
<td>APIC Access</td>
<td>49k/s</td>
</tr>
<tr>
<td>Interrupt Window</td>
<td>7k/s</td>
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Excessive context switches

- “Tackling the Management Challenges of Server Consolidation on Multi-core System”, Hui Lv, Xen Summit 2011 SC

Excessive ISR/softirq overhead both in Xen and guest

Similar impact for dom0 using multi-queue NIC
NUMA Status in Xen

Host CPU/Memory NUMA
- Administrable based on capacity plan

Guest CPU/Memory NUMA
- Not supported
- But extensively discussed

Lack of manageability for
- Host I/O NUMA
- Guest I/O NUMA
NUMA Related Structures

An integral combo for CPU, memory and I/O devices

- **System Resource Affinity Table (SRAT)**
  - Associates CPUs and memory ranges, with proximity domain

- **System Locality Distance Table (SLIT)**
  - Distance among proximity domains

- **_PXM (Proximity) object**
  - Standard way to describe proximity info for I/O devices

Solely acquiring _PXM info of I/O devices is not enough to construct I/O NUMA knowledge!
Host I/O NUMA Issues

No host I/O NUMA awareness in Dom0

- Dom0 owns the majority of I/O devices
- Dom0 memory is first allocated by skipping DMA zone
- DMA memory is reallocated for continuity later
- Above allocations are made within node_affinity mask round-robin
  - No consideration on actual I/O NUMA topology

Complex and confusing if dom0 handles host I/O NUMA itself

- Implicates physical CPU/Memory awareness in dom0 too
  - Virtual NUMA vs. Host NUMA?

Xen however has no knowledge of _PXM()
Guest I/O NUMA Issues

Guest needs I/O NUMA awareness to handle assigned devices

• Guest NUMA is the premise

Guest NUMA is not upstream yet!

• Extensive talks in previous Xen summits
  • “VM Memory Allocation Schemes and PV NUMA Guests”, Dulloor Rao
  • “Xen Guest NUMA: General Enabling Part”, Jun Nakajima

• Already extensive discussions and works...

• Now time to push into upstream!

No I/O NUMA information exposed to guest

Lack of I/O NUMA awareness in device assignment process
Proposals

Per-interrupt overhead has been studied extensively!

Now we want to reduce the interrupt number!
The Effect of Dynamic Interrupt Rate

A manual tweak on ITR based on VM number (8000 / vm_num)
Software Interrupt Throttling in Xen

Throttle virtual interrupts based on administrative policies

• Based on shared resources (e.g. bandwidth/VM_number)
• Based on priority and SLAs
• Apply to both PV and HVM guests

Fewer virtual interrupts reduces guest ISR/softirq overhead

It may further throttle physical interrupts too!

• If the device doesn’t trigger a new interrupt when an earlier request is still pending
Interrupt-Less NAPI (ILNAPI)

NAPI itself doesn’t eliminate interrupts

- NAPI logic is scheduled by rx interrupt handler
  - Mask interrupt when NAPI is scheduled
  - Unmask interrupt when NAPI completes current poll

What about scheduling NAPI w/o interrupts?

- If we can piggyback NAPI schedule on other events...
  - System calls, other interrupts, scheduling, ...
- Internal NAPI schedule overhead is much less than a heavy device->Xen->VM interrupt path

Yes, that’s ... “Interrupt-Less NAPI (ILNAPI)”
Interrupt-Less NAPI (Cont.)

**ILNAPI_HIGH watermark:**
- When there’re too many notifications within the guest
- Serve as the high watermark for NAPI schedule frequency

**ILNAPI_LOW watermark:**
- Activated when there’re insufficient notifications
- Serve as the low water mark to ensure a reasonable traffic
- May move back to interrupt-driven manner
Interrupt-Less NAPI (Cont.)

Watermarks can be adaptively chosen by the driver

- Based on bandwidth/buffer estimation

Or an enlightened scheme:

- **Xen** may provide guidance through shared buffer
  - Resource utilization (e.g. VM number)
  - Administrative policies
  - SLA requirements
- **ILNAPI** can be turned on/off dynamically under Xen’s control
  - E.g. in case where latency is much concerned
Proposals

We need close the Xen architecture gaps for both host I/O NUMA and guest I/O NUMA!
Host I/O NUMA

Give Xen full NUMA information:

• Xen already sees SRAT/SLIT
• New hypercall to convey I/O proximity info (_PXM) from Dom0
  • Xen need extend _PXM to all child devices
• Extend DMA reallocation hypercall to carry device ID
  • May need Xen version for set_dev_node
• Xen reallocates DMA memory based on proximity info

CPU access in dom0 remains NUMA-unaware...
• E.g. the communication between backend/frontend driver
Guest I/O NUMA

Okay, let’s help guest NUMA support in Xen! 😊

IOMMU may also spans nodes

• ACPI defines Remapping Hardware Status Affinity (RHSA)
• The association between IOMMU and proximity domain
• Allocate remapping table based on RHSA and proximity domain info
Guest I/O NUMA (Cont.)

Make up guest I/O NUMA awareness

• Construct _PXM method for assigned devices in DM
  • Based on guest NUMA info (SRAT/SLIT)
• Extend control panel to favor I/O NUMA
  • Assign devices which are in same proximity domain as specified nodes of the guest
  • Or, affine guest to the node where assigned device is affined
• The policy for SR-IOV may be more constrained
  • E.g. all guests sharing same SR-IOV device run on same node
• Warn user when optimal placement can’t be assured
Summary

I/O scalability is always challenging every time when we re-examine it! 😊

Excessive interrupts hurt I/O scalability, but there’re some means both in Xen and in guest to mitigate it!

CPU/Memory NUMA has been well managed in Xen, but I/O NUMA awareness is still not in place!
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