XenSummit Asia

November 2-3, 2011
Seoul, Korea

I/O Scalability in Xen

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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

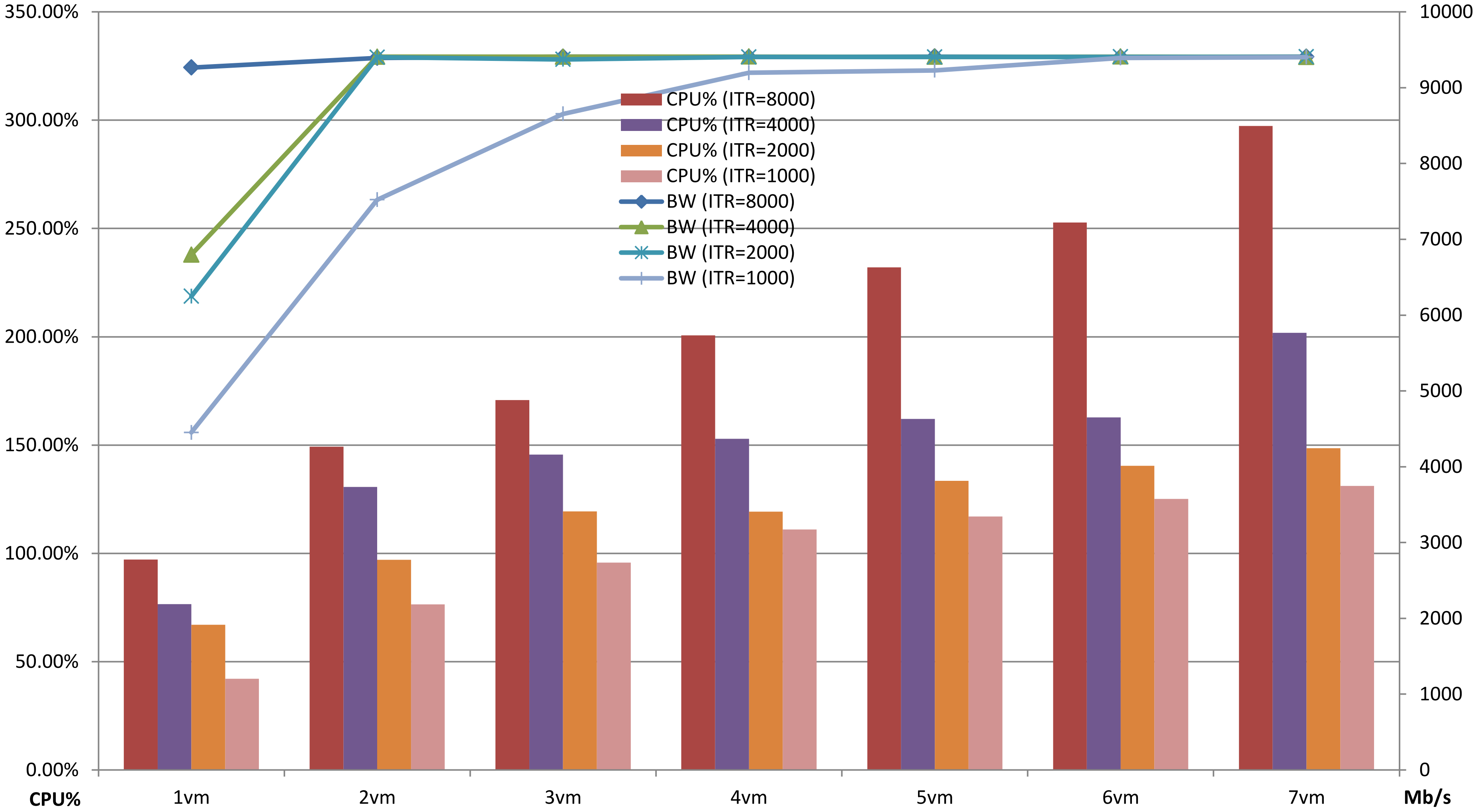
- One 10G Niantic NIC may incur 512k intr/s
  - 64 (VFs + PF) x 8000 intr/s
  - Similar for dom0 when multiple queues are used
- 40G NIC is coming

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

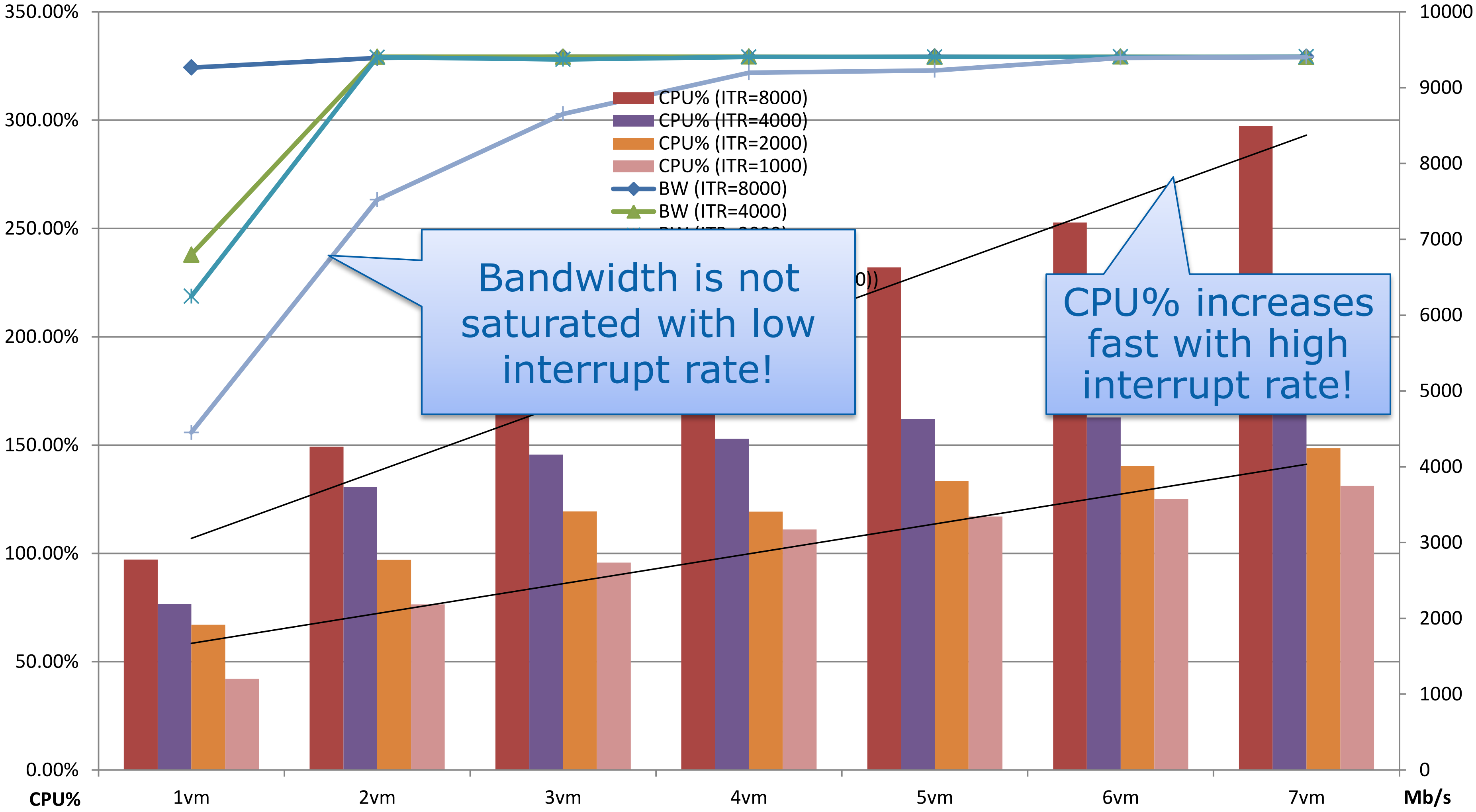
- The DMA distance to memory node matters (I/O NUMA)
- w/o I/O NUMA awareness, DMA accesses may be suboptimal

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!

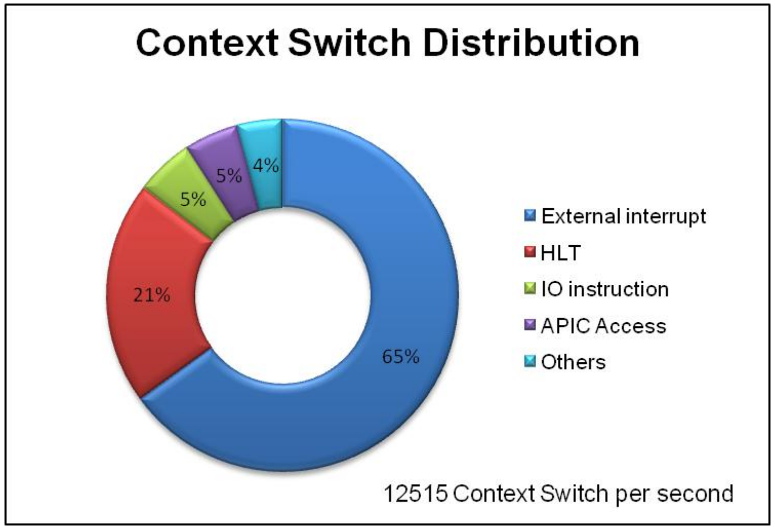
Excessive Interrupts Hurt! (Cont.)

Excessive VM-exits (7vm as example)

External Interrupts	35k/s
APIC Access	49k/s
Interrupt Window	7k/s

Excessive context switches

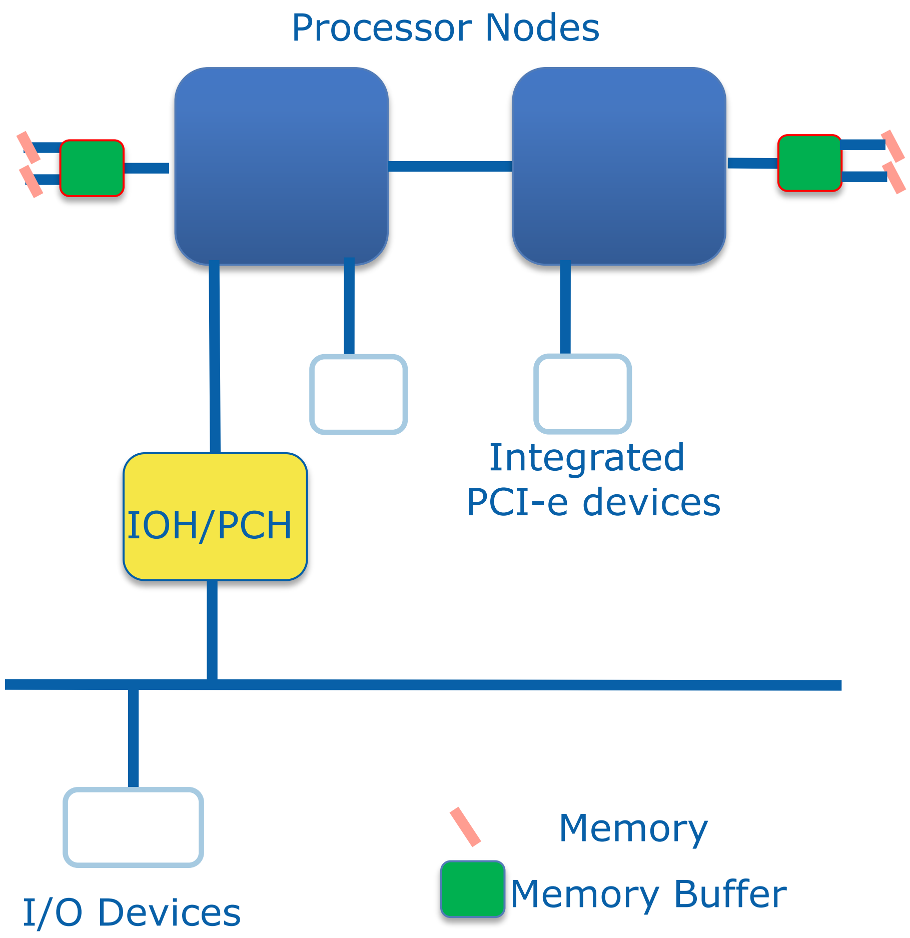
- “Tackling the Management Challenges of Server Consolidation on Multi-core System”, Hui Lv, Xen Summit 2011 SC



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

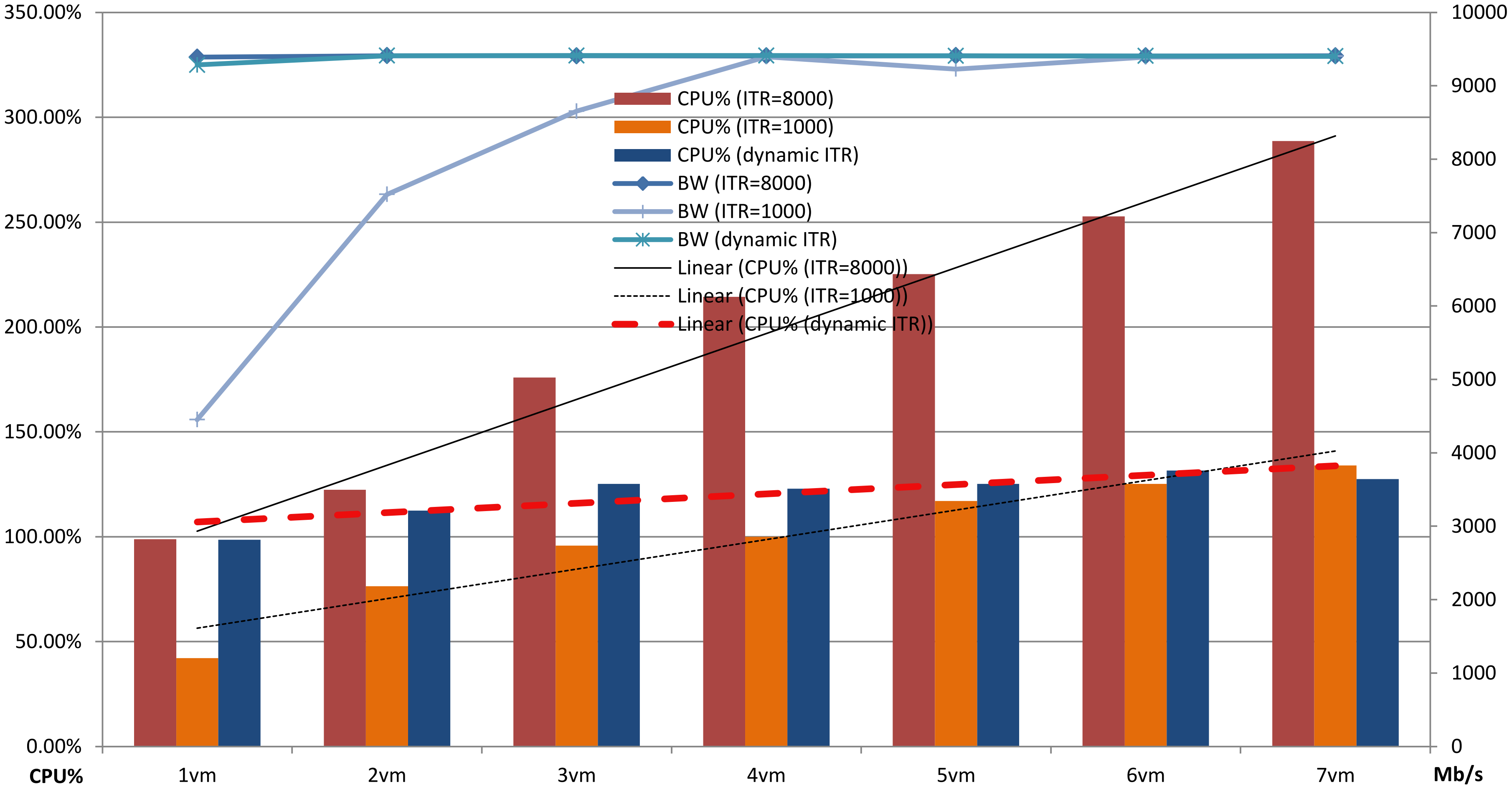
Proposals

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

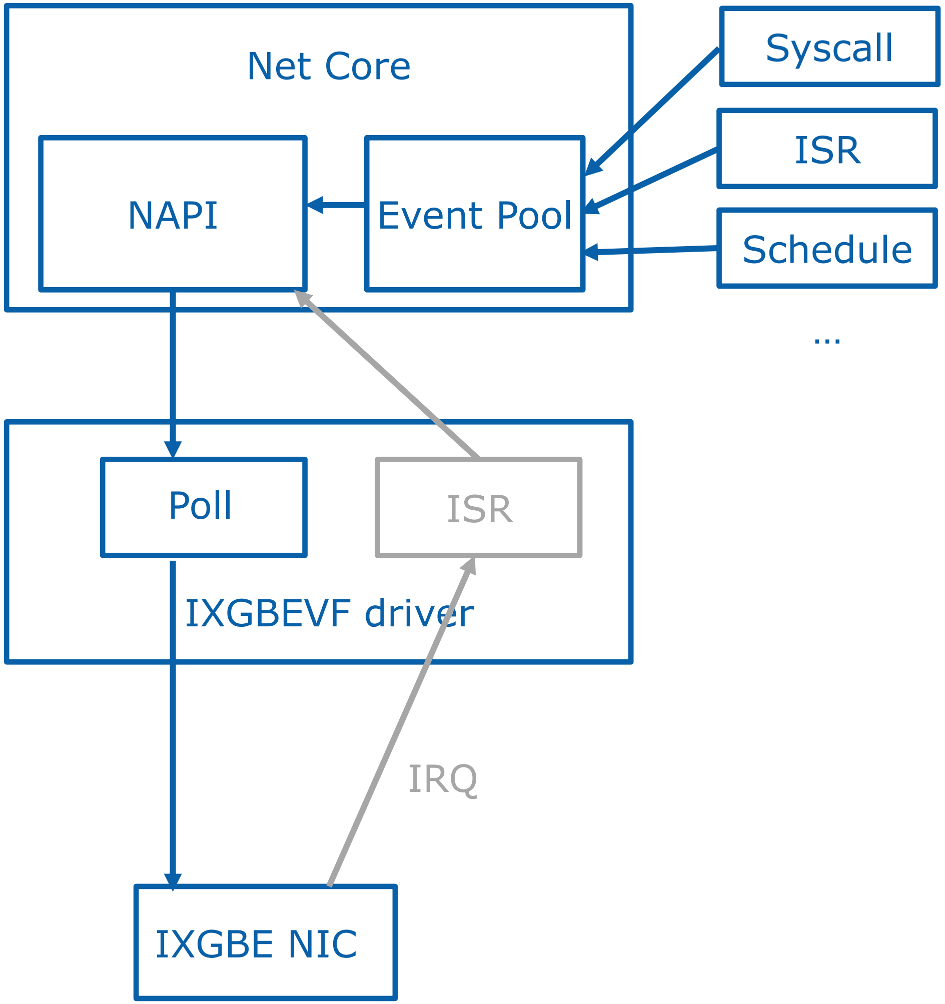
- NAPI logic is scheduled by rx interrupt handler
  - **Mask interrupt when NAPI is scheduled**
  - **Unmask interrupt when NAPI completes current poll**

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.)



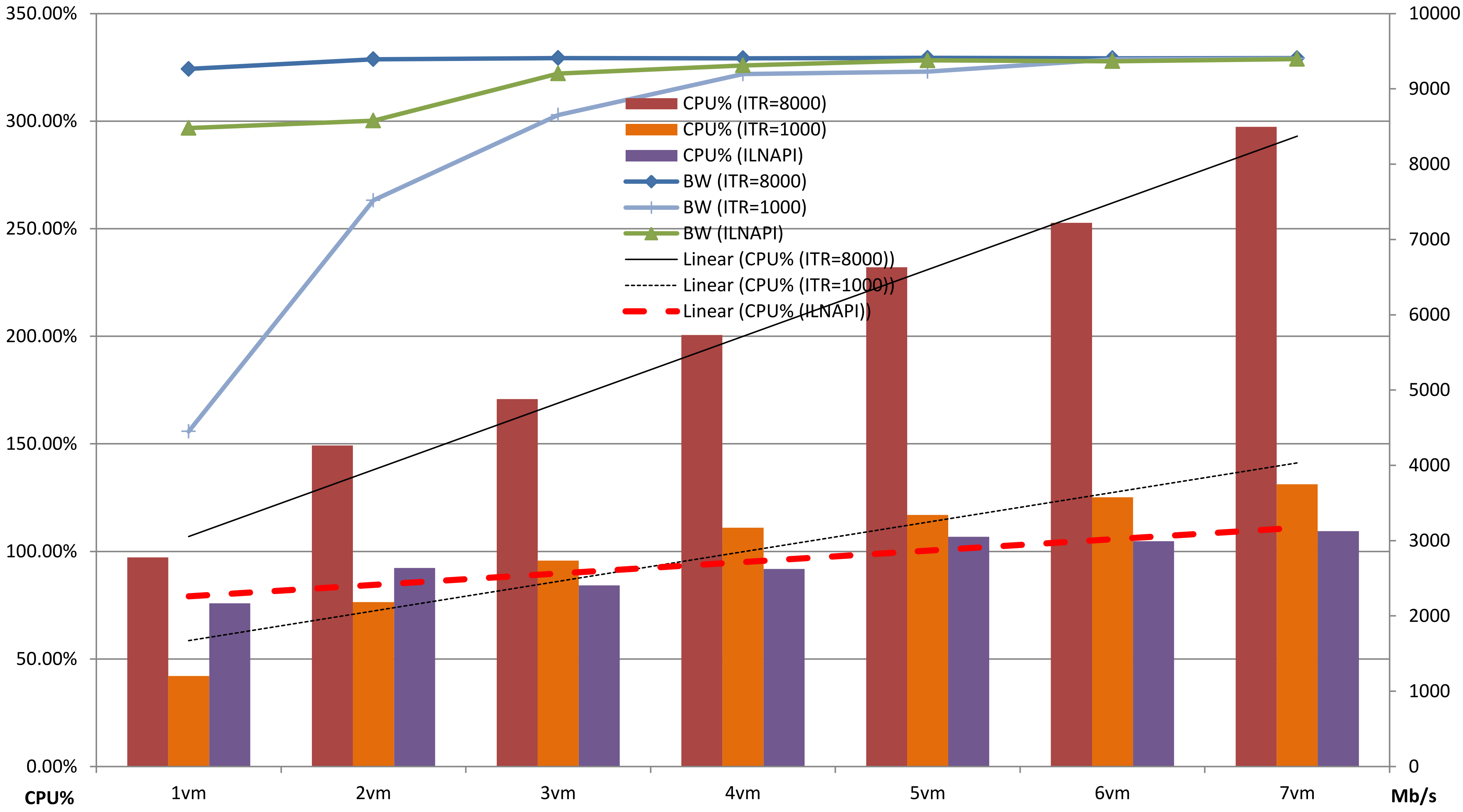
ILNAPI_HIGH watermark:

- 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.)



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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