Xen in Embedded Systems

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Intel Virtualization Technology requires a computer system with a processor, chipset, BIOS, virtual machine monitor (VMM) and applications enabled for virtualization technology. Functionality, performance or other virtualization technology benefits will vary depending on hardware and software configurations. Virtualization technology-enabled BIOS and VMM applications are currently in development.

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Summary & Agenda

This presentation examines the integration of *Xen* Virtualisation into embedded systems. It covers effective partitioning of system resources for deterministic embedded applications.

Agenda

- Overview of Xen Virtualisation
  - Types of hypervisor
  - Types of guest
  - Embedded use cases
- Xen in Embedded Systems
  - Partitioning CPU Time
  - Partitioning System Memory
  - Partitioning System I/O
  - Power usage
What is Xen?

- Xen is a bare metal hypervisor
  - Originally designed for data centre or server environments consolidation.
  - A privileged guest Domain 0 (Dom 0) will always exist.
  - Dom 0 owns all devices (PCI, Storage, USB, etc.) and arbitrates their usage between guests.
  - Xen includes mechanisms for device multiplexing such as “split drivers”.

- Xen’s design goal is the “separation of policy and mechanism”.
  - Policy is implemented in Dom 0 Daemons (Xen Daemon).
  - Mechanism is implemented in the Xen hypervisor layer.
Types of guests

Para-Virtualised (PV) Guests
- Are “aware” they are virtualised.
- PV guest will delegate many aspects of operating system function to the hypervisor via kernel hooks aka hypercalls.

Hardware-Virtual-Machine (HVM) Guests
- Are “not aware” that they are virtualised.
- Qemu* emulates common hardware for HVM guests and the operating system loads real world drivers.
- Graphics interface is exported through VNC.
Embedded use cases

**Application integration**
Integrating new and legacy applications onto same hardware.

**Resource isolation**
Restricting the resources assigned to each application.

**Un-trusted application**
Integrate an un-trusted application (a 3rd party application) onto same hardware.

**High availability**
Ensuring that an application is always available. Standby instances are always ready to run in case of failure.
Xen in Embedded Systems
Virtual CPU (VCPU)

- Are an abstraction layer created by Xen’s scheduler.
- Isolates guest from the actual number of physical CPUs.
- Xen has a scheduler similar to an OS scheduler that arbitrates between the guests contending for CPU time based on priority.
SSL Encrypt is a simple CPU-intensive application.

- It uses the pthreads library to parallelise an encrypted workload over multiple cores.
- It uses the OpenSSL* libraries to encrypt pools of 64-byte buffers using AES 128-bit CBC encryption.

**Equivalent performance native to virtualised**
The Credit Scheduler

The Xen *Credit* scheduler

- Default scheduler in Xen 4.0.0
  - The Credit scheduler is proportional fair share scheduler.
  - The Credit scheduler is a work-conserving scheduler.
- Scheduler parameters
  - Cap: Assign a time cap in hundredths of seconds to a guest, (0 – N *100), where N is the number of cores in the system.
  - Weight: Assign a weight to each guest (1 – 65536); default is a weight of 256.

*Scheduler partitioning of core time is effective*
The graph above shows the standard deviation of throughput with different scheduler settings, assignment, pinning, and capping.

Modest cost in determinism with scheduler partitioning
Virtual CPU Configuration

Caveat Emptor

Partitioning CPU Time:
• If possible, partition CPU resources by assigning cores to guests rather than using scheduler weighting or caps.

CPU Pinning:
• Make the number of Virtual CPUs equal to the number of cores.
• Use vcpu-pin to assign a guest VCPU to a specific core.

Remember:
• Dom 0 must service the hardware assigned to it.
• In all guests:
  - Switch off unnecessary OS kernel features; i.e., use a tickless kernel...
  - Turn off unnecessary OS services ... e.g., CentOS* Bluetooth* manager.
  - Remove unnecessary drivers; e.g., the USB driver.
Real-Time on Xen

Recommended reading:

Supporting Soft Real-Time Tasks in the Xen Hypervisor; Min Lee, A.S Krishnakumar, P. Krishnan, Navjot Singh, Shalini Yajnik; Georgia Institute of Technology, and Avaya Labs

Extending Virtualization to Communications and Embedded Applications; Edwin Verplanke, Don Banks; Intel Corporation, and Cisco Systems, Inc.; Intel Developer Forum (IDF) 2010

The Chinese Dragon Festival
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**Bubble Memory + NUMA**

*Bubble Memory*

Increase in cost of a page allocation

- The bubble memory driver can arbitrate (share) memory between guests. This is not the *default behaviour* on Xen.
  - Page allocation incurs a ~16% performance penalty during memory bubbling.

- Mitigate by statically assigning memory to guests. This is the default behaviour on Xen.
  - maxmem: set maximum amount of memory a domain can be allocated
  - memory: set initial amount of memory a domain is allocated

*NUMA*

- Xen is NUMA-aware
  - Non-Uniform Memory Architecture (NUMA)
  - Switched on in Xen 4.0.0 by default

- Guests are not NUMA-aware (yet!)
  - A patchset has been submitted to Xen, to enable NUMA awareness for PV and HVM guests.
NUMA Optimal Configuration

Sub-optimal Configuration
Guest crosses sockets, guest is bound to cores on more than one socket

Optimal Configuration
Guest does not cross sockets, bind guests to cores on one socket only.
Xen Networking – Software Switch

• Device sharing via the split driver model.
  - The backend driver located in the Dom0 is responsible for multiplexing guest access to physical hardware.
  - The frontend driver delivers data to the guest, implementing OS device driver interfaces.

• Xen networking
  1. Packets are received by the Dom0 Ethernet* driver.
  2. Packets then passed into the OS bridge driver, the destination Ethernet device is looked up, and the packets are forwarded to the Ethernet device driver.
  3. Packets are received the Netback driver in Dom0 and pushed onto a Xenbus ring.
  4. Packets are popped off the Xenbus ring by Netfront driver and passed to the guest operating system.
Xen Networking – Hardware Switch

**Xen device passthrough model**

- **PV Dom0**
  - Backend
  - OS driver
- **PV DomU**
  - OS driver
- **HVM Dom0**
  - Qemu

**SR-IOV hardware switching**

- **IGB**
- **PCIBack**
- **Igbvf**

**Intel® Architecture**

- **Packets**
- **Config Space**

**Single Root I/O Virtualisation (SR-IOV)**

Built on the following technologies available Intel® VT-c enabled Network Interface Cards (NIC)
- I/O Acceleration: Intel® VT-d (IOMMU)
- Filtering Technology: Virtual Machine Device Queues (VMDq) - Hardware MAC Filtering
- Queuing Technology: Multiple RX + TX Hardware Queues

Each guest has an exclusive NIC that has been virtualised in hardware (SR-IOV).

**Xen Passthrough**

- PCI configuration space is still owned by Dom0, guest PCI configuration read and writes are trapped and fixed by Xen PCI passthrough

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RX: Receive Queue
TX: Transmission Queue
HW: Hardware Queue
SW: Software Queue

MAC Filter
Hardware vs. Software Packet Switching

- **Hardware**
  - 2 x Intel® Xeon® Processor E5645 (12M Cache, 2.40 GHz, 5.86 GT/s Intel® QuickPath Interconnect) - 80W Thermal Design Power (TDP)
  - Intel® 82599 10Gb Ethernet Controller with SR-IOV capabilities

- **Software**
  - Measured with Xen 4.0.0 with CentOS 5.4 Guests
  - 1 Socket/6 Cores used to route traffic

*35x performance increase on small packet sizes*
Power Usage

<table>
<thead>
<tr>
<th>Watts</th>
<th>Idle</th>
<th>Idle (Dom0 only)</th>
<th>2 Idle guests (+Dom0)</th>
<th>1 socket active</th>
<th>1 active guest (+Dom0)</th>
<th>2 sockets active</th>
<th>2 active guests (+Dom0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CentOS 5.4</td>
<td>Xen 4.0.0 + CentOS 5.4</td>
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<td>Xen 4.0.0 + CentOS 5.4</td>
</tr>
</tbody>
</table>

Each guest is bound to the cores on a separate socket

Equivalent performance native to virtualised

- Hardware
  - 2 x Intel® Xeon® Processor L5530 (8M Cache, 2.40 GHz, 5.86 GT/s Intel® QPI) - 60W TDP
  - Intel® Server Board S5520HC
  - Enermax* EVR1050EWT* Power Supply Unit - 88.61% efficiency

- Software
  - Measured with Xen 4.0.0 with CentOS 5.4 Guests and CentOS 5.4 Native
Conclusions

- Equivalent performance native to virtualised.
- Potential benefits of virtualisation for embedded system designers:
  - Greater system security.
  - Greater system determinism.
  - Improved resource isolation.
  - Controlled 3rd party platform access.