Lightweight virtualization in the Cloud and at the Edge

Hypervisors gone rogue

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nubificus

Who we are

- Young SME doing research in virtualization systems
- ~7 people involved in various sub-projects:
  - Lightweight FaaS framework targeting low-power devices
  - Efficient storage solutions for microVMs / containers
  - Lightweight hypervisor development
  - Transparent application acceleration in the Cloud and at the Edge
- Based in Sheffield, UK / Athens, GR / Barcelona, ES

Overview

- Setting the scene
  - Microservices-based approaches
  - PaaS, SaaS, FaaS
  - Hybrid sandboxed environments with hypervisors and OS-level virtualization

Overview

- We examine the trade-offs of sandboxed vs fully virtualized deployments of micro-services, focusing on overall systems footprint of the management layers (runtime, hypervisor, I/O handlers).
- We present:
  - a minimal, lightweight Virtual Machine Monitor interfacing directly with KVM.
  - our port of Firecracker (AWS Lambda/Fargate hypervisor) to a Raspberry Pi 4

Setting the scene

- People move slowly to alternative methods of deploying applications:
    - Containers
    - Sandboxes
    - microVMs
    - Unikernels (?)
- The community introduces lower-overhead virtual machine monitors, suited to host the above approaches:
    - OS-level virtualization (containers/sandboxes)
    - Machine-level virtualization (solo5-hvt, firecracker)

Setting the scene

- What about the edge?
  - Small-factor devices, capable of running basic-to-medium sized applications are bloated using generic, conventional OS approaches (Linux variants, fully-blown operating systems) -- have you logged in to a Ubuntu 18.04 running on a RPi4?
  - Going one step further, these devices have a number of hardware accelerators, able to provide power-efficiency when doing compute-intensive tasks like Signal processing (Graphics/Sound), ML inference (Object/Pattern recognition) etc.

How VMs are running today

- Two popular open-source hypervisors:
  - Xen
    - Baremetal hypervisor & VMM, virtual machines running on top, PV drivers running on helper/privileged VMs
  - KVM
    - Linux Kernel patchset + user-space emulator (QEMU)
    - QEMU-lite, NEMU, custom-vmms: crossvm, rust-vmm, firecracker
    - Lightweight examples: kvmtool (mostly KVM API ref), solo5

How VMs are running today

KVM:

- VMM running in user-space, hypervisor in kernel-space (mode switches)
- Linux device drivers available (and schedulers, and memory mgt optimizations, and...)

However:

- Increased attack surface

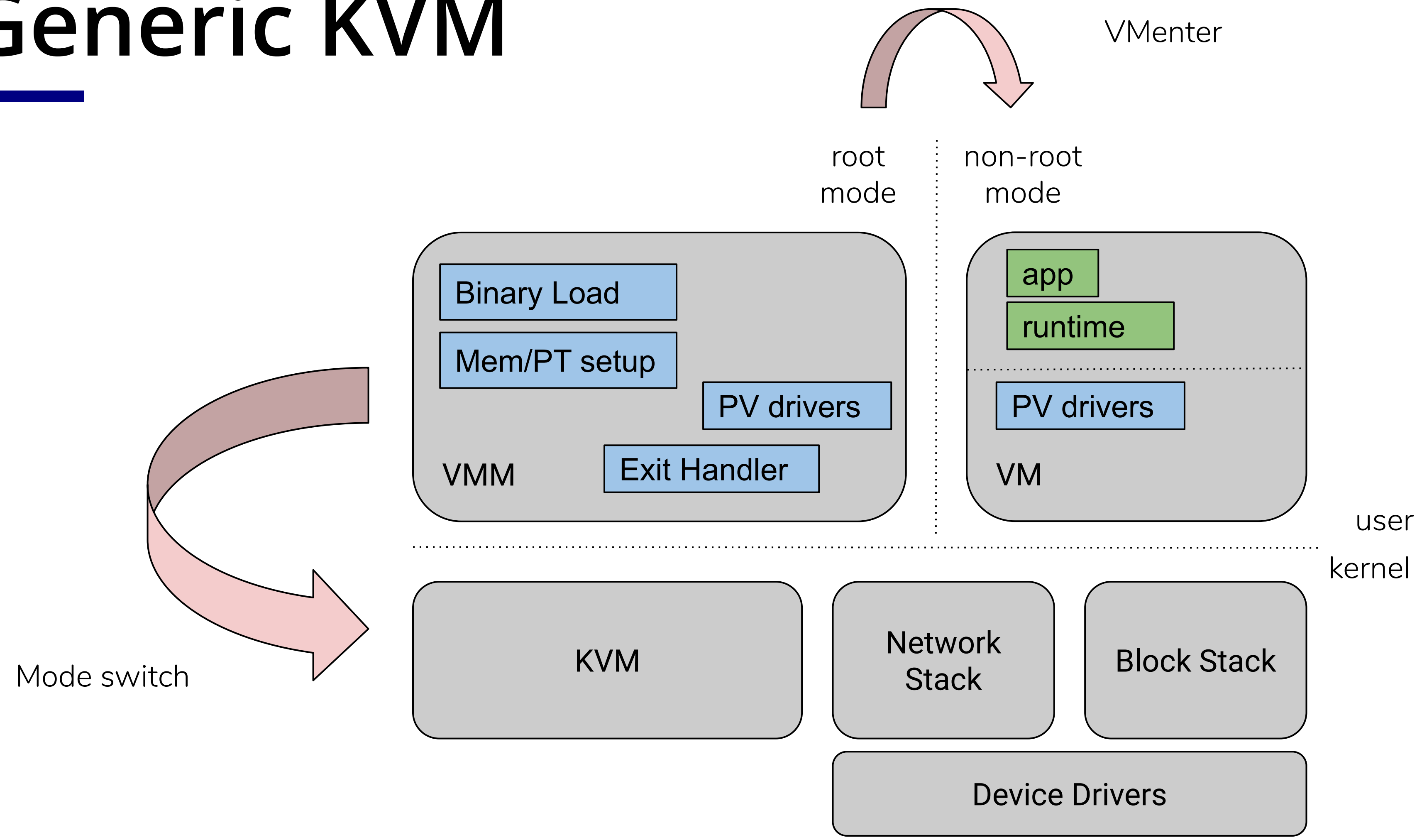
Xen:

- Hypervisor & VMM in the same context
- Faster spawn & execution times

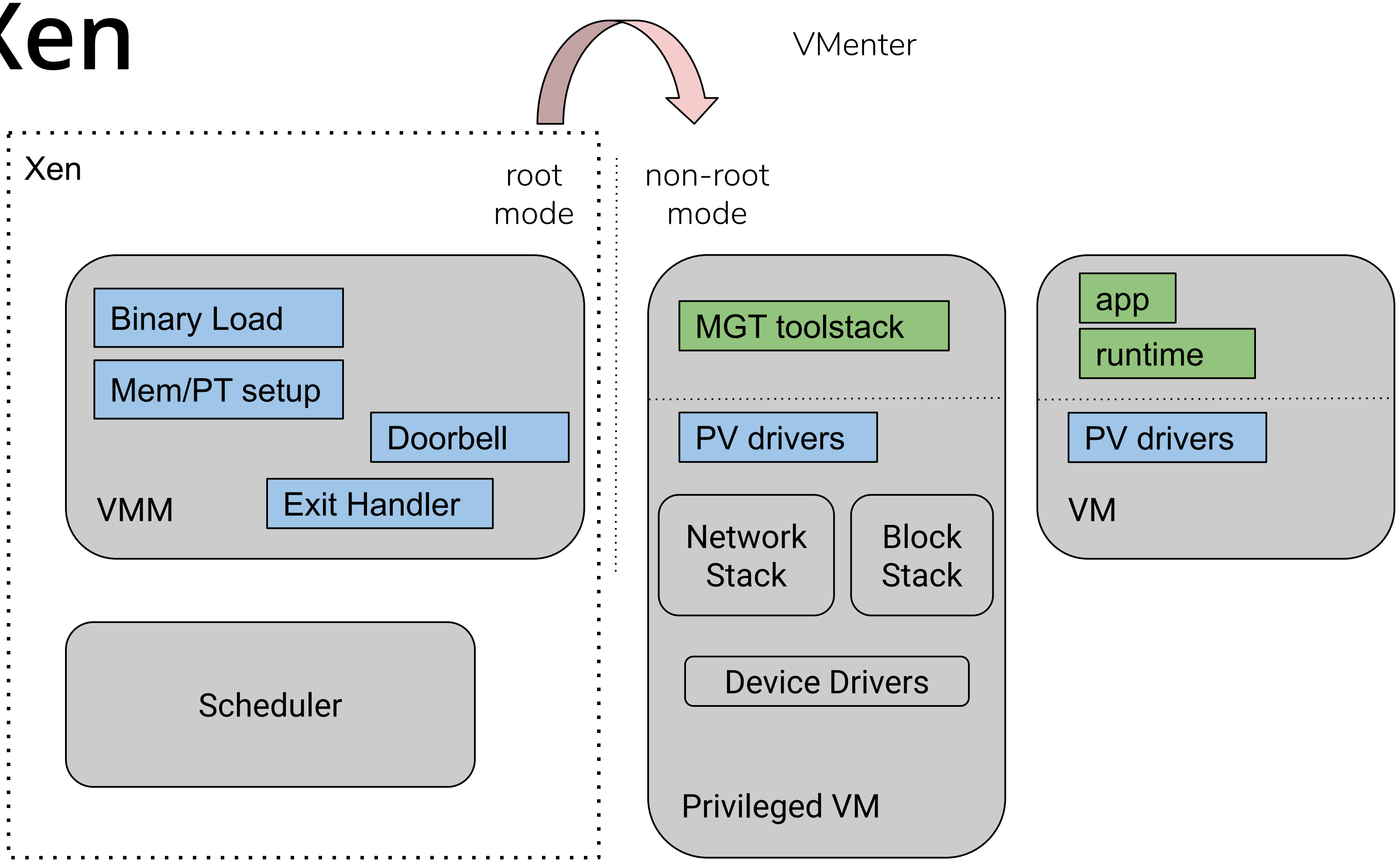
However:

- Needs a helper domain for I/O
- No device drivers (need to use linux or something else)

Generic KVM


VMenter
root
mode
non-root
mode
Binary Load
Mem/PT setup
PV drivers
VMM
Exit Handler
app
runtime
PV drivers
VM
user
kernel
KVM
Network
Stack
Block Stack
Device Drivers
Mode switch

Generic Xen



VMenter
Xen
root mode
non-root mode
Binary Load
Mem/PT setup
Doorbell
Exit Handler
VMM
Scheduler
MGT toolstack
PV drivers
Network Stack
Block Stack
Device Drivers
Privileged VM
app
runtime
PV drivers
VM

How VMs are running today

Running on any of those approaches in the cloud seems OK. What about low-power devices (the Edge)? Resources there are scarce, can we really afford unnecessary software stacks laying around just for the sake of being generic?

To explore options about virtualization at the edge, we tried running some of QEMU's alternatives on a number of low-power devices:

- Raspberry Pi 4
- Khadas VIM3
- NVIDIA Jetson nano

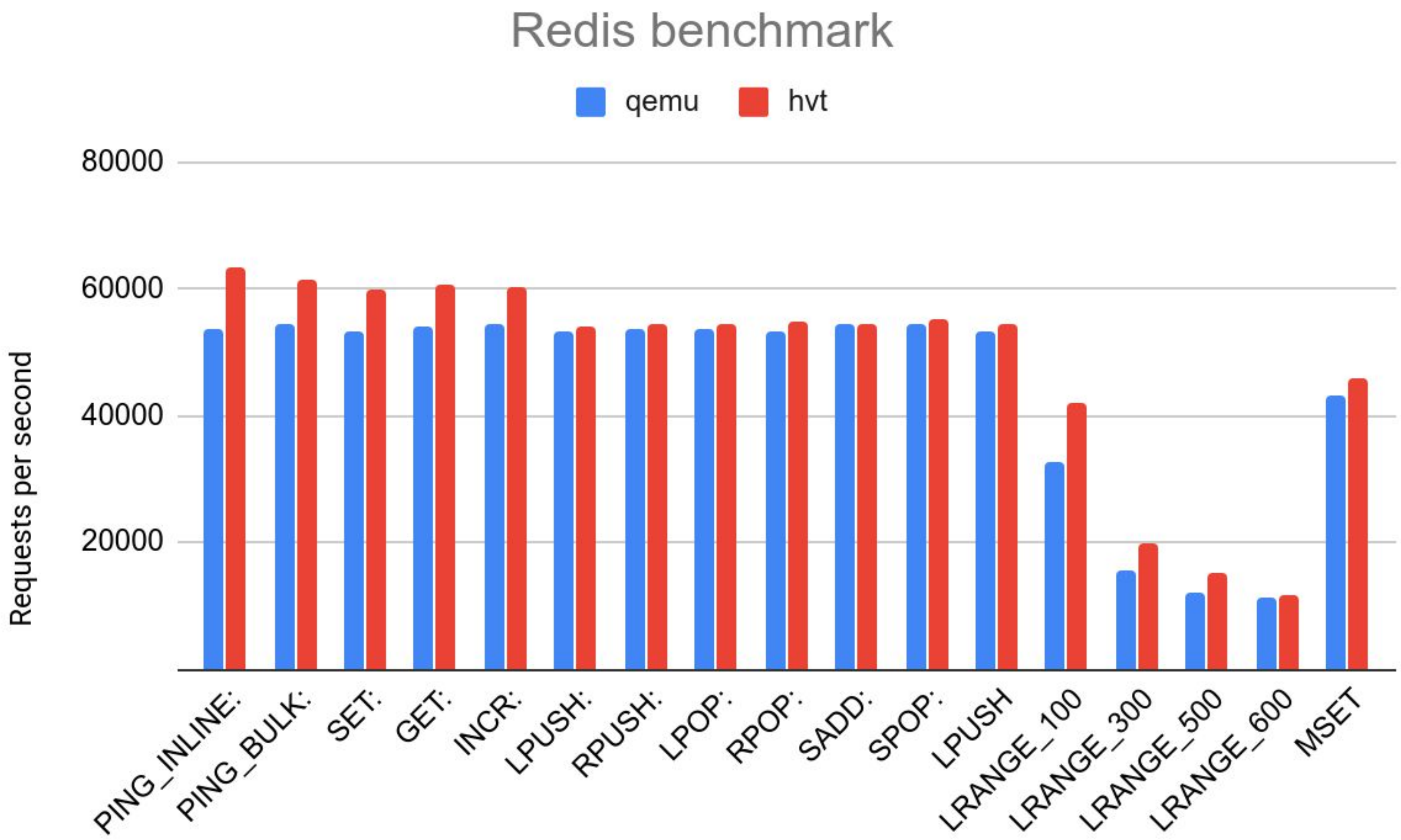
Lightweight VMMs

We ran simple unikernels (redis / nginx / mirage uDNS) on:

- Solo5-hvt (former ukvm)
- AWS Firecracker

While Solo5 worked out of the box (no interrupt handling whatsoever ;-)), firecracker found it hard to cope with GICv2

Redis Benchmark



The firecracker way of doing things

Firecracker Virtual Machine Monitor (VMM)

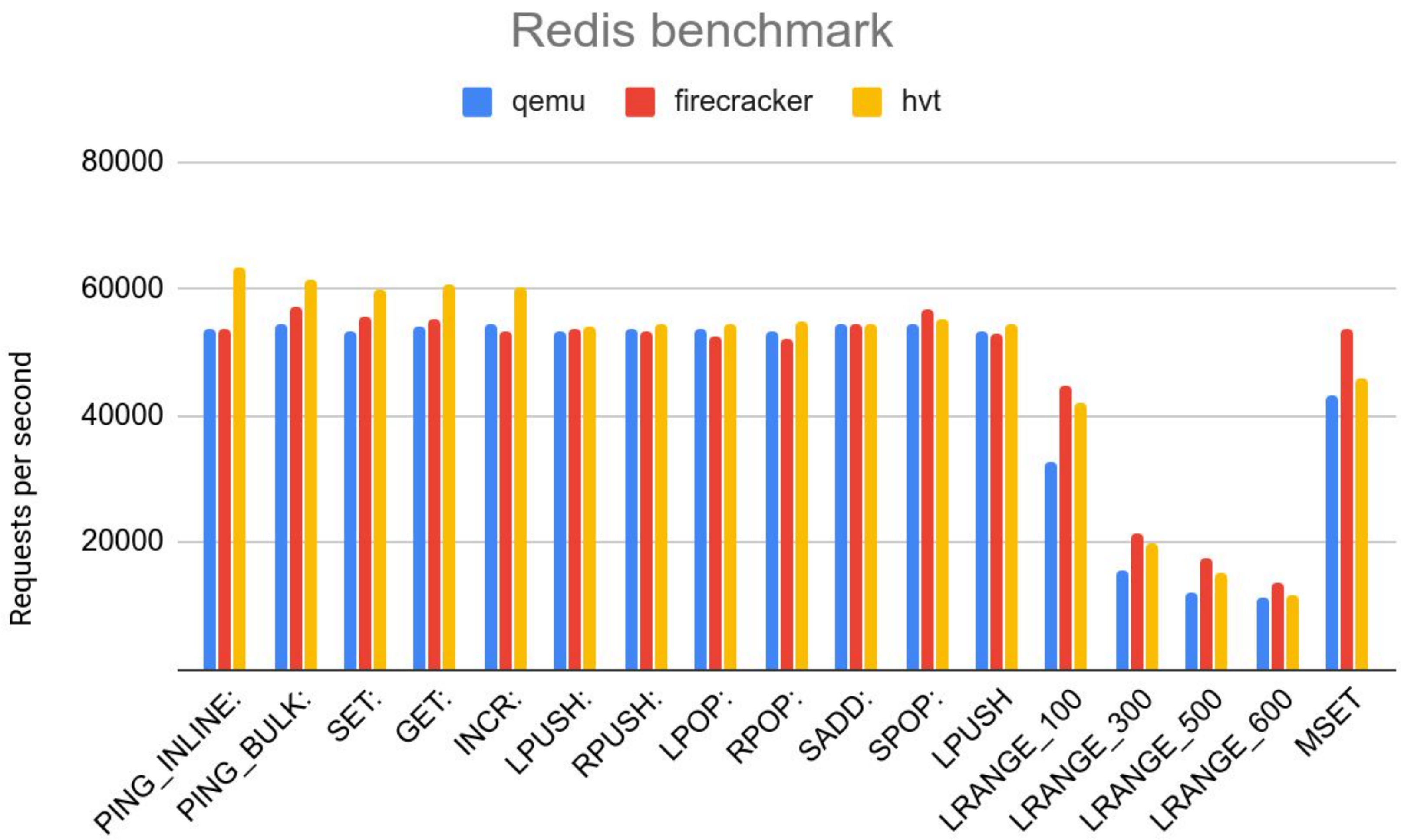
- Powers AWS Fargate & AWS Lambda
- Built on-top of KVM => tenant isolation
- Minimal device model => fast boot times / small attack surface
- Support x86, AMD, aarch64

Firecracker integrates with containerd

Firecracker

- Firecracker v0.19.0 had already support for aarch64 ISA
  - Only for GICv3 though
  - RPi4 uses the older GICv2 version
- Patchset for adding GICv2 support:
  - Make the GIC handling of firecracker generic
  - KVM setup of GICv2 devices
  - Create correct FDT for microVM
- Patch available at v0.20.0 version

Redis Benchmark



How ~~VMs~~ workloads ~~are~~ should be running today

What if we could take advantage of both worlds?

Following the generic approach, we need:

- a software interface to hardware virtualization extensions
- device drivers to access hardware (network/storage)
- a binary interface for workloads
- a piece of software to ensure isolation and handle VMenter/VMexit

How ~~VMs~~ workloads ~~are~~ should be running today

What if we could take advantage of both worlds?

Following the generic approach, we need:

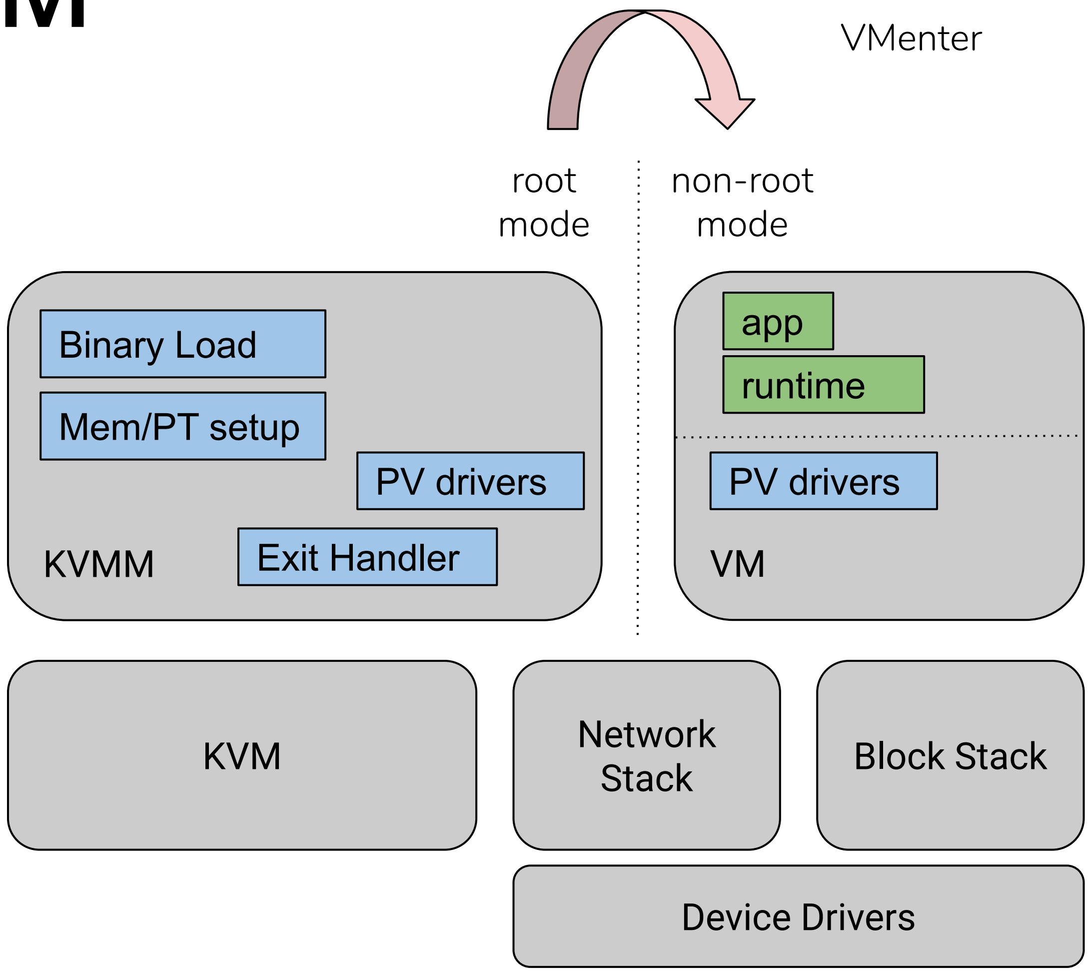
- a software interface to hardware virtualization extensions → **KVM**
- device drivers to access hardware (network/storage) → **Linux Kernel `drivers/`**
- a binary interface for workloads execute → **solo5, microvm, even the Linux ABI**
- a piece of software to ensure isolation and handle VMenter/VMexit → **KVMM**

Kernel VMM

Regarding the name, we know... any suggestions? :P

- KVMM is essentially a virtual machine monitor running in the Kernel
- Handles VMenter/VMexits the same way as a user-space VMM
- Interfaces with the network and the block stack directly in the Kernel

Kernel VMM



VMenter
root mode
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Exit Handler
KVMM
app
runtime
PV drivers
VM
KVM
Network Stack
Block Stack
Device Drivers

Kernel VMM

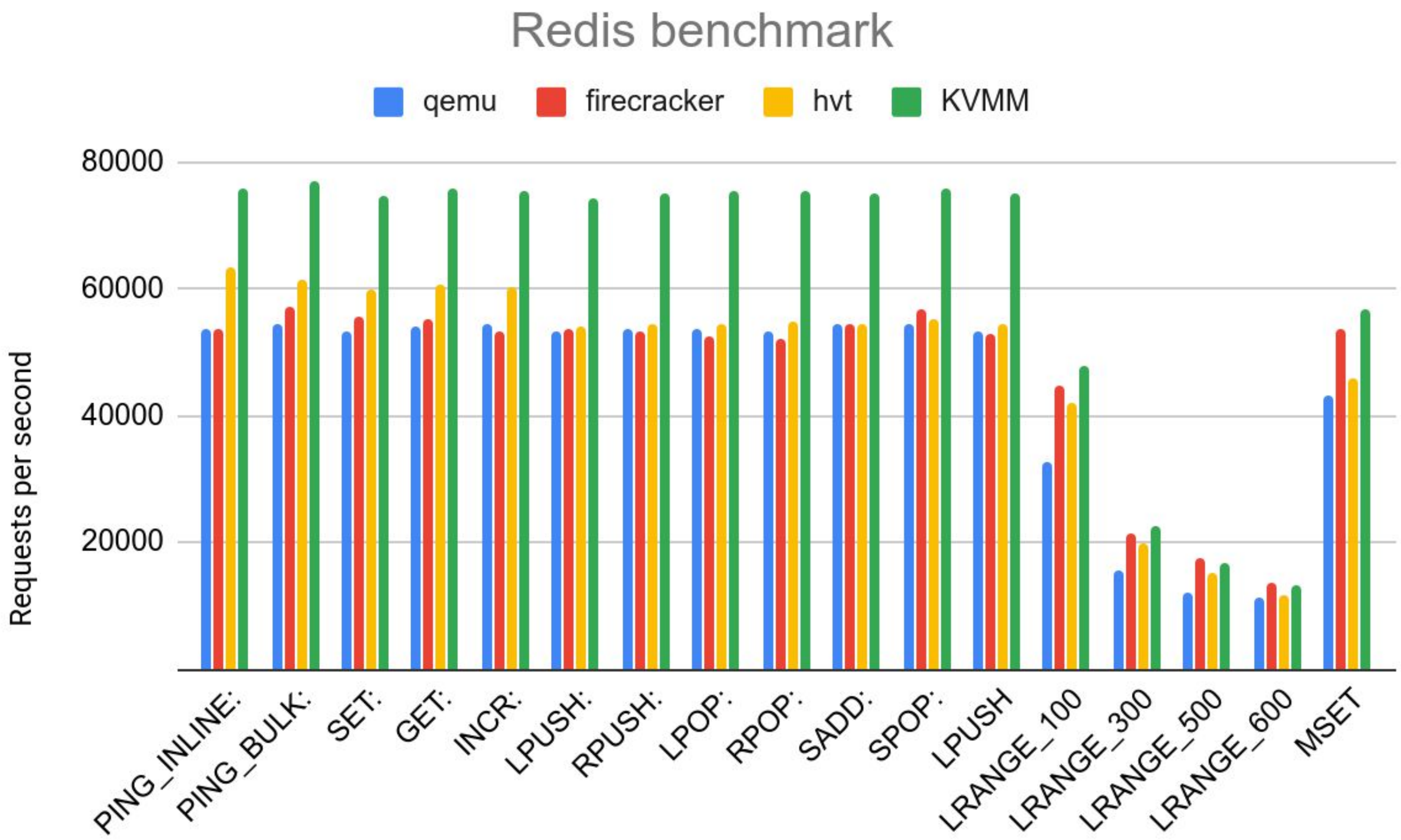
KVMM is WiP. Some of the features currently supported:

- x86_64 && aarch64
- the solo5 ABI:
  - solo5 apps / rumprun / mirageOS / unikraft unikernels
- OCI runtime [forked runnc from the Nabla containers team]

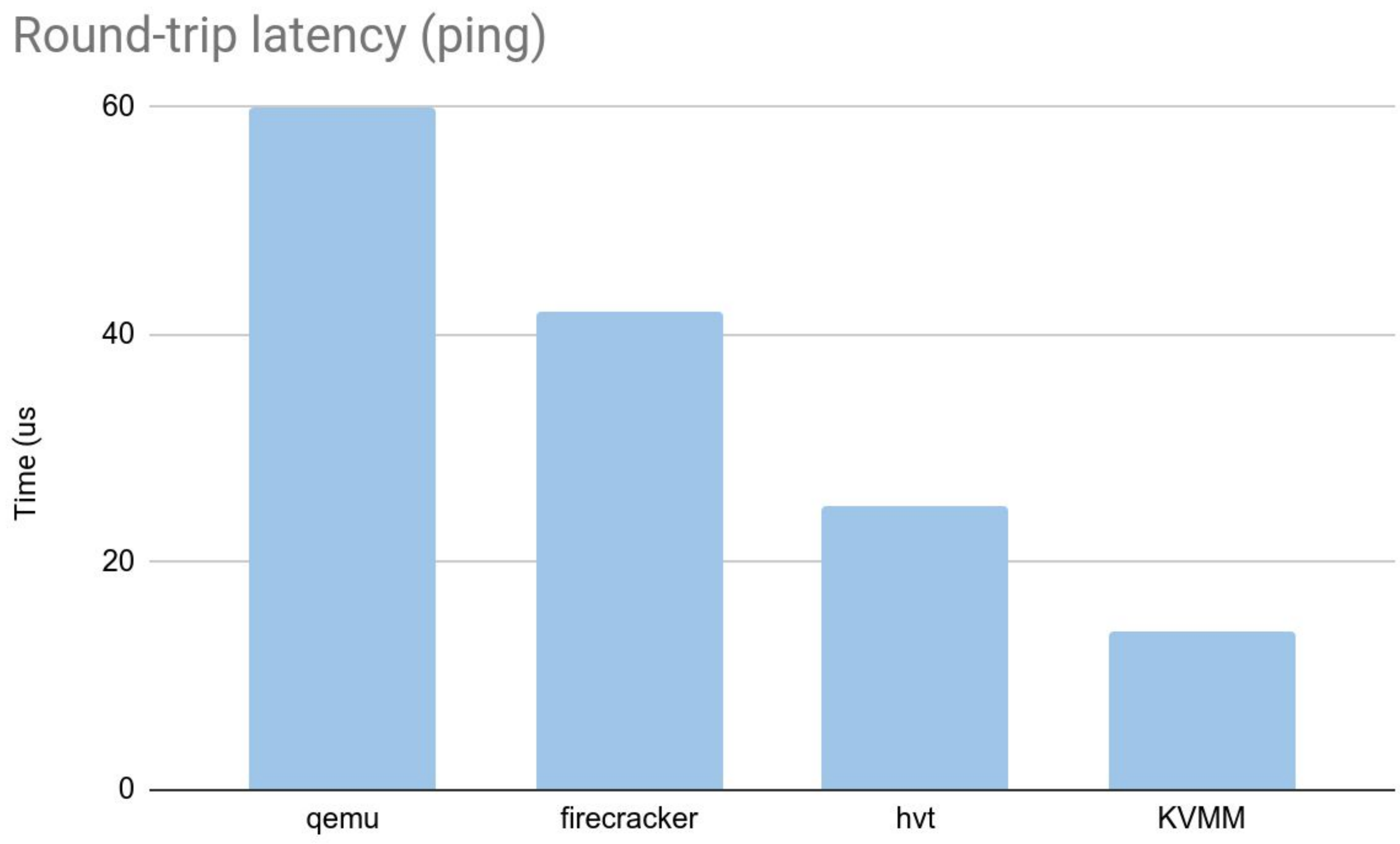
you can try it out on your raspberry pi:

```
# docker run --runtime=runcc cloudkernels/redis-kvmm:aarch64
```

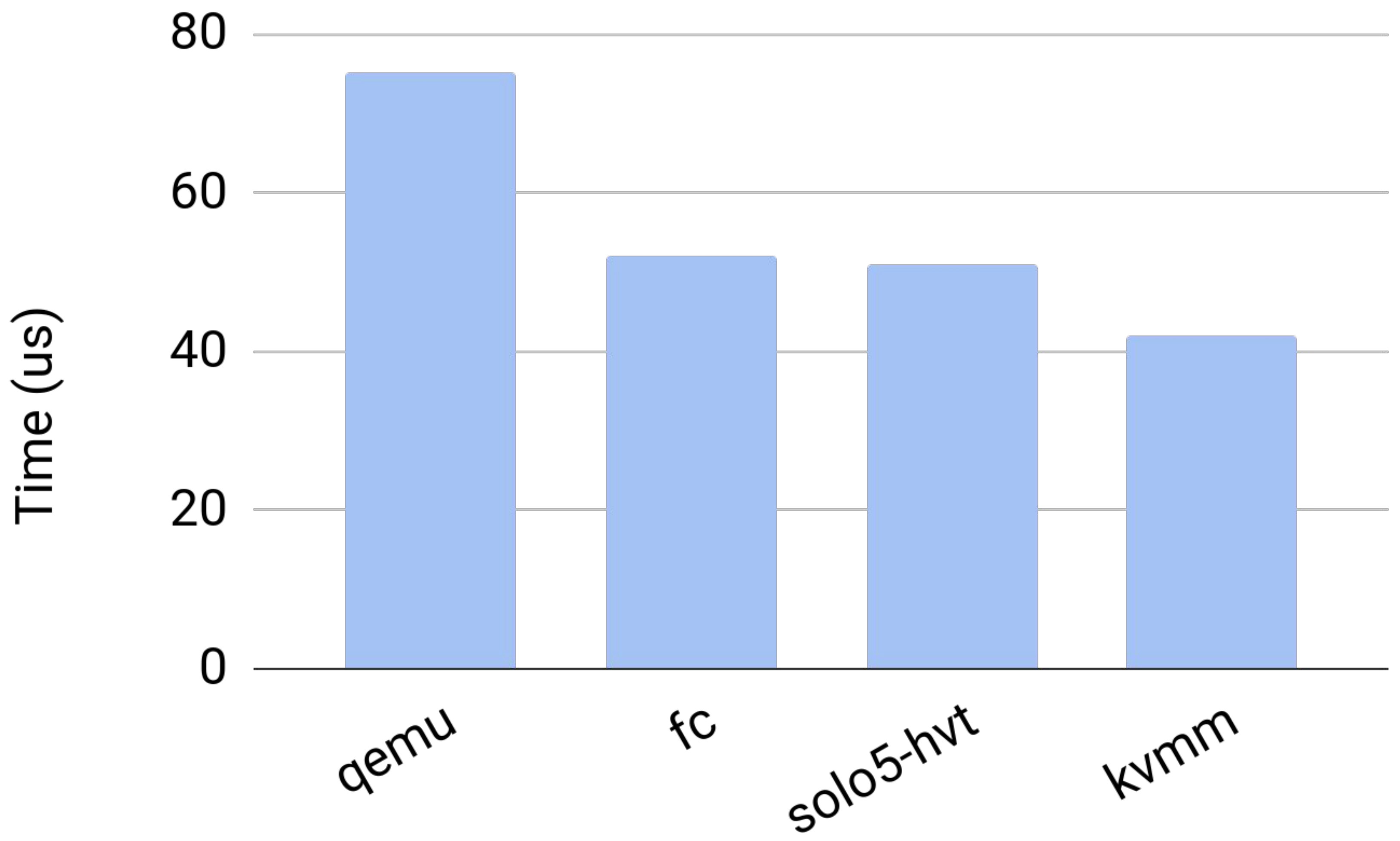
Redis Benchmark



Round-trip latency on x86_64



Round-trip ping latency on Khadas VIM3



Demo for mirageOS DNS

Summary & next steps

- We need to define the necessary requirements for running workloads at the edge.
- We propose KVMM, a minimal VMM in the Linux kernel
- Currently supports the Solo5 ABI (rumprun, mirageOS, unikraft)
- Pre-alpha release (mid Mar)

Next steps:

- Support more ABIs (qemu's microvm)
- Extend container integration (layered storage)
- Support VM/vCPU pre-allocation / forking

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VHPC 2020 -- https://vhpc.org

- 15 Workshop on Virtualization in High-Performance Cloud computing
- Co-located with ISC-HPC 2020, Frankfurt, Germany, **June 21 - 25**,

- Rolling Abstract registration
- Paper Submission Deadline: **Apr 05th**, 2020
- Springer LNCS Proceedings
- Sessions on Container orchestration, Lightweight virtualization, Hardware acceleration, Unikernels etc.

Thanks!

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