Linux Kernel Support for Kernel Thread Starvation Avoidance

Real-Time MC, Linux Plumbers Conference 2021

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VMware Photon OS Team

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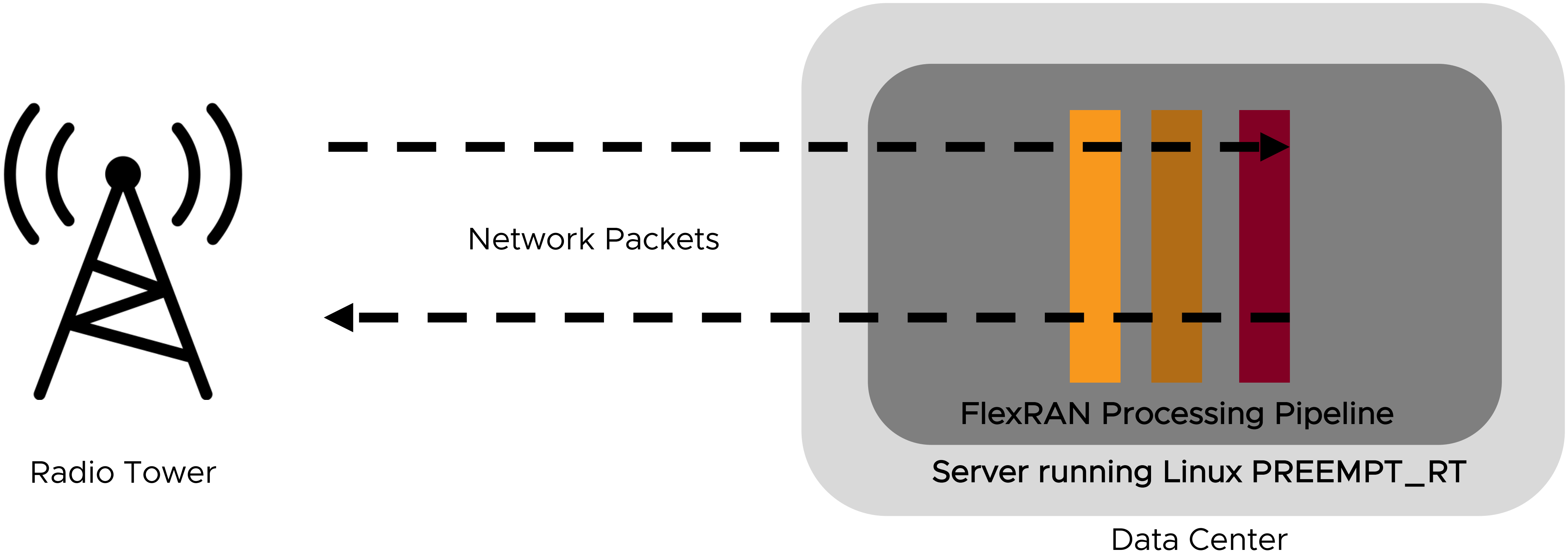
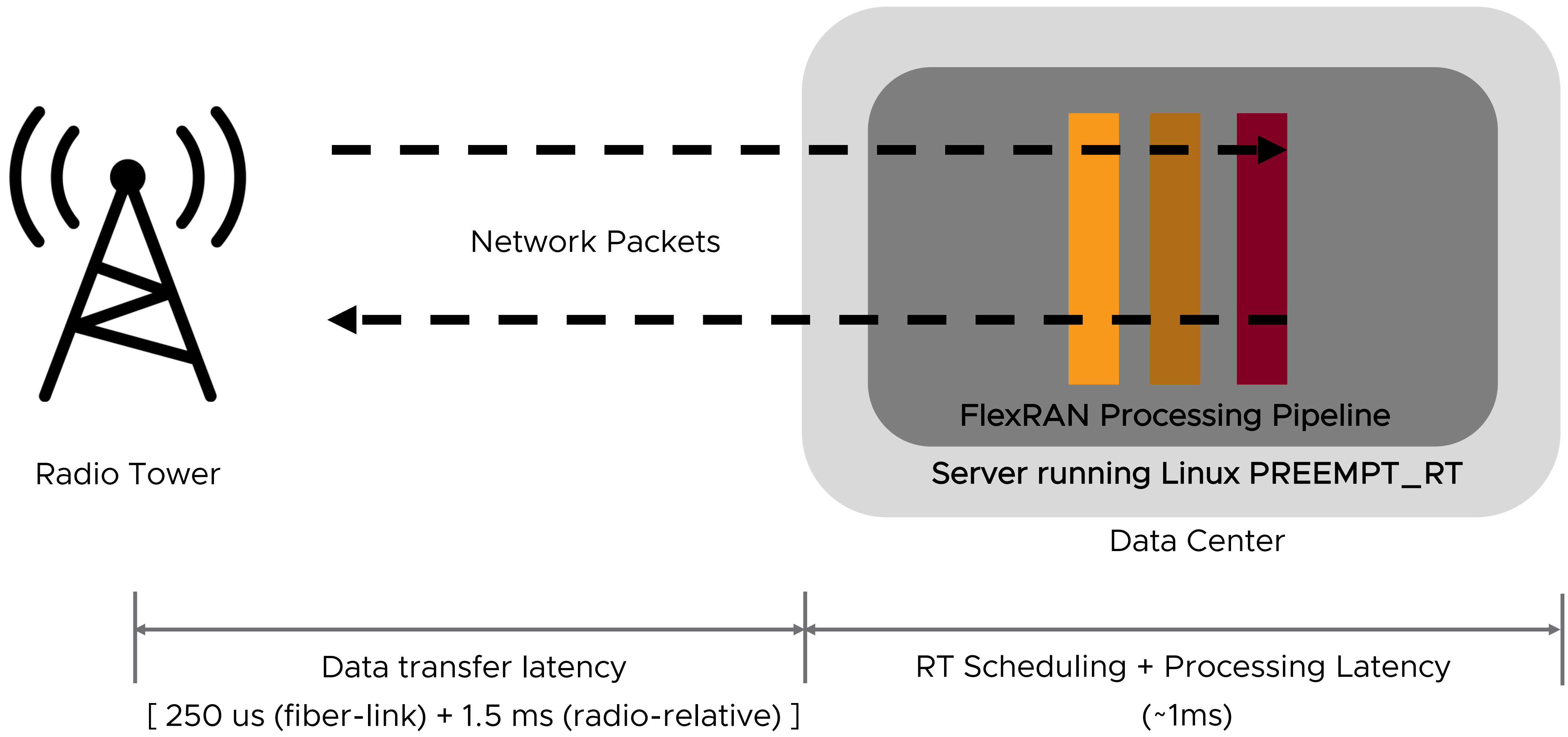
Agenda

Overview of Telco/RAN : Radio Access Network for 5G



Overview of Telco/RAN : Radio Access Network for 5G



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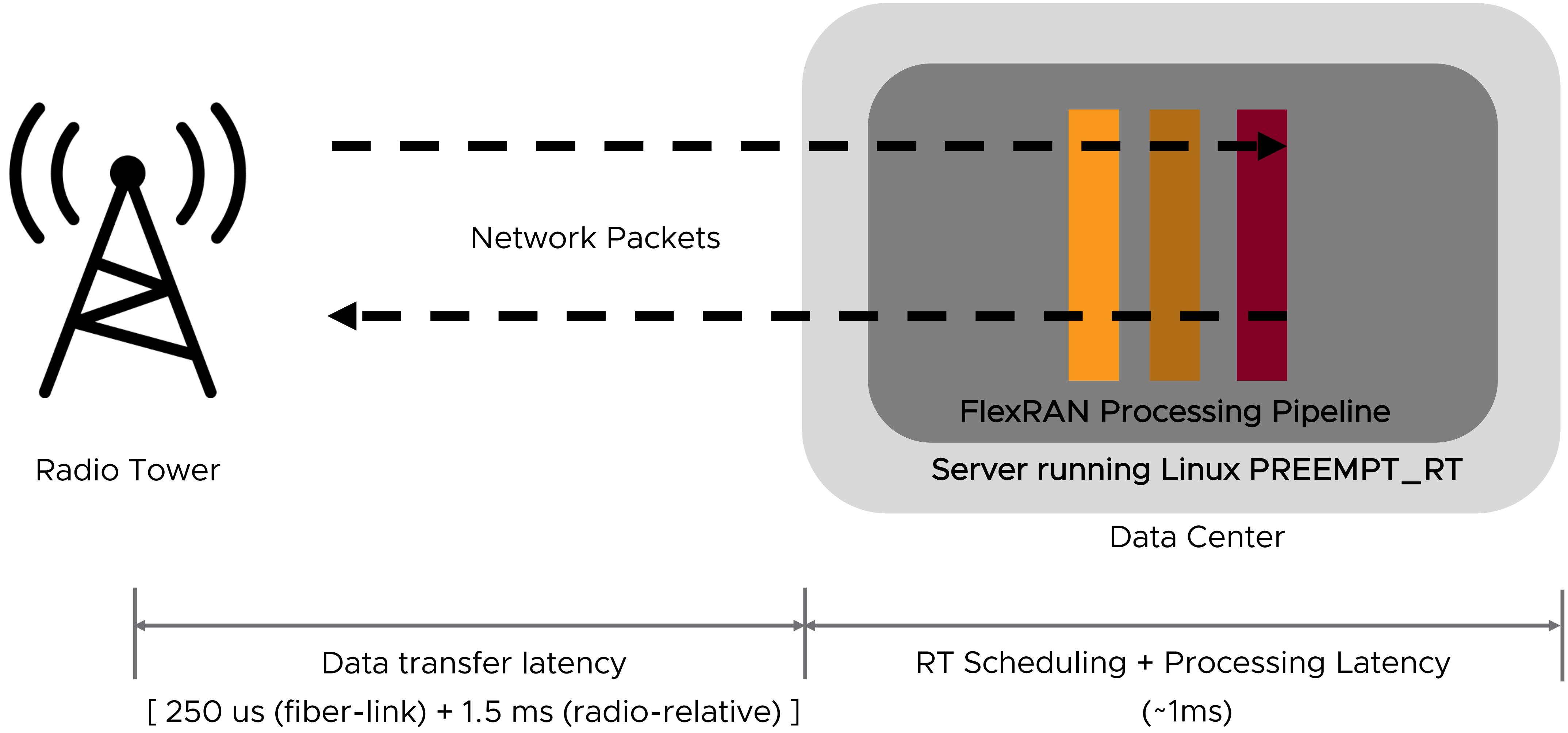
Overview of Telco/RAN : Radio Access Network for 5G



Fixed total latency budget for packet Tx + processing + ack (< 3ms)

Cyclictest latency < 10us

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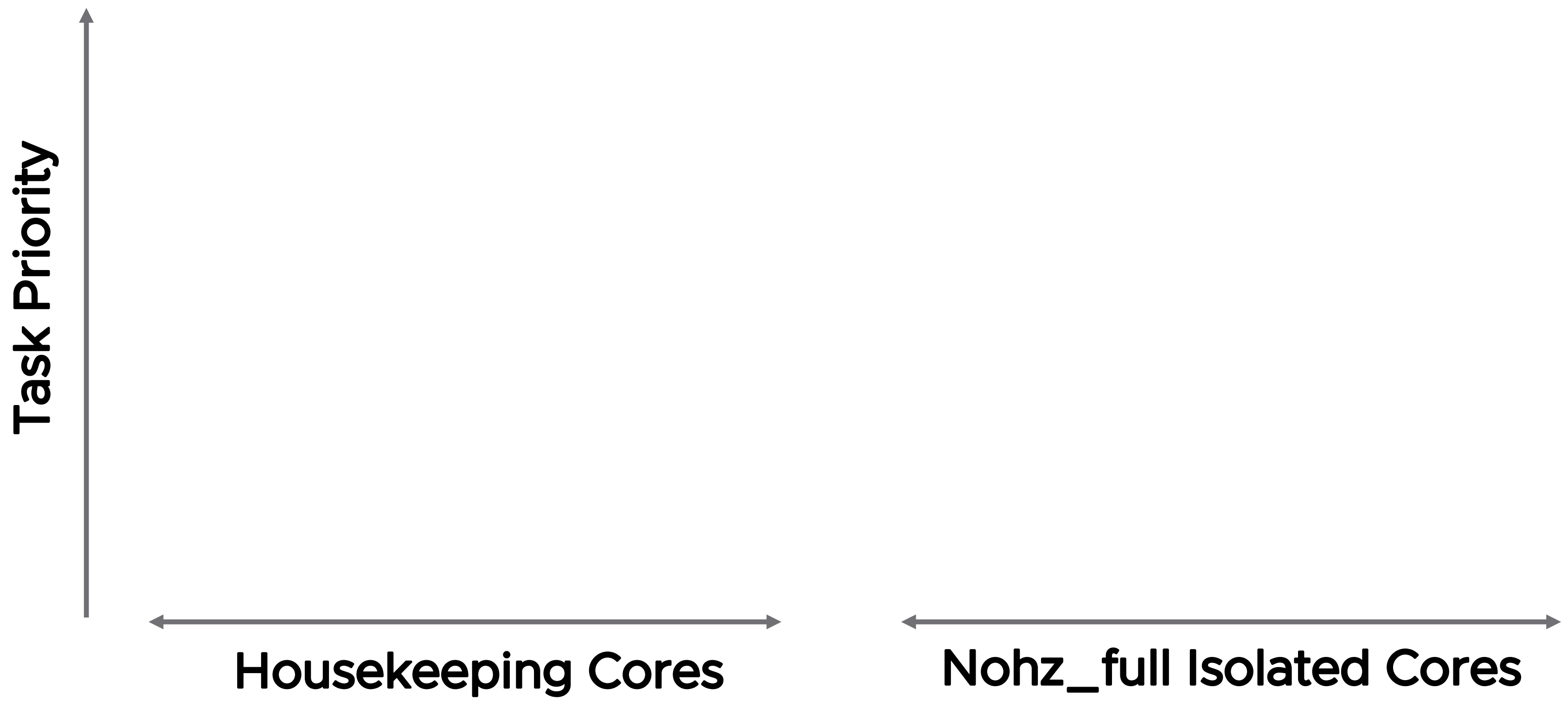
Problem Statement



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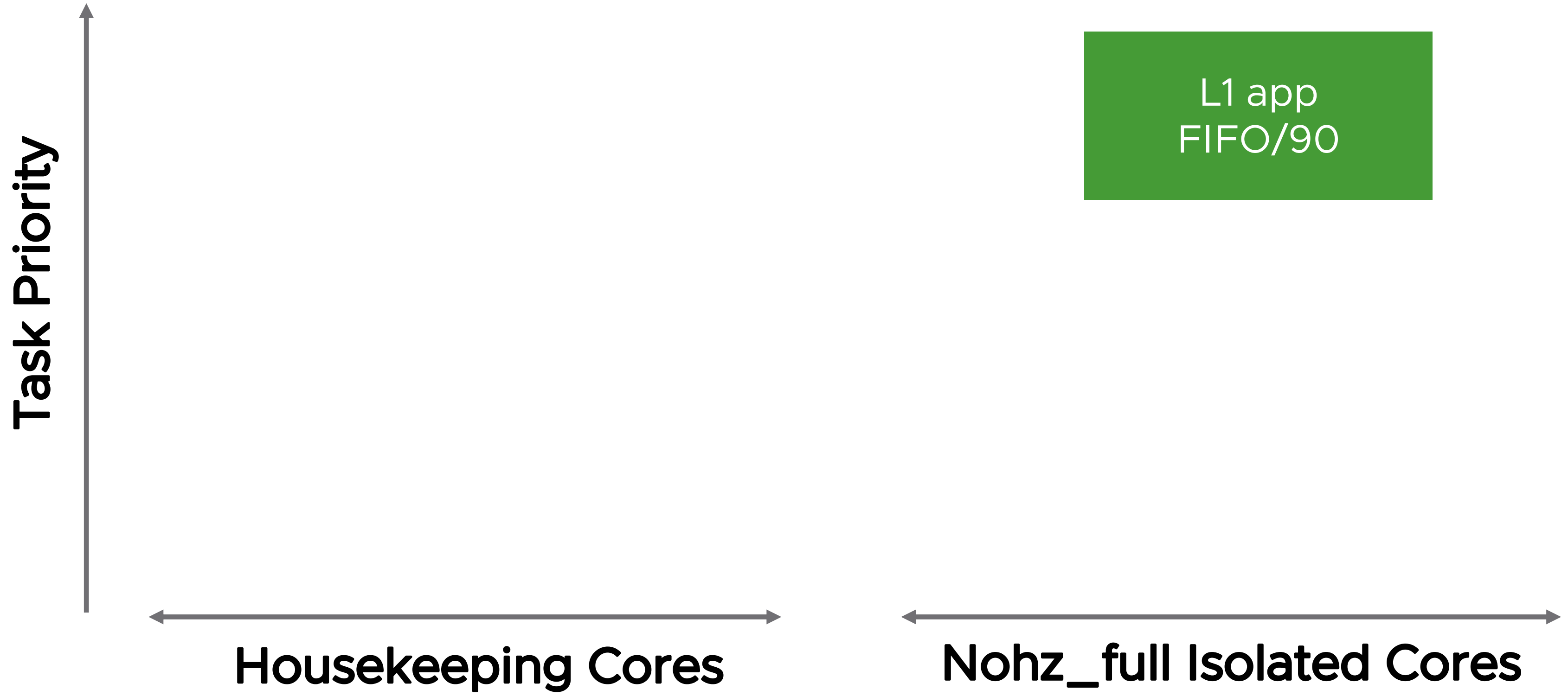

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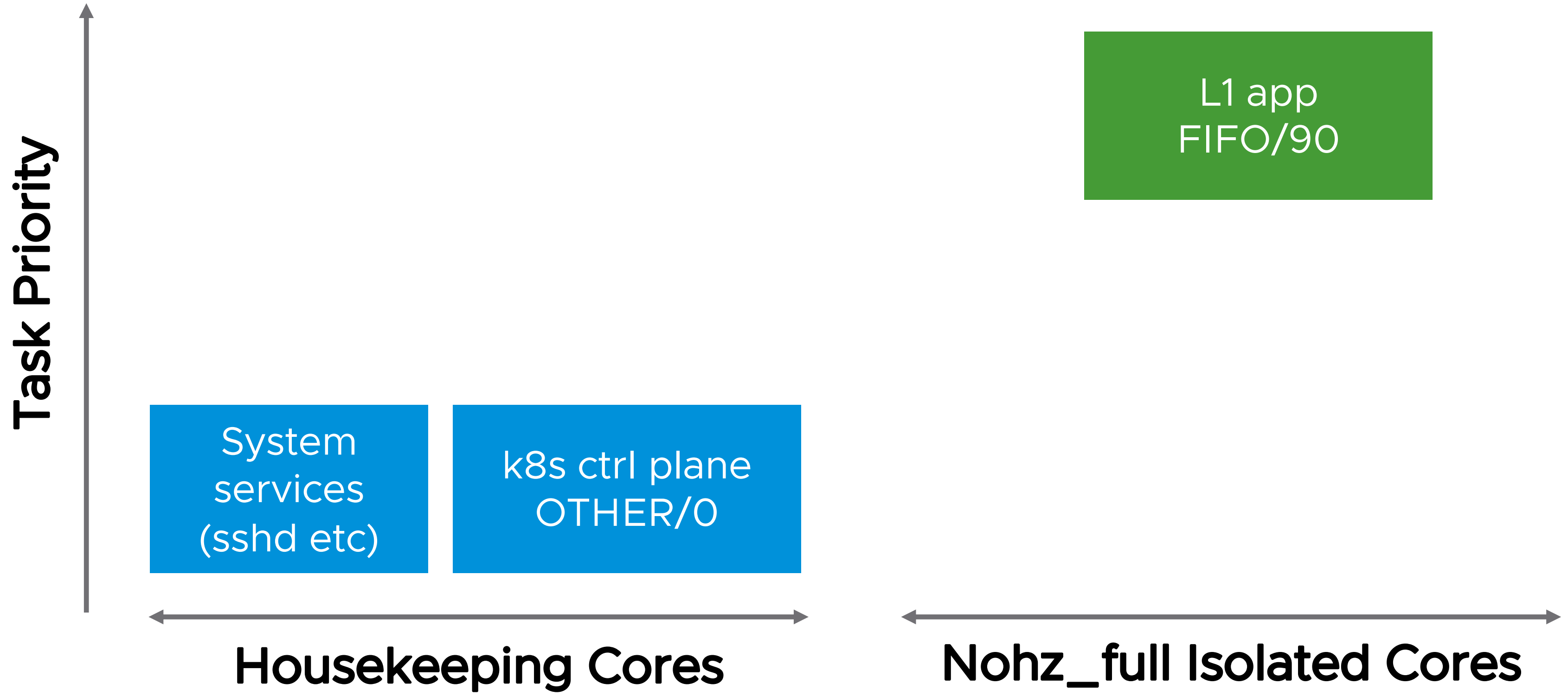

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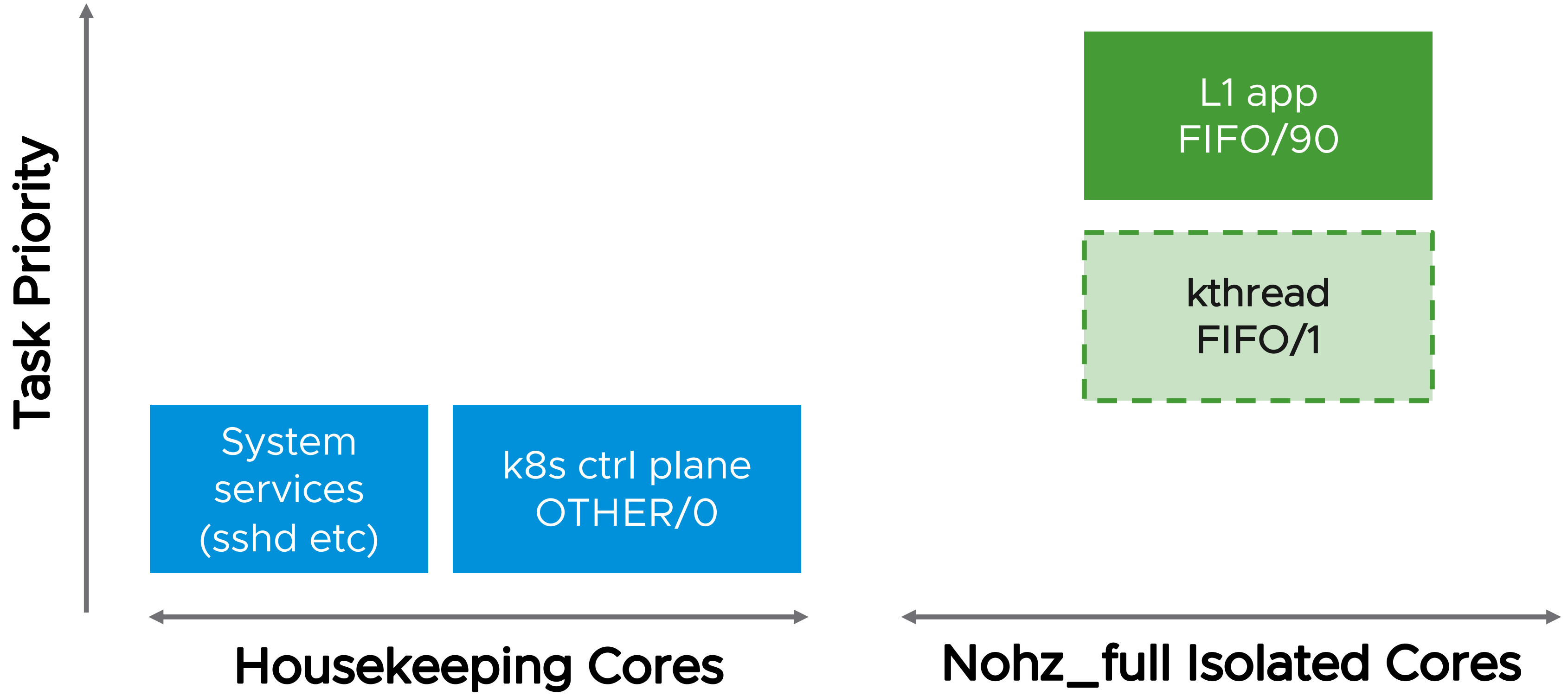

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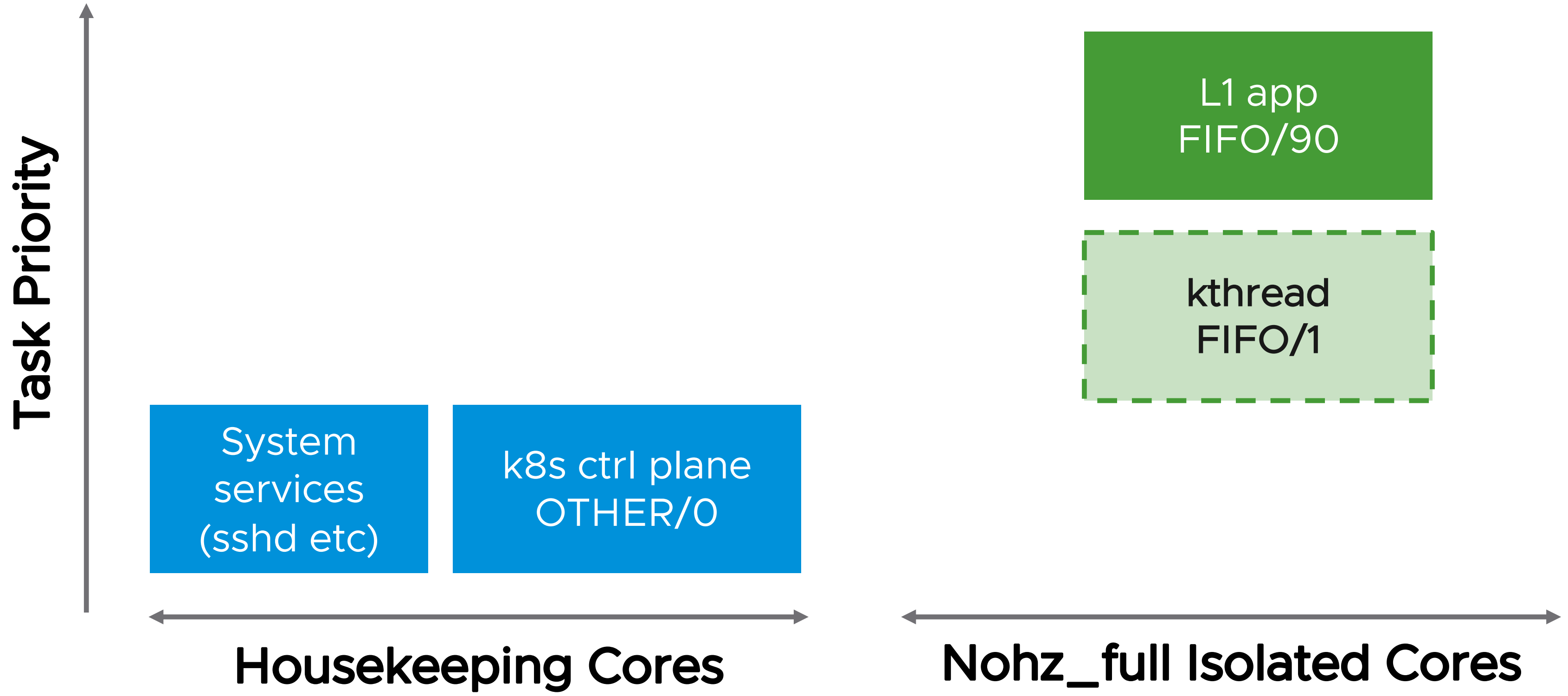

Problem: Starved kthreads lead to cascading lockups (hang)

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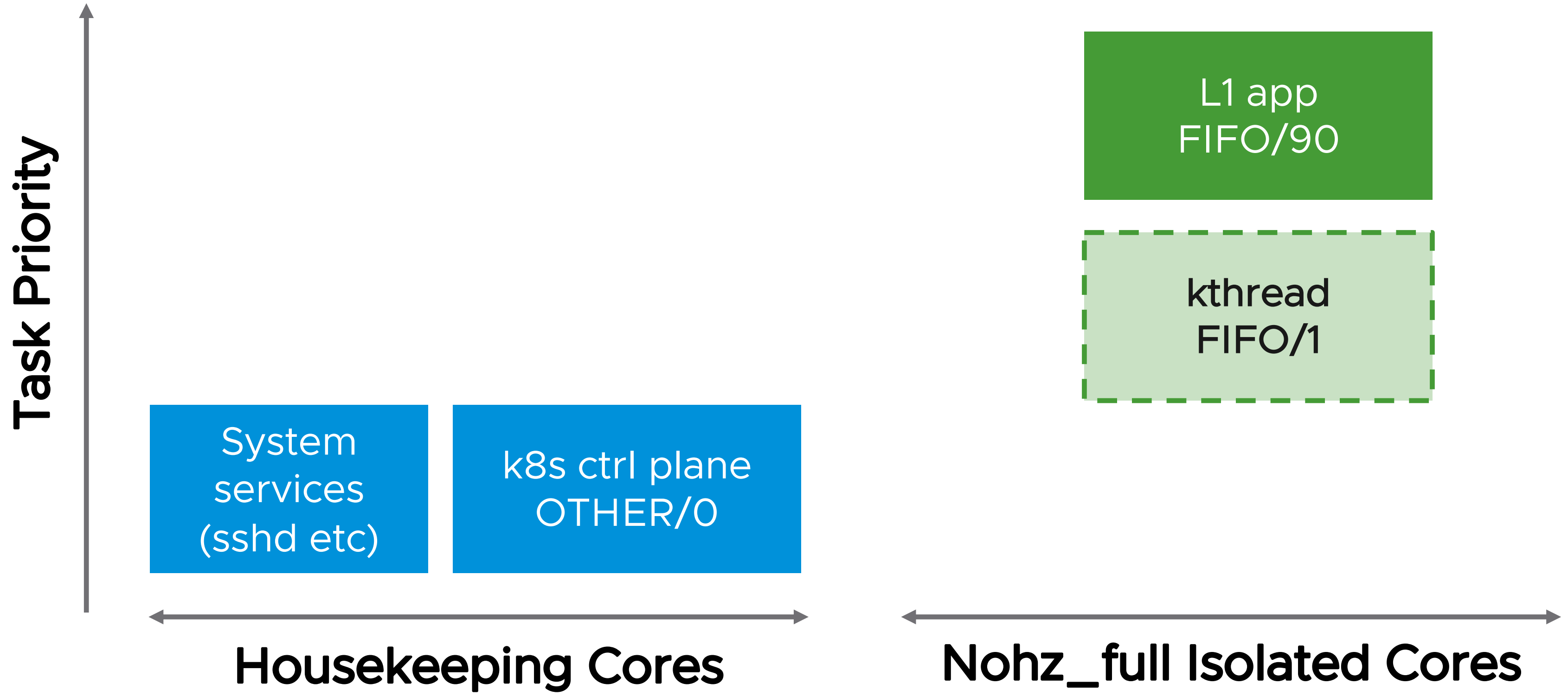

Problem: Starved kthreads lead to cascading lockups (hang)

Goal: OS must remain stable, limiting the fault-domain to the RT app

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Problem Statement Example: Container destroy causes hang

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Reproducer:

1. Run high prio CPU hog on an isolated CPU
2. Create & destroy a docker container on a housekeeping CPU

Problem Statement Example: Container destroy causes hang

PID	USER	PR	NI	VIRT	RES	%CPU	%MEM	TIME+	P	S	COMMAND
37	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[cpuhp/3]
38	root	rt	0	0.0m	0.0m	0.0	0.0	0:00.09	3	S	[migration/3]
39	root	rt	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[posixcputmr/3]
40	root	-2	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[rcuc/3]
41	root	-2	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[ktimersoftd/3]
42	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[ksoftirqd/3]
43	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	I	[kworker/3:0-mm_percpu_wq]
44	root	0	-20	0.0m	0.0m	0.0	0.0	0:00.00	3	I	[kworker/3:0H-events_highpri]
270	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	I	[kworker/3:1-mm_percpu_wq]
1334	root	0	-20	0.0m	0.0m	0.0	0.0	0:00.00	3	R	[kworker/3:1H-events_highpri]
3068	root	-56	0	2.1m	0.7m	99.9	0.0	1:32.52	3	R	./loop-rt

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37	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[cpuhp/3]
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CPU 3 is nohz_full isolated

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loop-rt has high RT prio (SCHED_FIFO/55)

Two runnable tasks on CPU 3: loop-rt and kworker/3

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loop-rt hogs the CPU

kworker/3 is starved

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```
Stalld DEBUG: Dumping Stack for dockerd(PID = 1021
[<0>] __flush_work+0x13e/0x1e0
[<0>] flush_work+0x10/0x20
[<0>] rollback_registered_many+0x168/0x540
[<0>] unregister_netdevice_many.part.124+0x12/0x90
[<0>] unregister_netdevice_many+0x16/0x20
[<0>] rtnl_delete_link+0x3f/0x50
[<0>] rtnl_dellink+0x121/0x2b0
[<0>] rtnetlink_rcv_msg+0x12a/0x310
[<0>] netlink_rcv_skb+0x54/0x130
[<0>] rtnetlink_rcv+0x15/0x20
[<0>] netlink_unicast+0x17b/0x220
[<0>] netlink_sendmsg+0x2b5/0x3b0
[<0>] sock_sendmsg+0x3e/0x50
[<0>] __sys_sendto+0x13f/0x180
[<0>] __x64_sys_sendto+0x28/0x30
[<0>] do_syscall_64+0x60/0x1b0
[<0>] entry_SYSCALL_64_after_hwframe+0x44/0xa9
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40	root	-2	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[rcuc/3]
41	root	-2	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[ktimersoftd/3]
42	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[ksoftirqd/3]
43	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	I	[kworker/3:0-mm_percpu_wq]
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[<0>] unregister_netdevice_many.part.124+0x12/0x90
[<0>] unregister_netdevice_many+0x16/0x20
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[<0>] netlink_sendmsg+0x2b5/0x3b0
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[<0>] __sys_sendto+0x13f/0x180
[<0>] __x64_sys_sendto+0x28/0x30
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```

```
static int rtnetlink_rcv_msg(…)
{
    rtnl_lock();
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```
Stalld DEBUG: Dumping Stack for systemd-network
[<0>] rtnetlink_rcv_msg+0xda/0x310
[<0>] netlink_rcv_skb+0x54/0x130
[<0>] rtnetlink_rcv+0x15/0x20
[<0>] netlink_unicast+0x17b/0x220
[<0>] netlink_sendmsg+0x2b5/0x3b0
[<0>] sock_sendmsg+0x3e/0x50
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42	root	20	0	0.0m	0.0m	0.0	0.0	0:00.00	3	S	[ksoftirqd/3]
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static int rtnetlink_rcv_msg(…)
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    rtnl_lock();
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```

Problem pattern is pervasive in Linux. Ex: ext4, cgroups, ftrace, sysctl etc.

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Existing solutions & limitations: stalld

Existing solutions & limitations: stalld

Overview of stalld

- Monitors for starving tasks + boosts them using SCHED_DEADLINE
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Limitations of stalld

Limitation	Reasons
Scalability	Stallds threads run on housekeeping CPUs
Stalld can get starved itself	Competes for time on housekeeping CPUs RT prio stalld is risky – can ***cause*** stalls itself!
Unreliable logging	systemd-journald can get stuck Verbose logging gets stalld itself stuck
Trade-off: Response-time vs CPU consumption	Per-CPU threads vs single-threaded mode

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Design Goals for Stall Monitor

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  - Avoid unnecessary periodic monitoring
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- Monitor and boost efficiently
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  - sched events like wakeup and dequeue equip the scheduler to take decisions efficiently
- Guarantee responsiveness
  - We must be able to prevent starvation under any scenario
  - Scheduler invocations inevitably offer the opportunity to monitor for starvation

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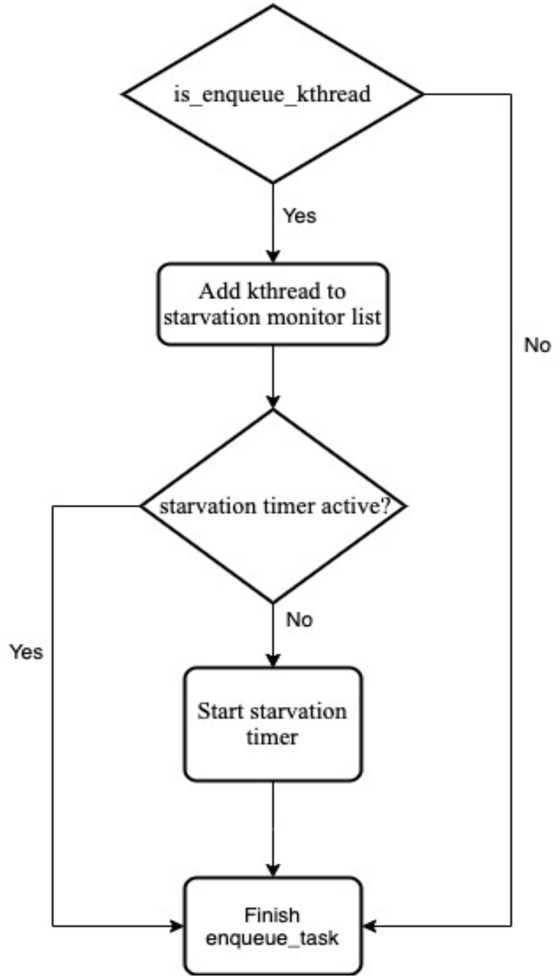
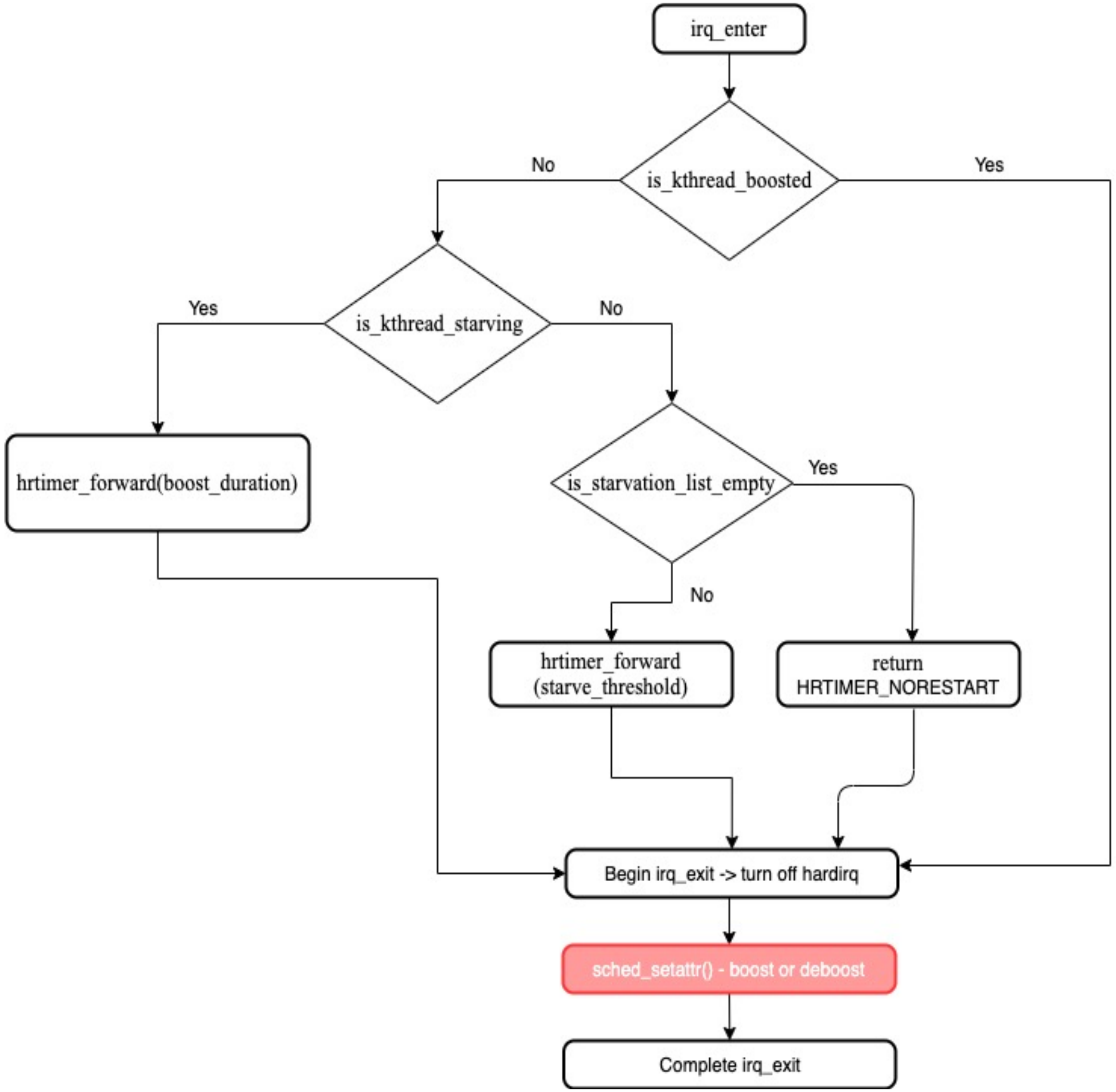
- Boost only one starving kthread on a CPU at any given time
- Boost or deboost happens in hardirq context of the hrtimer
- User defined OS jitter
  - With user configurable starvation_threshold_time, boost_duration_time as well as SCHED_DEADLINE parameters

Implementation of Stall Monitor

Enqueue Task



Hrtimer callback



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Challenges & Open Questions

- Priority boosting must happen in hardirq context
  - Cannot create more kthreads. Or can we use CPU stopper threads?
  - Better alternatives?
- Restrict the monitoring and boosting to isolcpus only?
- How much latency does it introduce?

Thank you!

Additional Data Points

- CFS code already has functions to track wait times spent by task on the runqueue –
  - Handled by update_stats_wait_start() and update_stats_wait_end()
  - This needs to be added to RT (SCHED_FIFO and SCHED_RR)
- __sched_setscheduler invoked by sched_setattr() has checks on pi being invoked from interrupt context. This is suspectedly due to rt_mutex_adjust_prio_chain() that enables interrupts using raw_spin_unlock_irq(&task->pi_lock) unconditionally