Nerve for real-time virtualization of control

Nerve is an open industrial edge computing platform that is intended to be used for consolidating all kinds of machine software onto a single platform. This includes critical machine-control functions for CNC mills, multi-axis robots, and other precision machinery. Nerve provides the software infrastructure that allows control logic to be moved from dedicated PLC hardware to standard industrial PCs, where it can run safely alongside other applications. To ensure that control programs operate without interruption, Nerve runs them within virtual machines that guarantee exclusive access to CPU, memory, and networking resources.

Nerve integrates the open-source ACRN™ hypervisor as a basis for real-time virtual machines. While there are many virtualization solutions available, most are not developed with the size and flexibility requirements of industrial IoT in mind. ACRN, a Linux Foundation project, is being developed to meet the unique needs of embedded IoT development, and in contrast to proprietary solutions, ACRN is inexpensive and backed by technology leaders. ACRN offers low latency, maximum jitter reduction, fast boot time, responsive hardware communication, and optimized real-time performance – all key features necessary for running real-time control in a virtualized environment.

TTTech Industrial conducted a series of tests to benchmark the real-time performance of ACRN on Nerve. These show how Nerve can be used to run critical machine-control programs in a virtualized environment without sacrificing real-time performance.

Test series 1

Measuring execution time of control tasks

In the first tests we measured the execution time of control tasks running in a CODESYS soft PLC. The soft PLC was running in a dedicated real-time virtual machine on a standard Intel Atom-based industrial PC. We compared the performance of the ACRN hypervisor with an optimized Xen hypervisor.

In the test setup, the industrial PC was connected to EtherCAT IOs that gather analog data from a signal generator. This signal is a ramp signal with the frequency of 1 kHz and the amplitude of 4 V peak-to-peak without any offset. This signal data was transferred via EtherCAT protocol to the IO port in the CODESYS virtual machine running on Nerve.

The test ran three tasks in CODESYS: EtherCAT Task, High Priority Task and Low Priority Task. The EtherCAT Task converts analog signal data to EtherCAT frames. It is configured with a cycle time of 1 ms and at CODESYS priority 1 with no sync offset. High Priority Task runs the PLC program with a 1 ms cycle time and at CODESYS priority 1. Low Priority Task runs a lighter PLC task with a 50 ms cycle time and at CODESYS priority 2.

The tests were run over a 24-hour period and measured the cycle time for the execution of each task as well as the jitter to show the point of time when tasks were completed within the 1 ms cycle.

EtherCAT Task

Task	Cycle Count	Average Cycle Time (µs)	Maximum Cycle Time (µs)	Maximum Jitter (µs)
ACRN	85299920	29	71	99
Xen	2368615	72	241	460

High Priority Task

Task	Cycle Count	Average Cycle Time (µs)	Maximum Cycle Time (µs)	Maximum Jitter (µs)
ACRN	85302186	36	110	67
Xen	2368592	28	112	432

Low Priority Task

Task	Cycle Count	Average Cycle Time (µs)	Maximum Cycle Time (µs)	Maximum Jitter (µs)
ACRN	1705968	7	26	97
Xen	1688058	8	100	386

Statistics	ACRN	Xen
Sent Frame Count	85299920	2368615
Frames Per Second	1000	1000
Lost Frame Count	0	0

The results of the tests show that when running CODESYS as a virtual machine on the ACRN hypervisor, tasks are executed with extremely low cycle times and tight jitter. This demonstrates that control can be run in a virtualized environment without negatively impacting real-time performance. The ACRN hypervisor on Nerve even showed considerable performance improvement when compared to the real-time optimized XEN hypervisor on Nerve. This makes the combination of Nerve and ACRN ideal for running high-speed machine control applications with maximum cycle times down to 100 µs.

Test series 2

Measuring and comparison of boot times

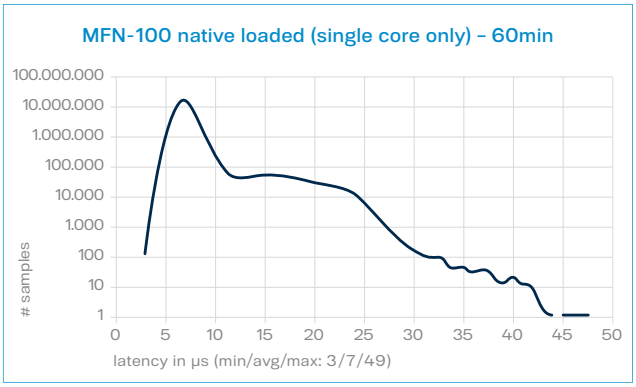
The second set of tests that TTTech Industrial ran were to measure the boot time of the system whilst running the ACRN hypervisor on Nerve. These tests were used to determine, whether running multiple real-time virtual machines on a hypervisor had any negative impact on performance when compared to a native system.

The test setup used the Linux cyclictest[1] real-time benchmark tool to measure the latency of system activation. The latency measures the deviation in µs between the intended system boot time and the time at which it actually boots. The test was run in two scenarios – under high load and with no load. In the high load case, the load was generated using a modified dohell[2] script.

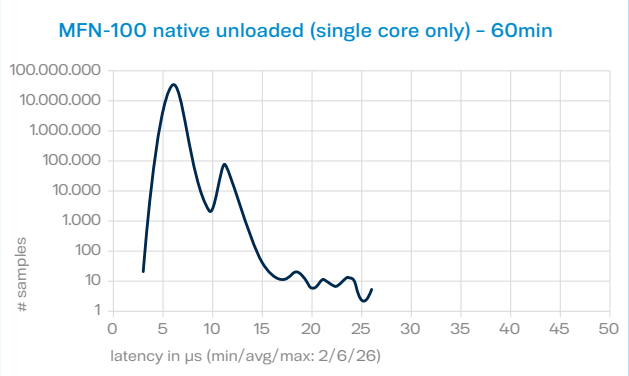
The activation latency of a Linux real-time native system was measured for comparison against the activation latencies of three Linux real-time virtual machines hosted on ACRN. All were running on an Intel Atom-based industrial PC.

The tests were run over a 1-hour period. Outlier data was most likely a result of measurement test software issues.

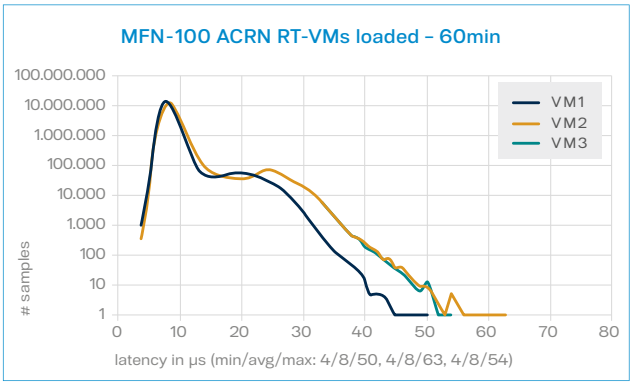
Native real-time Linux system on Atom class device (loaded)



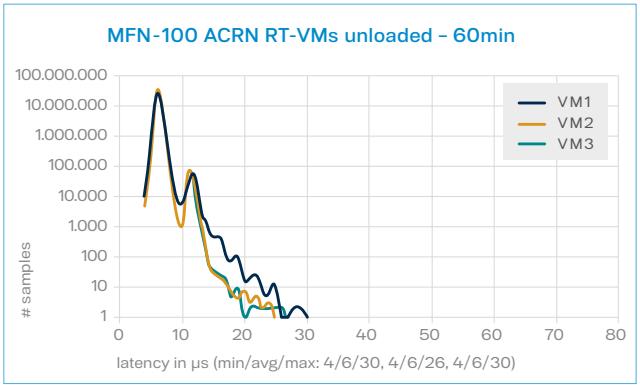
Native real-time Linux system on Atom class device (unloaded)



Real-time virtual machines on Atom class device (loaded)



Real-time virtual machines on Atom class device (unloaded)



1 https://wiki.linuxfoundation.org/realtime/documentation/howto/tools/cyclictest/start
2 https://xenomai.org/documentation/xenomai-2.6/html/dohell/index.html

The results of the tests show that running multiple virtual machines on ACRN does not significantly impact the boot time when compared to a native Linux system. This could be observed in both scenarios, i.e. under load and with no load.

Conclusion

This series of tests demonstrates that ACRN on Nerve provides a stable platform for running real-time tasks in a virtualized environment. The tests also confirm that virtualization using ACRN does not significantly impact real-time performance. Nerve provides the world's first commercially supported integration of ACRN, delivering a platform for the virtualization of industrial functions which enables users to save hardware costs, reduce maintenance efforts and improve application efficiency.