COMPARISON BETWEEN QNX RTOS V6.1, VXWORKS AE 1.1 AND WINDOWS CE .NET

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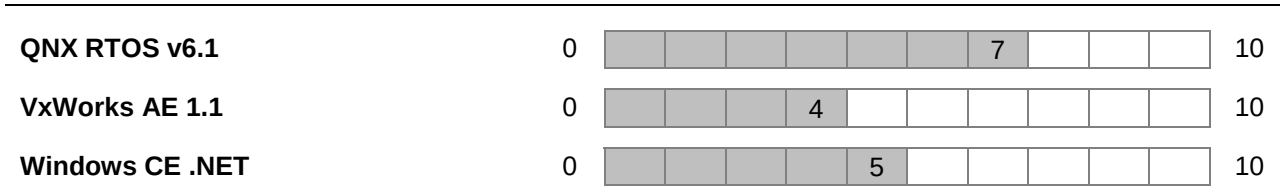
1 Introduction

Recently, Dedicated Systems Experts evaluated the following real-time operating systems (RTOS):

- The QNX RTOS v6.1 from QNX Software Systems Ltd.
- The VxWorks AE 1.1 RTOS from Wind River Systems, Inc.
- Windows CE .NET from Microsoft Corporation, Inc. Version 4.0.0708 with QFE number 020607_Q323461, a fix that fixes a known scheduler problem in Windows CE .NET was applied to the RTOS. The results reported in this paper can only be obtained when this fix is applied to the system.

This report summarizes and compares the key elements of the full evaluation reports of both RTOS.

2 Installation and Configuration



2.1 QNX RTOS v6.1

The QNX RTOS v6.1 is quick and easy to install. After only a few minutes the basic modules are installed i.e., the kernel and a user interface (Photon Windowing System). Additional packages like compilers etc, can be installed by means of the package manager.

Configuring the QNX RTOS v6.1 is reasonably straightforward. When installing the full environment, the most critical components like storage devices and network cards are detected automatically. If further configuration is necessary, it can be done through the graphical user interface.

Building a custom QNX image is done through build files. Modules can be added, removed and configured by manually editing these text-based files. The documentation contains plenty of examples of such build files. Although there's no graphical tool to accomplish this, customizing and configuring an image never proved to be a major problem during this evaluation.

2.2 VxWorks AE 1.1

The Tornado tool suite is easy to install. You do need to make sure you have the correct installation keys. Depending on the key, different parts and modules will be installed.

After the Tornado tool suite is properly installed, developers can start using it to create custom VxWorks AE images to run on their targets. As is usually the case with embedded operating systems, the VxWorks AE RTOS is highly configurable. All this flexibility makes the configuration process intricate, but the Tornado 3.0 tool suite provides a pretty good interface to this purpose to make the task more manageable.

Nevertheless, we experienced many configuration problems during this evaluation. In fact, the evaluation of VxWorks AE 1.1 has taken longer than any other RTOS product evaluated by us before. But this was more due to the lack of (good) documentation.

2.3 Windows CE .NET

The first step to using Windows CE .NET is to install the platform builder software. Platform builder 4.0 is the set of tools that is used to create a custom Windows CE .NET platform. The platform builder comes on a DVD and is capable of creating ARM, MIPS, SH or Intel x86 based platforms. For this evaluation, only the Intel x86 component was installed. Installing platform builder is similar to installing any other Microsoft software application, and is pretty straightforward and user-friendly.

Although the platform builder integrated development environment (IDE) includes wizards for creating platforms and components, most of the configuration work will happen through manually editing registry

files, manipulating a set of environment variables and modifying various other configuration scripts. This makes the configuration process a difficult task to newcomers. We were under the impression that Platform Builder 4.0 has made some progress compared to previous versions in terms of ease of configuration.

3 RTOS Architecture

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

QNX RTOS v6.1	0	9	10
VxWorks AE 1.1	0	7	10
Windows CE .NET	0	7	10

3.1 System Architecture

3.1.1 QNX RTOS v6.1

The QNX RTOS v6.1 has a true client-server architecture, consisting of a microkernel and optional cooperating processes. The microkernel implements only the core services, like threads, signals, message passing, synchronization, scheduling and timer services. Additional functionality is implemented in cooperative processes, which act as server processes and respond to the request of client processes (e.g. an application process). Examples of such server processes are the file system manager, process manager, device manager, network manager, etc. While the kernel runs at privilege level 0 of the Intel processor, the managers and device drivers run at levels 1 and 2 (to perform IO operations). Application processes on the other hand run at privilege level 3, and can therefore only execute general instructions of the processor.

☺ Every process runs in its own virtual memory space. The QNX RTOS is a message based OS, and can seamlessly be distributed over multiple nodes. The RTOS supports SMP, and implements several HA (High Availability) features.

3.1.2 VxWorks AE 1.1

The VxWorks AE 1.1 operating system was derived from VxWorks 5.x, hence their architectures are very similar. The reader is referred to the VxWorks 5.3.1 evaluation report for more details.

Nevertheless, a new feature was added to AE: the concept of *protection domains*. A protection domain provides a logical resource “container” that defines an execution environment: each protection domain has its own virtual address space and, depending on the configuration, may or may not be visible to other domains. Whereas VxWorks 5.x uses a single flat address space shared by the system and its applications, system designers can divide their AE system in as many virtual address partitions as they see fit. To maximize robustness and system reliability, the operating system kernel should run in its own private protection domain.

Several remarks can be made about AE’s architecture and protection domains in general:

– ☺ Protection domains are an improvement compared to previous versions of VxWorks (versions 5.x) that operated in a single flat memory space. Protection domains now provide memory protection resulting in a more robust system.

- ☺ Compared to traditional processes, protection domains include some new (and nice) parameters that dictate the priority range that the domain's threads are allowed to have, and against which libraries it can link. These features could be very useful. For example, consider a team that is working on the GUI application. By putting the GUI code in a separate protection domain, you can restrict the GUI thread priorities to a range where they could never starve the system or even impact the real-time performance of the more critical threads.
- ☹ Whereas traditional processes are automatically created by the system, protection domains need to be configured by the user. This configuration is tricky and puts extra responsibility in the hands of the developer; increasing the chances errors are made.
- ☹ The protection domains did not change anything to the overall (high-level) RTOS architecture. The kernel still doesn't have intrinsic message passing capabilities, poor support for inter-processor communication in systems without shared memory, etc.
- **?** An interesting question is how HA-capable (High Availability) VxWorks AE is, and if these capabilities are affected by the introduction of these protection domains. However, this issue is out of the scope of this study.

3.1.3 Windows CE .NET

Windows CE .NET is very scalable. The system is built from a set of discrete modules, each providing specific functionality. Several of these modules are divided into components, which can be individually selected. In its most compact configuration, CE .NET requires roughly 200K of ROM.

The prime modules are the kernel, the object store, the graphics subsystem and communications components. In addition to these primary modules, other modules are available and provide support for multimedia, COM (Component Object Model), Windows CE shell and device manager.

3.2 Basic System Facilities

3.2.1 Task Handling Method

All three operating systems are multi-threaded. The QNX RTOS and Windows CE both use traditional processes, while VxWorks AE has its protection domains.

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET
Model	Threads and processes	Threads and protected domains.	Processes and Threads
Priority levels	64	256	256 levels
Maximum number of tasks	4095 processes Every process can have 32767 threads	Limited by the amount of memory available.	The maximum number of *threads* in a process is only limited by the amount of memory available. Windows CE can run a

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET
			maximum of 32 *processes* simultaneously.
Scheduling policy	Prioritized FIFO Round-robin scheduling Adaptive Sporadic[1]	Preemptive priority. Round-robin.	Round-robin with adjustable time-slice (quantum) When the quantum is set to zero, the thread runs to completion
Number of documented states	14		5

3.2.2 Memory Management Method

All three operating systems use full virtual memory protection, significantly increasing the robustness and reliability of the system.

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET
MMU support	Yes	Yes	Yes
Physical page size	Depends on architecture	Depends on architecture	Depends on architecture
Swapping/Demand Paging	Yes/No	Never	Supported, but can be disabled to achieve real-time performance.
Virtual memory	Yes	Yes	Yes
Memory protection models	Full virtual memory protection	Full virtual memory protection.	Full virtual memory protection.

3.2.3 Interrupt Handling Method

The interrupt handling is prioritized, and interrupt handlers can be nested.

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET

[1] Will be supported in QNX 6.1.1. This algorithm is part of the latest POSIX specification and is documented in QNX's newest system architecture guide.

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET
Handling	Nested, prioritized	Nested, prioritized[2].	Nested, prioritized
Context	The ISR runs in the context of the thread that attached it	Interrupt handlers run in a special context, outside any task's context.	The ISR runs in a special context and uses virtual addresses statically mapped by the OEM. The IST is a normal application thread and has its own context.
Stack	The ISR has its own stack	Special interrupt stack. Only one system wide interrupt stack allocated from the kernel's memory	The IST is a normal application thread and has its own stack.
Interrupt to task communication	Signals and pulses	Shared memory and ring buffers (cannot create or delete ring buffers) Semaphores (release only), Message queues (send only), Pipes (write only), Signals (send only)	Only an event can be used from within the ISR to signal the IST. No other API is accessible from within the ISR. OEM can create a shared memory region by statically mapping a memory region into the ISR's address space

[2] This is what the documentation claims. Our tests however revealed a bug in the x86 BSP that caused interrupts between IRQ8 and IRQ15 not to be nestable. In the means time, Wind River has a cumulative patch available with a fix for this problem.

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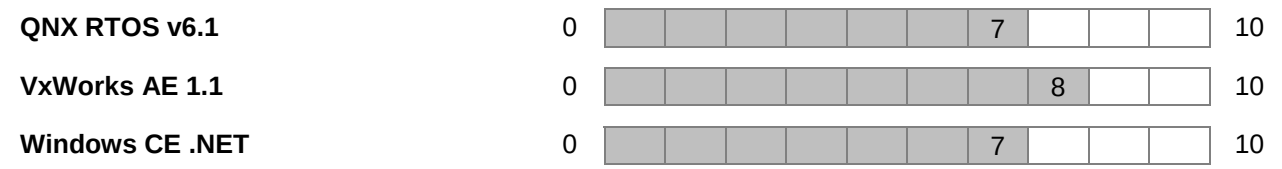
4 API Richness

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)



While interpreting these results, the reader should keep in mind that these tables cover a strictly defined set of the most commonly used system calls. All RTOS have system calls that are not covered by the table below. For more details on what features the different categories in the table below encompass, the reader is referred to the evaluation reports.

	QNX RTOS v6.1	VxWorks AE 1.1	Windows CE .NET
Task management	82%	88%	71%
Clock	100%	71%	85%
Timer	100%	100%	67%
Memory management	27%	77%	35%
Interrupt handling	88%	50%	50%
Semaphore	35%	90%	40%
Mutex	67%	92%	67%
Conditional Variables	60%	60%	0%
Event flags	0%	0%	75%
POSIX signals	100%	78%	0%
Message queue and Mailbox	41%	81%	75%

The API of the QNX RTOS, VxWorks AE 1.1 and Windows CE .NET are sufficiently rich APIs, but they have a different emphasis. As the QNX RTOS has a message based architecture, its API also focuses on messaging. Mechanisms like messages and signals are preferred over semaphores or other classic synchronization objects. This is less the case for the VxWorks AE and Windows CE .NET APIs.

5 Internet support

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

QNX RTOS v6.1	0	8	10
VxWorks AE 1.1	0	9	10
Windows CE .NET	0	9	10

5.1 QNX RTOS v6.1

QNX’s Internet Technology Suite contains the following products and tools:

- Voyager Web Server: an HTTP server to serve web pages. It has support for dynamic HTML pages via SSI (Server Side Includes).
- A Voyager Web Browser for viewing information. It has full HTML 3.2 support, frames support, javascript, cookies, etc. The Mozilla and Opera browsers have recently also been ported to run on the QNX RTOS v6.1.

A Voyager SDK (Software Development Kit) to build internet-enabled applications into an embedded system.

5.2 VxWorks AE 1.1

VxWorks AE 1.1 offers the same internet and network support as VxWorks 5.x, except some graphics options. As such, VxWorks AE has very extensive networking and protocol support. The reader is referred to the Wind River website for detailed information.

5.3 Windows CE .NET

Windows CE .NET has very extensive Internet support

Windows CE .NET comes with an extensive set of Internet products and tools. It includes, among others:

- An HTTP server to post information. The server supports active server pages, ISAPI extensions and filters.
- A web browser for viewing information. The browser is a miniature version of Internet Explorer. It supports frames, tables and Javascript, as well as JPEG, static and animated GIF and WAV files.
- A telnet server to remotely administer devices, or to administer devices that do not have displays.
- Networking protocol support for communicating across the internet/intranet.

Many other tools and utilities are available from third-party vendors.

6 Tools

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

QNX RTOS v6.1	0	7	10
VxWorks AE 1.1	0	8	10
Windows CE .NET	0	8	10

6.1 QNX RTOS v6.1

There are two sets of tools available for the QNX RTOS v6.1: the Metrowerks Codewarrior IDE and the GCC toolkit. Tools for both self-hosted and cross development are available. These toolkits contain the most commonly used tools.

6.2 VxWorks AE 1.1

The VxWorks AE RTOS comes with the Tornado 3 IDE. Tornado 3 comprises an extensive suite of tools and utilities that can be used during the development and debugging phase. The full evaluation report contains an inventory of the most commonly used tools available.

There is in fact only one negative aspect to the Tornado 3 IDE: its “clunkiness”. Huge TCL scripts need to be parsed whenever an action is taken, which requires a lot of processing power. Make sure to run Tornado on the latest and greatest hardware only.

6.3 Windows CE .NET

Platform Builder 4.0 (PB) has a few new features that make configuring a Windows CE .NET image somewhat easier. A new platform wizard that assists you while creating a new platform is one example. Still, we encountered some very annoying bugs in the tool. Quite often the PB crashes when one disconnects the host from the target. On one occasion, the crash apparently destroyed some key files on our host that rendered it inoperable. Our platform builder needed to be reinstalled for this reason.

7 Documentation and Support

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

QNX RTOS v6.1	0					5					10
VxWorks AE 1.1	0				4						10
Windows CE .NET	0					5					10

7.1 QNX RTOS v6.1

The documentation does a decent job giving a general overview of the system and its architecture, but fails to clearly document the API. The biggest issue is that the meaning of an API’s parameters is not always explained, and if they are, the explanation is usually “embedded” in a page-long text, which therefore needs to be read from top to bottom every time the developer needs to reference it. The documentation also contains several contradictions, and is in need of an update. The vendor informed us that efforts are being made to improve the quality of the documentation.

7.2 VxWorks AE 1.1

The VxWorks/Tornado documentation also doesn’t provide a good overview of the inner workings of the system. It also doesn’t contain all the information to guide users through the complex configuration process. We had to seek assistance of Wind River’s technical support staff to help us out with a variety of configuration chores (configuring network drivers, etc), simply because we could find no reference in the documentation of how to go about it.

7.3 Windows CE .NET

Windows CE comes with an online documentation set. This documentation set contains a lot of information, but it is not presented in a very structured way. The documentation can easily be used as a reference, but is less appropriate as a tutorial. Newcomers will have a hard time acquiring an overview of the system if this is the only documentation they have at their disposal. It also lacks in-depth information about the inner workings of the system. Documenting the APIs and available features is not enough to provide the reader with a sufficient understanding of a complex system like Windows CE .NET.

8 Development methodology

8.1 QNX RTOS v6.1

The QNX RTOS v6.1 originally used the host = target approach only i.e., host and target are the same machine. As was mentioned earlier, the QNX RTOS v6.1 can be configured with only a microkernel, as well as with many other modules turning it into a fully fledged multi-user operating system capable of serving as a development environment. The advantage of this approach is that the user has the option to do it all on one machine: the application can be tested on the same machine as it was developed on, debugging can be done locally, etc. There are no problems with communication between host and target.

Developers that prefer a standard MS-Windows desktop to the QNX desktop can use cross-development tools. The Metrowerks IDE for MS-Windows can be used to allow the user to do the compiling and debugging from the Windows based host machine.

There's often a lot of discussion about which development method is the better one: self-hosted or cross development. It all really depends on the quality of the tools. If the quality of the cross-development tools is poor, it is better to opt for self-hosted development, and vice versa. Unfortunately, evaluating the quality of the development tools is not within the scope of this report. Nonetheless, it is important advantage that an OS support both methods.

8.2 VxWorks AE 1.1

Wind River Systems uses the *host* ≠ *target* approach. Host and target are two different machines linked together (serial, LAN, bus, etc) for communication. The host is the machine on which the development environment (Tornado 3.0) runs. Tornado is available for both Windows and UNIX based hosts. The target is the machine on which the dedicated RTOS (VxWorks AE 1.1) runs with the real-time application.

The advantage of this approach over the host = target approach is that a separate host is more suitable as a system development host. Indeed, all the features of the GPOS (Windows NT or UNIX) can be used, which allows for a better and more complete development environment.

In this configuration however, the debugger is on the host, while the real-time application is executed on the target. To make interactive debugging possible, VxWorks installs so called "debug agents" on the target that communicate debug information to the host. These debug agents provide a virtual seamless integration of host and target while debugging i.e., the user is under the impression that he is debugging a local application.

A nice feature of VxWorks/Tornado is dynamic linking and loading of modules. This feature can reduce the edit-test-debug cycle. The user can download an individual object module into the target without having to reboot. The module is dynamically linked into the target. There is no need for the user to compile and link the complete executable on the host and download it to the target.

To assist developers of embedded systems using custom hardware, Wind River Systems also offers VxSim, which is a prototyping and simulation tool for Tornado/VxWorks. VxSim provides a simulation of VxWorks on the host. With this tool, application development can begin before the hardware becomes available. VxSim was not tested for this evaluation.

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8.3 Windows CE .NET

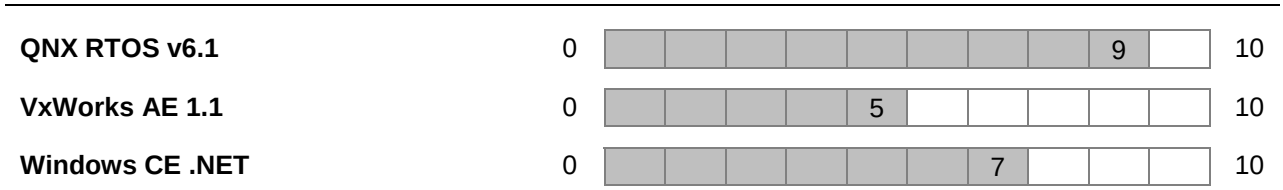
Microsoft provides development tools to cater the need of two categories of developers: the platform developers and the application developers.

Platform developers use an integrated development environment called Platform Builder on the Windows NT based host, while the target runs Windows CE with the (real-time) applications. Aside from this platform development tool, Microsoft also provides the Embedded Visual Tools for application development.

The Platform Builder can be used to create a custom SDK (Software Development Kit) based on the Windows CE OS to allow developers to write applications that run on the target platform. An SDK is a set of library, header, and Help files that developers use to write applications for a specific platform. The SDK is used in conjunction with the Embedded Visual Tools to create, debug and run custom applications.

9 Test results

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc).



9.1 QNX RTOS v6.1

The QNX RTOS exhibited fast and predictable behavior during all our test results. None of the tests revealed any problems of any kind. Hence the QNX RTOS was rated a score of 9 for this category.

9.2 VxWorks AE 1.1

In general, VxWorks AE 1.1 is slower than the QNX RTOS v6.1 (on a x86 platform). However, our tests also revealed some (serious) issues, hence VxWorks was rated a score of 5. The issues that were discovered are:

- A bug in the Pentium BSP that prevents interrupt nesting. This is a fundamental problem in any real-time system. Wind River Systems sent us a quick fix that corrected this problem. The vendor has informed us that this quick fix has developed into a cumulative patch in the mean time.
- The execution of the clock ISR can become pretty lengthy (>60µs under certain circumstances), making the system less responsive to other external interrupts. This was confirmed in our stress tests.
- A socket-related bug in the TCPIP stack that can severely hamper data transmission throughput.

9.3 Windows CE .NET

While Windows CE .NET performs slower than the QNX RTOS v6.1, it exhibited true real-time behavior during all of our tests.

9.4 Comparison test results

The same test suite was applied to all three operating systems.

Table 1 presents most of the performance test results for both RTOS. It does not include the results of the stress tests or the TCP/IP tests. When a test for a particular RTOS is marked “TNE”, it means this test was not executed. For a summary of the test identification codes, please refer to Appendix E : Summary test identification codes.

	QNX RTOS v6.1		VxWorks AE 1.1		Windows CE .NET	
Test identification	Average (µs)	Maximum (µs)	Average (µs)	Maximum (µs)	Average (µs)	Maximum (µs)
IL-a-1_ISR	1.7	4.1	1.7	6.8	2.4	5.6
IDL-a-1_ISR	1.8	2.1	1.9	8.4	TNE	TNE
IL-a-1_IST	TNE	TNE	6.5	14.2	7.7	12.9
SI-a-1_ISR_HI	1.7	3.0	1.8	4.7	2.5	5.8
SI-a-ISR_LO	4.1	5.8	4.3	8.3	7.2	10.4
TF-a-1	229	280	260	299	102	1006
TF-b-1	4.1	10.1	85	103	280	922
TSL-a-2	2.0	8.1	2.9	15.5	2.6	35.1
TSL-a-10	2.4	7.4	3.4	16.5	3.3	37.4
TSL-a-128	3.3	11.6	6.5	29.6	5.3	63.9
TSL-b-128	7.2	15.9	6.8	46.8	9.6	16.7
SEO-a-1	3.1	7.7	7.4	19.4	3.6	8.3
SEO-b-1	3.0	9.1	9.0	20.4	3.6	11.1
SEO-d-1	2.3	5.9	0.2	7.5	3.9	8.4
SEO-e-1	2.2	7.5	0.2	7.1	4.2	11.3
SEO-f-max	6.3	12	5.9	19.1	9.1	13.5
SEO-g-3 (mutex)	11.9	19.0	9.3	18.0	19.4	34.5
FS-a-1	6330	15424	TNE[3]	TNE	48[4]	162[4]
FS-b-1	706	909	TNE	TNE	23.1	28.4
FS-c-1 (1 byte)	106	475	TNE	TNE	17	58
FS-c-1 (1 block)	159	687	TNE	TNE	38	154
FS-c-1 (10 blocks)	449	1095	TNE	TNE	238	390
FS-d-1 (1 byte)	2660	3766	TNE	TNE	21	59
FS-d-1 (1 block)	38861	93070	TNE	TNE	47	229

[3] We were not able to mount a Hard Drive on the system

[4] As opposed to QNX 6.1 where a IDE hard drive was used, the file system tests on Windows CE .NET were executed with a RAM-based file system.

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	QNX RTOS v6.1		VxWorks AE 1.1		Windows CE .NET	
Test identification	Average (µs)	Maximum (µs)	Average (µs)	Maximum (µs)	Average (µs)	Maximum (µs)
FS-d-1 (10 blocks)	49779	151370	TNE	TNE	312	600

Table 1: Performance results for QNX RTOS v6.1, VxWorks AE 1.1 and Windows CE .NET

Aside from the performance tests in Table 1, we also executed stress tests. These stress test try to detect memory leaks or performance degradation when the system is loaded. No such problems we detected in either the QNX RTOS, Windows CE .NET or VxWorks AE.

Another stress test is the "billion interrupt" test. It generates a billion (10^9) interrupts (at the same IRQ level) at a programmable frequency, and we count how many interrupts were serviced, and how many of them were lost. The test is considered successful if not one single interrupt is lost. An interrupt is "lost" when by the time the next interrupt needs to be generated, the previous one is still being serviced or masked out by a higher priority interrupt (e.g. the clock interrupt). Therefore, this test gives a pretty good idea of the worst-case interrupt latency of the RTOS.

Table 2 presents the results. The QNX RTOS v6.1 served every single interrupt when they were generated every 10µs. Windows CE .NET only needed 1µs more. In VxWorks AE 1.1 however, this period needed to be increased to 25µs in order for the test to succeed.

	QNX v6.1	VxWorks AE 1/1	Windows CE .NET
Maximum Sustainable Interrupt Frequency	10µs	25µs	11µs

Table 2: Maximum sustainable interrupt frequency – Endurance Test

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10 Conclusion

The QNX RTOS v6.1, Windows CE .NET and VxWorks AE 1.1 Operating Systems were evaluated against the same criteria and test suite.

The QNX RTOS v6.1 performed very good during this evaluation. None of the performance or stress tests revealed any problems, the RTOS kept performing fast, predictable and reliable at all times. The QNX RTOS is also the only RTOS that has a true message-based client-server architecture well equipped to handle today's requirements concerning distributed processing, high availability, etc.

VxWorks AE 1.1 is Wind River Systems its latest RTOS product. It introduces the concept of protection domains. Protection domains provide a memory protection scheme and therefore present a big step forward compared to previous version of VxWorks, which operated in a single flat memory space. Aside from these protection domains, no other advancements were made to the RTOS architecture. Our test suite did expose some acute problems, the most serious one being a bug in the x86 Pentium BSP that prevented interrupt nesting. We found another problem in the TCPIP stack that causes the transmission throughput to collapse under certain circumstances. Aside from these issues, VxWorks AE's (real-time) performance is acceptable, but no match for the QNX RTOS.

Windows CE .NET is the successor of Windows CE 3.0. Windows CE .NET exhibited real-time behavior during our tests. None of the stress tests exposed any problems concerning stability and robustness either.

! Finally, the reader should bear in mind that we tested the QNX RTOS v6.1, VxWorks AE 1.1 and Windows CE .NET on an Intel x86 platform only. The results in this report apply to the x86 platform only, not to any of the other platforms these products support.

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11 References

[1] The QNX RTOS v6.1 evaluation report, Dedicated Systems Experts, 2001. (http://www.dedicated-systems.com)
[2] The VxWorks AE 1.1 RTOS evaluation report, Dedicated Systems Experts, 2002. (http://www.dedicated-systems.com)
[3] The Windows CE .NET evaluation report, , Dedicated Systems Experts, 2002. (http://www.dedicated-systems.com)

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12 Appendix A: Product ratings

This appendix contains the evaluation report summary pages for QNX RTOS v6.1, VxWorks AE 1.1 and Windows CE .NET.

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12.1 QNX RTOS v6.1

Product

The QNX RTOS v6.1, from QNX Software Systems Ltd.

Positive points

- Fast and predictable performance
- Excellent architecture for a distributed and robust system
- Good platform support

Negative points

- Documentation

Ratings

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

Installation and Configuration	0	7	10
RTOS Architecture	0	9	10
API Richness	0	7	10
Internet support	0	8	10
Tools	0	7	10
Documentation and Support	0	5	10
Test Results	0	9	10

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12.2 VxWorks AE 1.1

Product

VxWorks/x86 AE 1.1 from Wind River Systems, Inc. (http://www.windriver.com)

Corporate headquarters: 500 Wind River Way. Alameda, CA 94501 Tel: (800) 545 WIND

Positive points

– VxWorks AE now also provides memory protection by means of the protection domains

Negative points

– Quality of documentation is less than mediocre

– Major bug in x86 BSP that prevents interrupt nesting (cumulative patch available)

– Slow worst-case reaction to external interrupts (x86 platform)

– Poor TCP/IP network performance due to socket-related bug in IP-stack (cumulative patch available).

Ratings

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)

Installation and Configuration	0	4	10
RTOS Architecture	0	7	10
API Richness	0	8	10
Internet support	0	9	10
Tools	0	8	10
Documentation and Support	0	4	10
Test Results	0	5	10

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12.3 Windows CE .NET

Product

Windows CE .NET from Microsoft Corporation, Inc.

Positive points

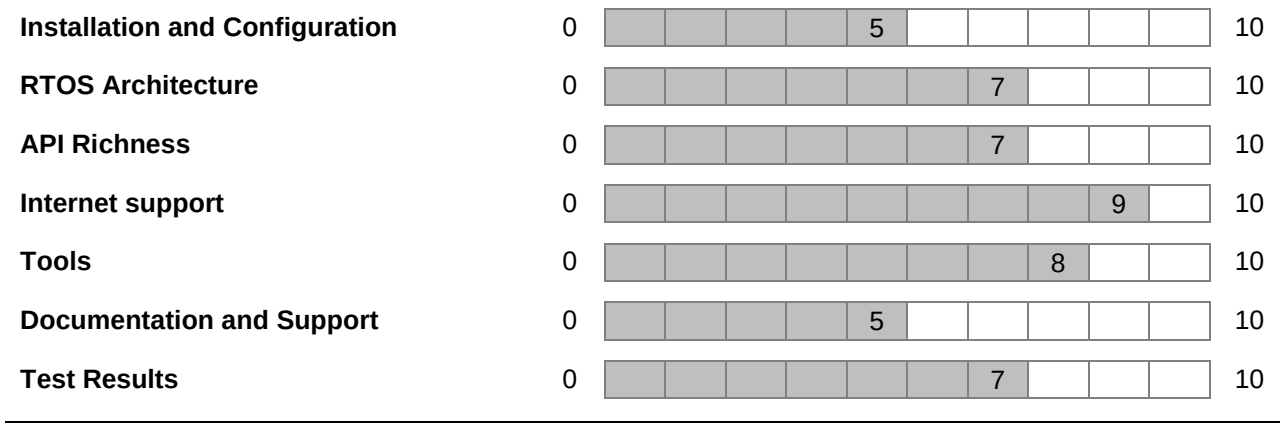
- Extensive platform support
- Generally good real-time performance

Negative points

- Documentation insufficient for such a complex system

Ratings

For a description of the ratings, the reader is referred to appendix D in the document “report definition and test plan”, which can be downloaded from our website (http://www.dedicated-systems.com/encyc)



13 Appendix B: QNX RTOS v6.1 report excerpts

Two simultaneous interrupts

In this test, two (nearly) simultaneous interrupts are generated. This is accomplished by adding a second PCI exerciser (PDrive) to the system.

- PDrive_HI (generates the high priority interrupt) uses PCI interrupt line C (INTC#) and generates interrupts with IRQ level 9.
- PDrive_LO (generates the low priority interrupt) uses PCI interrupt line B (INTB#) and generates interrupts with IRQ level 10.

Two interrupt service routines (ISR_HI and ISR_LO) are attached to IRQ 9 and IRQ 10 respectively. The interrupt latency was measured for both ISR_HI and ISR_LO. The interrupt latency was measured as the time elapsed between the last instruction of the interrupted thread and the first instruction of the ISR.

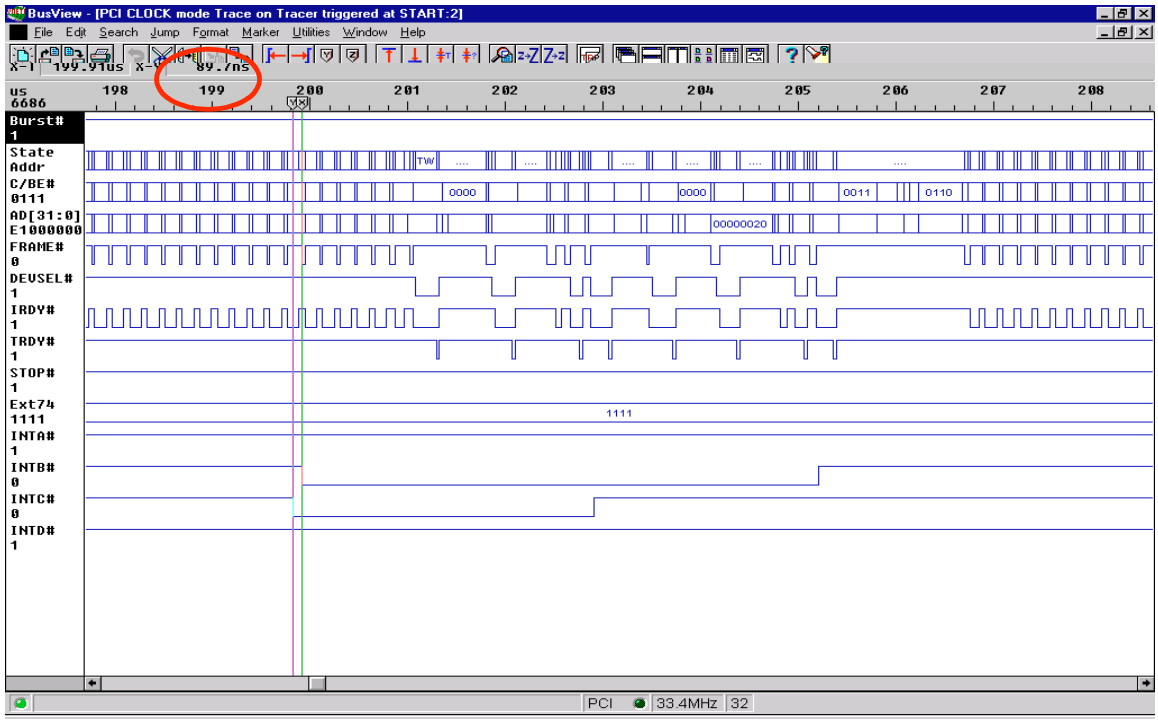


Figure 12.3-1: PCI bus analyzer screenshot

Figure 12.3-1 shows a snapshot of the PCI-bus analyzer when both interrupts occur. Marker Y is where the interrupt from PDrive_HI (INTC#; IRQ 9) occurs, while marker X is where the interrupt from PDrive_LO (INTB# ; IRQ 10) occurs. As can be seen (red circle on the bus analyzer snapshot), the difference between the X and the Y marker is a mere 90ns, which definitely qualifies as simultaneous interrupts.

☺ The system does not have any problems dealing with these interrupts. The high priority interrupt was serviced first by the system, with a maximum interrupt latency of 3µs. The low priority interrupt is serviced as soon as the high-priority interrupt is completely handles, but was still serviced less than 6µs after both interrupts occur.

13.1.1.1 Interrupt latency – ISR_HI

- Number of threads: 2
- Memory model: d

Number of samples	Minimum (µs)	Maximum (µs)	Average (µs)
130	1.6	3.0	1.7

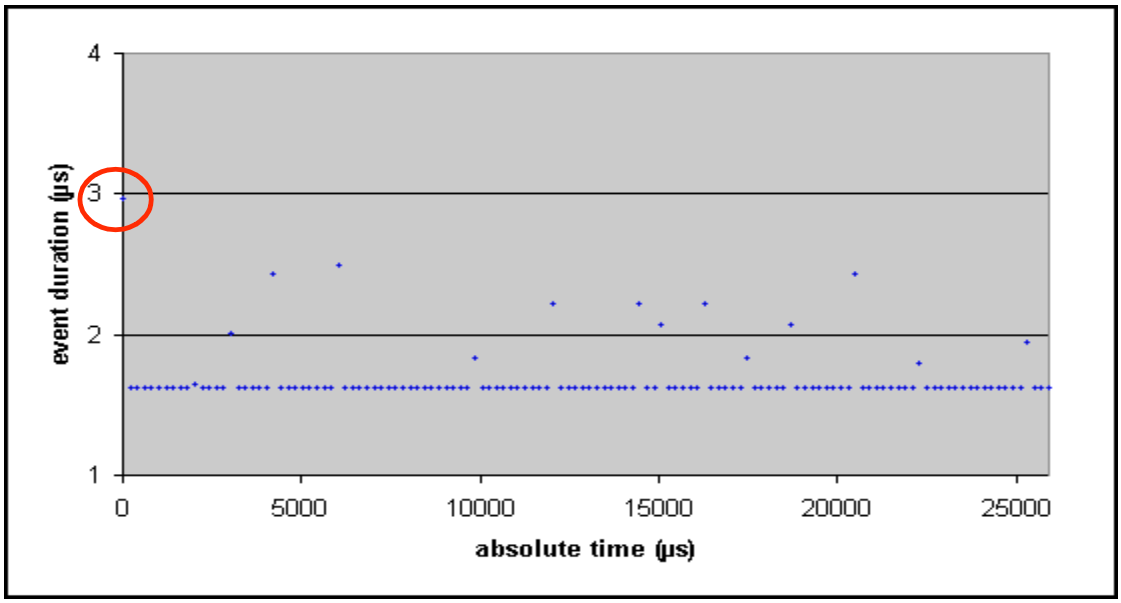


Figure 12.3-2 : Interrupt latency for the HIGH priority ISR

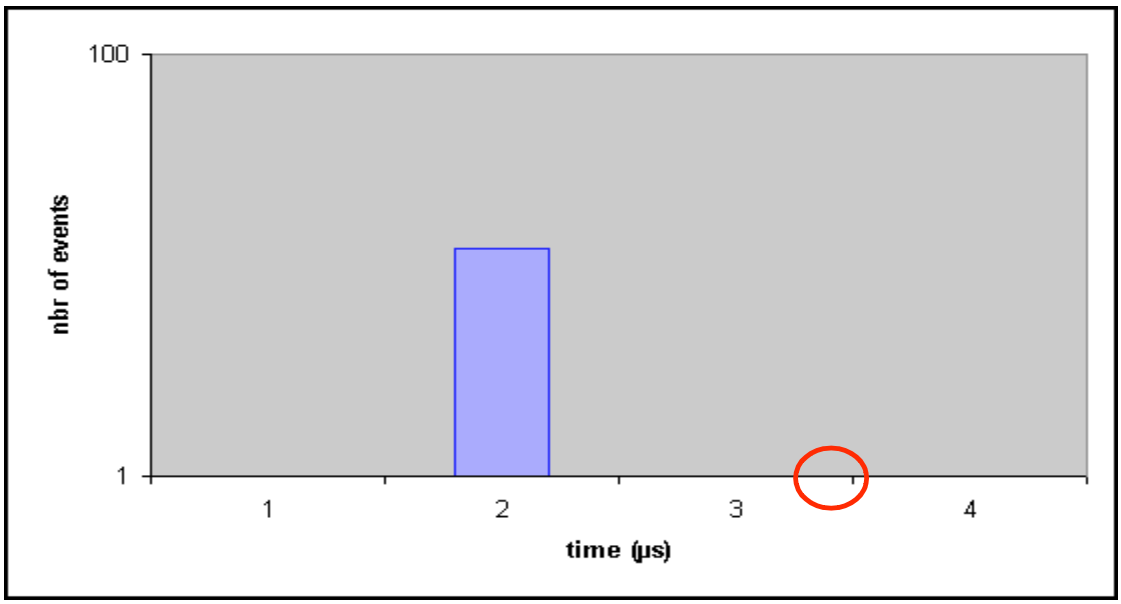


Figure 12.3-3: Interrupt latency for the HIGH priority ISR – Frequency Distribution

13.1.1.2 Interrupt latency – ISR_LO

- Number of threads: 2
- Memory model: d

Number of samples	Minimum (µs)	Maximum (µs)	Average (µs)
130	3.9	5.8	4.1

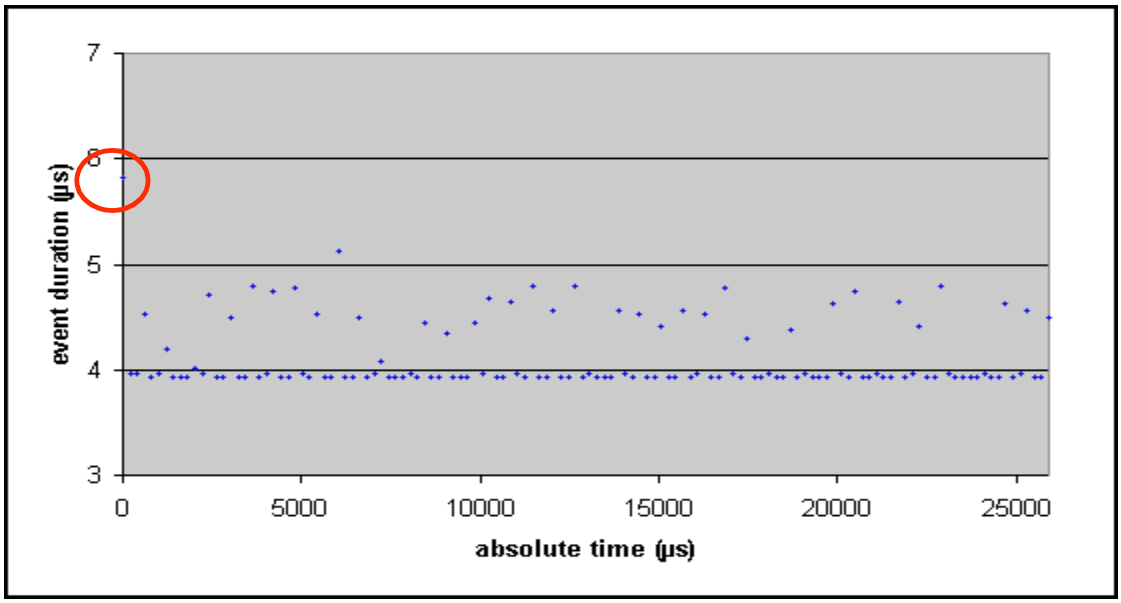


Figure 12.3-4: Interrupt latency for the LOW priority ISR

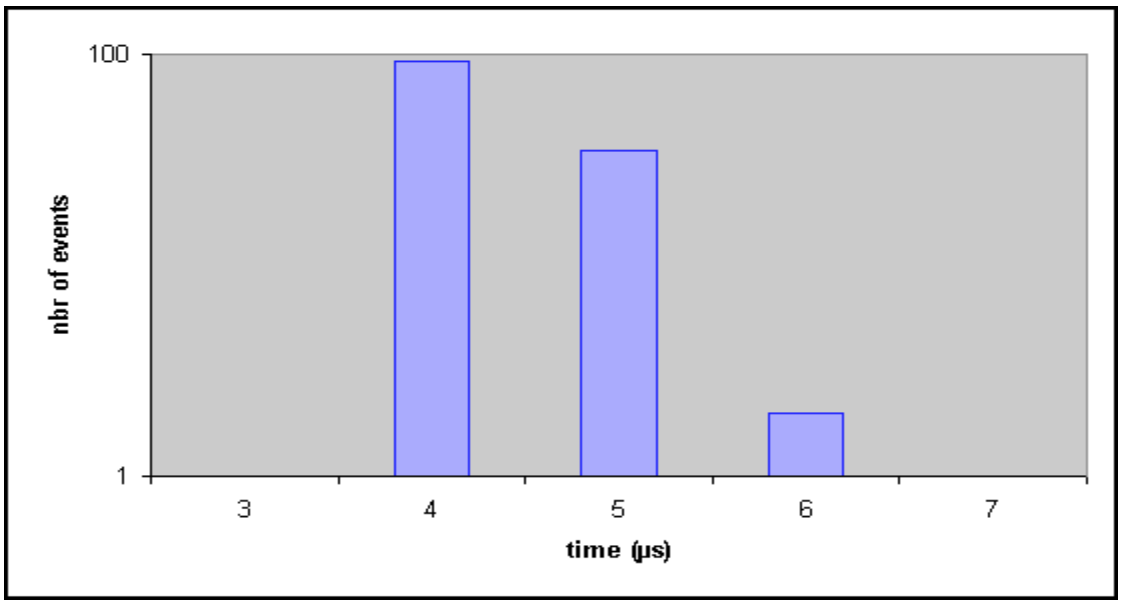


Figure 12.3-5: Interrupt latency for the LOW priority ISR – Frequency Distribution

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14 Appendix C: VxWorks AE 1.1 report excerpts

TCP/IP Performance Tests

In this section, we test the performance and efficiency of the TCP/IP network stack.

The purpose of the test is to measure bandwidth and CPU usage for varying packet sizes. The packet size varies from 1 to 2000 bytes, in increments of 40 bytes. For more information concerning the implementation of this test, the reader is referred to the document “report definition and test plan”, which can be downloaded from http://www.dedicated-systems.com/encyc/buyersguide/rtos/rtosmenu.htm.

The tests were executed on an isolated 10 Mbit/s ethernet network. The sender disables the NAGLE algorithm. This algorithm can bundle several small data payloads into one bigger data payload, which is then sent in one TCP/IP packet. This mechanism reduces the protocol overhead significantly, but is often inappropriate in real-time systems because of the delay that is introduced.

☹ It must be clear that the necessary care should be taken when these results are compared with those of competing RTOS in other evaluation reports. Whereas we always use an ISA NE2000 network card for this test, we could not do so in this case because of a problem in the VxWorks NE2000 driver. Therefore we switched to a 3COM 3C900B PCI Ethernet card for this test. Since the efficiency of the network driver is crucial in this test, the results should not be compared with those in other RTOS evaluation reports!

14.1.1 TCP/IP Stack – Receive Capacity

This test measures VxWorks AE's receive performance, and the CPU consumption while receiving the data.

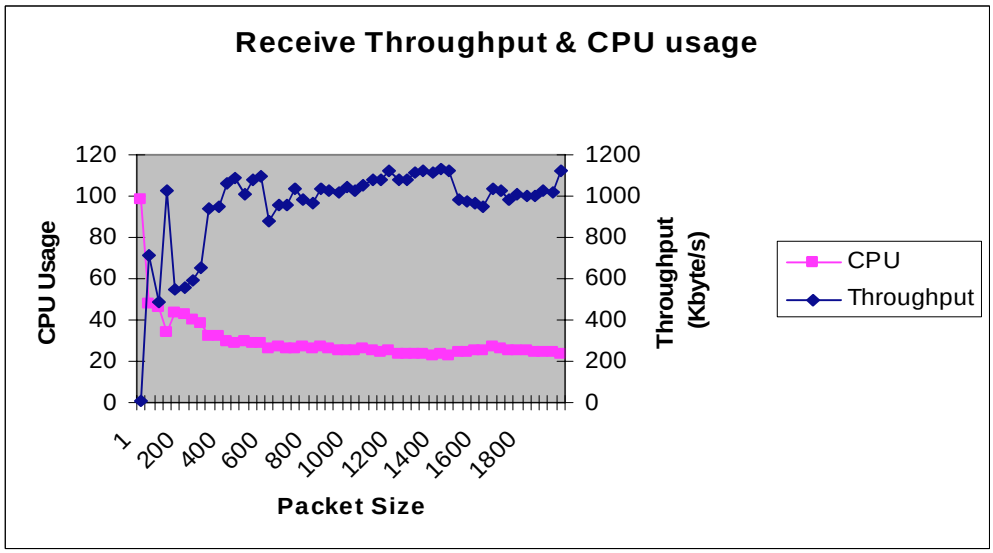

Figure 12.3-1: TCP/IP stack – receive capacity

☺ The results show a high receive throughput, while using little CPU power.

! Again, I want to remind the reader that great care should be taken when comparing these results with those from competing RTOS in our other evaluation reports. The CPU usage for example, is very dependent on the efficiency of the NIC driver (depending on the NIC driver, the majority of the CPU cycles are spent in the NIC driver copying data buffers). It is possible that the 3COM driver used is far more efficient than NE2000 drivers, hence the low CPU usage in our results.

14.1.2 TCP/IP Stack – Send Capacity

This test measures VxWorks AE's send performance, and the CPU consumption while sending the data.

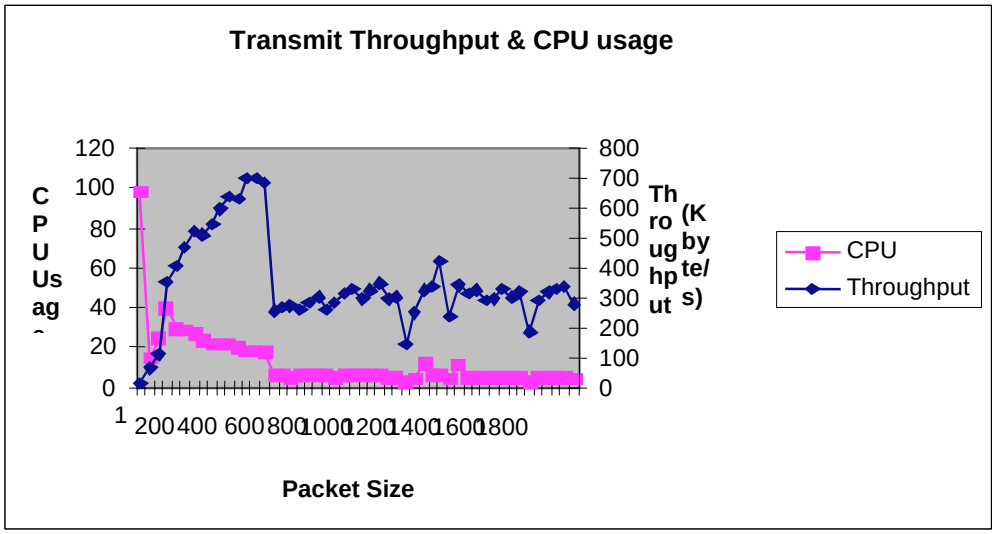

Figure 12.3-2: TCP/IP stack – send capacity (without patch)

☹ As can be seen from Figure 12.3-2, the results are good until the packet size reaches 600 bytes. From that point on, the performance reduces significantly. We found out that it is not so much the packet size that matters, but the fact that the performance drop always occurs after the 14th sequence in the test (independent of the packet size). Apparently, there is a problem when a socket is opened and closed more than 14 times.

WindRiver acknowledged this to be a bug and provided us with a patch (cumulative patch#2) that fixed this problem. Figure 12.3-3 shows the results of the same tests when the patch was used.

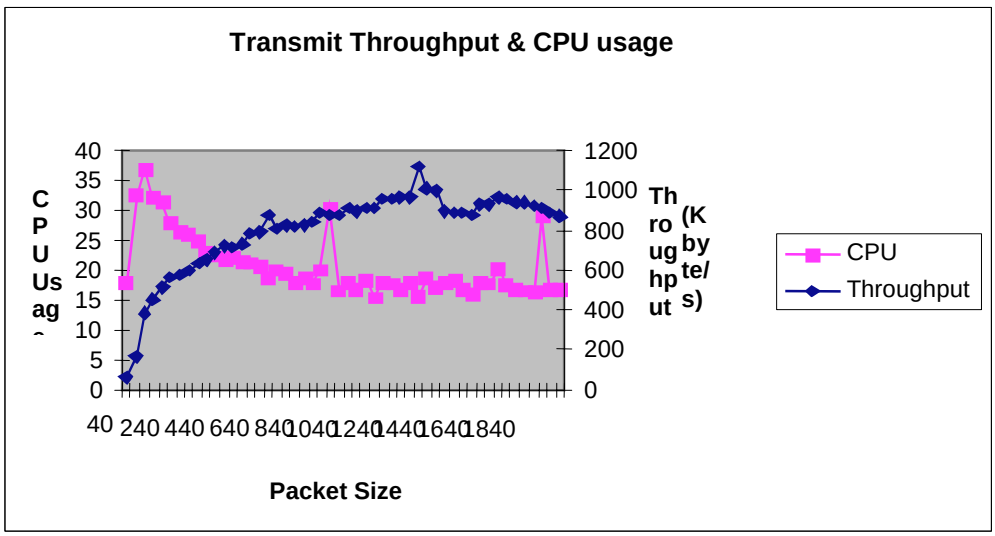

Figure 12.3-3: TCP/IP stack – send capacity (with patch)

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15 Appendix D: Windows CE .NET report excerpts

The purpose of the tests in this section is to determine the maximum sustainable (periodic) interrupt frequency without losing any interrupts.

Table 12.3-1 shows the results for the test where the system is exposed to one billion (10^9) periodic interrupts at a particular frequency. Due to the nature of the test set-up, it was not possible to determine the exact amount of interrupts that were lost if that amount exceeded 32768.

Period (µs)	#interrupts serviced	#interrupts lost
15	**1,000,000,000**	**0**
13	**1,000,000,000**	**0**
11	**1,000,000,000**	**0**
10	**999,999,991**	**9**

Table 12.3-1: One BILLION interrupts generated at varying frequencies

The reader should bare in mind that this test does not only stress test the RTOS, but also the PC hardware. So no hard conclusions can be drawn as to which part of the system is to blame for “losing” interrupts.

☺ The results in Table 12.3-1 show that when interrupts were spread 11µs apart, the system did not lose a single interrupt.

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16 Appendix E : Summary test identification codes

Test identification	Description
IL-a-1(_IST or _ISR)	Interrupt Latency (task to interrupt handler) – no rescheduling – 1 thread. Measured on IST or ISR level.
IDL-a-1(_IST or _ISR)	Interrupt Dispatch Latency (interrupt handler to task) – no rescheduling – 1 thread. Measured on IST or ISR level.
IDL-b-1	Interrupt Dispatch Latency (interrupt handler to task) – with rescheduling – 1 thread.
IDL-b-10	Interrupt Dispatch Latency (interrupt handler to task) – with rescheduling – 10 threads.
IDL-b-128	Interrupt Dispatch Latency (interrupt handler to task) – with rescheduling – 128 threads.
SI-a-1_ISR_HI	Simultaneous interrupts. Interrupt latency of the high priority ISR
SI-a-1_ISR_LO	Simultaneous interrupts. Interrupt latency of the low priority ISR
TF-a-1	Thread Creation time
TF-b-1	Thread Deletion time, thread did not execute
TF-c-2	Thread Deletion time, thread has executed.
TSL-a-2	Thread Switch Latency – 2 threads in the same process
TSL-a-10	Thread Switch Latency – 10 threads in the same process
TSL-a-128	Thread Switch Latency – 128 threads in the same process
TSL-b-128	Thread Switch Latency – 128 threads in different processes
SEO-a-1	Synchronization & Exclusion Object (semaphore) Creation time
SEO-b-1	Synchronization & Exclusion Object (semaphore) Deletion time – semaphore was not used.
SEO-c-1	Synchronization & Exclusion Object (semaphore) Deletion time – semaphore was used.
SEO-d-1	Synchronization & Exclusion Object (semaphore) Acquisition time – no contention.
SEO-e-1	Synchronization & Exclusion Object (semaphore) Release time – no contention.
SEO-f-max	Synchronization test executed with a number of threads equal to the number of task priority levels.

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Test identification	Description
SEO-g-3	Synchronization & Exclusion object (Mutex) – Priority inversion prevention time.
FS-a-1	File creation.
FS-b-1	File deletion.
FS-c-1	File synchronous read.
FS-d-1	File synchronous write.

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17 Appendix F: Document revision history

17.1 Issue 2.50 (May 27, 2002)

Initial issue.

Remark that the main version number increases if tests are added to our test suite. The extended test suite (Version 2) contains also network, disks and memory leak tests.

17.2 Issue 2.51 (May, 31 2002)

- Windows CE .NET does not support the PowerPC (it was supported until Windows CE 3.0)
- Windows CE .NET browser also supports animated GIF

17.3 Issue 2.52 (June 21, 2002)

- The Windows CE .NET QFE reference number (020607_Q323461) has been added.