Xilinx Zynq-7000 All Programmable SoC and Express Logic’s ThreadX RTOS Combine to Achieve Near-Wire-Speed on Iperf Network Throughput Benchmark

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Overview
Express Logic’s NetX™ Duo TCP/IP stack has achieved an outstanding near-wire speed of 910-940 Mbps on Xilinx’s Zynq™-7000 All Programmable SoC. Because TCP/IP stacks typically achieve significantly less than 100% of the hardware’s maximum capability, developers often have to choose faster, more expensive, power-hungry processors to gain desired network performance. In contrast, NetX Duo achieves 91-94% of maximum wire speed on Zynq-7000 devices running on only one of its 2 Cortex™-A9 processors, freeing up the other A9 processor for functions that can run simultaneously without slowing network performance. NetX Duo’s functionality and efficiency enable Zynq-7000 devices to deliver a combination of maximum performance and robust connectivity, reducing design costs, and speeding time to market.

To achieve near-wire speeds, NetX Duo takes advantage of Zynq-7000’s Gigabit Ethernet controller, hardware checksum accelerator, and dedicated Ethernet MAC DMA engine that is integrated into its processing system, to maximize network transfer speed.

Xilinx Zynq-7000 All-Programmable SoC
The Xilinx Zynq-7000 AP SoC is a new category of devices which combine an ARM® dual-core Cortex™-A9 MPCore™ processing system with advanced 28nm programmable logic. The Zynq-7000 family offers the flexibility and scalability of an FPGA, while providing performance, power, and ease of use typically associated with ASIC and ASSPs. The range of devices in the Zynq-7000 All Programmable SoC family allows designers to target cost-sensitive as well as high-performance applications from a single platform using industry-standard tools. While each device in the Zynq-7000 family contains the same PS, the PL and I/O resources vary between the devices.

As a result, the Zynq-7000 All Programmable SoCs are able to serve a wide range of applications including:
• Automotive driver assistance, driver information, and infotainment
• Broadcast camera
• Industrial motor control, industrial networking, and machine vision
• IP and Smart camera
• LTE radio and baseband
• Medical diagnostics and imaging
• Multifunction printers
• Video and night vision equipment

The Zynq-7000 architecture enables implementation of custom logic in the PL and custom software in the PS. It allows for the realization of unique and differentiated system functions. The integration of the PS with the PL allows levels of performance that two-chip solutions (e.g., an ASSP with an FPGA) cannot match due to their limited I/O bandwidth, latency, and power budgets.

Xilinx offers a large number of soft IP for the Zynq-7000 family. Stand-alone and Linux device drivers are available for the peripherals in the PS and the PL. The award-winning ISE® Design Suite: System Edition development environment enables a rapid product development for software, hardware, and systems engineers. Adoption of the ARM-based PS also brings a broad range of third-party tools and IP providers in combination with Xilinx’s existing PL ecosystem. The inclusion of an application processor enables high-level operating system support, e.g., Linux. Other standard operating systems used with the Cortex-A9 processor are also available for the Zynq-7000 family.

The PS and the PL are on separate power domains, enabling the user of these devices to power down the PL for power management if required. The processors in the PS always boot first, allowing a software centric approach for PL configuration. PL configuration is managed by software running on the CPU, so it boots similar to an ASSP.

How The Test Was Run
NetX Duo performance was measured using Iperf, the open-source benchmark tool that has become the industry standard for measuring network throughput. Iperf runs on a Windows or Linux host, connected to a Xilinx Zynq-7000 SoC ZC702 Evaluation Kit using its 100Mbps Ethernet. Theoretical maximum speed (“wire speed” for this configuration is 100Mbps. As will be shown, NetX Duo achieves over 90% of this theoretical limit, achieving “near-wire” speed. The Iperf TCP and UDP results were served by NetX Duo as a web page and displayed by Internet Explorer on the host PC.

The NetX Iperf Demonstration is designed to run a variety of evaluation boards in order to assess NetX performance as well as the performance of the underlying hardware. This demonstration may also be used as a general platform for doing some limited network programming using NetX. All software programs and files referenced in this document are available from Express Logic.

The Iperf Benchmark
Iperf is a standard network testing program that runs on both Windows and Linux hosts. Iperf is designed to test TCP and UDP network throughput. The examples in this document are based on the Java-based Iperf implementation called Iperf. For more information on Iperf, please reference the Wikipedia link: http://en.wikipedia.org/wiki/Iperf.
NetX™ and NetX Duo™ TCP/IP Protocol Stacks
NetX and NetX Duo are Express Logic’s high-performance implementations of TCP/IP protocol standards. NetX provides a streamlined, IPv4 capable TCP/IP stack, while NetX Duo is Express Logic’s new TCP/IP stack that provides both IPv4 and IPv6 capabilities in a dual-stack product. Both NetX and NetX Duo are fully integrated with ThreadX and are available for all supported processors. NetX and NetX Duo have a unique Picone™ architecture. Combined with a zero-copy API, they are a perfect fit for today’s deeply embedded applications that require network connectivity.

Zero-Copy API
NetX and NetX Duo provide zero-copy TCP/IP communication to eliminate processor cycles consumed by moving data to and from user buffers. This results in very high performance and frees processor cycles back to the application for useful activities.

BSD Sockets Interface
In addition to the zero-copy, highly-optimized NetX API, NetX also provides a BSD sockets compatible API for applications with legacy BSD application code.

UDP Fast Path™ Technology
Basic UDP packets pass through NetX and NetX Duo without any copying and without any system context switches. Many commercial network stacks process all packets received within a system thread thereby adding a context switch to the packet overhead. In NetX and NetX Duo, simple UDP packets are delivered directly to waiting threads.

NetX and NetX Duo Protocol Components
NetX and NetX Duo provide a complete set of protocol components that comprise the TCP/IP standard, including the following:
- Full TCP/IP Networking
- IPv4 and IPv6 Support
- Flexible Packet Management
- Internet Protocol (IP)
- Address Resolution Protocol (ARP)
- Reverse Address Resolution Protocol (RARP)
- Internet Control Message Protocol (ICMP)
- Internet Group Management Protocol (IGMP)
- User Datagram Protocol (UDP)
- Transmission Control Protocol (TCP)

NetX and NetX Duo Applications
Additional components, including AutoIP, DHCP, DNS, FTP, HTTP, NAT, POP3, PPP, SMTP, SNMP, SNTP, Telnet, TFTP, HTTPv6, FTPv6, DNSv6, Telnetv6, DHCPv6 and a BSD-compatible socket layer, are also available for NetX or NetX Duo.

IPsec
NetX Duo (optionally) incorporates IPsec (Internet Protocol Security), a protocol suite for securing Internet Protocol (IP) communications by authenticating and encrypting each IP packet of a communication session. IPsec also includes protocols for establishing mutual authentication between agents at the beginning of the session and negotiation of cryptographic keys to be used during the session. IPsec protects any application traffic across an IP network. Applications do not need to be specifically designed to use IPsec.
**IPv6 Features**

NetX Duo conforms to IPv6 related RFC standards and offers complete interoperability with devices from other vendors. NetX Duo offers several new capabilities. For the first time, nodes can configure their interface addresses automatically through the Stateless Address Autoconfiguration protocol. Nodes also can use layered structures to enable devices more efficiently to process IPv6 headers. NetX Duo implements the following protocols:

- All IPv4 features available in NetX
- IPv6 header and extension header processing
- Neighbor Discovery Protocol
- Router Discovery Protocol
- Stateless Address Autoconfiguration
- Duplicate Address Detection

**Phase-II IPv6 Ready Logo Certification**

NetX Duo has achieved IPv6-Ready Logo certification, evidence that it has passed conformance and interoperability tests, administered and validated by the IPv6 Forum. There are two phases of testing, Phase-I and Phase-II. Phase-I is relatively basic and limited to verification of select IPv6 capabilities. Phase-II is much more rigorous and extensive, and is a superset of Phase-I.

Express Logic chose to seek Phase-II approval, which required NetX Duo to pass an extremely challenging set of 373 test cases, which cover the following RFCs:

- RFC 2460 - IPv6 Specification
- RFC 4861 - Neighbor Discovery for IPv6
- RFC 4862 - IPv6 Stateless Address Autoconfiguration
- RFC 1981 - Path MTU Discovery for IPv6
- RFC 4443 - ICMPv6

These test cases make sure the implementation conforms to core IPv6 operations.

The Phase-II Interoperability tests ensure that the implementation is able to work with other devices and routers. This test requires setting up a test network with multiple routers and hosts, and to validate that NetX Duo follows the IPv6 standard and correctly interacts with other hosts and routers.

NetX Duo has successfully performed these tests and has received official IPv6-Ready Logo certification, enabling Express Logic to join a select, small group of embedded software companies who can proudly display the IPv6 Ready logo, indicating that they have successfully completed this rigorous testing and validation process.

**Demo Setup**

The demonstration described here was performed with the Iperf host machine (Linux PC) and the target board (Zynq-7000 ZC702) running the NetX Iperf Demonstration connected to a 100Mbps full-duplex Ethernet switch. To achieve best performance, there was no other traffic on the test network. It is also possible to connect the Iperf host and the NetX target board back-to-back with a cross-over Ethernet cable.
Running Jperf
Running Jperf is easy, simply double-click on the Windows batch file *jperf.bat*. This launches the Jperf IDE, as shown below:

Once the Jperf IDE is displayed, the *Server Address* field must be set to the IP address of the NetX Iperf Demonstration target board. In this example, the NetX target board IP address is **192.168.1.10**. Also worth noting are the *UDP Bandwidth* and *UDP Packet Size* fields. These need to be setup for optimal UDP receive performance, as shown below.
Running the UDP Transmit Test

The UDP Transmit Test determines the performance of NetX UDP transmission to the host. In this test, the NetX target is the client and the Jperf host is the server. Assuming the host browser is displaying the NetX Iperf Demonstration web page as shown above and Jperf is running on the host, select **Server** and **UDP** in the Jperf IDE. Next, select **Run IPerf!** to initiate the Iperf server, as shown below:

Now, from the NetX Iperf Demonstation web page, select the **Start UDP Transmit Test** button to initiate the test. You should now observe performance statistics in the Jperf IDE and the NetX web page updated, as shown below.
To complete the test, select *here* link on the NetX Iperf Demonstation web page.

You should now observe the performance results of the test. In this example, the UDP transmission performance on the NetX target to the Iperf host was 95Mbps with 72% idle time on the NetX target, as shown below:
Running the UDP Receive Test
The UDP Receive Test determines the performance of NetX UDP reception on the NetX target. In this test, the NetX target is the server and the Jperf host is the client. First, select **Client** and **UDP** in the Jperf IDE. Next, select **Start UDP Receive Test** on the NetX Iperf Demonstration web page, as shown:

Now select **Run IPerf!** from the Jperf IDE and observe statistics in the Jperf IDE, as shown below:
To complete the test, select the here link on the NetX Iperf Demonstation web page. You should now observe the performance results of the test. In this example, the UDP reception performance on the NetX target was 95Mbps with 71% idle time, as shown below:

Running the TCP Transmit Test
The TCP Transmit Test determines the performance of NetX TCP transmission to the host. In this test, the NetX target is the client and the Jperf host is the server. First, select Server and TCP in the Jperf IDE. Next, select Run IPerf! to initiate the Iperf server, as shown below:
Now, from the NetX Iperf Demonstation web page, select the **Start TCP Transmit Test** button to initiate the test. You should now observe performance statistics in the Jperf IDE and the NetX Iperf Demonstation web page updated, as shown below:

To complete the test, select the *here* link on the NetX Iperf Demonstation web page. You should now observe the performance results of the test. In this example, the TCP transmission performance on the NetX target was 92Mbps with 62% idle time, as shown:
Running the TCP Receive Test
The TCP Receive Test determines the performance of NetX TCP reception on the NetX target. In this test, the NetX target is the server and the Jperf host is the client. First, select Client and TCP in the Jperf IDE. Next, select Start TCP Receive Test on the NetX web page, as shown:

Now select Run IPerf! from the Jperf IDE and observe statistics in the Jperf IDE, as shown below:
To complete the test, select the *here* link on the NetX Iperf Demonstation web page. You should now observe the performance results of the test. In this example, the TCP reception performance on the NetX target was 82Mbps with 63% idle time, as shown:

![NetX Iperf Demonstation](image)

**Summary**

Express Logic’s NetX Duo TCP/IP stack delivers outstanding network performance results on Xilinx Zynq-7000 All-programmable SoC. The table below summarizes these results for the 4 modes of operation that were tested:

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>TCP</th>
<th>UDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit</td>
<td>92%</td>
<td>95%</td>
</tr>
<tr>
<td>Receive B</td>
<td>82%</td>
<td>95%</td>
</tr>
</tbody>
</table>
About Xilinx: [www.xilinx.com](http://www.xilinx.com)

Xilinx is the world’s leading provider of All Programmable technologies and devices, going beyond traditional programmable logic to enable both hardware and software programmability, integrate both digital and analog mixed-signal functions, and allow new levels of programmable interconnect in both monolithic and multi-die 3D ICs. The company’s products are coupled with a next-generation design environment and IP to serve a broad range of customer needs, from programmable logic to programmable systems integration.

Xilinx has a complete portfolio to enable design teams to develop All Programmable electronic systems. This expands their system value advantages, addresses the industry’s “Programmable Imperative” by reducing exploding design costs, and dramatically increases flexibility and lowers risk in a rapidly changing market environment.

Today, Xilinx is the company of choice for the design of tens of thousands of products that improve the quality of our everyday lives. Xilinx All Programmable devices are used by more than 20,000 customers to:

- Deliver innovative new products to market in a matter of weeks
- Drastically reduce research and development costs
- Change or upgrade end product features and functions "on the fly" to meet new market demands and adapt to changing industry standards

Xilinx chips are designed into automotive infotainment, ultrasound imaging, robotically-assisted surgical systems, IT gear for wireless computing and mobile applications, consumer 3-D TVs, mobile communications used on the networked battlefield – and even sophisticated space vehicles exploring the outer reaches of the universe.

The Xilinx Alliance Program is a worldwide ecosystem of qualified companies collaborating with Xilinx to further the development of All Programmable technologies. Leveraging open platforms and standards, Xilinx has built this ecosystem to meet customer needs and is committed to its long-term success. Comprised of IP providers, EDA vendors, embedded software providers, system integrators, and hardware suppliers, Alliance members help accelerate design productivity while minimizing risk.

About Express Logic: [www.rtos.com](http://www.rtos.com)

Express Logic is a leading provider of royalty-free RTOS, Middleware and Eclipse-based development tools for small-memory-footprint, high-volume devices. Over 1.25 billion such devices have been deployed using ThreadX. Express Logic’s products include:

- **ThreadX®** – our small, fast, real-time operating system (RTOS).
- **NetX™** – our full TCP/IP networking stack.
- **FileX®** – our full MS-DOS compatible file system.
- **USBX™** – our full implementation of the Universal Serial Bus (USB) for Host and Device.
- **PEGX™** - our embedded GUI development kit.
- **TraceX®** - Our graphical event analysis for real-time systems
Express Logic’s royalty-free, full source code, professional support combination makes us an attractive business partner for companies producing high-volume SoCs and electronic devices in today’s competitive market for consumer electronics, industrial automation, and medical equipment.

**About the authors:**

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