TI Designs

OPC UA DA Server Reference Design for Industrial Automation

TEXAS INSTRUMENTS

Overview

OPC UA is an industrial machine-to-machine protocol designed to allow interoperability and communication between all machines connected under Industry 4.0. This TI Design demonstrates use of the MatrikonOPC™ OPC UA server development kit (SDK) to allow communications using an OPC UA data access (DA) server running embedded in a project or design. The OPC UA DA deals with real-time data and is best suited for industrial automation applications where time is an important aspect of the data. A reference OPC UA server implementation is provided that accesses the GPIO capabilities of the AM572x IDK. The reference code can be extended to provide an OPC UA interface to any data the AM572x IDK board can access including data acquired through Profibus, RS-485, CAN bus, and industrial Ethernet-based protocols such as EtherCAT™ or PROFINET™ using the Programmable Real-time Unit Industrial Communication Subsystems (PRU-ICSS).

Resources

TIDEP0078	Design Folder
AM572x	Product Folder
TMDXIDK5728	Tools Folder
PROCESSOR-SDK-LINUX	Tools Folder

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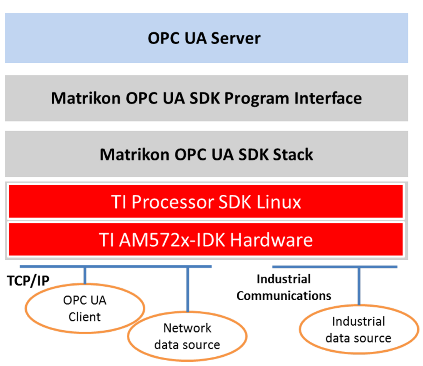
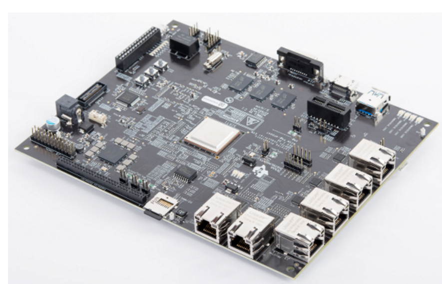
Features

- Fully-Embedded OPC UA Server Running on Sitara™ AM57x Family
- MatrikonOPC OPC UA SDK Version R100 and Sample OPC UA Server
  - Note: Demo Version is Time Limited to Two Hours
- Linux™ Operating Environment Through Processor-SDK-Linux
- Control GPIO Read/Write from OPC UA Client over TCP/IP Communication
- Tested on TMDXIDK5728 Board and Includes Documentation, Software, Demonstration Application, and Hardware Design Files

Applications

- Programmable Logic Controllers (PLCs)
- Sensors and Actuators
- Gateway Products for Protocol Translation
- Building Automation Controllers
- Smart Meters





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1 Introduction

One key concept of Industry 4.0 and the Industrial Internet of Things (IIoT) is creating distributed intelligent systems which requires intercommunication of information horizontally across similar levels of a network and vertically between the levels. The problem of interoperability is important to solve as these concepts begin to be implemented in real-world industrial systems such as factory automation systems, building automation systems, and grid infrastructure (utilities). The OPC UA is a lightweight communication standard intended to be used on embedded platforms such as PLCs, drives, or I/O modules on factory floors. The OPC UA addresses the communication challenges that exist between equipment on different networks in a factory or plant, which may be using different communication standards. This solution allows these devices to communicate data such as sensor information, event notifications, and more, which can be used for anything from predictive maintenance analytics to billing for hardware-as-a-service. The OPC UA is a good fit for industrial automation systems as it provides the standardized communication, security, and abstraction required for enabling machine-to-machine communications as well as serving as a gateway to the cloud.

The AM572x Sitara ARM® processor is built to meet the complex processing needs of modern embedded industrial products. The AM572x provides high-processing performance through the flexibility of a fully-integrated mixed processor solution with two ARM® Cortex®-A15 cores, two ARM Cortex-M4 cores, and two TI C66x digital signal processor (DSP) cores as well as two industrial communication subsystems (PRU-ICSS), which can be used for real-time communications and I/O applications such as EtherCAT, PROFINET, and more. The AM572x is well-suited to industrial applications due to its support for industrial temperature ranges, high reliability, real-time software support, and extensive peripheral set including two PRU-ICSSs, which allow the device to support two industrial protocols at once. The AM572x is supported with Mainline LTS Linux as well as RT Linux and TI-RTOS, all provided through TI’s processor SDK.

2 System Description

This TI Design combines the Linux environment on the AM527x IDK with the MatrikonOPC OPC UA SDK. Figure 1 lays out all of the components in the system for reference. The bottom of the diagram shows data sources from either TCP/IP or industrial Ethernet data sources, such as EtherCAT or CANbus. The OPC UA SDK components sit on top of the TI platform SDK, which includes the processor SDK Linux, Matrikon OPC UA SDK stack, the program interface, and the server implementation.

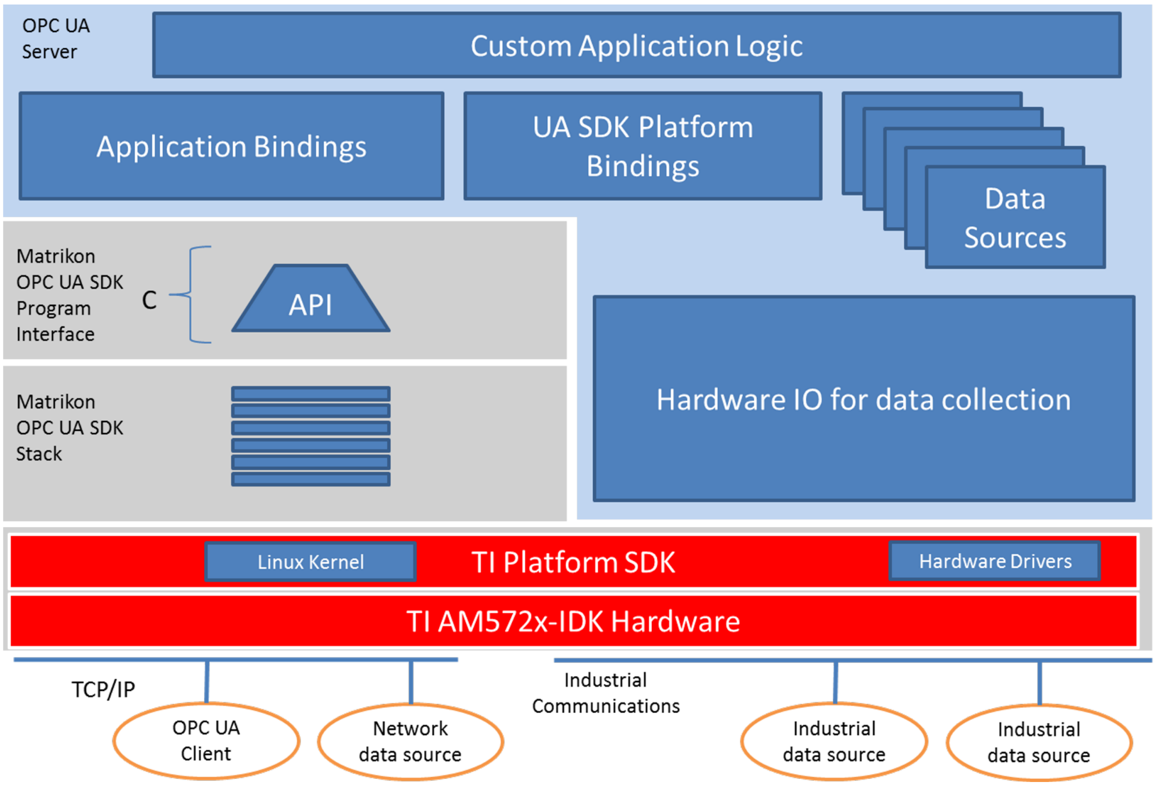

Figure 1. System Overview

2.1 Multi-Core AM572x Processor

The AM572x is a high-performance Sitara processor based on two ARM Cortex-A15s and two TI C66x DSPs. TheAM572x is designed for embedded applications including PLCs, industrial network switches, industrial gateways for protocol translation, human machine interface (HMI), grid infrastructure protection and communications, and other industrial use applications. The device includes the following subsystems:

- ARM Cortex-A15 microprocessor unit (MPU) subsystem, including two ARM Cortex-A15 cores
- Two DSP C66x cores
- Two Cortex-M4 subsystems, each including two ARM Cortex-M4 cores
- Two dual-core PRU-ICSS
- Graphics, video, real-time clock (RTC) and debug subsystems

The device supports memory management unit (MMU) and MPU:

- MMU used for key masters (Cortex-A15 MPU, Cortex-M4, C66x DSP, EDMA)
- Memory protection of C66x cores
- MMU inside the dynamic memory manager

The device also integrates:

- On-chip memory

External Memory Faces:

- Memory management
- Level 3 (L3) and level 4 (L4) interconnects
- System and serial peripherals

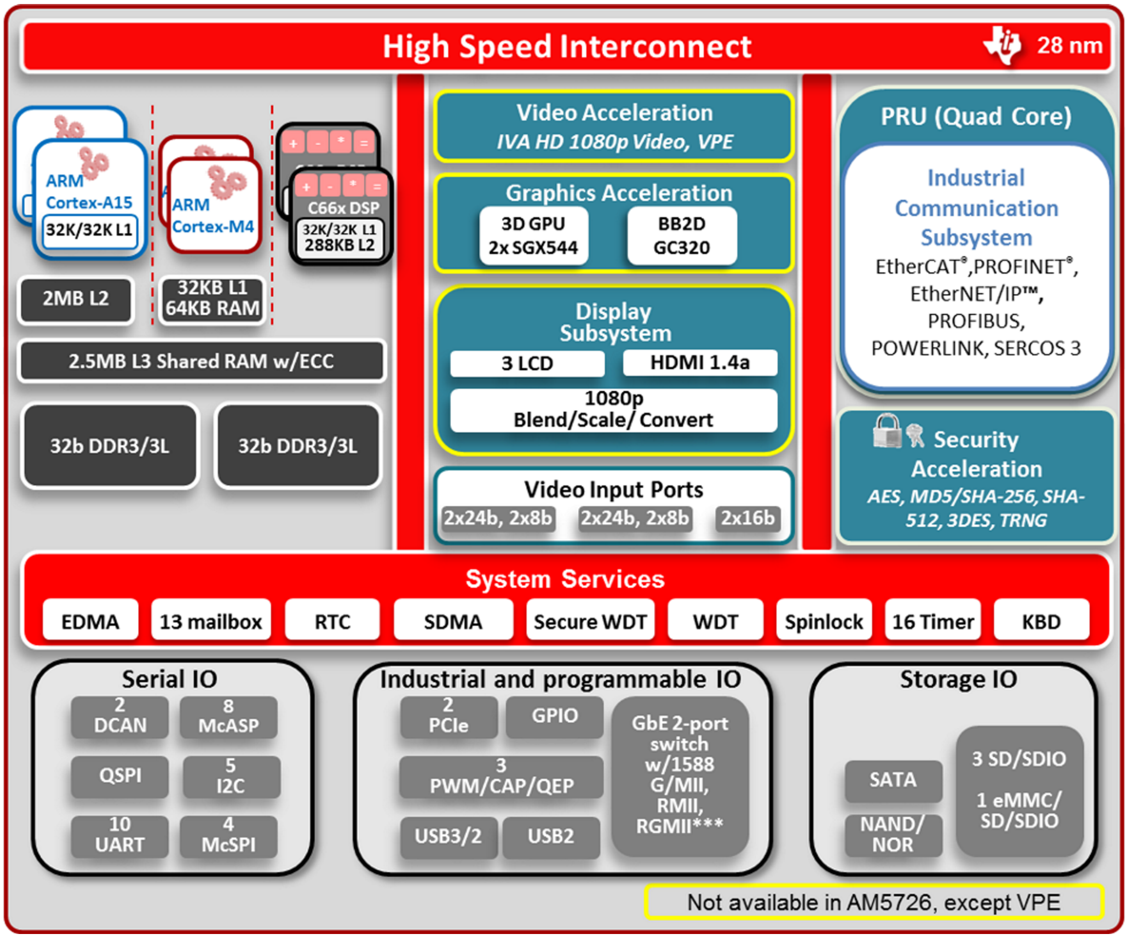

Figure 2. AM572x Block Diagram

2.1.1 Cortex® A-15 MPU Subsystem

The Cortex-A15 MPU subsystem integrates the following sub-modules:

- ARM-Cortex-A15 MPCore
  - Two central processing units (CPUs)
  - ARM Version 7 ISA: Standard ARM instruction set plus Thumb® –2 Jazelle® RCT Java™ accelerator, hardware virtualization support, and large physical address extensions (LPAE)
  - Neon SIMD co-processor and VFPv4 per CPU
  - Interrupt controller with up to 160 interrupt requests
  - One general-purpose timer and one watchdog timer per CPU
  - Debug and trace features
  - 32-KiB instruction and 32-KiB data level 1 (L1) cache per CPU
- Shared 2-MiB level 2 (L2) cache
- 48-KiB bootable ROM
- Local power, reset, and clock management (PRCM) module
- Emulation features

- Digital phase-locked loop (DPLL)

2.1.2 DSP C66x Subsystem

There are two DSP subsystems in the device. Each DSP subsystem contains the following sub-modules:

- TMS320C66x VLIW DSP core extends the performance of existing C64x+ and C647x DSPs through enhancements and new features.
  - 32-KiB L1D and 32-KiB L1P cache or addressable SRAM
  - 288-KiB L2 cache
  - 256-KiB configurable as cache or SRAM
- 32-KiB SRAM
- Enhanced direct memory access (EDMA) engine for video and audio data transfer
- MMUs for address management
- Interrupt controller (INTC)
- Emulation capabilities

2.1.3 Cortex®-M4 IPU Subsystem

There are two Cortex-M4 subsystems in the device:

- IPU1 subsystem is available for general purpose usage
- IPU2 subsystem is dedicated to IVA-HD support and is not available for other processing

Each subsystem includes the following components:

- Two Cortex-M4 CPUs
- ARMv7E-M and Thumb-2 instruction set architectures
- Hardware division and single-cycle multiplication acceleration
- Dedicated INTC with up to 63 physical interrupt events with 16-level priority
- Two-level memory subsystem hierarchy
  - L1 (32-KiB shared cache memory)
  - L2 ROM + RAM
  - 64-KiB RAM
- 16-KiB bootable ROM
- MMU for address translation
- Integrated power management
- Emulation feature embedded in the Cortex-M4

2.1.4 PRU-ICSS

There are two PRU-ICSSs in the device. Each PRU-ICSS consists of dual 32-bit RISC cores (PRUs), shared data and instruction memories, internal peripheral modules, and an interrupt controller (INTC). Among the interfaces supported by the PRU-ICSS are real-time industrial protocols used in master and slave mode, such as:

- EtherCAT
- PROFINET
- EtherNet/IP
- PROFIBUS
- Ethernet POWERLINK
- SERCOS III
- HSR
- PRP

For more details about the processor features, refer to the AM572x Sitara Processors Silicon Revision 2.0, 1.1, Technical Reference Manual.

2.2 MatrikonOPC™ OPC UA Software Development Kit

The OPC UA SDK from Matrikon is a SDK that allows the developer to quickly and easily add an OPC UA Server to the embedded product. The Matrikon OPC UA SDK is a scalable, standards-based SDK that can be integrated into every product type, from discrete sensors and actuators to programmable controllers and beyond. OPC UA server integration adds real value to embedded products by enabling direct point and click configuration, management, and monitoring from any OPC UA client. This single OPC UA SDK is fully configurable and scalable from microcontrollers (MCUs) with 128kB RAM up to high-end embedded systems based on ARM9 and ARM Cortex-A class cores. The OPC UA SDK can be optimized for minimum RAM and FLASH utilization or for large data sets and multiple concurrent client connections.

Key Features:

- RAM-based address space that can be fully reconfigured on-the-fly
- Simple, single-threaded ANSI C API implementation for embedded systems
- Number of sessions, subscriptions, monitored items, and address space nodes supported is solely dependent on the available target resources.

Benefits of Matrikon OPC UA SDK:

- Robust, scalable solutions developed from first principles for embedded systems
- ANSI C linkable multiplatform software that runs on any OS or RTOS or even on bare-metal systems
- Supports the smallest RAM footprint in the industry and scales from 128-kB MCUs up to ARM9, ARM Cortex-A class cores, and beyond
- Easy to use with prototype development in days, not weeks or months
- Quick runtime with minimum CPU utilization

2.3 TI AM572x Industrial Development Kit (IDK)

The AM572x industrial development kit (IDK) is a development platform for evaluating the industrial communication and control capabilities of Sitara AM572x processors for applications in factory automation, drives, robotics, grid infrastructure, and more. AM572x processors include dual PRU-ICSS sub-systems, which can be used for industrial Ethernet protocols such as PROFINET, EtherCAT, Ethernet/IP, and others. The TMDXIDK5728 breaks out six ports of Ethernet, four of which can be used concurrently: 2x GB Ethernet ports and 2x 10/100 Ethernet ports from the PRU-ICSS subsystems.

Features

- Four Ethernet ports with concurrent operation including two from PRU-ICSS
- 2-GB DDR3
- Profibus connection, EtherCAT and RS485 Headers
- On-board eMMC
- Mini PCIe, USB3, and HDMI connectors

2.3.1 TI Processor SDK for AM57x SitaraTM Processors

The Processor SDK is a unified software platform for TI embedded processors providing easy setup and fast out-of-the-box access to benchmarks and demos. All releases of Processor SDK are consistent across TI's broad portfolio, allowing developers to seamlessly reuse and migrate software across devices. Developing scalable platform solutions has never been easier than with the Processor SDK and TI's embedded processor solutions. Processor SDK includes support for both Linux and TI-RTOS operating systems.

Linux Highlights:

- Long-term stable (LTS) mainline Linux kernel support
- U-Boot bootloader support
- Linaro GNU compiler collection (GCC) tool chains

- Yocto Project™ OE Core compatible file systems

3 System Design Theory

The Matrikon OPC UA toolkit is designed to be integrated into a wide range of embedded applications. The toolkit is highly configurable to be tailored to fit the embedded environment it is running in. The SDK is designed to be used without access to a standard C/C++ library and can be used on both bare metal and hosted embedded platforms (that is, Linux based).

Refer to Figure 3 for an overview of the components of an OPC UA Server built with the Matrikon OPC UA Server SDK.

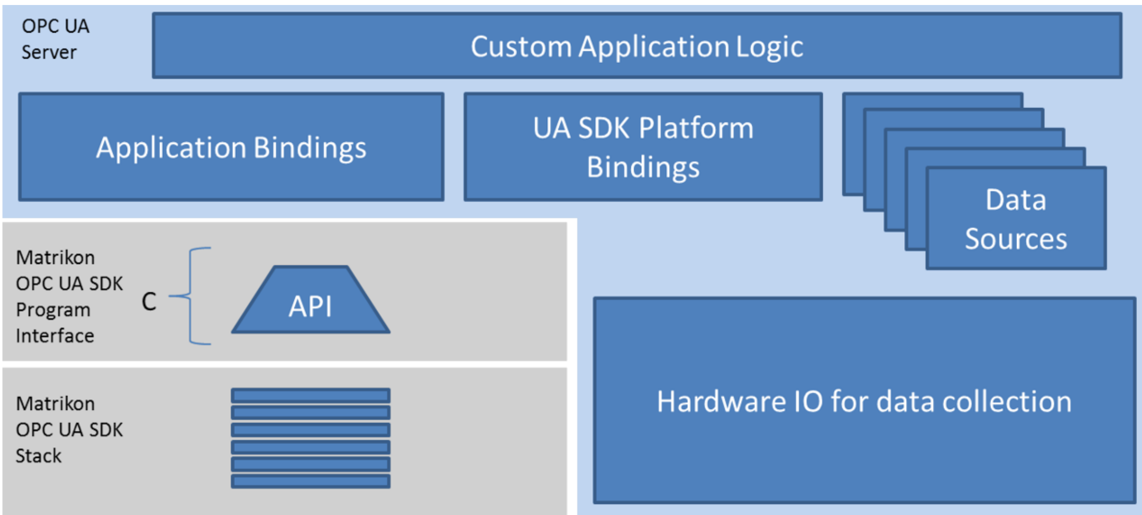

Figure 3. Matrikon OPC UA SDK Server Components

3.1 *Custom Application Logic*

The Matrikon OPC UA SDK is designed to be integrated with existing applications and new applications without forcing the application to be built around the UA SDK. The sample UA server uses a number of the available peripherals on the AM572x-IDK board to provide data points for the UA server.

3.2 *Application Bindings*

The application bindings connect the Matrikon OPC UA SDK to the custom application logic. The application bindings are responsible for setting up the address space in the OPC UA server and for providing call backs used by the OPC UA stack to request data as needed to handle the OPC UA client requests.

3.3 *Platform Bindings*

In order to support a wide range of platforms, the SDK separates out platform specific duties from the API. A basic reference implementation is provided that is appropriate basic servers and development/testing. The platform code needs to provide the following services:

- Timekeeping – timestamps and millisecond resolution counter
- Memory management (optional)
- Memory copying and comparison
- Logging (optional)
- Encryption and certificate management (optional)
- TCP/IP services
- Regular polling of the SDK

The reference implementation provided for this reference design uses the Linux OS provided in Processor-SDK-Linux to host the application and a socket-based TCP/IP implementation.

3.4 Data Sources & Hardware IO for Data Collection

The UA server can collect data from a variety of sources. The MatrikonOPC UA SDK uses the application bindings to access the data, and the custom application logic is responsible for gathering or generating the data. The sample UA server uses Linux GPIO access to access data from a number of on-board peripherals.

3.5 API

The API is C language compatible and provides the interface between the remainder of the components. The user application must make calls into the API and must implement callbacks defined by the API for use by the SDK internals. The API can be used in a single-threaded environment and is non-reentrant. However, the Matrikon OPC UA SDK may also be used in a multithreaded application, provided that the user application prevents re-entrant calls to the SDK. The SDK must be periodically polled by the user application. The API is designed to minimize memory use by avoiding unnecessary copying of data into and out of the SDK and platform code. Full API documentation is included in the install.

3.6 SDK Internals

The SDK internals run the OPC UA stack. The internals manage packet encoding and decoding, the address space, monitored items, error handling, and interface with security code implemented in the platform code layer to perform encryption and certificate management. As needed, the SDK internals interact with the user application and platform code through callbacks declared in the API.

4 Getting Started Hardware

The required hardware for this design includes:

- AM572x IDK
- Micro USB Cable
- Router and standard Ethernet cable for connection through router or crossover cable for direct connection to the PC
- Ubuntu™ 12.04+ 64 bit PC or laptop
- 5.0 VDC power supply
- HDMI cable and HDMI-compatible display
- USB keyboard and mouse
  – A USB hub may also be required to connect both the mouse and keyboard at the same time.

4.1 AM572x IDK EVM (TMDXIDK5728)

See Figure 4 while setting up AM572x IDK.

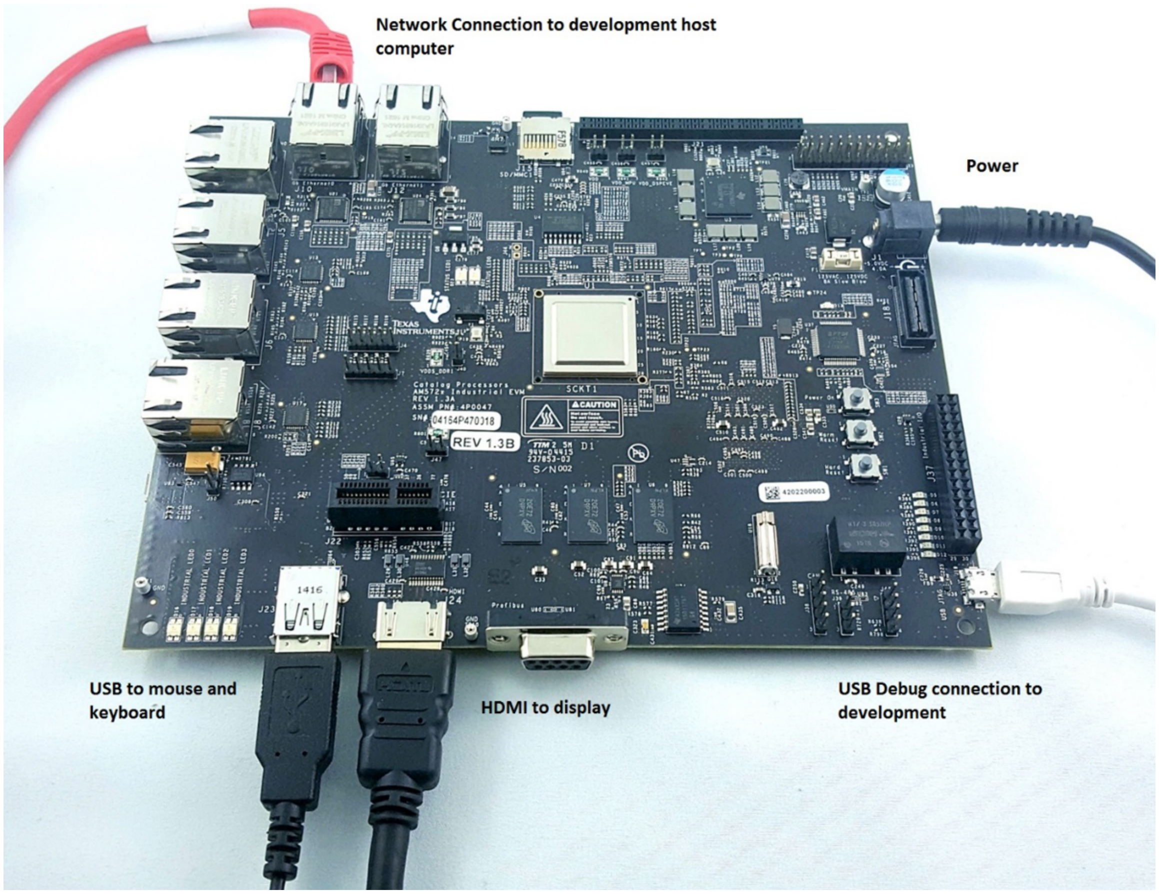

Figure 4. AM572x IDK Setup

NOTE: The power supply for the IDK is 5.0 VDC whereas other Sitara EVMs may use 12 VDC.

5 Getting Started Software

The Matrikon OPC UA SDK includes an example OPC UA Server that accesses the GPIO capabilities of the AM572x IDK board. It is written against a Linux hosted platform layer, Processor-SDK-Linux, and is meant to be installed on the TI provided evaluation system, TMDXIDK5728.

5.1 Requirements

The following software and tools are required:

1. Texas Instruments processor SDK for AM572x Sitara processors – Linux version 03.00.00.04 or newer(PROCESSOR-SDK-AM57X)
2. Matrikon OPC UA sample server for AM572x IDK (https://www.matrikonopc.com/downloads/1359/index.aspx)
3. OPC UA Client application
   - The OPC Foundation provides a sample client that can be downloaded from https://opcfoundation.org/developer-tools/developer-kits-unified-architecture/sample-applications/.

NOTE: The Matrikon OPC UA Sample Server for AM572x IDK software package includes a user manual and API reference documentation. Once the software has been downloaded and installed, please consult that documentation for more information about working with the SDK and adding functionality to the sample server.

5.2 Source Structure:

The Matrikon OPC UA Software Development Toolkit for AM572x IDK is distributed as a gzipped tar file. Uncompress the file and extract the contents to a directory of your choice on the Linux build host environment.

$ tar xzvf matrikonopc-ua-sdk-ti-demo.tar.gz

The following folder structure will be created:

Table 1. OPC UA Software Source Structure

DIRECTORY	DESCRIPTION
matrikon-embedded-ti-demo/	Project base directory
matrikon-embedded-ti-demo/docs/	Contains end user license agreement, API and user documentation
matrikon-embedded-ti-demo/matrix-app/	Contains the files used to integrate the sample server into the TI Matrix GUI demonstration UI
matrikon-embedded-ti-demo/scripts/	Contains start/stop scripts used by the TI Matrix GUI Demonstration
matrikon-embedded-ti-demo/share/	Empty, reserved for future use
matrikon-embedded-ti-demo/uasdk/	Contains the Matrikon OPC UA Embedded Server Toolkit
matrikon-embedded-ti-demo/uasdk/SDK_Configuration	Build configuration
matrikon-embedded-ti-demo/uasdk/SDK_Source/API	Contains the SDK API header files
matrikon-embedded-ti-demo/uasdk/Debug/libuasdk.a	Matrikon OPC UA SDK library, debug build
matrikon-embedded-ti-demo/uasdk/Release/libuasdk.a	Matrikon OPC UA SDK library, debug build
matrikon-embedded-ti-demo/uaserver	Contains the source code for the example server

5.3 TI Processor SDK Setup

5.3.1 Install Processor SDK Linux

Processor SDK Linux is available at http://software-dl.ti.com/processor-sw/esd/PROCESSOR-SDK-LINUXAM57X/latest/index_FDS.html. Check this site to get the most recent version. The remainder of these instructions use version 03.00.00.04.

$ wget http://software-dl.ti.com/processor-sdk-linux/esd/AM57X/latest/exports/ti-processor-sdk-linux-am57xx-evm-03.00.00.04-Linux-x86-Install.bin

$ chmod +x ti-processor-sdk-linux-am57xx-evm-03.00.00.04-Linux-x86-Install.bin

$ ./ti-processor-sdk-linux-am57xx-evm-03.00.00.04-Linux-x86-Install.bin.

5.4 Initial Setup

1. Install and configure the TI Processor SDK for AM57x Sitara Processors per Section 5.3. Build the entire package for the IDK.

2. Build the Linux kernel and all of the sample applications:
   $ cd ~/ti-processor-sdk-linux-am57xx-evm-03.00.00.04
   $ ./setup.sh
   $ make && sudo make install

3. Change the current directory to the demonstration package:
   $ cd ~/matrikon-embedded-ti-demo

4. Edit the PROCESSORSDK file in this directory and set the PROCESSOR_SDK variable to point to the location that the processor SDK was installed too. Ensure the correct path and version number have been created. It is recommended that you enter the absolute path to the processor SDK.

5. Build and install the demonstration. This will compile the executable and copy the executable and all resource files required to the TI Processor SDK target directory structure.
   $ cd ~/matrikon-embedded-ti-demo
   $ make && sudo make install

6. Change the current directory to the TI Processor SDK installation directory and install the TI Linux kernel and u-boot images. The AM572x-IDK board can be configured to boot from either over the network, or from the micro SD card. Consult the Processor SDK documentation for details.

5.5 Running the Sample Server

1. Boot the AM572x-IDK board.
2. Start the server.
   If you have a monitor or LCD panel and mouse or touchscreen connected to the AM572x-IDK board, a *Matrikon OPC UA Sample Server* icon will show up on the Matrix App Launcher as shown in Figure 5.

Figure 5. Matrix App Launcher Main Menu

Click on the *Matrikon OPC UA Sample Server* icon, and select the *Start Matrikon OPC UA Sample Server* icon as shown in Figure 6.

Figure 6. Matrikon OPC UA Sample Server Menu

Click on the *Run* button to start the sample server as shown in Figure 7.

Figure 7. Matrikon OPC UA Sample Server Start Page

The server will run as a daemon and will keep running until the *Stop Matrikon OPC UA Sample Server* command is run.
Alternately, you can remotely log into the board using SSH or a terminal program using the serial channel on the debug USB port. Log in as root (no password by default), and start the server:
$ /usr/bin/runUaserver
The server will start in the background. The Matrix GUI Matrikon submenu has a *Stop OPC UA Sample Server* icon. From the command line, the UA server can be stopped using:
$ /usr/bin/stopUaserver

3. Connect a UA client The UA Server will listen on all available TCP/IP addresses on the AM572x-IDK board, which by default requests an address through DHCP. The OPC UA server is on port 4840:
opc.tcp://<ip address>:4840
The OPC Foundation provides a sample client that can be downloaded from https://opcfoundation.org/developer-tools/developer-kits-unified-architecture/sample-applications/.
The sample client should be run from a windows machine that is connected to the same network as the AM572x-IDK board. Run the sample client from the start menu, under *OPC Foundation\1.02\Sample Applications\Opc.Ua.SampleClient*. Enter the address (opc.tcp://<ip address>:4840) of the AM572x-IDK board into the drop-down field and click on *Connect* (Figure 8).

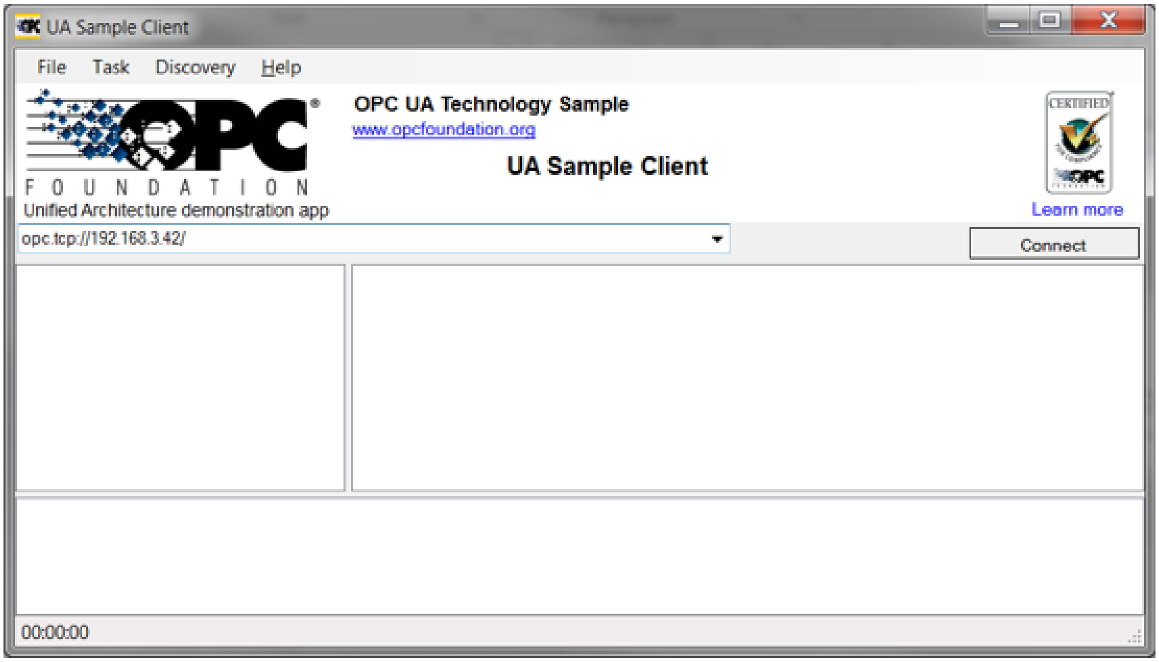

Figure 8. OPC Foundation UA Sample Client Connection

To connect with no encryption, select the connection listed as *None – None – Binary*. To connect with message signing and encryption, select the *SignAndEncrypt – Basic128Rsa15-Binary* option from the list. Click on *OK* (see Figure 9).

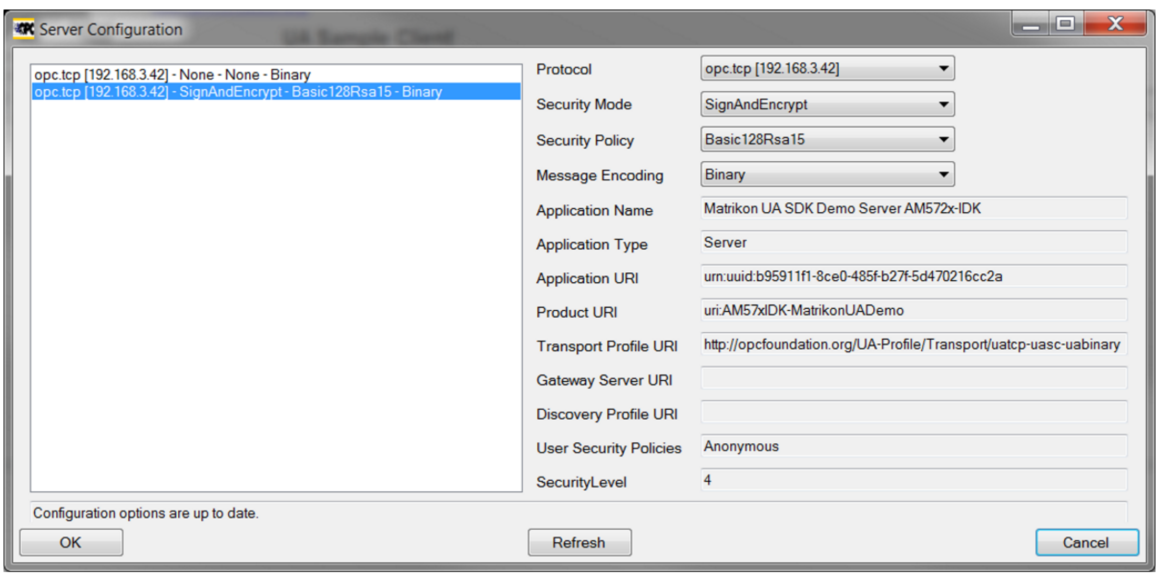

Figure 9. Default Connection Options

Note: Make sure that the IDK board has the clock set to a reasonable time via Linux date command, which is close to what the host is using. Because that board doesn't have a battery backup, make sure the clock is set every time it boots.

The *Open Session* dialog should list the *Authentication Mode* as *Anonymous*. Accept the defaults, and click *OK* (Figure 10).

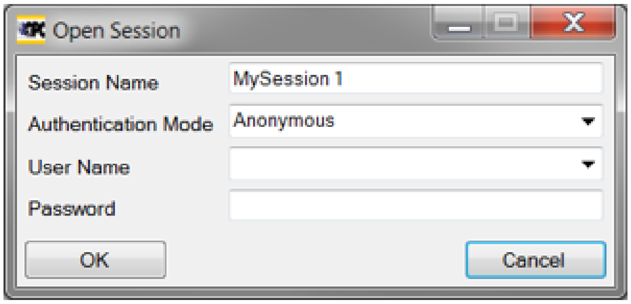

Figure 10. Open Session Options

The OPC Foundation UA Sample Client may report that the certificate could not be validated. The demonstration server provides a self-signed certificate, and this is expected. Select *Yes* to accept the certificate (Figure 11).

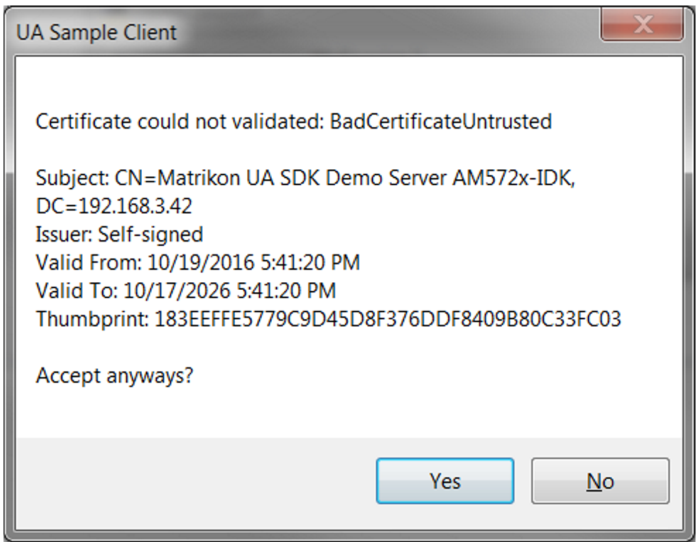

Figure 11. Certificate Trust Warning

The OPC Foundation Sample client is now connected to the Matrikon OPC UA SDK sample server running on the AM57x-IDK.

The server address space contains a variety of variables that are mapped to the I/O on the board. You can observe the inputs and activate the outputs through the OPC UA server. The items listed under the GPIO tree can be accessed to control hardware on the board (Figure 12).

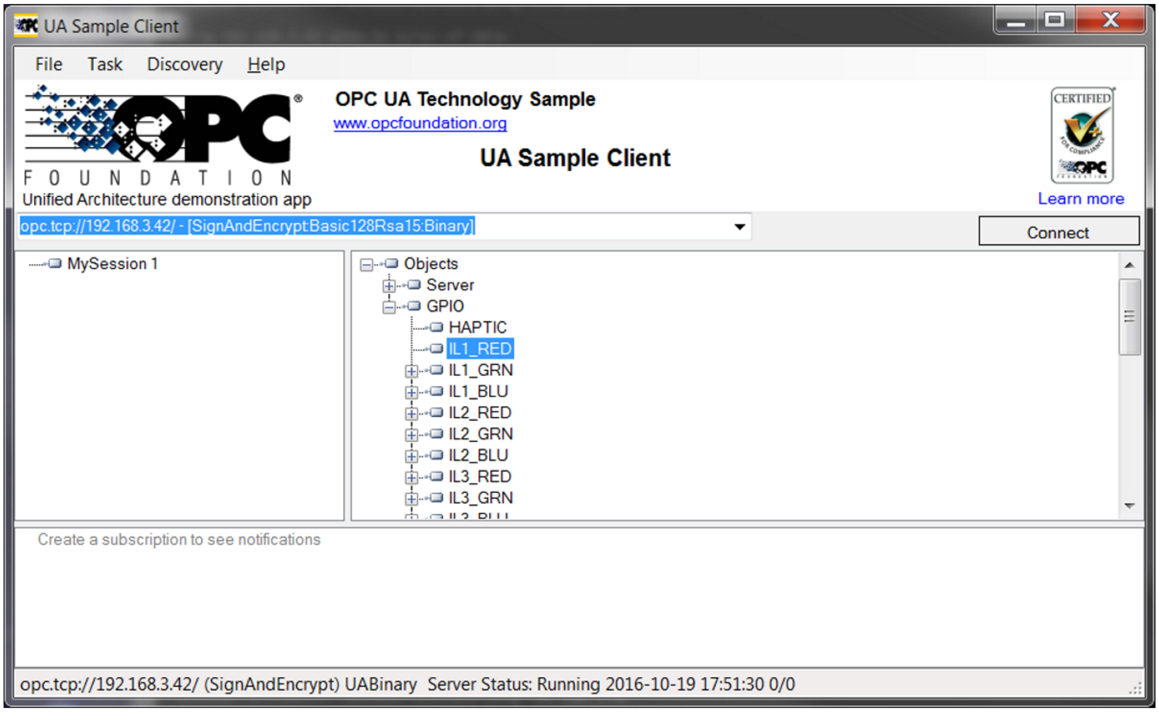

Figure 12. Connected to the Matrikon OPC UA SDK Sample Server

For more information and instructions on how to use the OPC Foundation UA Sample client, see http://opcfoundation.github.io/UA-.NET/help/index.htm#ua_sample_client.htm.
Note that the server is for evaluation purposes only and will only operate for two hours and then must be restarted. To run the server for longer or develop products using the SDK, please contact Matrikon for a license string by emailing OPCUASDK@matrikonopc.com.

6 Testing and Results

The following graphs are the result of performance analysis testing conducted against the Matrikon OPC UA sample server running on the TI AM572x. The purpose of these tests are to determine a baseline for time to execute specific client actions (Read/Write/Read, Registered/Write, Registered/Create, Monitored Items/Delete Monitored Items). All tests were loop executed 10,000 times (cycles).

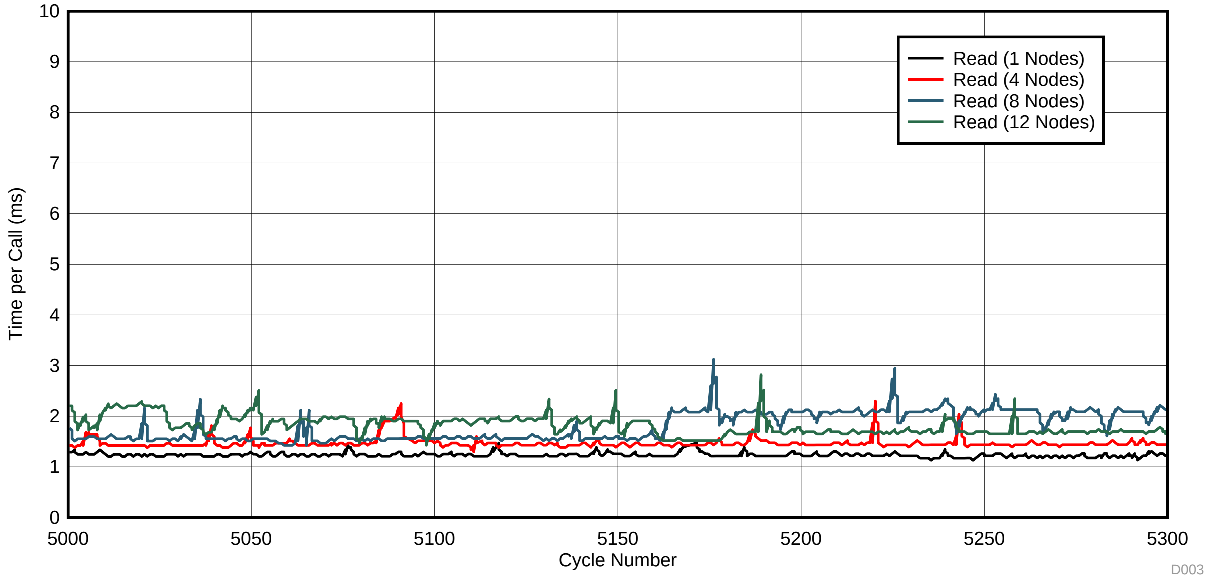

Figure 13. Client Read Call (Non-Registered Node ID)

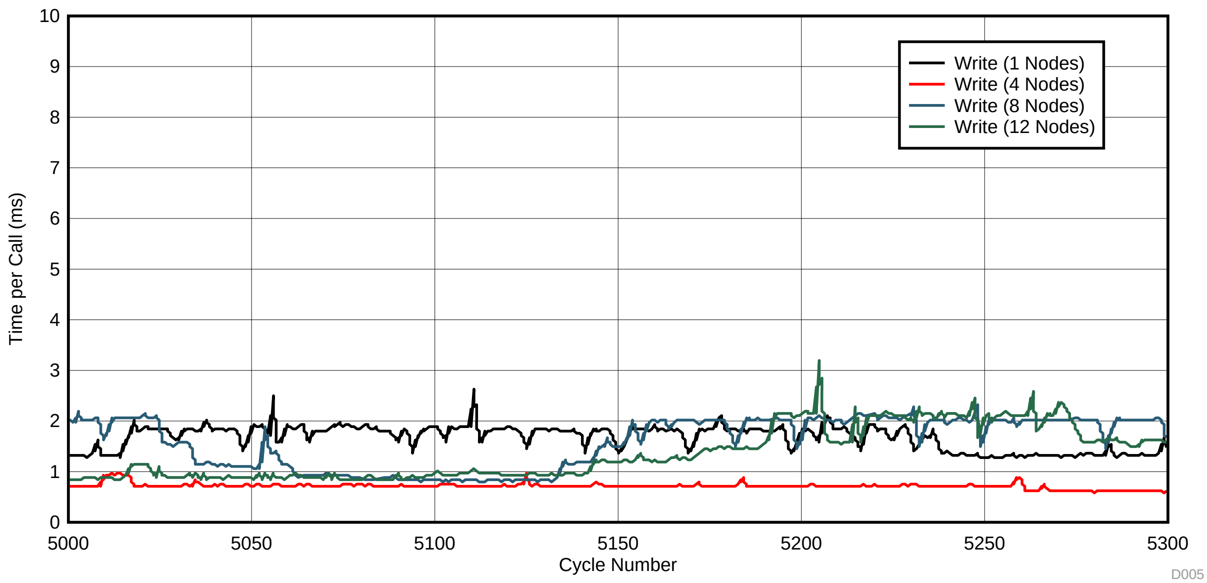

Figure 14. Client Write Call (Non-Registered Node ID)

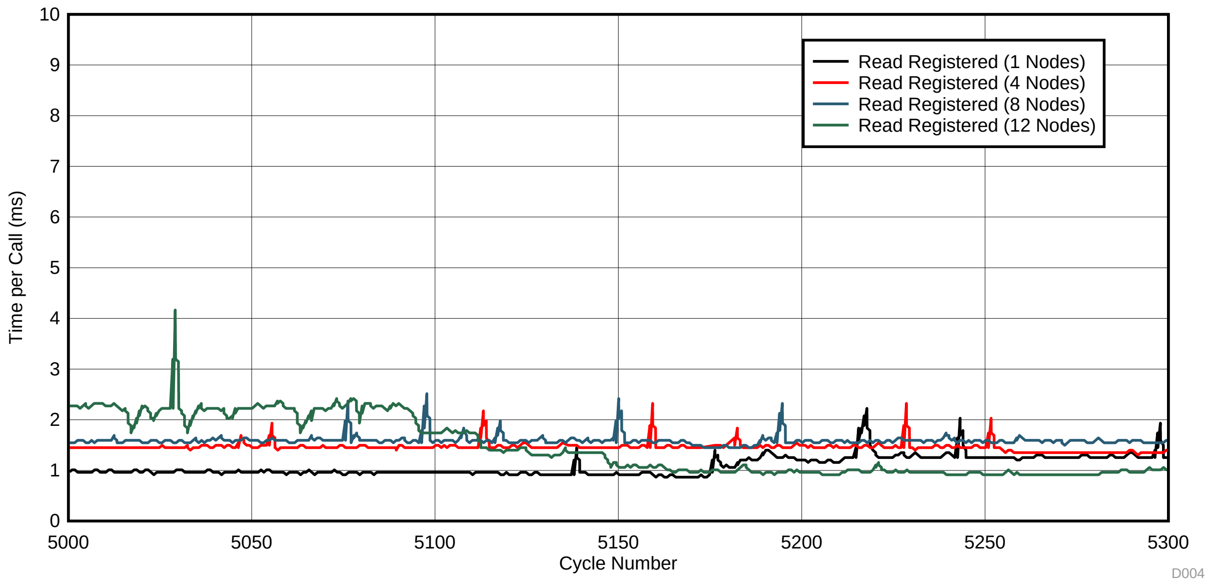

Figure 15. Client Read Call (Registered Node ID)

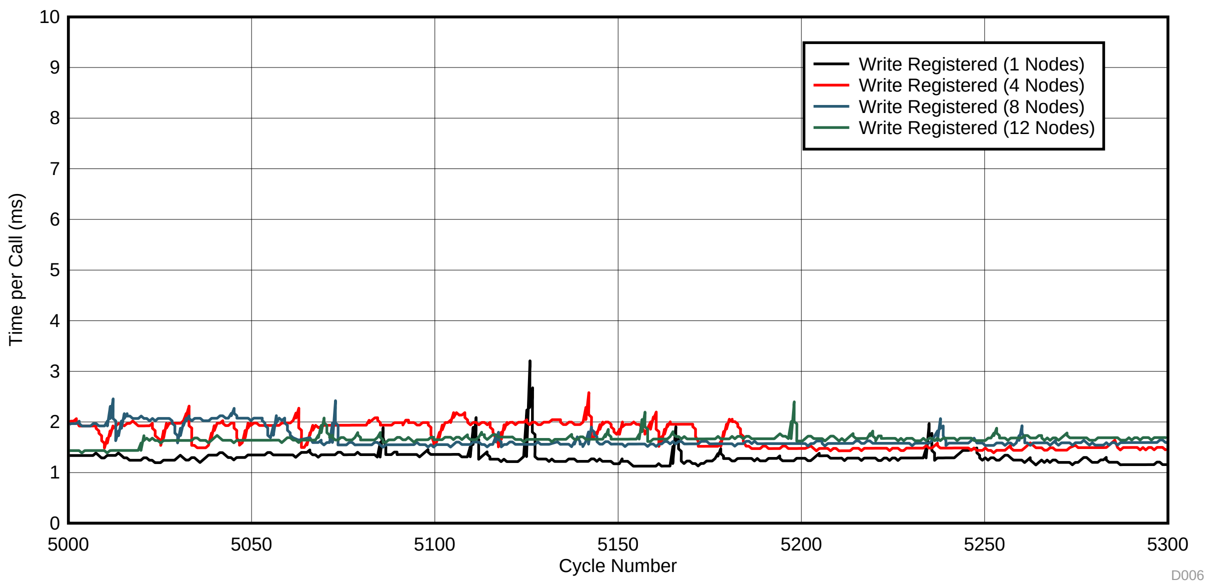

Figure 16. Client Write Call (Registered Node ID)

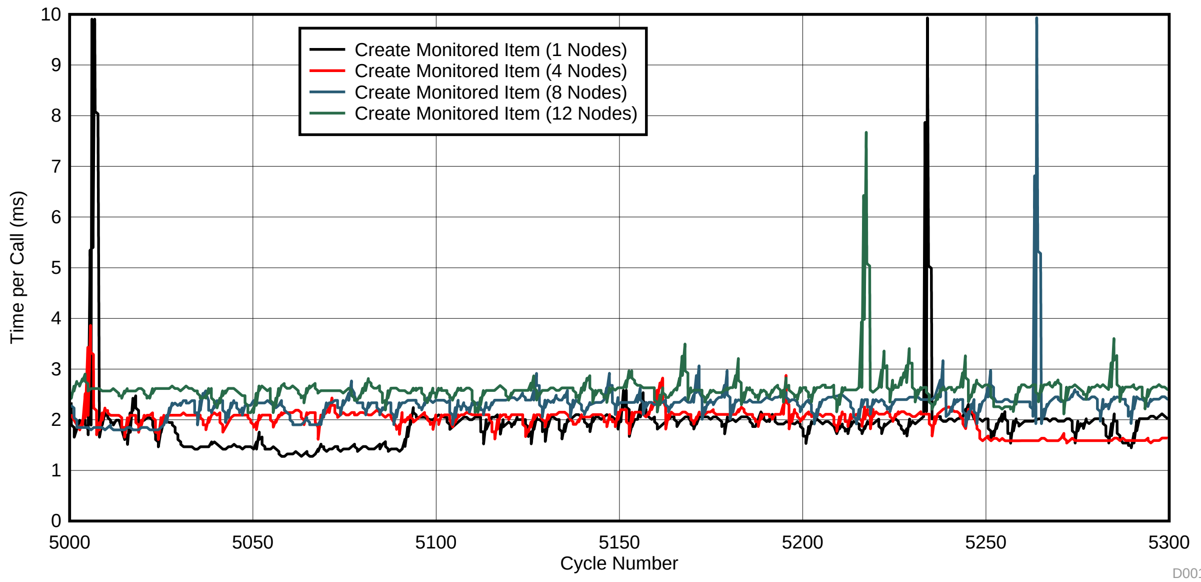

Figure 17. Client Create Monitored Item Call

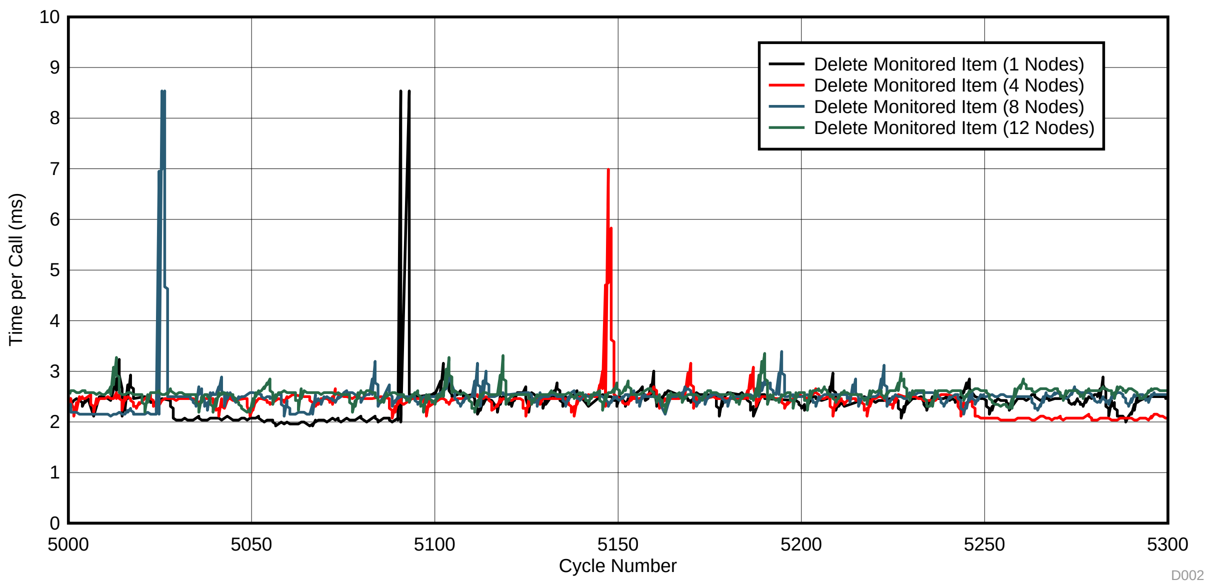

Figure 18. Client Delete Monitored Item Call

7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDEP0078.

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDEP0078.

7.3 Software Files

To download the software files, see the design files at https://www.matrikonopc.com/downloads/1359/index.aspx and PROCESSOR-SDK-AM57X.

8 Related Documentation

1. Matrikon, *OPC UA Software Development Kit (SDK),* http://www.matrikonopc.com/opc-ua/embedded/sdk.aspx
2. OPC Foundation, https://opcfoundation.org/
3. Texas Instruments, *AM572x Industrial Development Kit*, TMDXIDK5728 Tools Folder
4. Texas Instruments, *Processor SDK Linux for AM57x SitaraTM Processors - Linux and TI-RTOS support*, PROCESSOR-SDK-AM57X Tools Folder

8.1 Trademarks

9 About the Author

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Revision A History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (September 2016) to A Revision	Page
• Changed link for item 1 in Section 8	20

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