SimpliciTI

Users Guide
Sample Applications

Document Number: swra243

Texas Instruments, Inc.

www.ti.com/simpliciti

Low-Power RF

Table of Contents

Table of Tables

Table of Figures

i Revision History

Version	Description	Date
1.0	Initial release	03/20/2009
1.1	Updated to include CC430	04/21/2009
1.2	Updated items pertaining to CC430	05/06/2009
1.3	Updated for Code Composer Studio v4, IAR Kickstart editions	10/28/2009

ii References

[1] SimpliciTI Specification Version

[2] SimpliciTI Developers Notes

[3] SimpliciTI Channel Table Information

[4] Application Note on SimpliciTI Frequency Agility Description

iii Definitions

- API Application Programming Interface.
- BSP Board Support Package
- CCA Clear Channel Assessment
- CCS Code Composer Sstudio (TMDFCCS-MCULTD)
- EW Embedded Workbench (toolset from IAR Systems)
- FHSS Frequency Hopping Spread Spectrum
- GPIO General Purpose Input Output
- IAR IAR Systems (http://www.iar.com/)
- IDE Integrated Development Environment
- ISR Interrupt Service Routine
- LED Light Emitting Diode
- LQI Link Quality Indication.
- LRU Least Recently Used
- MAC Medium Access Control.
- PHY Physical layer.
- RSSI Received Signal Strength Indicator
- SoC System on Chip (MCU and radio are on the same integrated circuit)
- SRF04 SmartRF04 Evaluation Board
- SRF05 SmartRF05 Evaluation Board (Rev 1.7 or later)

iv Nomenclature

Fixed pitch fonts `such as this` refer to program source code or source file names.

1. Introduction

1.1. Purpose

This document provides basic information necessary for a first-time SimpliciTI™ user to try the sample applications that are included in Texas Instruments' SimpliciTI package. This includes a guide to programming the development kit hardware, a description of what each application does, and a step-by-step procedure to run the application.

1.2. Contents

This document is organized in two main sections. Section 2, Development Environment, introduces the available hardware and software tool options for working with SimpliciTI. Section 3, Sample Applications, discusses four easy-to-use sample applications that demonstrate some of the capabilities of SimpliciTI.

1.3. Audience

This document is intended for use by engineers, managers, and students who are new to SimpliciTI and would like to evaluate some of its capabilities. The user is expected to be capable of obtaining and installing Windows-based tools and software on their PC and then following instructions on building, loading, and running sample applications on the hardware included with their development kit.

2. Development Environment

In order to evaluate the SimpliciTI sample applications, you will need to obtain some tools to build and download the software and some hardware to run it on. Currently, the SimpliciTI package has support for 14 different hardware development kit configurations, which use various combinations of Texas Instruments processors and radios. For each hardware configuration, there are software development projects to build each of the four sample applications. All of these projects are supported by IAR Systems Embedded Workbench (EW) development tools. Projects based on the MSP430 processors are also supported by Texas Instruments' Code Composer Studio (CCS) development tools. Both toolsets include an IDE, compiler, assembler, linker, downloader, debugger, and documentation. The following two tables show which CCS or IAR toolset you will need and which SimpliciTI project you will use, based on the development kit hardware that you have:

System-On-Chip Development Hardware	Frequency	Project	CCS Toolset	IAR Toolset
SmartRF04EB + CC1110EM	< 1 GHz	SRF04	N/Ahttp://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html	EW8051
CC1111EM USB Dongle	< 1 GHz	RFUSB	N/A	EW8051
EM430F6137RF900 or FET430F6137RF900	< 1 GHz	CC430EM	CCSv4	EW430
CC2430DB	2.4 GHz	CC2430DB	N/A	EW8051
SmartRF04EB + CC2430EM	2.4 GHz	SRF04	N/A	EW8051
SmartRF04EB + CC2431EM	2.4 GHz	SRF04	N/A	EW8051
SmartRF04EB + CC2510EM	2.4 GHz	SRF04	N/A	EW8051
SmartRF05EB + CC2530EM	2.4 GHz	SRF05	N/A	EW8051
CC2511EM USB Dongle	2.4 GHz	RFUSB	N/A	EW8051

Table 1: SoC Development Hardware and Tool Options

Dual-Chip Development Hardware	Frequency	Project	CCS Toolset	IAR Toolset
EXP430FG4618 + CC1100:433 or CC1100:868 + USB Debug IF	< 1 GHz	EXP461x	CCSv4	EW430
EXP430FG4618 + CC1101:433 or CC1101:868 + USB Debug IF	< 1 GHz	EXP461x	CCSv4	EW430
EXP430FG4618 + CC1100E:470 or CC1100E:950 + USB Debug IF	< 1 GHz	EXP461x	CCSv4	EW430
EXP430FG4618 + CC2500 + USB Debug IF	2.4 GHz	EXP461x	CCSv4	EW430
eZ430 + RF2500	2.4 GHz	eZ430RF	CCSv4	EW430
SmartRF05EB + MSP430F2618 + CC2520	2.4 GHz	SRF05	CCSv4	EW430

Table 2: Dual-Chip Development Hardware and Tool Options

As shown in the tables above, SimpliciTI is available for a wide variety development kits. Target hardware for this release is shown in the following table. The ‘Platform’ column corresponds to the project folder names in the installed SimpliciTI directory structure. An entry of SoC in the ‘Radio’ column indicates a single-chip platform. The ‘Radio Version’ and the ‘EM Revision’ indicate the hardware level with which the code was tested. Some platforms, such as the EXP461x, RFUSB, SRF04, and SRF05 support multiple radios.

The target radio for these platforms is selected during the build by defining the appropriate pre-processor value in the project file.

Platform	MCU	Radio Version	EM Revision Comments
CC2430DB	CC2430	SoC E	1.3
CC430EM	CC430F6137	SoC 0.7	3.2 MSP430 SoC
EXP461x	MSP430FG4618	CC1100 F	http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html 3.2 Radio on EM daughter board
EXP461x	MSP430FG4618	CC1101 A	1.0 http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html http://www.iar.com/website1/1.0.1.0/220/1/index.php Radio on EM daughter board
EXP461x	MSP430FG4618	CC1100E H	1.0 Radio on EM daughter board
EXP461x	MSP430FG4618	CC2500 F	2.2 Radio on EM daughter board
eZ430RF	MSP430F2274	CC2500 F	1.0 Debug via USB
RFUSB	CC1111	SoC D	http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html 1.2 http://www.iar.com/website1/1.0.1.0/220/1/index.php Debug via SmartRF04
RFUSB	CC2511	SoC E	1.3 Debug via SmartRF04
SRF04	CC1110	SoC D	2.0 http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html SoC on EM daughter board
SRF04	CC2430	SoC E	http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html 1.2 http://www.iar.com/website1/1.0.1.0/220/1/index.php SoC on EM daughter board
SRF04	CC2431	SoC E	http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html 1.3 http://www.iar.com/website1/1.0.1.0/220/1/index.php SoC on EM daughter board

SRF04	CC2510	SoC	http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html 2.0
		E	http://www.iar.com/website1/1.0.1.0/220/1/index.php SoC on EM daughter board
SRF05	MSP430F2618	CC2520	2.1
			http://www.iar.com/website1/1.0.1.0/220/1/index.php Chip ID 0x84 to validate, not radio version
SRF05	CC2530	SoC	1.0http://focus.ti.com/docs/toolsw/folders/print/msp-cce430.html
		2.1	http://www.iar.com/website1/1.0.1.0/220/1/index.php SoC on EM daughter board

Table 3: Radio and Evaluation Module Versions

2.1. Getting the Tools You Need

The best way to evaluate SimpliciTI is to obtain a development kit from Texas Instruments. The tables in the previous section provide links to the available hardware development kits and the associated software development toolsets. Note that some of the development kits have more than one link, indicating that you need to obtain more than one hardware package to proceed. Typically, this means that the “motherboard”, “radio”, and “debugger” modules are not bundled in the same package. Also note that some radio modules are offered with different frequency ranges – make sure that you have the correct one for your evaluation purposes.

Once the hardware development kit is selected, the software development toolset can be obtained. As shown above, kits based on the MSP430 are supported by both toolsets. To get started with Code Composer Studio (CCS), you can download the Core edition, which allows unlimited use on programs up to 16KB in size. Later, if your program grows to exceed 16KB, you can get the Platinum version of CCS. To begin with IAR Embedded Workbench (EW), you can download the 30-day evaluation edition (extended to 60 days when a development kit is purchased), which is a full-featured toolset. After the evaluation period expires, you can get a permanent version of EW. SimpliciTI is also configured to work with the IAR EW8051 Kickstart editions (see Table 3), which can be used indefinitely but limits the size of the source code that can be compiled.

The RFUSB-CC1111 and RFUSB-CC2511 are programmed using the SmartRF04 board. If there are problems with programming the CC1111/CC2511 target, it is possible that the firmware on the SmartRF04 requires an upgrade. This upgrade can be installed using the SmartRF04 Flash Programmer. For instructions on programming the RFUSB-CC2511 (also applicable to RFUSB-CC1111), download the document “CC2511 USB Dongle User Manual (swru082.pdf)”: http://focus.ti.com/docs/toolsw/folders/print/cc2510-cc2511dk.html

2.2. Installing SimpliciTI and Development Tools

SimpliciTI and the software development tools are provided as Microsoft Windows-based product installers. These can be installed on a computer that is running Windows XP (or later). Simply double-click on the product installer file and follow the instructions for loading and registering the products.

After installing SimpliciTI on your computer, you can use the Windows browser to examine the folders and files that were placed in the C:\Texas Instruments\SimpliciTI directory. In the Projects\Examples folder there are sub-folders for each of the available development kits that contain project files to build the four SimpliciTI sample applications. The examples in this tutorial are based on the eZ430RF and SRF04 platforms (see Table 3), as shown below:

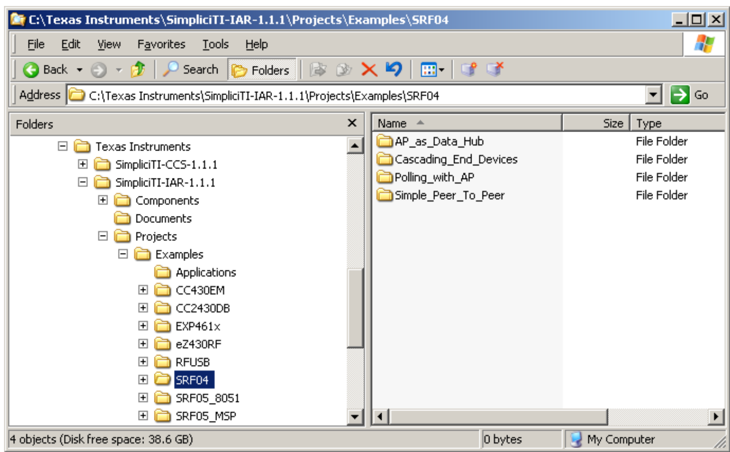


Figure 1: Windows Folder View of SimpliciTI Installation

2.3. Building a Sample Application

SimpliciTI has four different sample applications for you to try. To demonstrate the process of building, loading, and running an application, we'll use the "Simple_Peer_To_Peer" example, in conjunction with the eZ430RF (CCS tools) or SRF04 (IAR tools) platform. To build other applications, just select the desired project file in the software development IDE, and follow the steps provided in section 2.3.1 if you're using the IAR tools, or section 2.3.2 if you're using the CCS tools.

2.3.1. Using IAR Embedded Workbench

To begin working with a SimpliciTI sample application, start the IDE -- double-click on either (1) the IAR icon on the PC desktop, or (2) the IDE program file located in the installed IAR tools folder, such as: "C:\Program Files\IAR Systems\Embedded Workbench 5.0\common\bin\IarIdePm.exe". Prepare to open a project workspace by clicking through the File→Open→Workspace…options, as shown below:

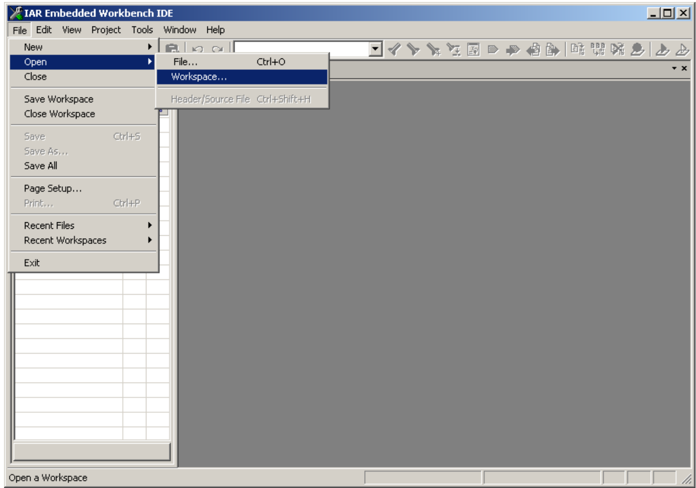


Figure 2: Opening an IAR Project Workspace

At this point, find the folder that corresponds to the development kit that you have, by navigating through several levels to the C:→Texas Instruments→SimpliciTI-IAR-1.1.1→Projects→Examples folder. Here you see one folder for the Applications source files and many others for the available development kits. In this example, we use a kit for a SmartRF04EB motherboard and CC2430 radio module – so, double-click on the SRF04 folder:

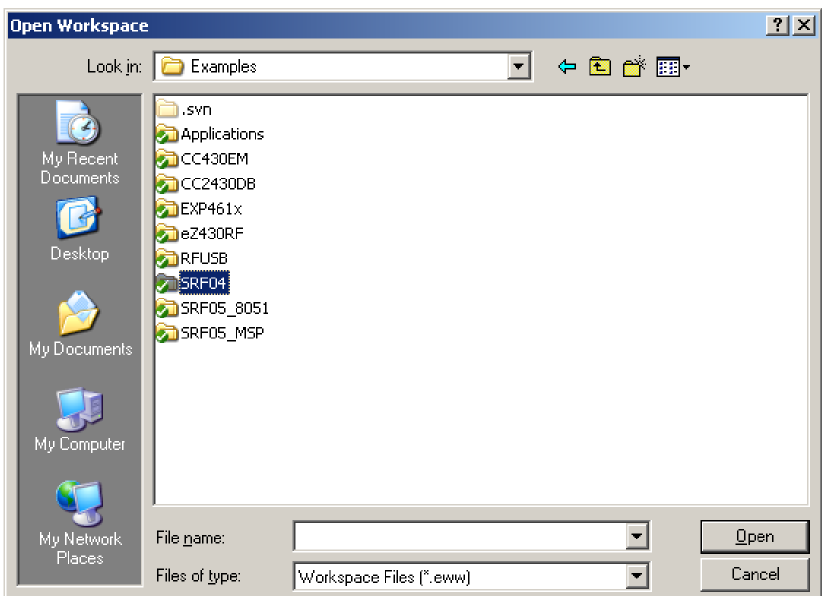


Figure 3: Selecting an IAR Workspace for Development Kit

For each development kit, there are four folders which contain IAR project files for the sample applications. In this demonstration, we use “Simple Peer to Peer”, so double-click on the Simple_Peer_To_Peer folder:

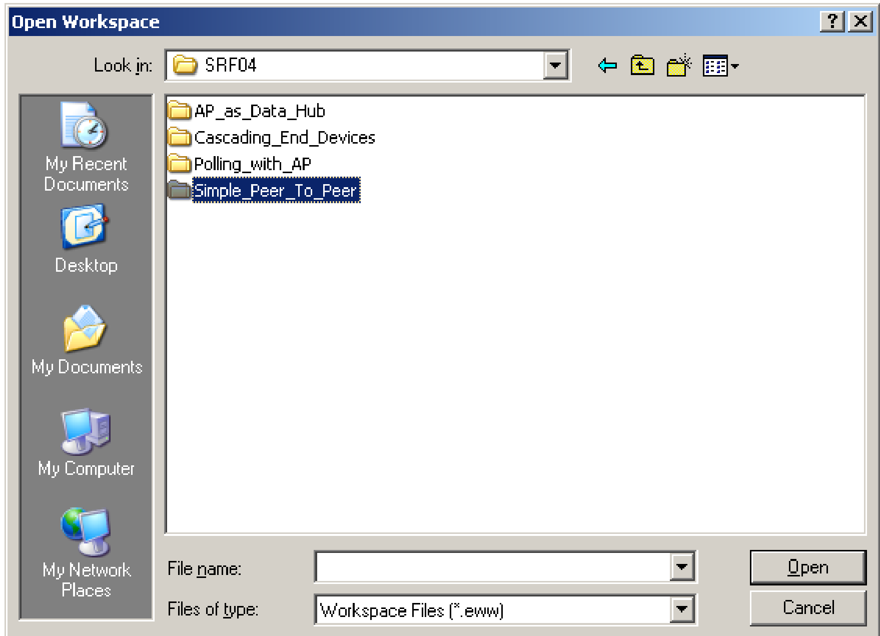


Figure 4: Selecting IAR Workspace for Sample Application

Within each of the sample application folders, there is an IAR folder which contains an Embedded Workbench “workspace” project file (with filename extension of .eww). To open the demonstration project, double-click on the Simple_Peer_To_Peer.eww file:

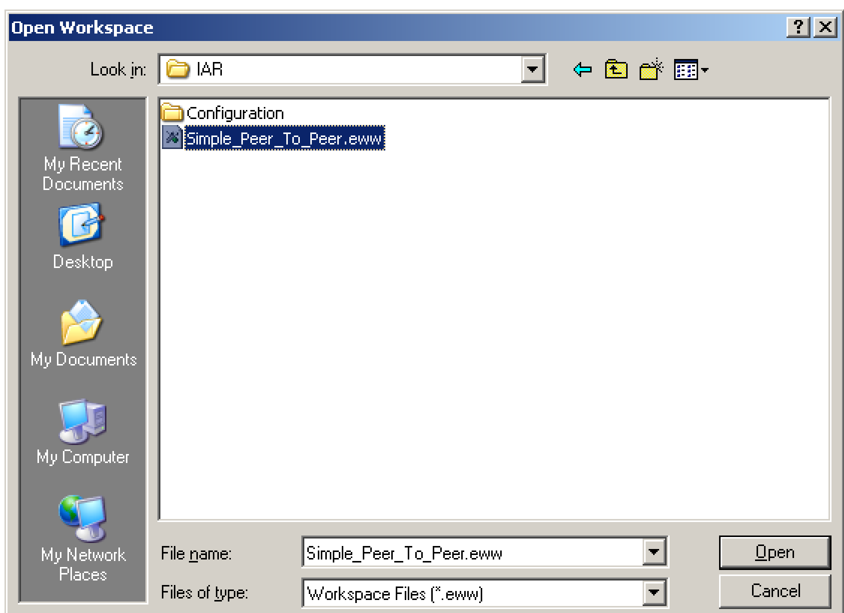


Figure 5: Opening IAR Workspace for Sample Application

Looking back at Table 3, you’ll see that three different development kits are supported by the SRF04 project. In addition, the Simple_Peer_To_Peer example uses two different devices, LinkTo and LinkListen. To select the target device for the kit that you are using, pull down the menu below the “Workspace” label and click on the proper device. This demonstration uses the CC2430-LinkTo target, as shown below:

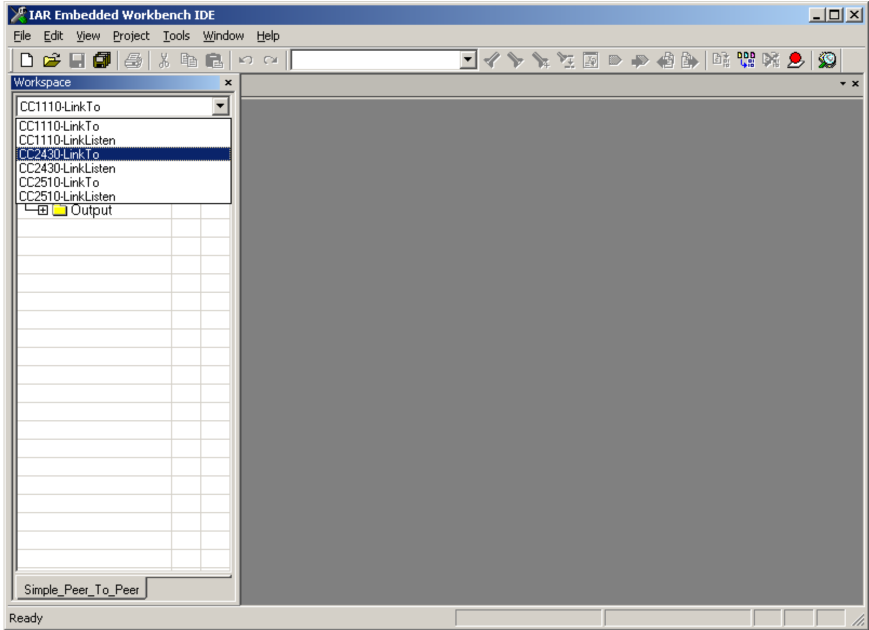


Figure 6: Selecting Target Device for IAR Sample Application

Before building a sample application program, it's best to clean up any residual files from previous builds. From the IDE's menu bar, click through Project→Clean in the pull-down menu to remove old files:

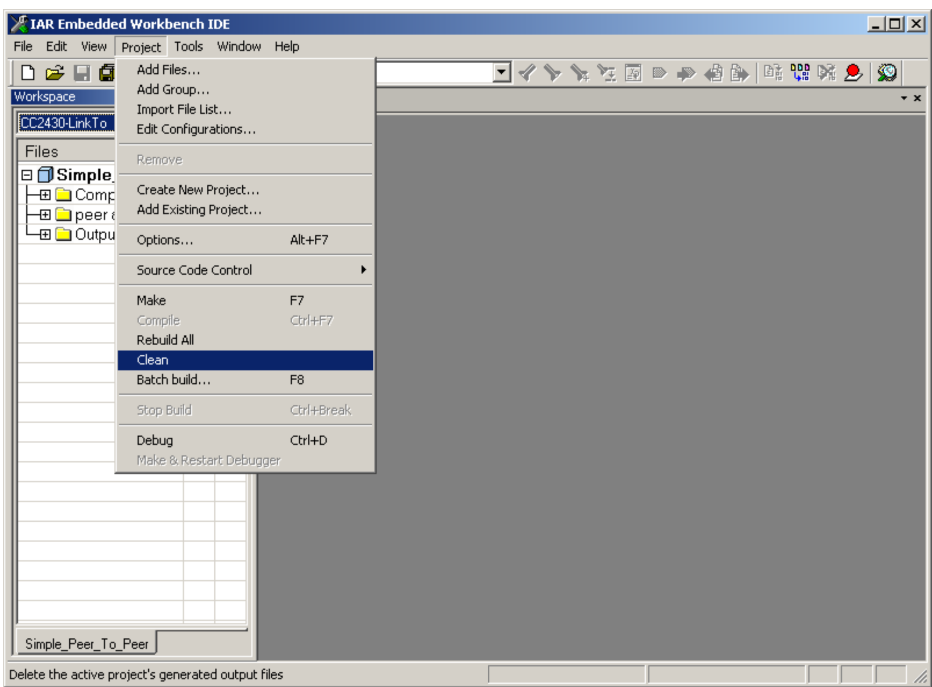


Figure 7: Cleaning Up Workspace Before Building IAR Sample Application

Now, start the build of the sample application by clicking through Project→Rebuild All in the pull-down menu:

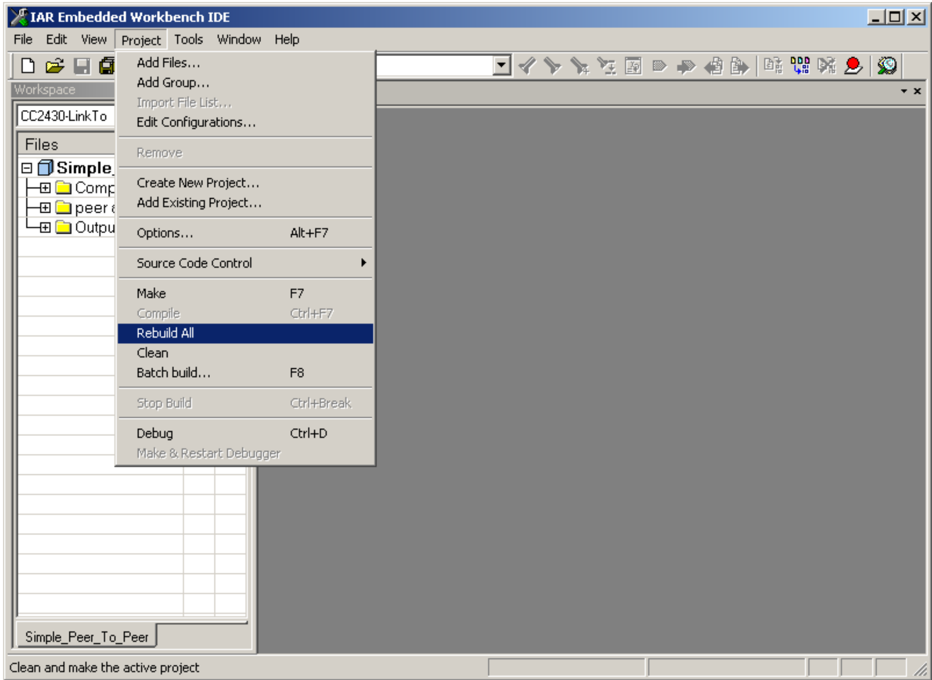


Figure 8: Building IAR Sample Application

During the building process, the status of compiling and linking the sample application program is displayed in a window at the bottom of the IDE. When the linking phase is complete, the total number of errors and warnings is indicated – normally there should not be any errors or warnings, as shown below:

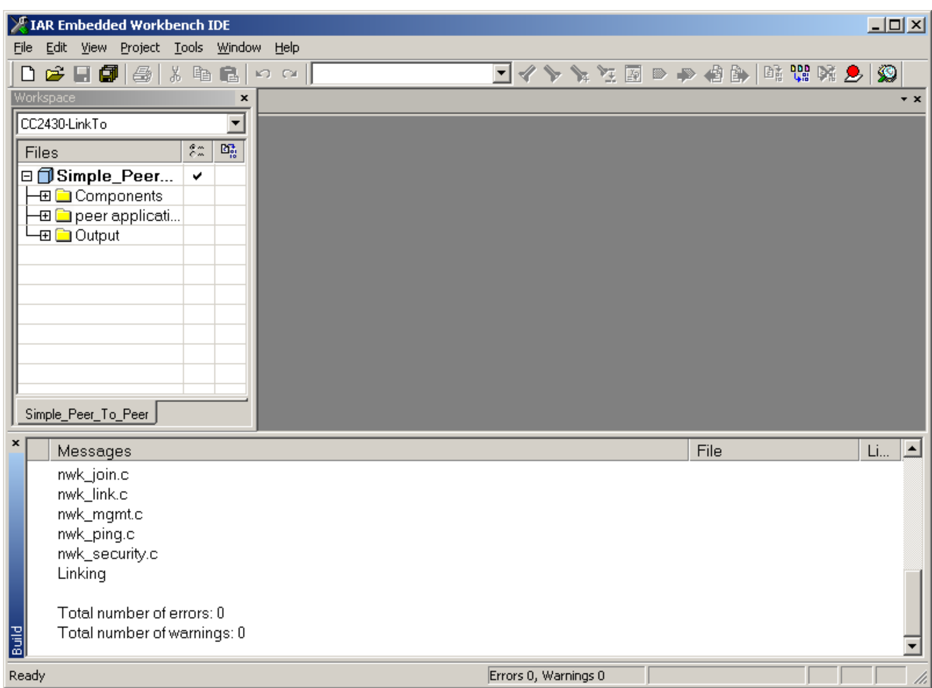


Figure 9: Successful Build of IAR Sample Application

Connect the SRF04 board to your computer (with a USB cable) and turn on the power. If Windows prompts you to install a driver for new hardware, don't let Windows look for it automatically:

Figure 10: Installing the USB Driver for IAR – Step 1

Select the option to install the driver from a list or specific location:

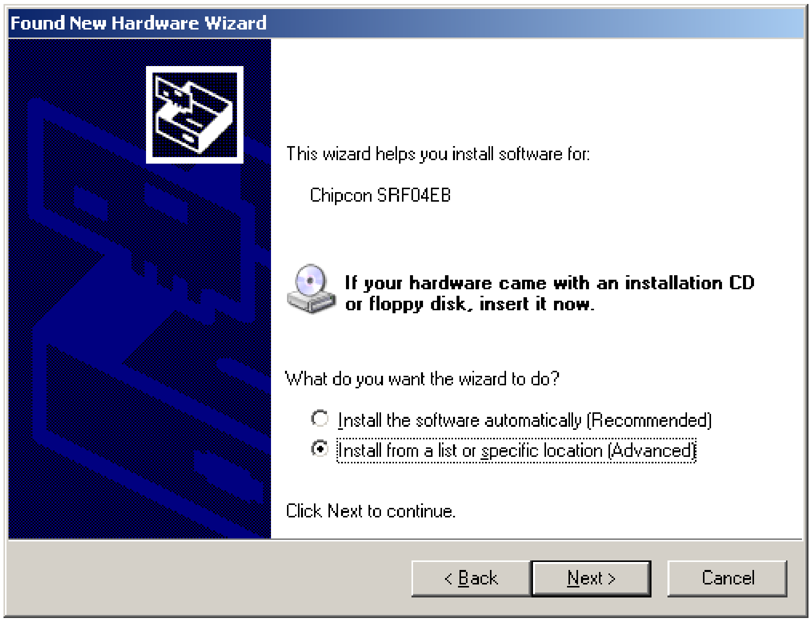


Figure 11: Installing the USB Driver for SRF04 – Step 2

Browse to drivers, such as: "C:\Program Files\IAR Systems\ Embedded Workbench 5.0\8051\drivers\Chipcon":

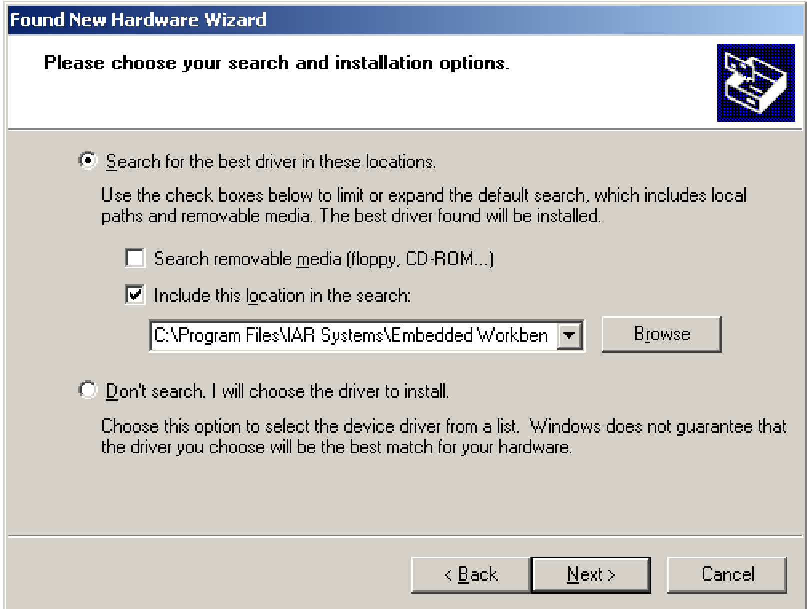


Figure 12: Installing the USB Driver for SRF04 – Step 3

Start the download of the application to the **SRF04** by clicking through ***Project→Debug*** in the pull-down menu:

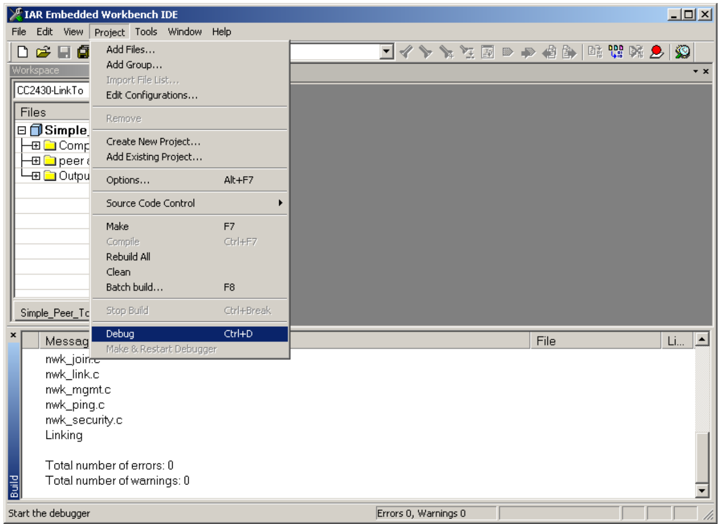


Figure 13: Starting Download of an IAR Sample Application

If asked “Do you want to Make before debugging”, click the No button:

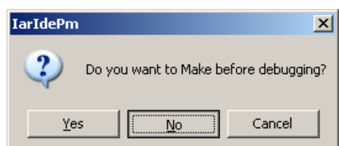


Figure 14: Continue Download

When download is complete, the IDE will enter debug mode, with the next line of code to run highlighted in green:

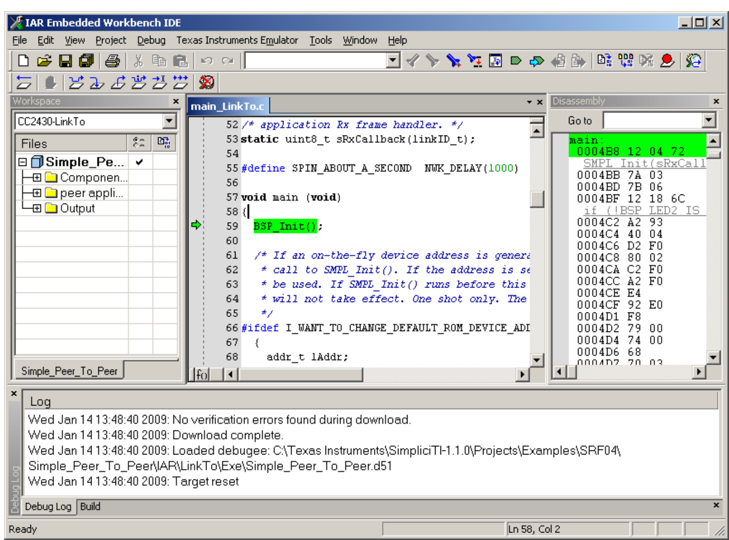


Figure 15: Completed Download to SRF04+CC2430

Up to this point, no changes have been needed to any SimpliciTI source code or configuration files. The first device was built and programmed with "out-of-the-box" settings. In order to build another LinkTo device for this sample application, one change must be made to the smpl_config.dat file. Each SimpliciTI device must have a unique address – the address shown below is the one that was used for the first LinkTo device. Before building another device, change the value of THIS_DEVICE_ADDRESS – the first byte is suggested, like, from 0x79 to 0x97.

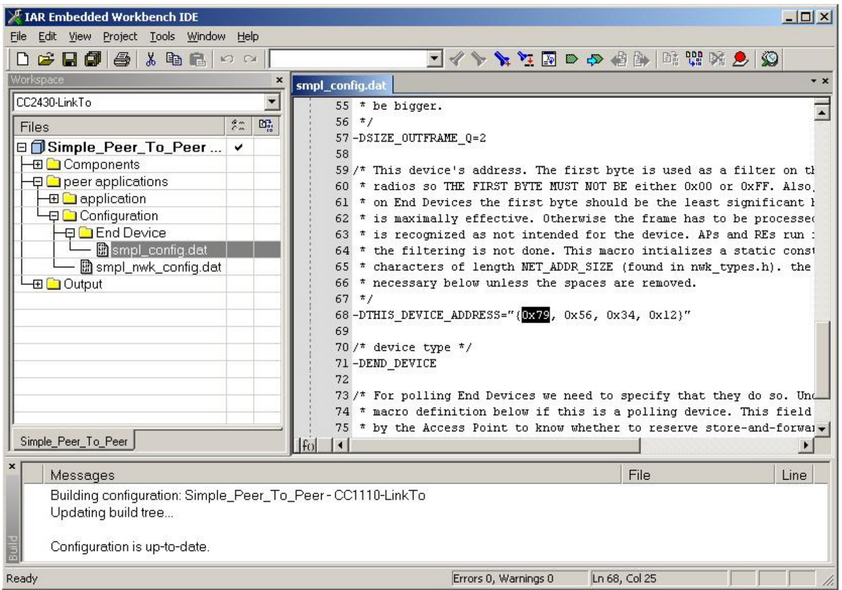


Figure 16: Changing the SimpliciTI Device Address

Repeat the steps shown in Figure 6 through Figure 16 to build and program your second SimpliciTI device. Proceed to section 3.1 for instructions on running the Simple Peer-To-Peer sample application.

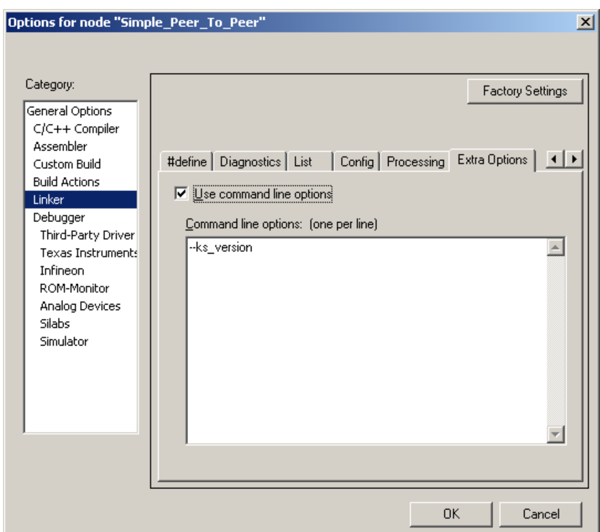


Figure 17: Enabling Use of IAR Kickstart Version

The Kickstart version of IAR's EW8051-7.51 allows compilation and download of programs that have 16-Kbytes of source code or less. To enable use of the Kickstart version, place a 'check mark' in the Use command line options as shown above in Figure 17. See Table 3 for the list of development platforms that can be used with Kickstart.

2.3.2. Using Code Composer Studio

To begin working with a SimpliciTI sample application, start the IDE -- double-click on either (1) the CCS icon on the PC desktop, or (2) the program file located in the installed CCS tools folder, such as: "C:\Program Files\Texas Instruments\ccsv4\eclipse\eclipse.exe". This will display the product splash-screen:

Figure 18: Code Composer Studio Splash Screen

For each development kit, there are four folders which contain CCS project files for the sample applications. Each CCS project for SimpliciTI is located in a CCS "workspace" folder associated with each sample application. In this demonstration, we use "Simple Peer to Peer" in conjunction with the eZ430RF development kit. Use the Browse button to select the Workspace that we will use, and hit the OK button:

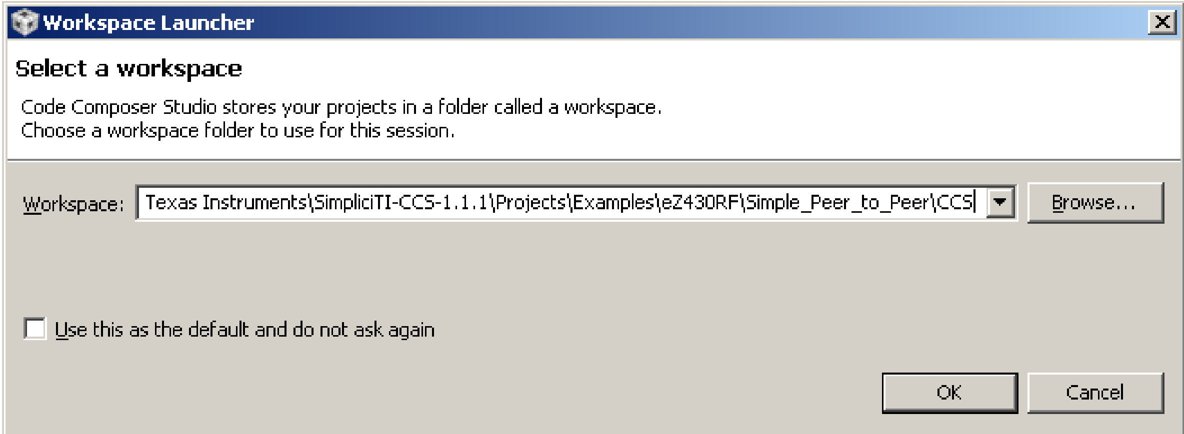


Figure 19: Selecting CCS Workspace for a Sample Application

If this is the first time that the project has been accessed by Code Composer Studio, the "Welcome" screen will be displayed. Click on the white cube icon to exit and launch the Code Composer Workbench:

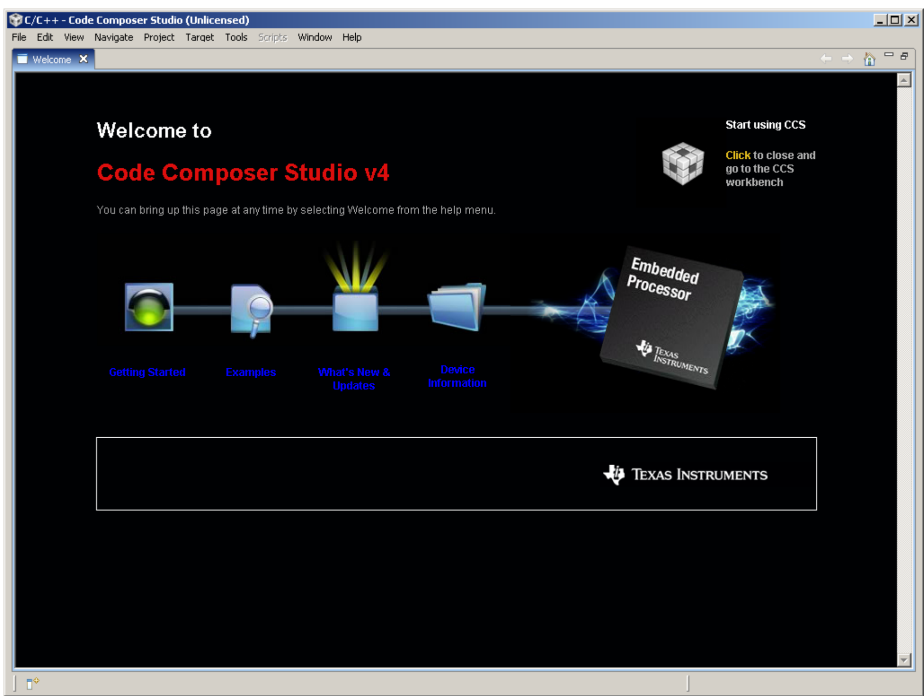


Figure 20: CCS Welcome Screen

SimpliciTI projects are designed to be portable, allowing the "root" folder to be moved or renamed if desired. The default root folder for this SimpliciTI installation in this example is C:\Texas Instruments\SimpliciTI-CCS-1.1.1, as shown when selecting the CCS workspace in Figure 19. The root folder location, referred to in the project files as DEV_ROOT, needs to be entered into each new CCS workspace, using the process shown in the next 4 screenshots.

Select the Preferences item from the Window pull-down menu:

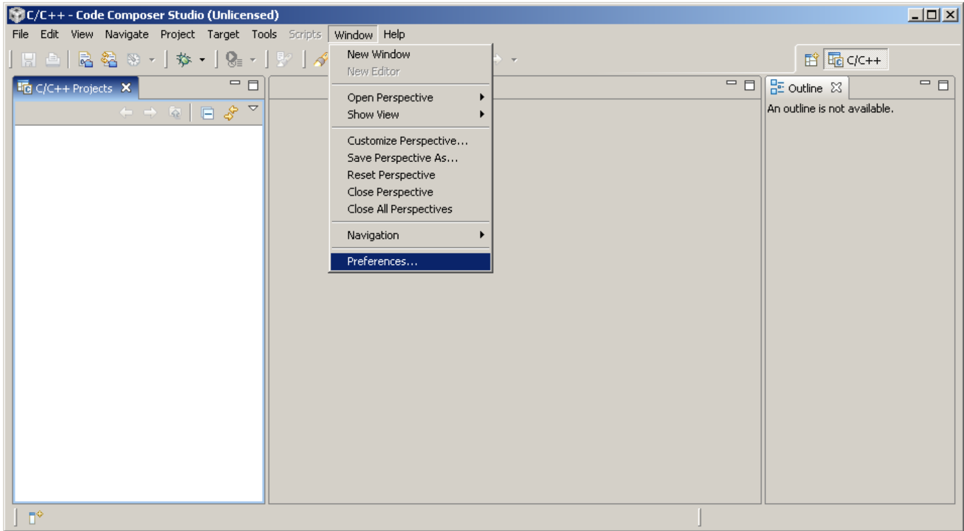


Figure 21: Setting the Root Folder Location for a CCS Workspace – Step 1

Select the Linked Resources item from the General→Workspace settings, ensure that"Enable linked resources" is checked, and hit the New… button:

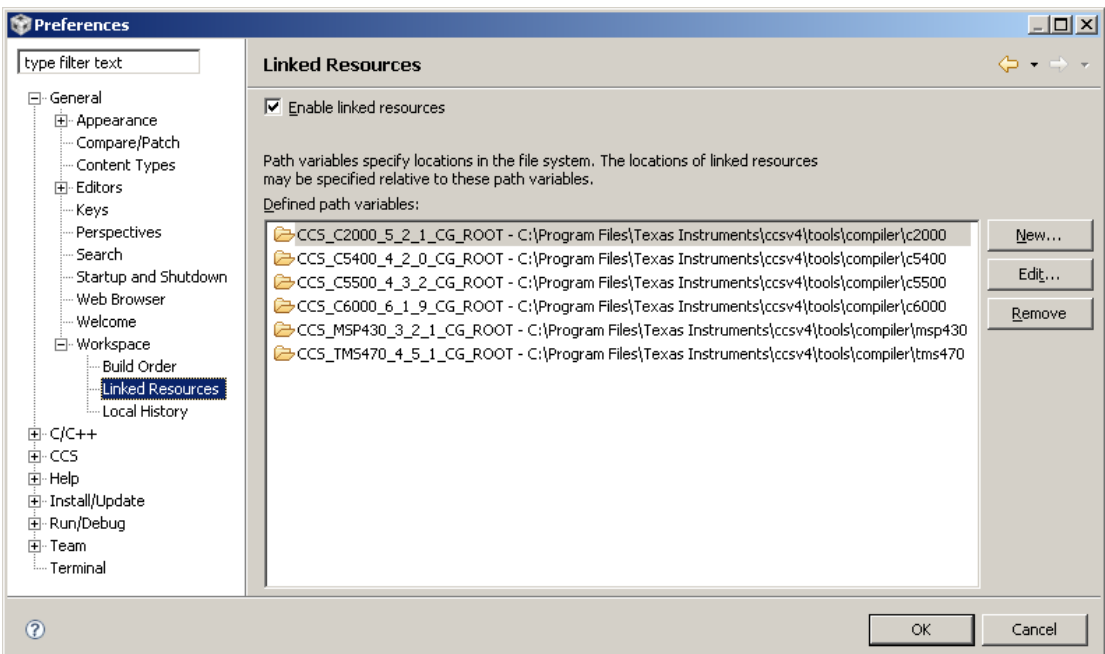


Figure 22: Setting the Root Folder Location for a CCS Workspace – Step 2

All source and configuration files in the CCS sample application projects are linked to the SimpliciTI root folder by the path variable known as DEV_ROOT. Each time a new CCS workspace is set up, the DEV_ROOT path variable must be defined. Enter DEV_ROOT into the Name: box and the root folder location of your SimpliciTI installation into the Location: box (you can type it directly or browse using the Folder… button). Hit the OK button to proceed:

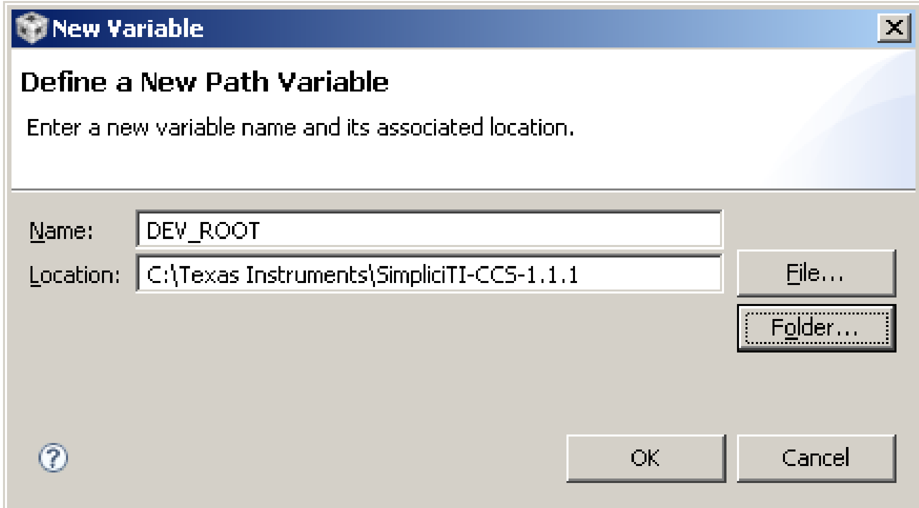


Figure 23: Setting the Root Folder Location for a CCS Workspace – Step 3

Verify that the Defined path variable: for DEV_ROOT is correct and hit the OK button to proceed:

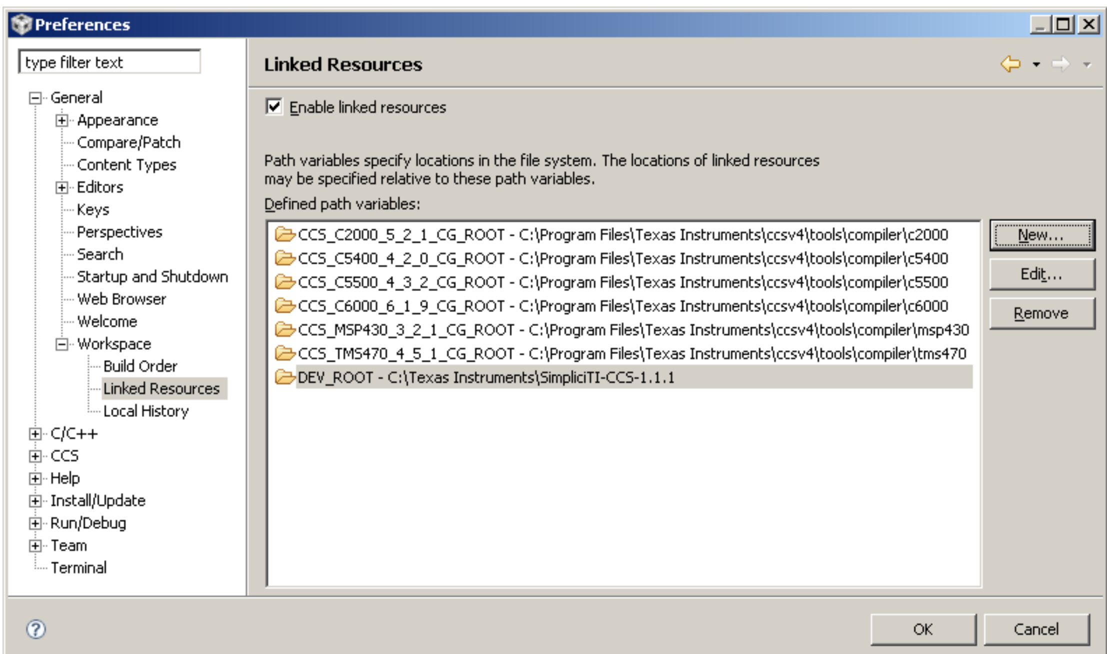


Figure 24: Setting the Root Folder Location for a CCS Workspace – Step 4

To open a sample application project, elect the Open Existing Project item from the Window pull-down menu:

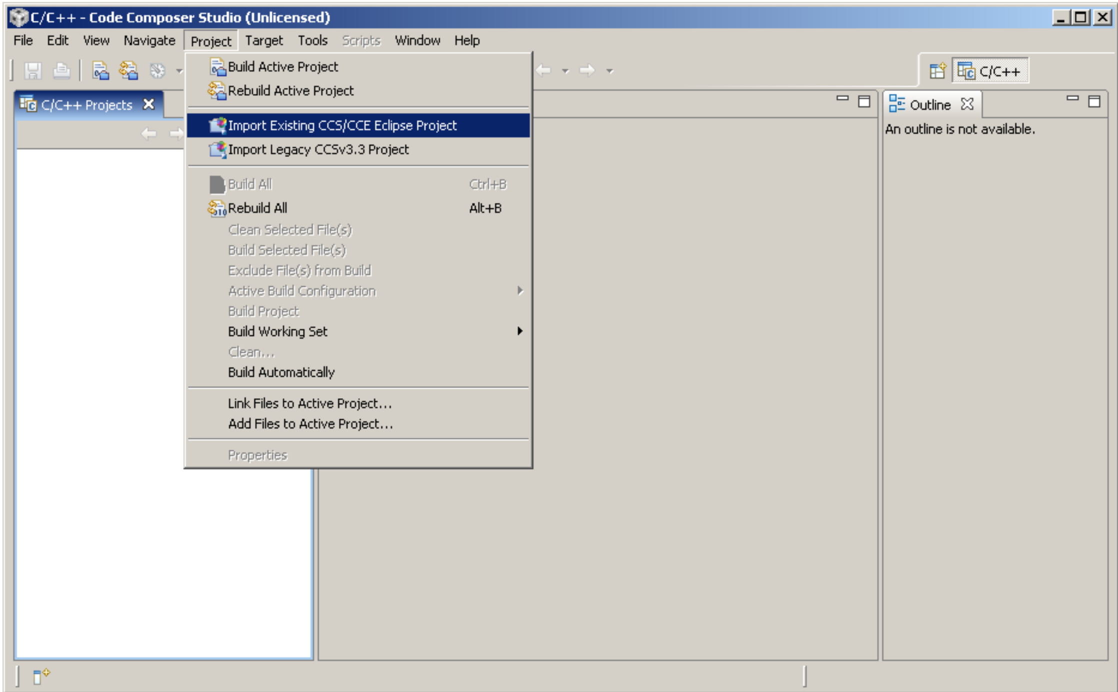


Figure 25: Opening a CCS Project – Step 1

Hit the Browse… button to fill the Select root directory: box:

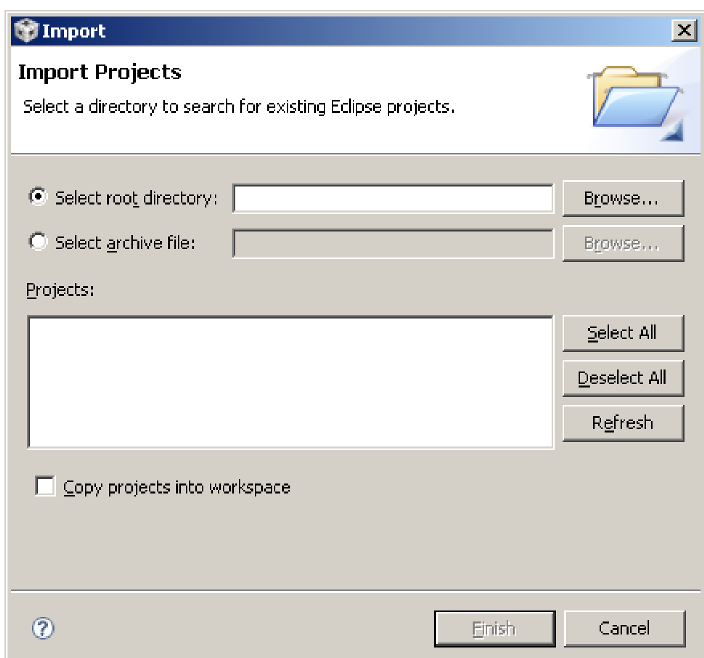


Figure 26: Opening a CCS Project – Step 2

Select the CCS folder for the project to be used (Simple_Peer_to_Peer). As shown below, CCS defaults to the folder that was selected for the workspace (see Figure 19). Hit the OK button to continue:

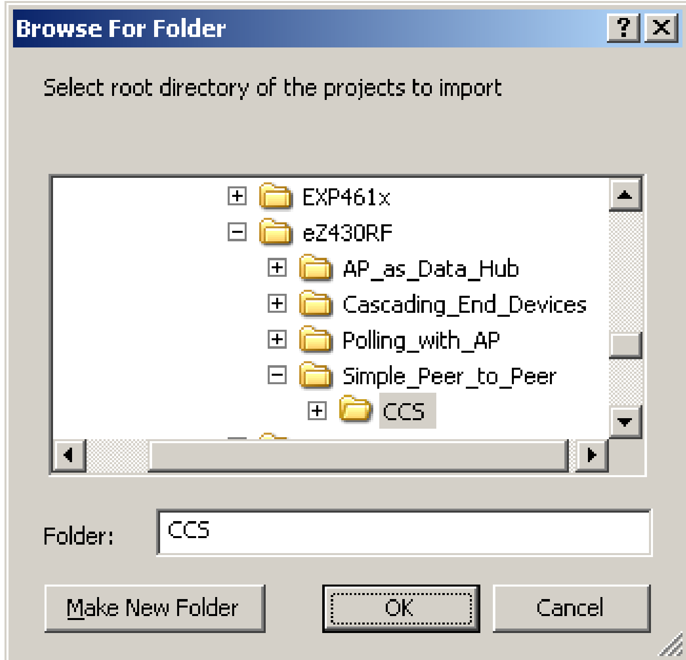


Figure 27: Opening a CCS Project – Step 3

At this point, CCS searches the selected folder for project files and displays them in the Projects box. SimpliciTI provides a folder named Project for each sample application. Hit the Finish button to open the project:

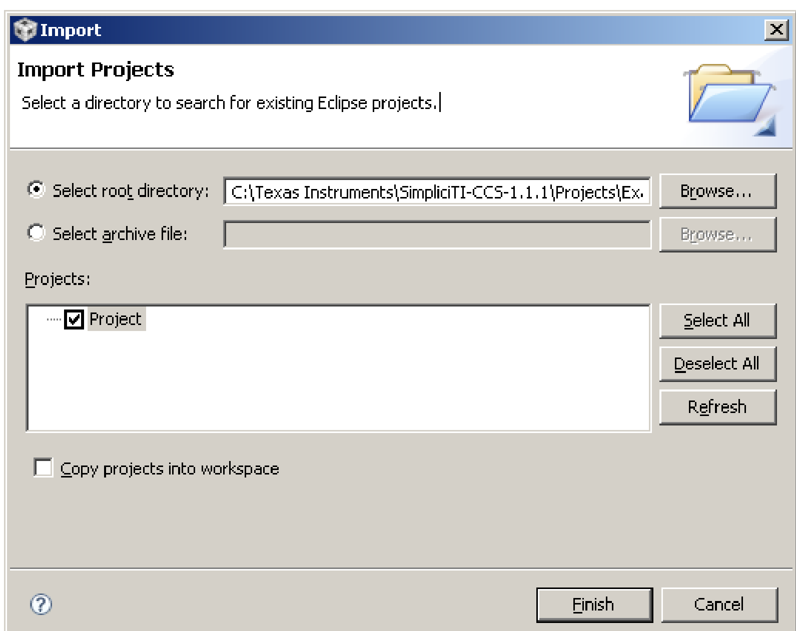


Figure 28: Opening a CCS Project – Step 4

The first time that CCS opens a specific project, it will display the basic project development window, and then will take a few seconds to generate workspace and project related files. There is a status display area located in the lower right corner that indicates various actions during this time (the screen capture shows “C/C++ Indexer”). When complete, the C/C++ Projects panel on the left side of the window will display the default device configuration. For this example, the CC2500-LinkTo configuration is active:

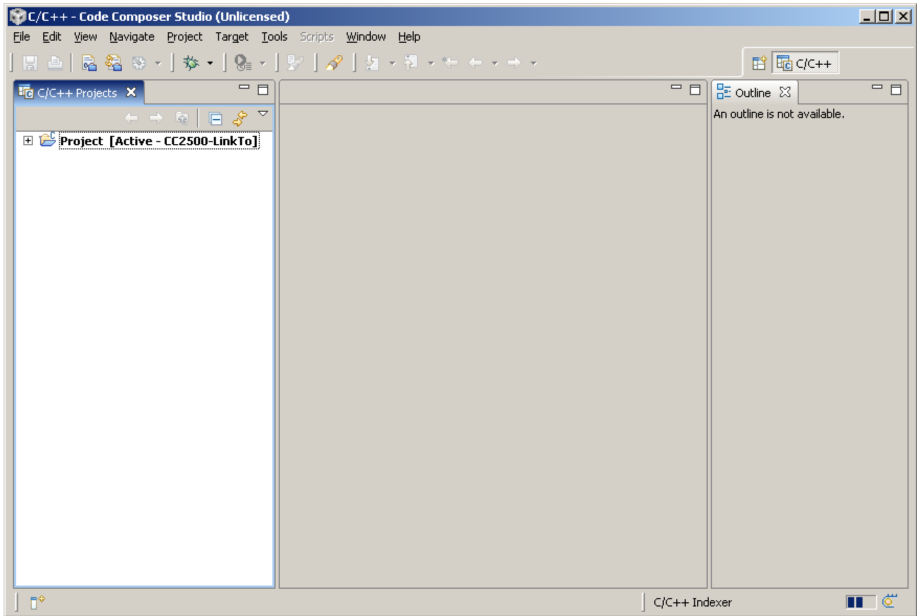


Figure 29: Opening a CCS Project – Step 5

To expand the Project folder in the C/C++ Projects pane, click on the □ next to the Project folder icon. Before building a sample application, it's best to clean up any residual files from previous builds. From the IDE's menu bar, click through Project→Clean in the pull-down menu to remove old files:

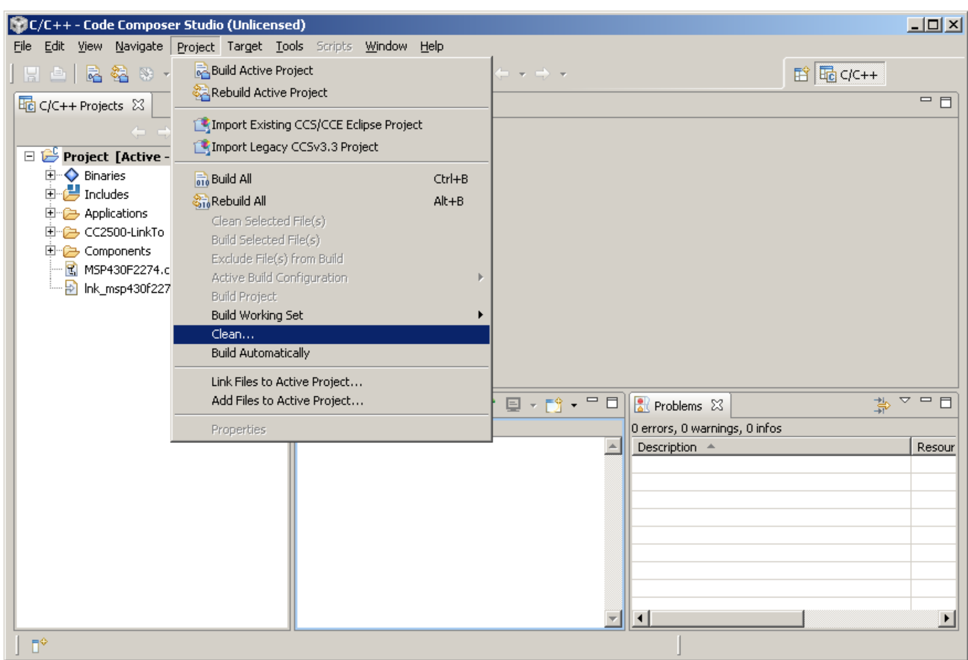


Figure 30: Cleaning the Workspace Before Building a CCS Project

Now, start the build of the sample application by clicking through Project→Rebuild All in the pull-down menu:

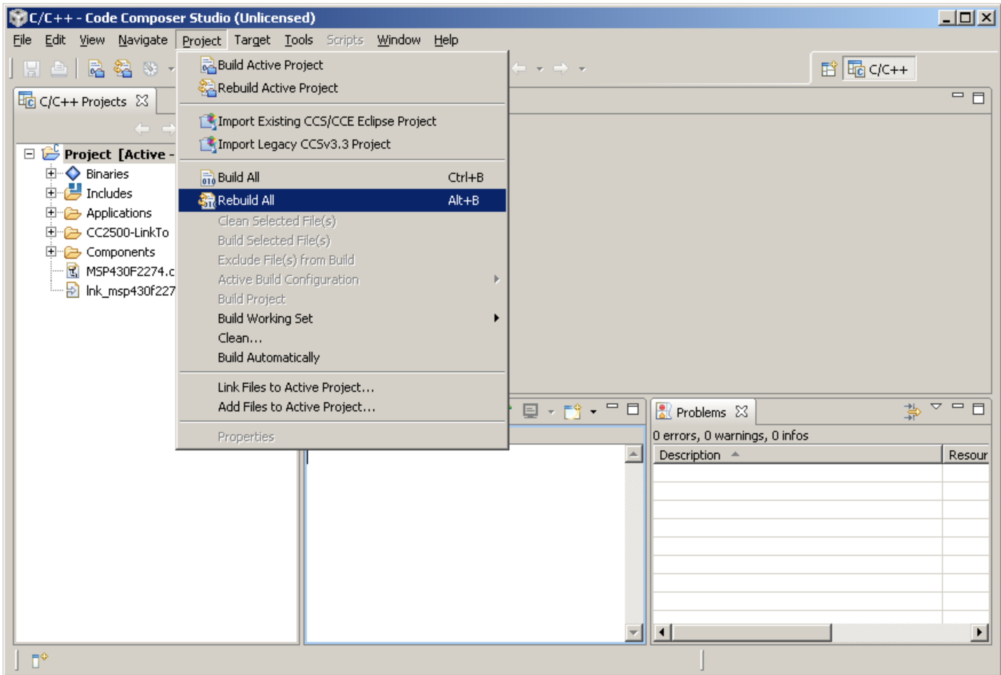


Figure 31: Building a CCS Project

During the building process, the status of compiling and linking the sample application program is displayed in the Console pane at the bottom/center of the IDE. When the linking phase is complete, the total number of errors and warnings is indicated in the Problems pane at the bottom/right of the IDE – normally there should not be any errors or warnings, as shown below:

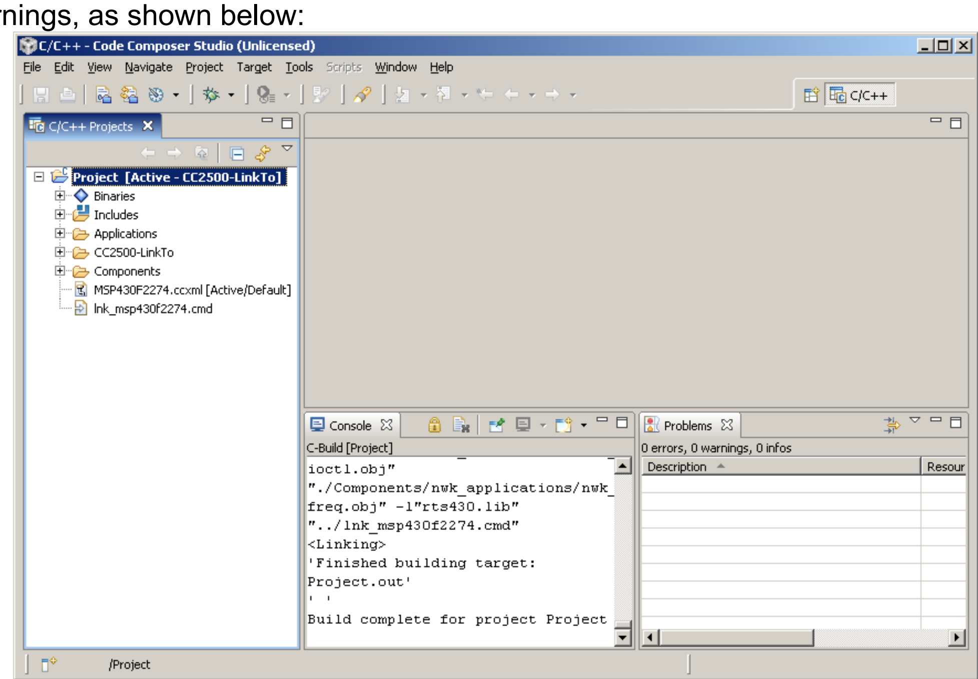


Figure 32: Successful Build of a CCS Project

Plug an eZ430RF board into a USB port on your computer. Start the download of the sample application to the eZ430RF by clicking through Target→Debug Active Project in the pull-down menu:

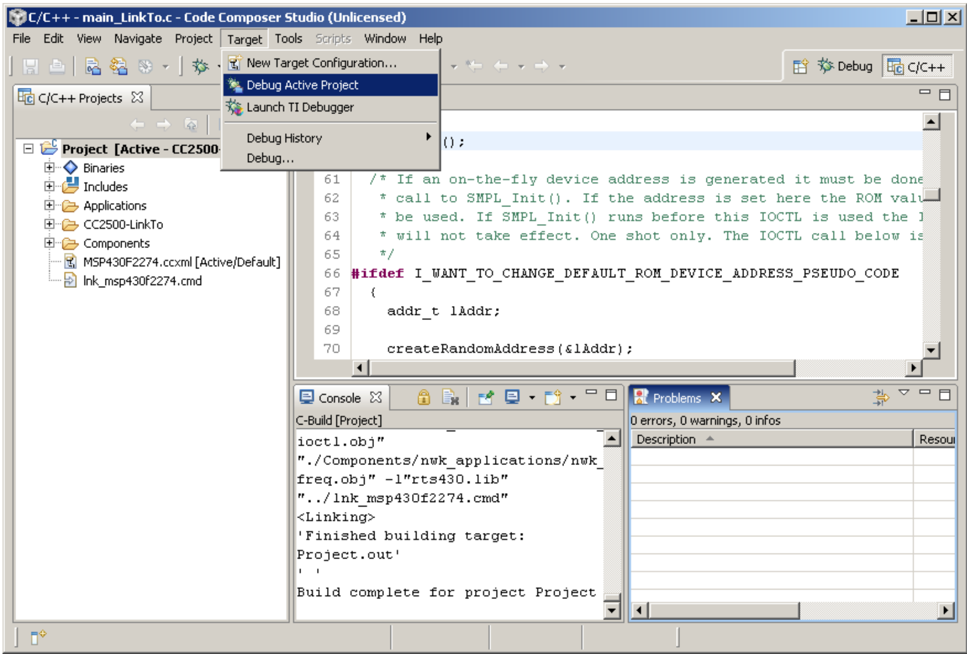


Figure 33: Downloading a CCS Sample Application

When the download is complete, the IDE enters debug mode, with the next line of code to run highlighted in green:

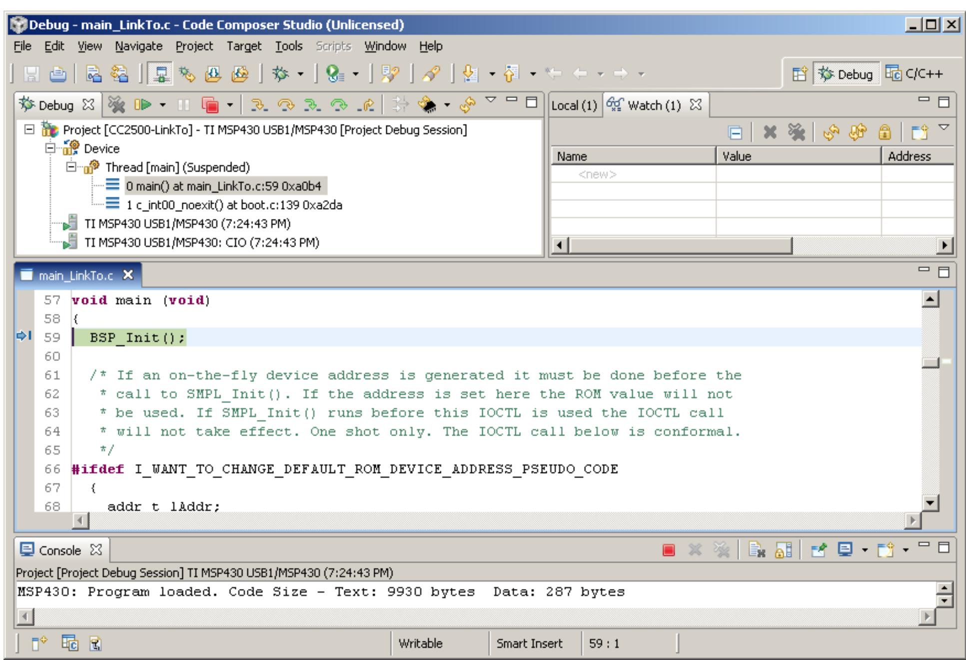


Figure 34: Completed Download to eZ430RF+CC2500

Up to this point, no changes have been needed to any SimpliciTI source code or configuration files. The first device was built and programmed with “out-of-the-box” settings. In order to build another LinkTo device for this sample application, one change must be made to the smpl_config.dat file. Each SimpliciTI device must have a unique address – the address shown below is the one that was used for the first LinkTo device.

Before building another device, change the value of THIS_DEVICE_ADDRESS – the first byte is suggested, like, from 0x78 to 0x87:

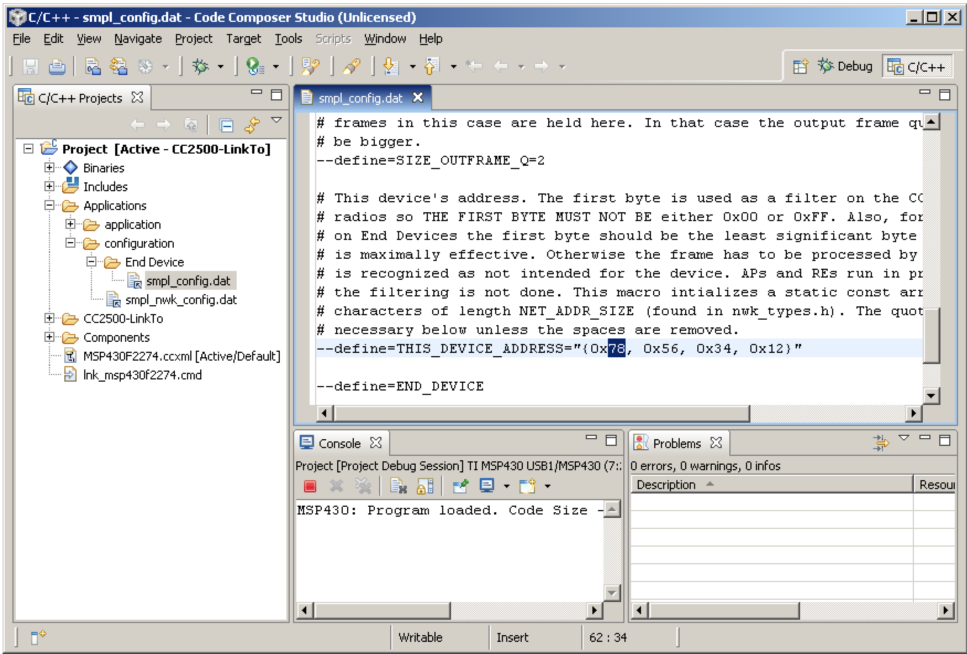


Figure 35: Changing the SimpliciTI End-Device Address

This sample application provides for two different device configurations, LinkTo and LinkListen. To change to another device, click through Project→Active Build Configuration to show the pull-down menu of devices:

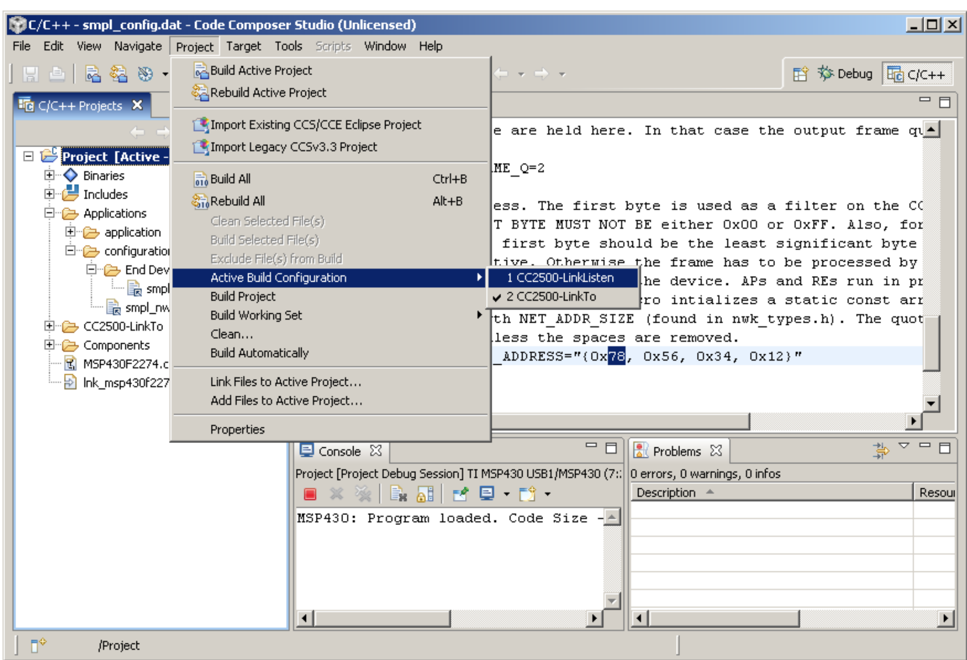


Figure 36: Changing the SimpliciTI Device Configuration

3. Sample Applications

This section introduces 4 simple sample applications to demonstrate various features and capabilities of SimpliciTI. Each example has an explanation what the application does, a detailed procedure for running the application, and a discussion of specific features of SimpliciTI that are used. These four sample applications are presented in order of increasing complexity:

- Simple Peer-To-Peer – two linked End-Devices communicate directly with each other
- Polling with AP – one End-Device sends data to another sleeping/polling End-Device via an Access Point
- Cascading End Devices – three un-linked End-Devices continually broadcast an alarm
- Access Point as Data Hub – two End-Devices send data to AP Data Hub, with Frequency Agility

All of the sample applications involve End-Devices sending data to other End-Devices or to an Access Point, using different topologies. For each application, there is a simple diagram that represents the topology, as supported by SimpliciTI. The following legend applies to the line formats in the topology diagrams:

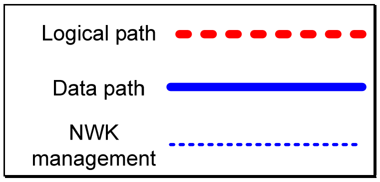


Figure 37: Legend for Topology Block Diagrams

Each of the sample applications require some form of user input, via two “logical” buttons and provide status display via two “logical” LEDs. SimpliciTI runs on various development kits, each having a unique combination of button and LED hardware on board. Most provide at least two button/switch inputs and at least two LEDs, but there are some exceptions (ez430RF and RFUSB). The mapping of physical to logical buttons and LEDs for each one of the development kit platforms is as follows:

Platform	Button1	Button2	LED1	LED2
CC2430DB	S1 Pushbutton	Joystick Push	Green (D1)	Red (D2)
CC430EM	S2 Pushbutton	None (see Note below)	Green (D1)	Red (D2)
EXP461x	S1 Pushbutton	S2 Pushbutton	Green (LED1)	Red (LED2)
eZ430RF	TS1 Pushbutton (see Note below)	None (see Note below)	Red (D1)	Green (D2)
RFUSB	S1 Pushbutton (see Note below)	None (see Note below)	Green (D2)	None
SRF04	S1 Pushbutton	Joystick Push	Green (LED1)	Yellow (LED3)
SRF05-8051	S1 Pushbutton	Joystick Push	Green (LED1)	Red (LED2)
SRF05-MSP	S1 Pushbutton	S2 Pushbutton	Green (LED1)	Red (LED2)

Table 4: Sample Application Buttons and LEDs

Note: These boards only support one button, which acts as logical Button1 except in the Polling with AP sample application (see Section 3.2).

3.1. Simple Peer-to-Peer

In this example, there are two End-Devices, a Listener and a Talker, that establish a direct peer-to-peer connection. Initially, the Listener (ED2 in the diagram below) waits for a link message, and the Talker (ED1) sends the link message. After a connection has been established, the Talker periodically sends a 2-byte message to the Listener, which then sends a 2-byte reply to the Talker. The connection is actually bi-directional but the initial connection negotiation assigns the roles of Talker and Listener.

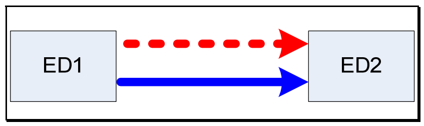


Figure 38: Network Topology for Simple Peer-To-Peer

The observable functionality of this application is periodic toggling of an LED on each device. The Listener toggles an LED specified in messages received from the Talker. Then the Talker toggles an LED specified in replies received from the Listener. The Talker's message and the Listener's reply payload formats are identical:

LED to toggle (1 or 2)	Transaction ID

Figure 39: Message Payload for Simple Peer-To-Peer

Both devices in this example demonstrate use of the Rx Callback feature of SimpliciTI. In the Listener, incoming messages invoke the Rx Callback, where the specified LED is toggled and a semaphore gets posted to the main application before returning to the Rx ISR. In the Talker, incoming replies invoke the Rx Callback, which toggles the specified LED and returns. Note that execution of the Rx Callback is performed in the Rx ISR context – proper callback design dictates minimal code execution and return to the ISR as quickly as possible.

To run this sample application, follow these steps:

1. Using the process explained in Section 2, program and download a Talker (LinkTo) device.
2. Using the process explained in Section 2, program and download a Listener (LinkListen) device.
3. Power up both devices – LED1 and LED2 should be lit on both devices. Note that some platforms only have one LED (for example, CC1111 and CC2511 dongles).
4. Press a button on the Listener to listen for a link message - LED2 should turn on.
5. Press a button on the Talker to send a link message. Both LEDs should turn off if linking was successful. Both LEDs will blink if linking failed – if so, reset both devices and return to step 4.

6. At this point, the devices have established a connection and will continually perform the following actions:
   a. The Talker sends a message with a 2-byte payload to the Listener. The message indicates an LED for the Listener to toggle and a transaction ID. The transaction ID is incremented for each new message. It is treated as an unsigned number and wraps to zero after reaching the maximum value.
   b. The Listener receives the 2-byte message, immediately toggles the indicated LED, posts a semaphore to its main application, and returns to complete Rx interrupt processing.
   c. The main application on the Listener device eventually runs and detects that the semaphore has been posted. This allows it to send a 2-byte reply to the Talker, indicating an LED for the Talker to toggle and the received transaction ID.
   d. The Talker receives the 2-byte reply, immediately toggles the indicated LED, and returns.
   e. After a variable time interval on the Talker device, it returns to step (a) to do it all over again.

The following diagram illustrates the sequences followed by the Talker and the Listener devices:

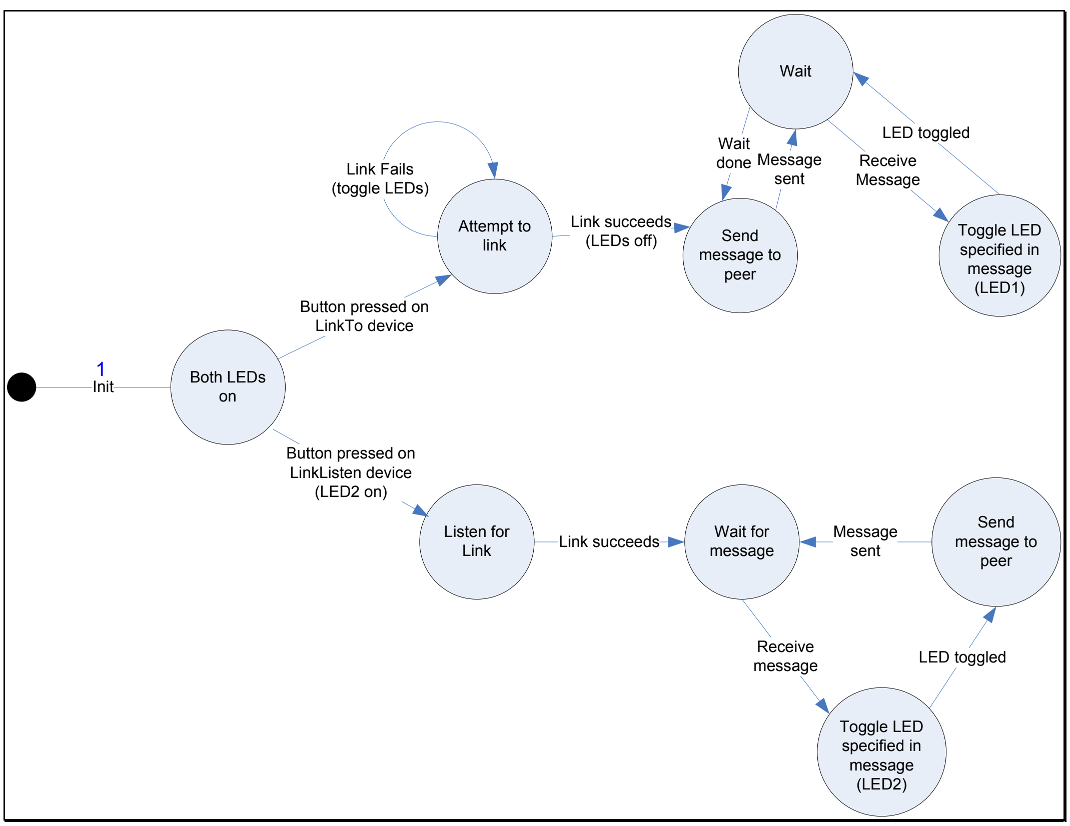


Figure 40: Sequence Diagram for Simple Peer-To-Peer

3.2. Polling with AP

In this example, two End-Devices, a Receiver and a Sender, establish a unidirectional peer-to-peer connection. The Receiver (ED2 in the diagram below) is a polling device, so the indirect connection to the Sender (ED2) requires an Access Point to support store-and-forward functionality. In this type of network, the Sender does not need to know or care that the Receiver is a polling device.

Initially, the Receiver joins the network and waits for a link message, and the Sender joins the network and sends a link message. After a connection has been established, the Sender periodically sends a 2-byte message to the Listener, which is stored by the Access Point, and later forwarded to the Receiver when it polls for a message.

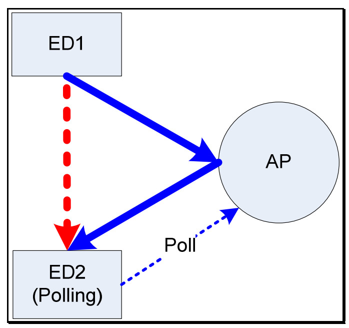


Figure 41: Network Topology for Simple Peer-To-Peer with Polling

The observable functionality of this application is periodic toggling of LEDs on the End Devices. The Sender toggles an LED each time it sends the 2-byte message. The Receiver toggles an LED specified in the message received from the Access Point. The Sender's message payload consists of an LED number and a transaction ID:

LED to toggle (1 or 2)	Transaction ID

Figure 42: Message Payload for Simple Peer-To-Peer with Polling

To run this sample application, follow these steps:

1. Using the process explained in Section 2, program and download a Sender (LinkTo) device.
2. Using the process explained in Section 2, program and download a Receiver (LinkListen) device.
3. Using the process explained in Section 2, program and download an Access Point device.
4. Power up the Access Point. LED1 and LED2 should be on and not change while running the application. This Access Point will supply subsequent joining devices with the network's link token. In addition, it will determine which devices need store-and-forward support. It will then provide that support for any messages that are sent to the polling device.

5. Power up the Receiver. LED1 and LED2 should be on. Press button 2 to join the network and receive the link token from the Access Point. Upon receipt of this frame, the device can glean the address of the Access Point, which it will use later to send the polling requests. Only LED1 should be on, and the device now listens for a link message. NOTE: as shown below in Figure 43, on boards with only one button (ez430RF, RFUSB, or CC430EM), press and hold button 1 for less than 3 seconds.
6. Power up the Sender. LED1 and LED2 should be on. Press button 1 to join the network, receive the link token from the Access Point, and send a link message to the Receiver. LED1 and LED2 should turn off at both the Sender and Receiver if linking is successful. Both LEDs will blink on the Sender if linking fails – if so, power down all three devices and return to step 4. NOTE: as shown below in Figure 43, on boards with only one button (ez430RF, RFUSB, or CC430EM), press and hold button 1 for longer than 3 seconds.
7. At this point, the devices have established a connection and will continually perform the following actions:
    a. At 3-6 second intervals, the Sender sends a message with a 2-byte payload to the Receiver, and toggles its LED1. The message contains an LED number for the Receiver device to toggle and a transaction ID. The transaction ID is incremented for each new message. It is treated as an unsigned number and wraps to zero after reaching the maximum value. Every 8th message, the LED number is set to LED1, otherwise it is set to LED2.
    b. At approximately 1 second intervals, the Receiver polls the Access Point. If the reply message from the Access Point has a payload, the Receiver checks the LED number and the transaction ID. If they both appear to be valid, the Receiver toggles the indicated LED.

The following diagram illustrates the sequences followed by the Sender and the Receiver devices:

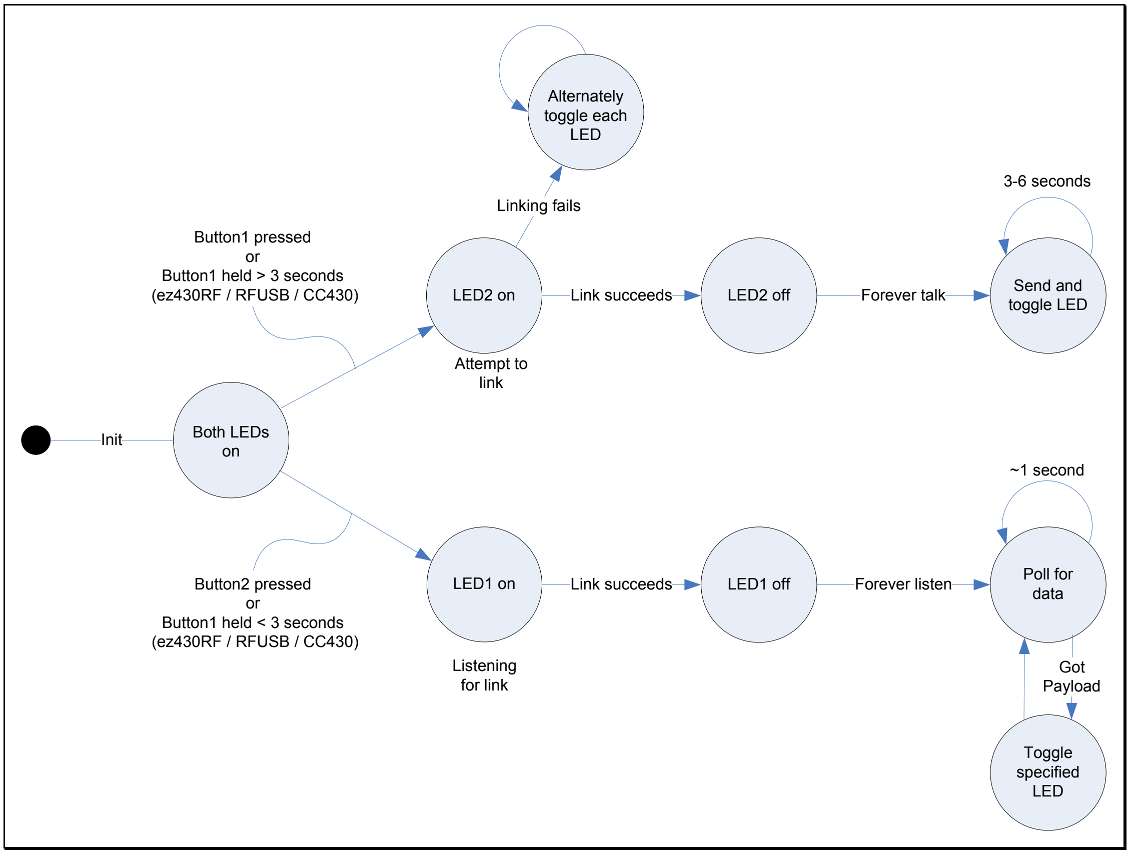


Figure 43: Sequence Diagram for Simple Peer-To-Peer, with Polling

3.3. Cascading End Devices

In this example, there are two or more End Devices, forming a broadcast network in which explicit links are not established. Each device can talk to any other devices that are in radio range. The diagram below shows a network in which three End Devices can communicate with each of the others.

The idea is that messages will cascade through the network. For example, imagine an array of smoke alarms, each of which can communicate with at least one other device. When one detects a problem, it not only activates its alarm, but propagates the alert to other devices in the array, which also sound the alarm and continue to propagate the alert.

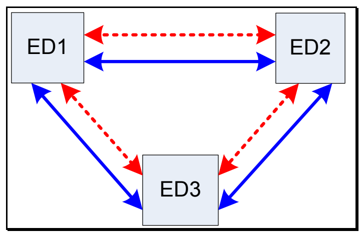


Figure 44: Network Topology for Cascading End Devices

The observable functionality of this application is periodic toggling of LEDs on each device to indicate current status. These devices emulate an array of smoke alarms or similar sensors that check their environment periodically. Initially, each device “sleeps” for a while (about 5 seconds) and then wakes up and checks its sensor (in the sample case, a button press). If the sensor is not activated, the device stays awake for a short time to see if it receives a message from another device. If no message is received, it toggles LED1 and goes back to sleep. If the device either detects that the sensor is activated or receives a “bad news” message, it sounds its alarm (toggles LED2) and then “babbles” a “bad news” message over air to alert other devices.

The key SimpliciTI feature that is demonstrated by this example is the operation of a broadcast network in which explicit links between devices are not established. The communication among End Device objects (applications) is via an unconnected datagram port mapped to a special Link ID. Each device may send to and receive from this Link ID without explicit linking as in the normal SimpliciTI scenario.

Connections between peers are not established. However, from the application perspective the send and receive API is the same. A special Link ID is used in place of a Link ID assigned by the stack during a normal SimpliciTI Link operation. Support for this unconnected user datagram capability consumes an entry in the Connection Table managed by the stack. This scenario does not prohibit either normal peer-to-peer connections or the presence and support of an Access Point. The Rx callback mechanism can also be used transparently.

In this sample application, devices “sleep” most of the time, waking up periodically to check for alert situations. In the sample code, sleep mode is actually implemented as a simple busy-wait loop, so this application is not suitable for power consumption evaluations. The user can substitute “real” sleep logic as needed.

To run this sample application, follow these steps:

1. Using the process outlined in Section 2, program and download an End-Device (ED1).
2. Using the process outlined in Section 2, program and download another End-Device (ED2).
3. If another device is available, using the process outlined in Section 2, program and download one more End-Device (ED3).
4. Power up all of the devices. LED1 and LED2 should be lit on all devices. Note that some platforms only have one LED (for example, CC1111 and CC2511 dongles).
5. Press a button on ED1. In response, its LEDs should turn off, indicating that the device has entered a cycle where it “sleeps” for about 5 seconds, “wakes up” to check for problems, and toggles LED1.
6. About 1 second later, press a button on ED2. Its LEDs should turn off, indicating the device has entered a cycle where it “sleeps” for about 5 seconds, “wakes up” to check for problems, and toggles LED1.
7. If available ED3 is available, about 1 second later, press a button on it. Its LEDs should turn off, indicating that the device has entered a cycle where it “sleeps” for about 5 seconds, “wakes up” to check for problems, and toggles LED1.
8. In this state, each device periodically wakes up from “sleep” to check for a “problem”:
    a. The device checks its sensor (in this example, a button press) to determine whether an alert situation has occurred. If so, go to step 9 to propagate the “bad news”.
    b. The device turns on its radio for about ¼ second and checks for receipt of a “bad news” message. If a message is received with the “bad news” payload, go to step 9 to propagate the “bad news”.
    c. The device toggles LED1 to indicate that no “problem” has been detected.
    d. The device “sleeps” for about 5 seconds.
    e. Return to step 8a to repeat the cycle.
9. After each device has performed several alert monitoring cycles in step 8, simulate a “problem” event by pressing and holding a button on one of the End Devices. Let go of the button when LED2 on that device begins to blink quickly (it has transitioned from step 8 to step 9). The other devices are expected to detect the “bad news” message, and also transition to step 9.
10. In this state, a device has encountered a “problem”, so it continuously broadcasts the “bad news” message:
    a. The device sends a message with a 1-byte “bad news” payload via an unconnected datagram.
    b. The device toggles LED2 to indicate that a message has been sent.
    c. The device “sleeps” for about 1/10th of a second.

d. Return to step 10a to repeat the cycle.

The following diagram illustrates the sequence followed by all End Devices in this example:

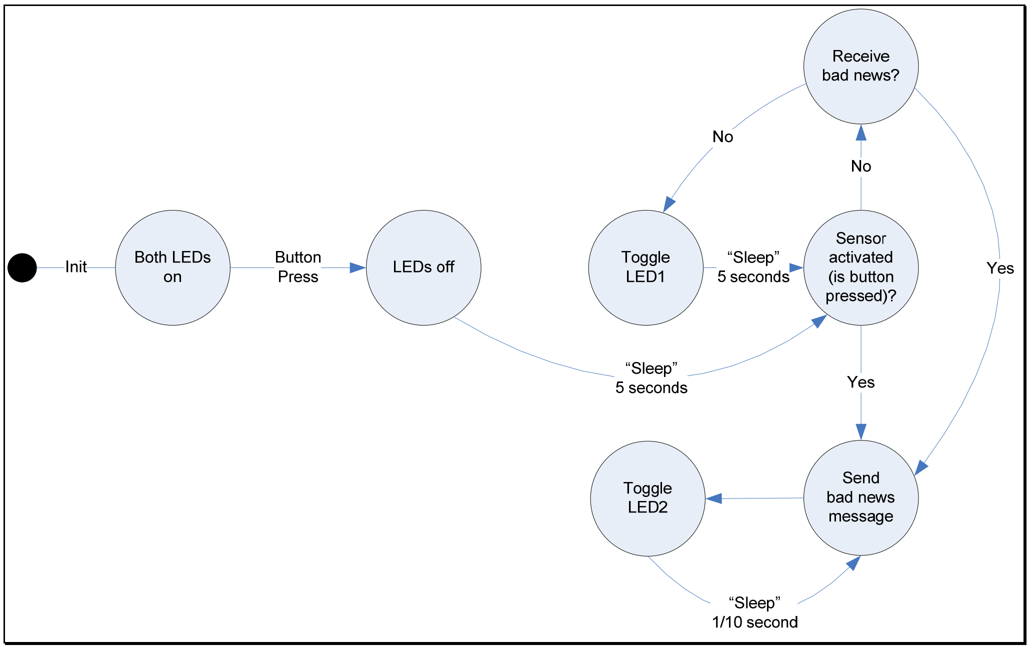


Figure 45: Sequence Diagram for Cascading End Devices

3.4. Access Point as Data Hub

This example is a special case of a network with an Access point in which the peer for one or more End-Devices is on the Access Point. So, while each End-Device may have peers on other devices, it always has a peer on the Access Point. In this scenario the Access point may act as a data collector or gateway for information coming from and going to distributed sensors/actuators. In addition, this sample application can be used to demonstrate the Frequency Agility feature of SimpliciTI (selection of the number of channels and channel settings are available to the application developer and may be changed from the default settings to suit the application).

Initially, each End-Device joins the network and sends a link message to the Access Point. After a connection has been established, the Access Point will toggle a specified LED when a message is received from an End-Device (pressing button 1 toggles LED1 and pressing button 2 toggles LED2). In this example, two End-Devices (ED1 and ED2) are shown to control the LEDs on the Access Point. Note that this sample application is provided as a simple example of how an Access Point may be used. It is expected that the developer will make appropriate changes to utilize other design criteria that fit their specific application needs.

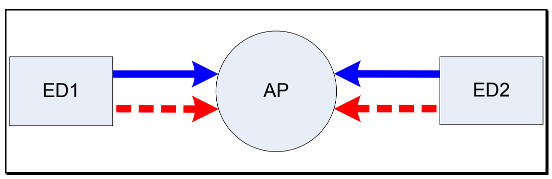


Figure 46: Network Topology for Access Point as Data Hub

The observable functionality of this application is toggling of LEDs on the Access Point, corresponding to button presses on the End-Devices. This implements a simulation of a multi-button RF remote control. The End-Device message payload consists of an LED number and a transaction ID:

LED to toggle (1 or 2)	Transaction ID

Figure 47: Message Payload for Access Point as Data Hub

To run this sample application, follow these steps:

1. Using the process outlined in Section 2, program and download an End-Device (ED1).
2. Using the process outlined in Section 2, program and download another End-Device (ED2).
3. Using the process outlined in Section 2, program and download an Access Point device (AP).
4. Power up the Access Point. LED1 and LED2 should turn on. This Access Point will supply subsequent joining devices with the network's link token. In addition, it

will listen for a link frame from a peer on each new joining End-Device. While running this application, LED1 and LED2 might start flashing together. This indicates that Frequency Agility noise detection caused an automatic channel change (see section 3.4.1). The LEDs continue to blink until a message is received from an End-Device on the new channel.

5. Power up the End-Devices (ED1 and ED2). LED1 and LED2 should flash once (indicating a successful join to the network) and then turn off (indicating a successful link with a peer on the Access Point).
6. Press button 1 on one of the End-Devices. LED1 on the Access Point should toggle, followed by LED1 toggling in this End-Device (indicates reply message received from the AP).
7. Press button 1 on the other End-Device. LED1 on the Access Point should toggle, followed by LED1 toggling in this End-Device (indicates reply message received from the AP).
8. Press button 2 on one of the End-Devices. LED2 on the Access Point should toggle, followed by LED1 toggling in this End-Device (indicates reply message received from the AP).
9. Press button 2 on the other End-Device. LED2 on the Access Point should toggle, followed by LED1 toggling in this End-Device (indicates reply message received from the AP).
10. Repeat steps 6 through 9 in other orders and verify expected toggling of LEDs. Since this example is using the Auto Acknowledge feature, the expectation is that LED1 will toggle on the End-Devices when the message ACK is received, otherwise LED2 will toggle.
11. Press button 1 on the Access Point. LED1 and LED2 on the AP should begin flashing, indicating that the Frequency Agility feature has executed a “forced” channel change (see section 3.4.1). When a button is pressed on an End-Device, LED1 and LED2 should stop blinking, indicating that the End-Device has found the new channel. Repeat steps 6 through 11 to test the Frequency Agility logic more times.

3.4.1. Frequency Agility

SimpliciTI has an optional feature, called Frequency Agility (refer to the Application Note on SimpliciTI Frequency Agility Description document), which can be used to increase a network’s reliability by changing channels to avoid noise. This feature uses a small, fixed list of channels from which the devices can choose. The fixed channel set distributed with SimpliciTI varies depending on the radio (refer to the SimpliciTI Channel Table Information document). The size and content of this table can be changed. The Access Point can be stimulated to change channels in two ways, forced and automatic.

In this sample application, pressing button 1 on the Access Point will force it to move to the next channel in its list, wrapping when leaving the last logical channel. There is also an “auto-detect” algorithm implemented in this application, where the Access Point monitors the current channel for excess noise. If the channel is too noisy, the Access Point will change channels without user intervention. The channel monitoring algorithm is shown below. NOTE: The algorithm below is sensitive to the data rate used. If the data rate is too low the noise criterion shown below will actually be met by a valid frame sent by any device and the AP will change channels. It is recommended that for demonstration purposes the default data rate be used.

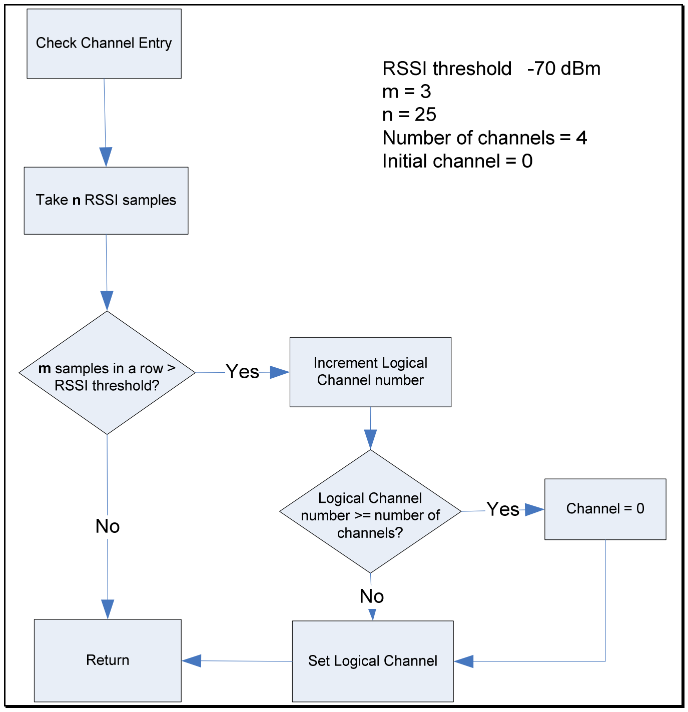


Figure 48: Frequency Agility Channel Change Algorithm

3.4.2. Channel Sniffer

When using Frequency Agility, it is useful to know what channel the network is currently on. Included with this sample application, is a project to build a channel Sniffer that will continually scan the channel list and display the logical channel number on its LEDs:

Logical Channel	LED1	LED2
0	Off	Off
1	Off	On
2	On	Off
3	On	On

Table 5: Channel Indication LEDs on a Sniffer Device

The Channel Sniffer is actually an End-Device with no peer application – it only scans for the active channel designated by the Access Point. The key configuration item (in smpl_config.dat) is to set the NUM_CONNECTIONS macro to 0. The AP will not listen for a link frame if the joining device does not support a peer application. Normally this is true of Range Extenders but the scenario is also true for this sniffer device.

To run the Channel Sniffer device with this sample application, follow these steps:

1. Using the process outlined in Section 2, program and download a Sniffer device.
2. Run at least steps 1 through 4 of the process described in section 3.4 above.
3. Power up the Sniffer. LED1 and LED2 should toggle alternately for about 5 seconds while scanning the channels. When the toggling stops, the LEDs indicate the current channel, according to the table above.
4. Run steps 5 through 11 of the process described in section 3.4 above to demonstrate channel

3.5. UART Bridge

This example shows a simple wireless UART in which a peer to peer network is established automatically without user intervention. Once the network is established, full duplex communications can take place over the UART connection. This project assumes a pair of HyperTerminal windows are being used but any mechanism which can communicate across an RS232 port should be acceptable.

Initially each end device assumes either a listener or linking responsibility. The listening device continuously attempts to detect a link request from the linking device while the linking device continuously attempts to link to the listening device. In this manner, it is irrelevant which device is powered up first. As soon as the link is established, the two devices begin symmetric operation of routing data between the UART and radio.

The observable functionality of this example is a data link between two HyperTerminal (or other COM interface) windows.

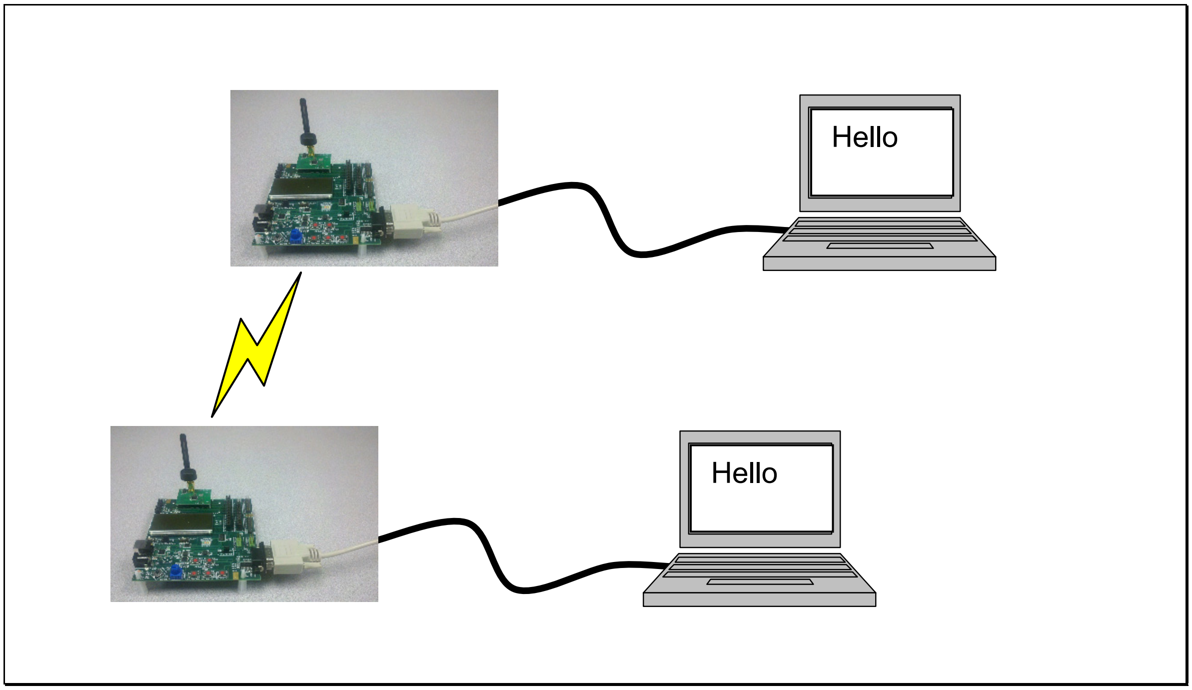


Figure 49: UART Bridge Topology

The setup shown in Figure 49 utilizes two SmartRF05 boards which have RS232 signal translators on them. If using a platform which has no signal translator (i.e. a CC430EM) communications with the PC will not work without an external translator such as the MAX3221 from TI.

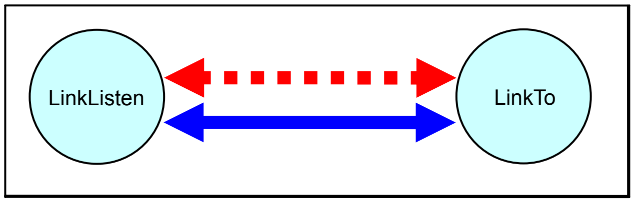


Figure 50: Network Topology for UART Bridge Application

Data packets for the UART Bridge application are simply an array of data bytes up to **`APP_MAX_PAYLOAD`** in length. The actual number of bytes per packet is dependent upon the number of bytes received from the UART channel since the last iteration through the main loop. There is no length byte transferred with the application payload data as SimpliciTI automatically manages this value through its header information.

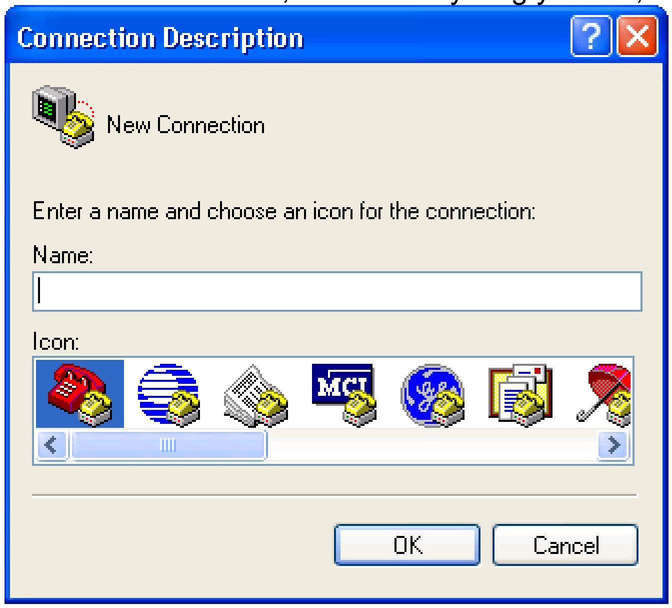
Platform	Needs External Translator	Comments
CC430	Yes	TX = port P1.6 (CON1.7), RX = port P1.5 (CON1.6)
CC2430DB	Yes	TX = port P0.3 (P6.9), RX = port P0.2 (P6.7)
EXP461x	No	TX = port P2.4, RX = port P2.5, DB9 connector. Note: cable must connect all pins to power opto-isolators
EXP543x	Yes	TX = port P3.4, RX = port P3.5
EZ430RF	No	TX = port P3.6, RX = port P3.7 Virtual COM Port over USB connector is used
RFUSB	Yes	TX = port P0.3 (P4.5), RX = port P0.2 (P4.6)
SRF04	No	TX = port P0.3 (P6.9), RX = port P0.2 (P6.7)
SRF05_8051	No	TX = port P0.3 (P6.9), RX = port P0.2 (P6.7) Jumper pins 2-3 on P10
SRF05_MSP	No	TX = port P3.4, RX = port P3.5, Jumper pins 2-3 on P10 on SRF05 board, Jumper pins 1-2 & 4-5 on P8 on 4618 board
TRXEB	Yes	TX = port P3.4 (P7.9), RX = port P3.5 (P7.7)

Table 6: RS232 Connections for UART Bridge Application

To run this sample application, follow these steps:

1. Using the process outlined in Section 2, program and download a LinkListen device.
2. Using the process outlined in Section 2, program and download a LinkTo device.
3. Hook up the RS232 connections as shown in Figure 49.
4. On each computer open up the HyperTerminal application. It can usually found in Start→All Programs→Accessories→Communications→HyperTerminal. Note: it is possible to run two separate HyperTerminal windows on a single PC if there are multiple RS232 ports. Also, a USB-RS232 adapter can work as well.
5. For each HyperTerminal window

a. Name the connection, it can be anything you like, click OK.

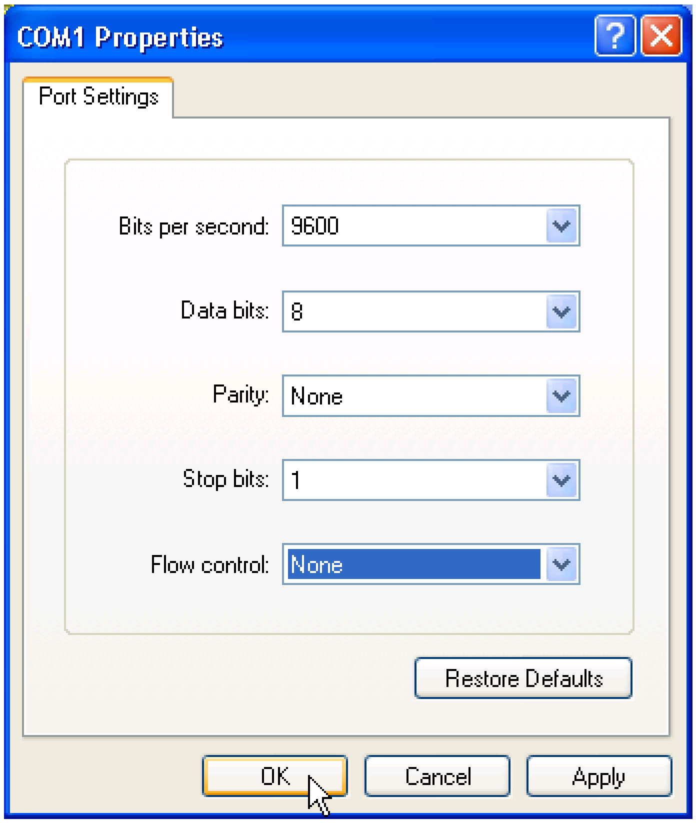


b. Select the COM port to use, click OK.

c. Set the COM port settings to:

Bits per Second	9600
Data Bits	8
Parity	None
Stop Bits	1
Flow Control	None

then click OK.



6. Turn on both devices, order is not important. In the HyperTerminal window associated with the LinkListen device the message
   `Listening for Link...`
   Should appear and in the HyperTerminal window associated with the LinkTo device the message
   `Linking to...`
   Should appear.
7. Once linking is accomplished both HyperTerminal windows should display the message
   `Link Established!`
   `Ready...`
8. Type something in one of the HyperTerminal windows. Note the text you type will appear in the other HyperTerminal window.
9. Now type some text in the other HyperTerminal window. Notice the text displays in the previous HyperTerminal window.

One LED is tied to the UART and every time a character is transmitted or received across the UART, the LED is turned on for a short amount of time. This provides a visual indication to the user that data is being transferred.

4. Frequency Hopping Spread Specrum (FHSS)

All of the sample applications described previously can be run with Frequency hopping enabled. This section describes the general modifications required for operation when FHSS is enabled. Note that FHSS and Frequency Agility are mutually exclusive configurations and if both are enabled a compiler error will be generated.

To begin using FHSS with SimpliciTI, simply enable the **`FREQUENCY_HOPPING`** macro in the configuration file by removing the "**`x`**" character just after the **`-D`**. Once FHSS has been enabled, recompile the code for all radios in the network. Don't forget to change the addresses of the end devices for those sample applications that require it!

In order for FHSS to operate, all radios in the network must lock to a reference clock. Therefore, each network must define one of the radios to be the reference clock. For the AP_as_Data_Hub and Polling_with_AP sample applications, the configuration files automatically select the AP as the reference clock. In the UART_Bridge sample application, the LinkListen node is automatically selected as the reference clock. For the Cascading_End_Devices and Simple_Peer_to_Peer applications, the user must choose one node as the reference clock.

To choose a node as the reference clock, locate the configuration file with the **`-DxNWK_PLL_REFERENCE_CLOCK`** definition. Remove the "**`x`**" character so it looks like this

```
-DNWK_PLL_REFERENCE_CLOCK
```

Make sure only one radio in the network is compiled with this definition active. Be sure to replace the "**`x`**" character to disable the macro for all other radios in the network otherwise the FHSS algorithm will not be able to lock on as there will be multiple reference clocks in the network.

As a visual indication to aid in identifying when a radio is attempting to lock onto the reference clock, two LEDs on the board will be blinked in a 00→01→11→10→00… repeating order at the minimum sample period (default of 50ms). These two LEDs will continue to blink in this fashion until the FHSS algorithm has located and locked onto the reference clock and the hop schedule is determined. Once the FHSS algorithm for the radio has locked to the hop schedule, the LEDs will cease to blink in this fashion and normal LED operation of each sample application will resume.

For end user applications where these LEDs either do not exist or the indication is unwanted, disable or remove the following macro in the configuration file

```
-DNWK_PLL_SHOW_LOCATION_INDICATORS
```

To disable the macro, simply insert an "x" character (or any alphabetic character) just after the **`-D`** as is done for other unused macros in the configuration files.

When FHSS is operating properly, and once the radio has locked to the reference clock, there should be no discernable difference in operation from a user point of view.

Should a radio lose lock with the reference clock, and the **`NWK_PLL_SHOW_LOCATION_INDICATORS`** macro is enabled, the cyclic blinking pattern will start and continue until the radio re-acquires lock. Note that if this is forced by turning off a radio, normal operation of the application may fail due to a lost link.

Note also that even if the **`NWK_PLL_SHOW_LOCATION_INDICATORS`** macro is enabled for the radio acting as the reference clock, the LEDs will not blink. This is not a bug, but rather a validation that the reference clock need not lock to any other clock since, by definition, it is always locked to itself.