Crossbow

MoteWorks Getting Started Guide

Revision C, December 2006

PN: 7430-0102-01

www.xbow.com

About This Document

The following annotations have been used to provide additional information.

◀ NOTE

Note provides additional information about the topic.

☑ EXAMPLE

Examples are given throughout the manual to help the reader understand the terminology.

⚐ IMPORTANT

This symbol defines items that have significant meaning to the user

⚠ WARNING

The user should pay particular attention to this symbol. It means there is a chance that physical harm could happen to either the person or the equipment.

The following paragraph heading formatting is used in this manual:

1 Heading 1

1.1 Heading 2

1.1.1 Heading 3

This document also uses different body text fonts (listed in Table 0-1) to help you distinguish between names of files, commands to be typed, and output coming from the computer.

Table 0-1. Font types used in this document.

Font Type	Usage
`Courier New Normal`	Sample code and screen output
`Courier New Bold`	Commands to be typed by the user
Times New Roman Italic	TinyOS files names, directory names
Franklin Medium Condensed	Text labels in GUIs

1 Introduction

MoteWorks™ is the end-to-end enabling platform for the creation of wireless sensor networks. The optimized processor/radio hardware, industry-leading mesh networking software, gateway server middleware and client monitoring and management tools support the creation of reliable, easy-to-use wireless OEM solutions. OEMs are freed from the detailed complexities of designing wireless hardware and software enabling them to focus on adding unique differentiation to their applications while bringing innovative solutions to market quickly.

1.1 *MoteWorks* Network Landscape

A wireless network deployment is composed of the three distinct software tiers:

1. The **Mote Tier**, where *XMesh* resides, is the software that runs on the cloud of sensor nodes forming a mesh network. The *XMesh* software provides the networking algorithms required to form a reliable communication backbone that connects all the nodes within the mesh cloud to the server. (Refer to *XMesh* User's Manual)
2. The **Server Tier** is an always-on facility that handles translation and buffering of data coming from the wireless network and provides the bridge between the wireless Motes and the internet clients. *XServe* and *XOtap* are server tier applications that can run on a PC or Stargate. (Refer to *XServe* User's Manual)
3. The **Client Tier** provides the user visualization software and graphical interface for managing the network. Crossbow provides free client software called *MoteView*, but *XMesh* can be interfaced to custom client software as well. (Refer to *MoteView* User's Manual)

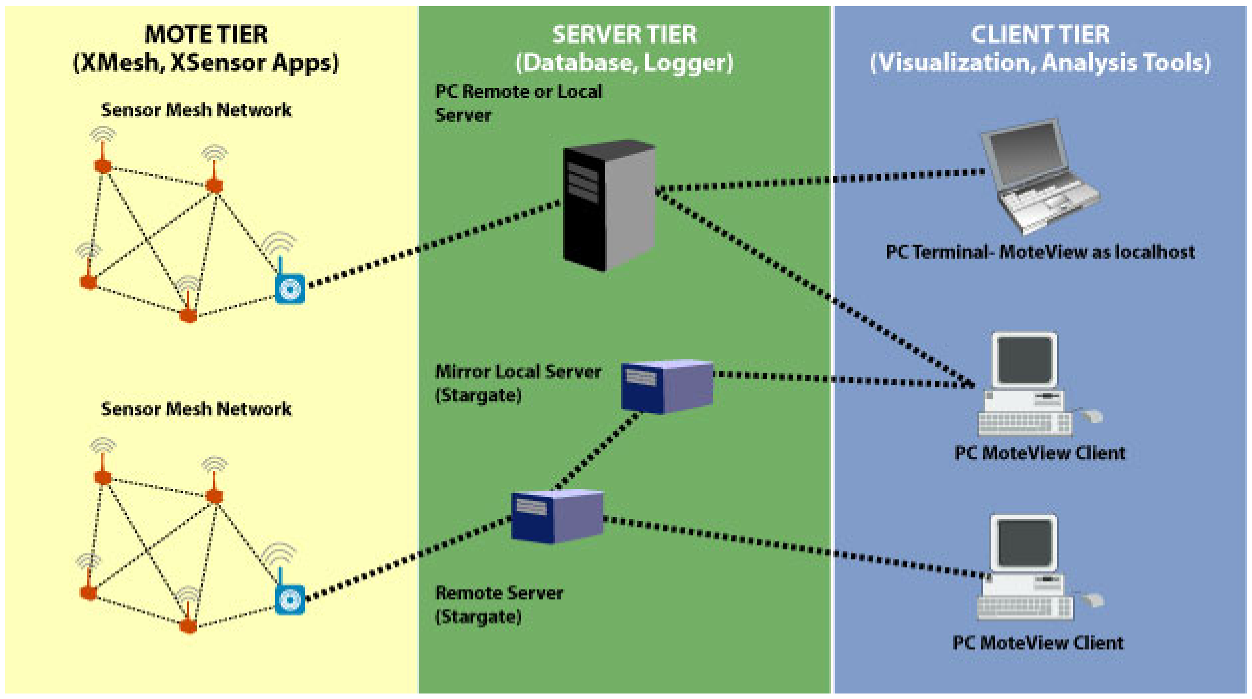


Figure 1-1. XMesh Landscape

The software platform provided with MoteWorks™ is optimized for low-power battery-operated networks and provides an end-to-end solution across all tiers of wireless sensor networking applications.

1.1.1 XMesh Mote Tier

XMesh is a full featured multi-hop, ad-hoc, mesh networking protocol developed by Crossbow for wireless networks. An *XMesh* network consists of nodes (Motes) that wirelessly communicate to each other and are capable of hopping radio messages to a base station where they are passed to a PC or other client. The hopping effectively extends radio communication range and reduces the power required to transmit messages. By hopping data in this way, *XMesh* can provide two critical benefits: improved radio coverage and improved reliability. Two nodes do not need to be within direct radio range of each other to communicate. A message can be delivered to one or more nodes in-between which will route the data. Likewise, if there is a bad radio link between two nodes, that obstacle can be overcome by rerouting around the area of bad service. Typically the nodes run in a low power mode, spending most of their time in a sleep state, in order to achieve multi-year battery life.

XMesh provides a TrueMesh networking service that is both self-organizing and self-healing. *XMesh* can route data from nodes to a base station (upstream) or downstream to individual nodes. It can also broadcast within a single area of coverage or arbitrarily between any two nodes in a cluster. QOS (Quality of Service) is provided by either a best effort (link level acknowledgement) and guaranteed delivery (end-to-end acknowledgement). Also, *XMesh* can be configured into various power modes including HP (high power), LP (low power), and ELP (extended low power).

1.1.2 XServe Server Tier

XServe serves as the primary gateway between wireless mesh networks and enterprise applications interacting with the mesh. At its core, *XServe* provides services to route data to and from the mesh network with higher level services to parse, transform and process data as it flows between the mesh and the outside applications. Higher level services are customizable using XML based configuration files and loadable plug-in modules.

XServe offers multiple communication inputs for applications wishing to interact with *XServe* or the mesh network. Users can interact with *XServe* through a terminal interface applications can access the network directly or through a powerful XML RPC command interface.

1.1.3 MoteView Client Tier

MoteView is the client user interface that enables *MoteWorks*™ to deliver an end-to-end solution across all tiers of wireless sensor networks. *MoteView* displays the information from the network to developers or end-users. The entire network or individual nodes can be displayed and analyzed in graphical charting or textual format. *MoteView*’s playback capability allows historical viewing of network status and sensor readings over time, and is based on the logging information stored in *XServe*. *MoteView*’s analysis capabilities allow automatic e-mail alerts when user-definable conditions are met. For example, if RF links are re-routed because of changes in the environment or sensor readings exceed a specified threshold, an e-mail will alert an operator or field technician via PDA or mobile phone. *MoteView* enables end-users to optimize network layout and configuration, analyze sensor information interactively and then take corrective action. *MoteView* provides an interface to remotely configure motes in the wireless network. Each node can be individually updated with configuration parameters provided by the mote. This makes it transparent for the user of an installed wireless sensor network to configure motes, e.g. change frequency of sensor readings, without requiring any programming knowledge. *MoteView* also has built-in support for Crossbow’s entire range of sensor boards, enabling very fast prototyping. If custom sensor boards are required for an application, these boards can be integrated for management in *MoteView* as well.

1.2 Low-Power Operating System – TinyOS

MoteWorks™ includes TinyOS, the open-source operating system originally developed by University of California, Berkeley. TinyOS has developed a broad user community with thousands of developers, making it the standard operating system for wireless sensor networking in the research community. It is also the most widely-deployed wireless sensor network operating system for commercial applications. TinyOS is a component-based, event-driven operating system designed from the ground up for low-power devices with small memory footprint requirements.

TinyOS supports microprocessors ranging from 8-bit architectures with as little as 2 KB of RAM to 32-bit processors with 32 MB of RAM or more. It provides a well-defined set of APIs for application programming. These APIs provide access to the computing capabilities of the sensor node, allowing for intelligence within the network. Using these capabilities, sensor data can be preprocessed on the node, optimizing both network throughput and battery life by avoiding unnecessary send and receive messages.

1.3 Software Development Tools

MoteWorks is provided with a set of software development tools for custom Mote applications, including custom sensor board drivers, sensor signal conditioning and processing and message handlers. MoteWorks includes an optimized cross-compiler for the target mote platform and an advanced editor for TinyOS application development. MoteWorks automatically installs and configures these development tools for quick set-up and rapid start of development.

2 Installation of MoteWorks

This chapter describes how to install MoteWorks on a Windows®-based PC from the CD that comes with the product. You will learn

- Installing MoteWorks and its tools
- MoteWorks installation tree structure
- How to uninstall MoteWorks

The issues that come up during installation such as choosing an installation directory and installing with other versions of TinyOS, nesC, and Cygwin are also covered here. Following the installation, read Chapter 3 which covers many important programming topics, instructions for compiling and downloading the application firmware into your Motes, and useful programming environment customizations.

2.1 What You Need for Installation

- ❑ Crossbow's *MoteWorks* CD-ROM
- ❑ A Windows-based PC
  Operating System: Microsoft Windows (XP, 2000, NT)
  1 GB or more of free space in destination drive
  550 MB or more of space in C drive, regardless of destination drive

The *MoteWorks InstallShield Wizard* setup offers the following software packages:

TinyOS and MoteWorks Tools	An event-driven OS for wireless sensor networks; tools for debugging
nesC compiler	An extension of C-language designed for TinyOS
Cygwin	A Linux-like environment for Windows
AVR Tools	A suite of software development tools for Atmel's AVR processors
Programmer's notepad	IDE for code compilation and debugging
XSniffer	Network Monitoring Tool for the RF environment
MoteConfig	GUI environment for Mote Programming and OTAP
Graphviz	To view files made from make docs
PuTTY and TortoiseCVS	Source access through CVS server for Enterprise Users

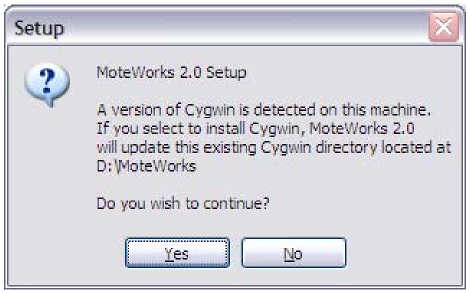
2.2 Installing from the CDROM

IMPORTANT

Prior to installing MoteWorks, it is strongly recommended that you shut down all the programs running on your computer.

1. Insert *MoteWorks* CD into the PC's CD-ROM drive and double-click on *MoteWorks_<version>_Setup.exe*

2. The installer will check for previously installed Cygwin and if detected will display the message. You need to click on **Yes** before you can proceed further.

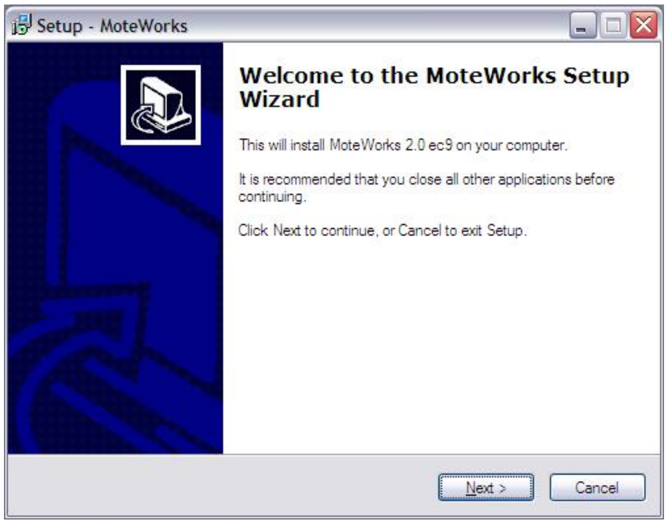


MoteWorks 2.0 Setup

A version of Cygwin is detected on this machine.
If you select to install Cygwin, MoteWorks 2.0
will update this existing Cygwin directory located at
D:\MoteWorks

Do you wish to continue?

3. At the Welcome to the MoteView Setup Wizard window, click on **Next>**.



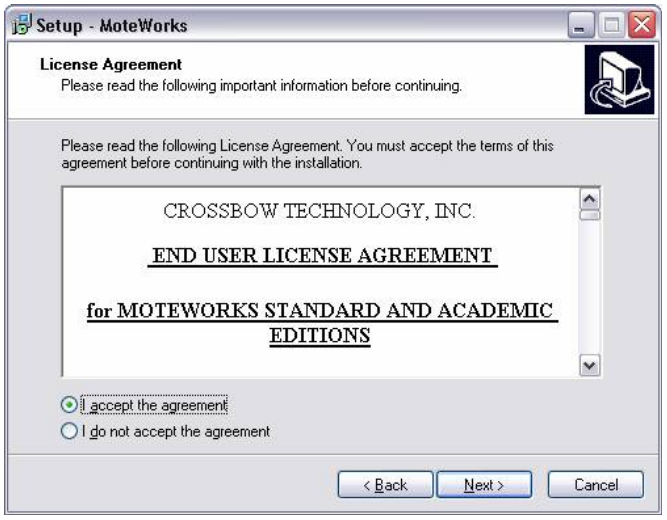
Welcome to the MoteWorks Setup Wizard

This will install MoteWorks 2.0 ec9 on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

4. At the License Agreement page, you should read and check on "I accept the agreement. Click on **Next>**.



License Agreement
Please read the following important information before continuing.

Please read the following License Agreement. You must accept the terms of this agreement before continuing with the installation.

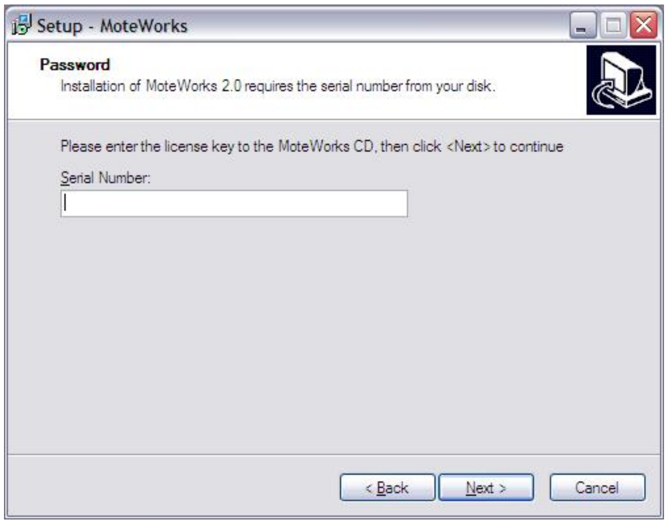
CROSSBOW TECHNOLOGY, INC.

END USER LICENSE AGREEMENT

for MOTEWORKS STANDARD AND ACADEMIC EDITIONS

[✓ I accept the agreement] I do not accept the agreement

5. Enter the license key from the MoteWorks CD in the Serial Number text box and click on **Next>**.



Setup - MoteWorks

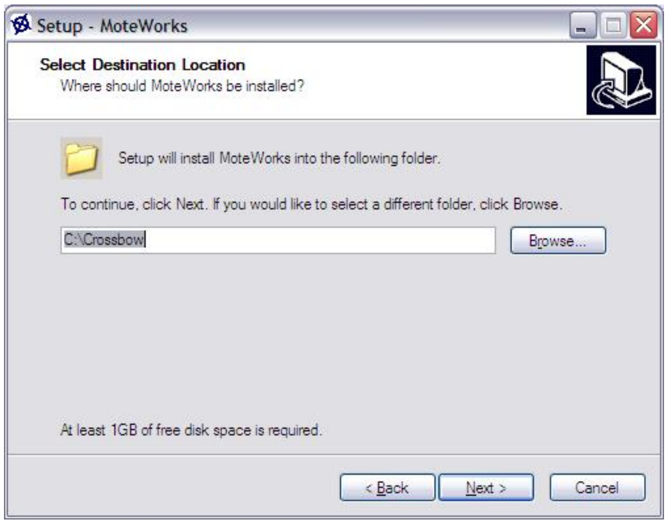
Password

Installation of MoteWorks 2.0 requires the serial number from your disk.

Please enter the license key to the MoteWorks CD, then click <Next> to continue

Serial Number:

6. Specify the destination directory for the MoteWorks (default is **C:\Crossbow**) and click on **Next>**. Moteworks should not be installed to **C:\Program Files\Crossbow**



Setup - MoteWorks

Select Destination Location

Where should MoteWorks be installed?

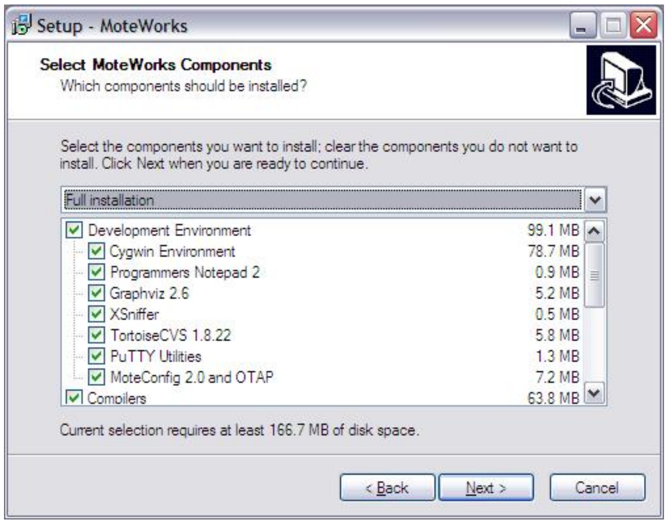
Setup will install MoteWorks into the following folder.

To continue, click Next. If you would like to select a different folder, click Browse.

C:\Crossbow

At least 1GB of free disk space is required.

7. In the Select MoteWorks Components dialog, select Full installation from the drop down (recommended) and check all the options. If you are upgrading the *MoteWorks* components over a previous version, then you can check only the relevant components. Click on **Next>**.



Setup - MoteWorks

Select MoteWorks Components

Which components should be installed?

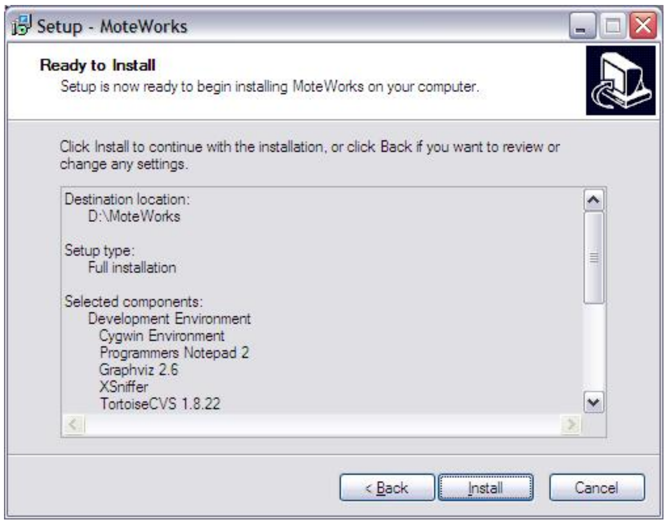
Select the components you want to install; clear the components you do not want to install. Click Next when you are ready to continue.

Full installation

☑ Development Environment	99.1 MB
☑ Cygwin Environment	78.7 MB
☑ Programmers Notepad 2	0.9 MB
☑ Graphviz 2.6	5.2 MB
☑ XSniffer	0.5 MB
☑ TortoiseCVS 1.8.22	5.8 MB
☑ PuTTY Utilities	1.3 MB
☑ MoteConfig 2.0 and OTAP	7.2 MB
☑ Compilers	63.8 MB

Current selection requires at least 166.7 MB of disk space.

8. The next window will display the selections you specified. Verify and click on **Install** to begin installation process.



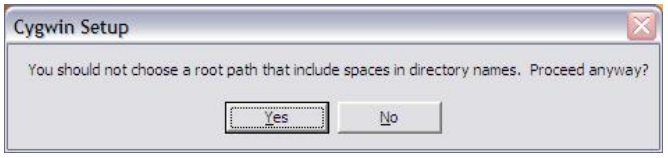
Setup - MoteWorks

Ready to Install
Setup is now ready to begin installing MoteWorks on your computer.

Click Install to continue with the installation, or click Back if you want to review or change any settings.

```
Destination location:
    D:\MoteWorks

Setup type:
    Full installation

Selected components:
    Development Environment
      Cygwin Environment
      Programmers Notepad 2
      Graphviz 2.6
      XSniffer
      TortoiseCVS 1.8.22
```

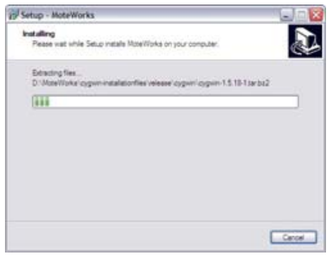
9. You may get the Cygwin Setup warning shown on the right. Click on **Yes.**



Cygwin Setup

You should not choose a root path that include spaces in directory names. Proceed anyway?

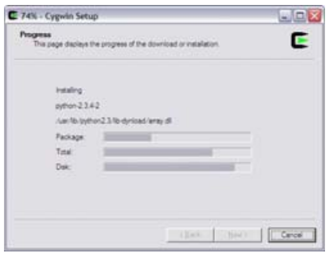
10. The windows shown will appear as the installation progresses. Wait patiently for further instructions.



Setup - MoteWorks

Installing
Please wait while Setup installs MoteWorks on your computer.

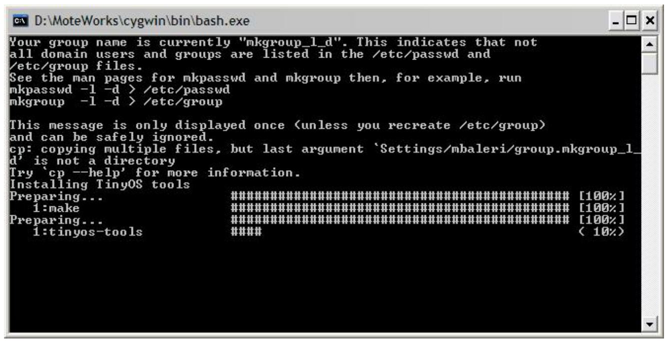
Extracting files...
D:\MoteWorks\cygwin-installationfiles\release\cygwin\cygwin-1.5.18-1.tar.bz2



74% - Cygwin Setup

Progress
This page displays the progress of the download or installation.

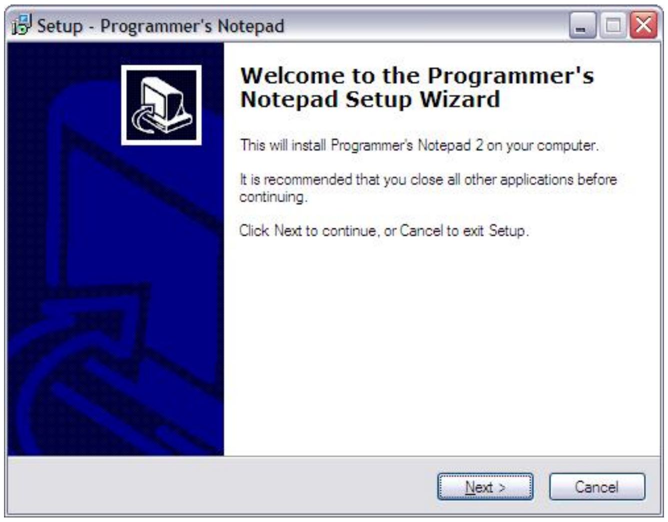
Installing
python-2.3.4-2
/usr/lib/python2.3/lib-dynload/array.dll



D:\MoteWorks\cygwin\bin\bash.exe

```
Your group name is currently "mkgroup_l_d". This indicates that not
all domain users and groups are listed in the /etc/passwd and
/etc/group files.
See the man pages for mkpasswd and mkgroup then, for example, run
mkpasswd -l -d > /etc/passwd
mkgroup  -l -d > /etc/group

This message is only displayed once (unless you recreate /etc/group)
and can be safely ignored.
cp: copying multiple files, but last argument `Settings/mbaleri/group.mkgroup_l_
d' is not a directory
Try `cp --help' for more information.
Installing TinyOS tools
Preparing...                ########################################### [100%]
   1:make                   ########################################### [100%]
Preparing...                ########################################### [100%]
   1:tinyos-tools           ####                                        ( 10%)
```

11. The next step is the installation of Programmer's Notepad. Click **Next>** on the welcome window.



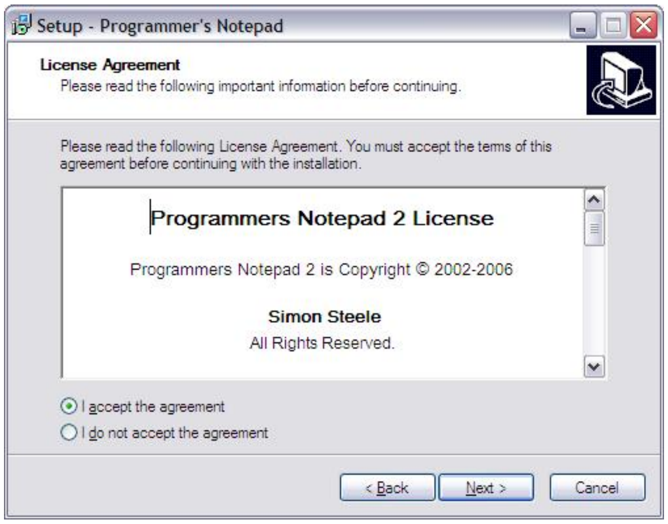
Welcome to the Programmer's Notepad Setup Wizard

This will install Programmer's Notepad 2 on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

12. At the License Agreement page, you should read and check on "I accept the agreement" before you can proceed further. Click on **Next>**. (Programmer's Notepad gets installed under the default folder **C:\ Crossbow\pn**)



License Agreement

Please read the following important information before continuing.

Please read the following License Agreement. You must accept the terms of this agreement before continuing with the installation.

Programmers Notepad 2 License

Programmers Notepad 2 is Copyright © 2002-2006

Simon Steele

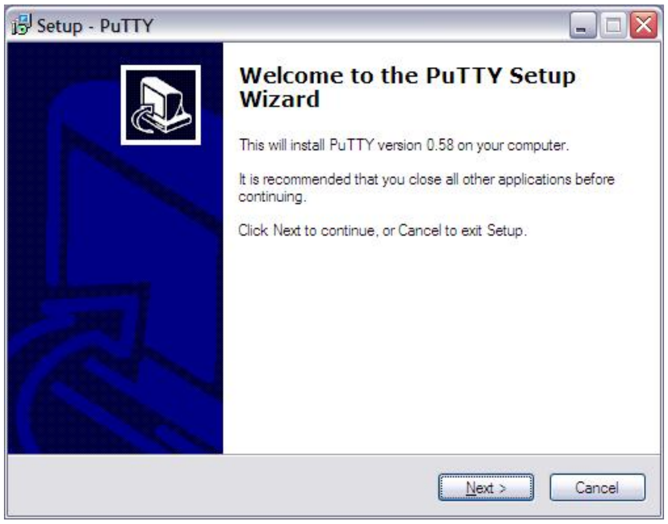
All Rights Reserved.

[✓ I accept the agreement]

I do not accept the agreement

13. The Setup Wizard will then install Graphviz utility. Wait patiently for further instructions.

14. The next step is the installation of PuTTY. Click **Next>** on the welcome window.



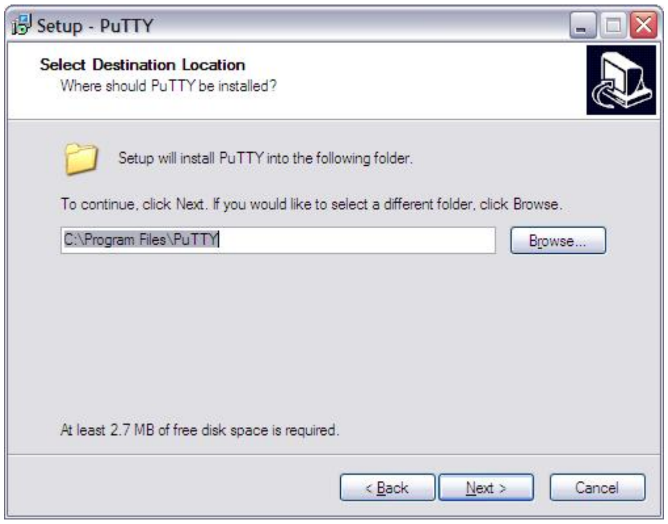
Welcome to the PuTTY Setup Wizard

This will install PuTTY version 0.58 on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

15. Specify the destination directory for the PuTTY (default is **C:\Program Files\PuTTY**) and click on **Next>**.



Select Destination Location
Where should PuTTY be installed?

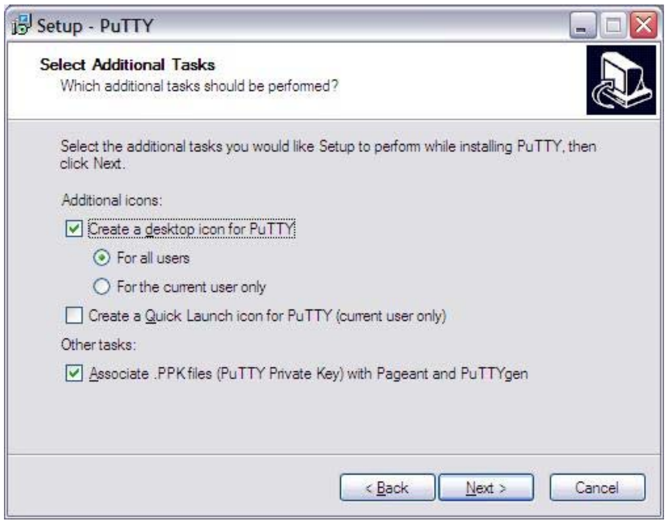
Setup will install PuTTY into the following folder.

To continue, click Next. If you would like to select a different folder, click Browse.

C:\Program Files\PuTTY

At least 2.7 MB of free disk space is required.

16. In the Select Additional Tasks dialog window, make sure to check "**Associate .PPK files**" and click on **Next>**.



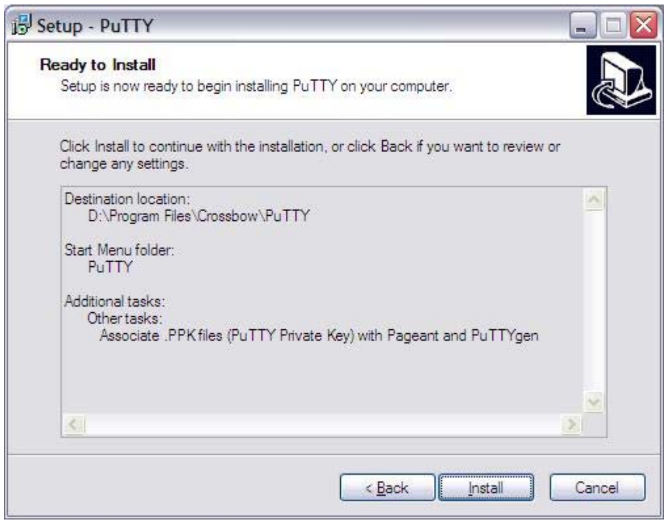
Select Additional Tasks
Which additional tasks should be performed?

Select the additional tasks you would like Setup to perform while installing PuTTY, then click Next.

Additional icons:
- [✓] Create a desktop icon for PuTTY
  - (●) For all users
  - ( ) For the current user only
- [ ] Create a Quick Launch icon for PuTTY (current user only)

Other tasks:
- [✓] Associate .PPK files (PuTTY Private Key) with Pageant and PuTTYgen

17. The next window will display the selections you specified. Verify and click on **Install** to proceed further. The installer will guide you through the rest of the process.

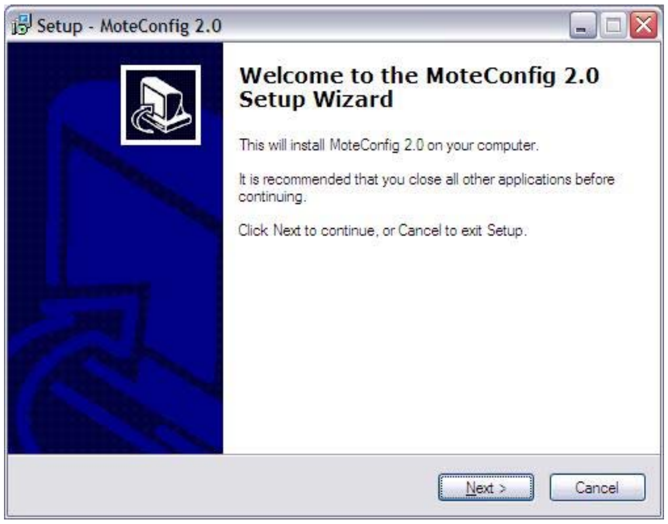


Ready to Install
Setup is now ready to begin installing PuTTY on your computer.

Click Install to continue with the installation, or click Back if you want to review or change any settings.

```
Destination location:
    D:\Program Files\Crossbow\PuTTY

Start Menu folder:
    PuTTY

Additional tasks:
    Other tasks:
      Associate .PPK files (PuTTY Private Key) with Pageant and PuTTYgen
```

18. The next step is the installation of MoteConfig. Click **Next>** on the welcome window. The installer will guide you through the rest of the process. (MoteConfig gets installed under the default folder **C:\ Crossbow\MoteConfig)**



Setup - MoteConfig 2.0

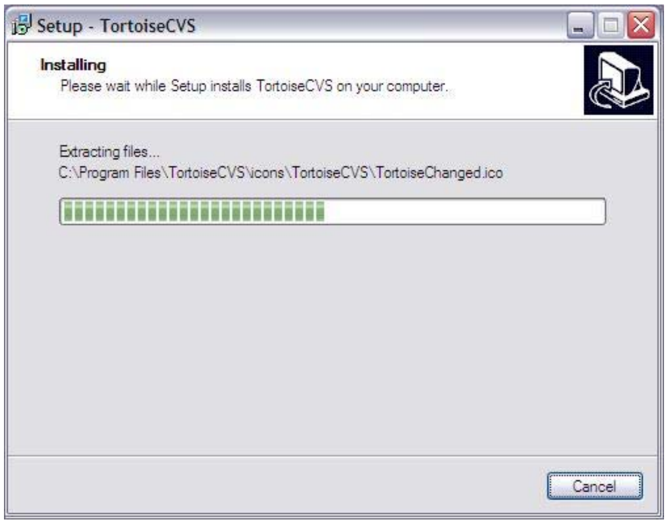
Welcome to the MoteConfig 2.0 Setup Wizard

This will install MoteConfig 2.0 on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

19. The next step is the installation of TortoiseCVS. The installer will guide you through the process.



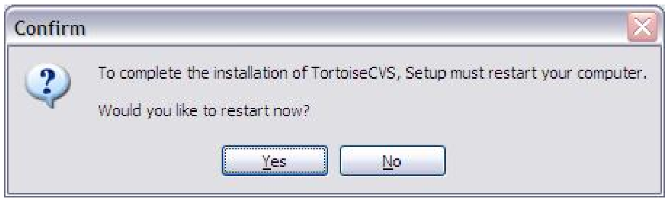
Setup - TortoiseCVS

Installing

Please wait while Setup installs TortoiseCVS on your computer.

Extracting files...
C:\Program Files\TortoiseCVS\icons\TortoiseCVS\TortoiseChanged.ico

20. After the completion of the TortoiseCVS installation, you will be prompted to restart the computer.

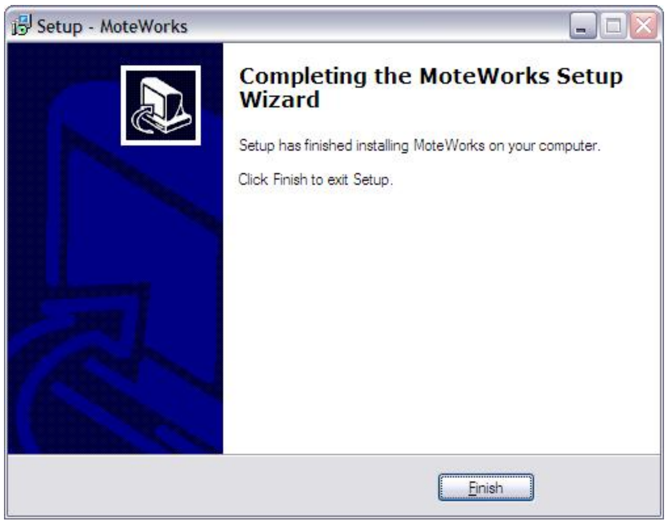


Confirm

To complete the installation of TortoiseCVS, Setup must restart your computer.

Would you like to restart now?

21. Upon successful installation, you will see this message. Click on **Finish** to exit set-up.



Setup - MoteWorks

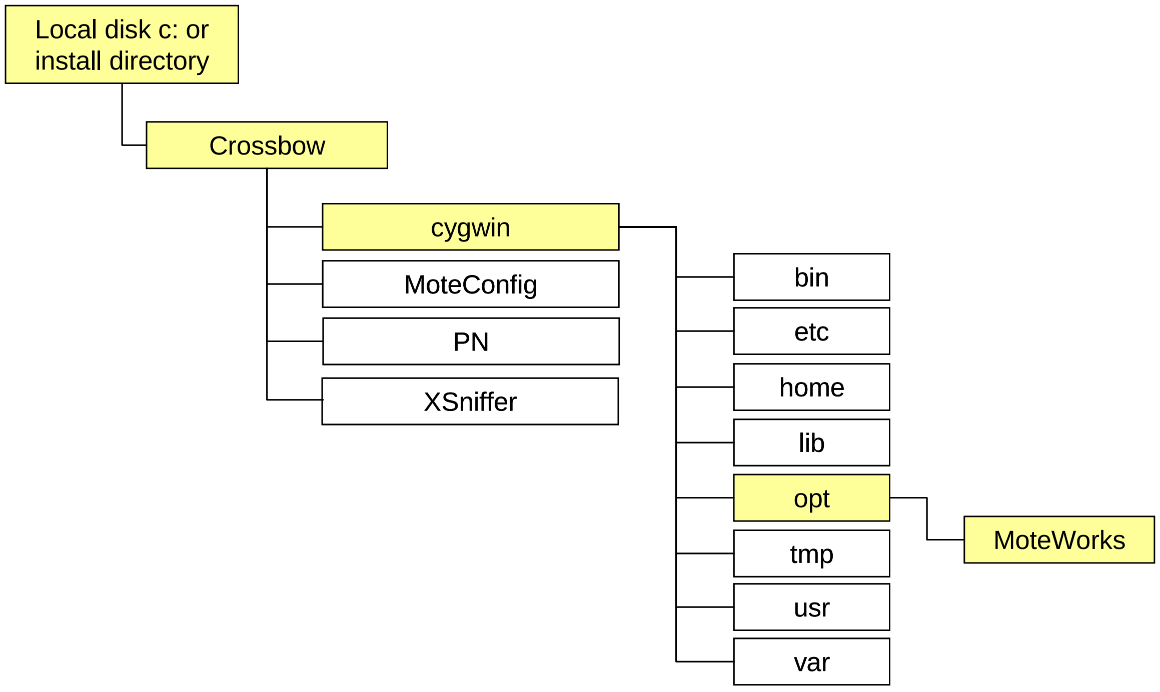
Completing the MoteWorks Setup Wizard

Setup has finished installing MoteWorks on your computer.

Click Finish to exit Setup.

2.3 *MoteWorks* Installation Structure

All the *MoteWorks* components such as *apps/*, *doc/*, *tools/*, and *tos/* directories are located under ***<install dir>/cygwin/opt/MoteWorks/***. In addition the *Makefile* is in this folder. The environment variables for TOSROOT is set to *<install dir>*. Typically the default *<install dir>* is the ***C:\ Crossbow***



(a) MoteWorks top level directory structure

MoteWorks	
apps	XMesh, XSensor applications and example programs
make	nesC Compile utilities for different processor platforms
doc	Documents generated by make utility
tools	Developers utilities and programs
tos	TinyOS "operating system," modules, and interfaces

(b) MoteWorks and subdirectories

apps	
examples	Example applications described in XMesh manual
general	Basic applications such as Blink and XSniffer
tutorials	Applications described in Getting Started Guide
xmesh	Multi-hop apps for various sensorboards
xsensor	Single-hop apps for various sensorboards

(c) apps and subdirectories

tools	
bin	Executables for automated tools
motelist	Lists attached USB devices
uisp	Mote UISP programming utility
xserve	XServe server tier middleware

(d) tools and subdirectories

tos	
interfaces	Definitions of TinyOS component interfaces
lib	Major "libraries" such as *XMesh*, *TimeSync*
platform	Mote platform specific hardware drivers
radio	Radio specific drivers
sensorboards	Sensor and data acquisition board drivers
system	TinyOS "services" such as the timers, scheduler
types	TinyOS data structures such as Active Messages

(e) tos and subdirectories

Figure 2-1. MoteWorks and Subdirectory Map

2.4 Uninstalling MoteWorks

To uninstall *MoteWorks*, you can use the Remove option for MoteWorks found under **Start>Control Panel>Add/Remove Programs**. This will remove *MoteWorks* Tree, Programmer's Notepad and MoteConfig from your PC. Similarly, other installed components (viz. *Graphviz*, *XSniffer*, PuTTY and TortoiseCVS) need to be separately removed using the **Add/Remove Programs Wizard**.

◀ **NOTE:** In certain cases, depending on your system security, the MoteWorks uninstaller does not automatically remove Cygwin and its registry files. You have to manually remove following items to fully uninstall Cygwin:

Cygwin shortcuts and start menu entry (**Programs>Cygwin**)

Cygwin registry entries under **HKEY_LOCAL_MACHINE>Software>Cygnus Solutions** (run `regedit`)

Everything under the Cygwin root directory. Save useful files of course; you could just rename the cygwin root to say, cygwin-old, to be extra safe.

3 Programming Environment Customization

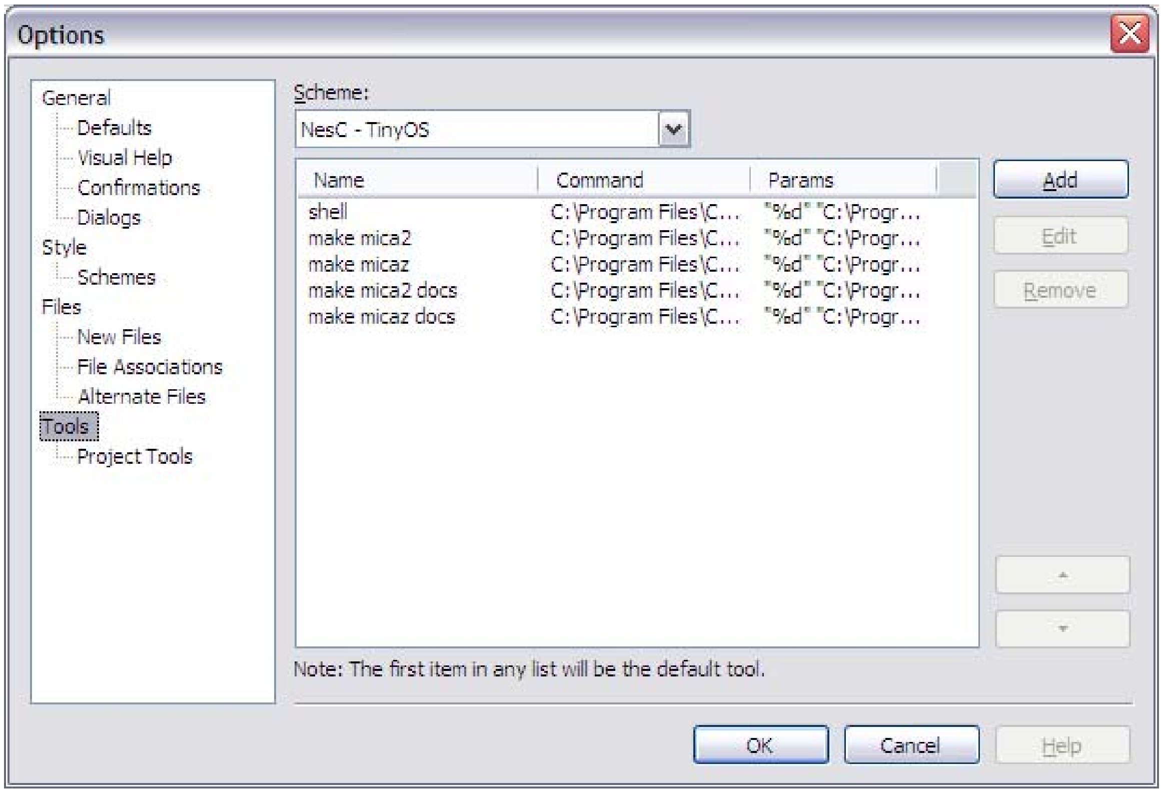
In this chapter, you will learn:

- Customizing Programmer's Notepad
- Cygwin interface
- Compiling and Programming Tools
- Environment variables
- Interoperability between TinyOS 1.1.10 and MoteWorks 2.0

3.1 Programmer's Notepad 2

MoteWorks includes a version of Programmer's Notepad that is configured as a simple IDE for nesC code. In the Tools menu there are "compile," "make mica2", and "make micaz" options. If you installed to a non-default directory, you have to edit these tools manually to get them to work:

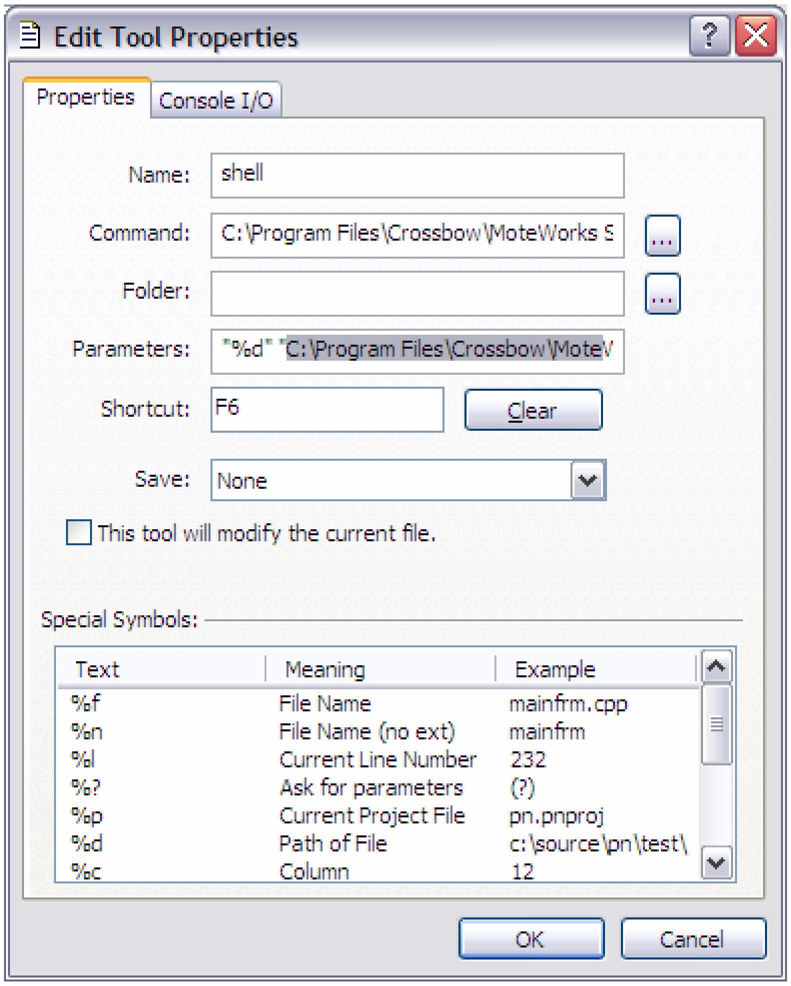
1. Open Programmer's Notepad from **Start>Programs>Crossbow>PN**
2. Open a nesC file within an application directory (eg. *Blink.nc* from ***/MoteWorks/apps/general/Blink***).
3. Go to menu **Tools > Options**



Name	Command	Params
shell	C:\Program Files\C...	"%d" "C:\Progr...
make mica2	C:\Program Files\C...	"%d" "C:\Progr...
make micaz	C:\Program Files\C...	"%d" "C:\Progr...
make mica2 docs	C:\Program Files\C...	"%d" "C:\Progr...
make micaz docs	C:\Program Files\C...	"%d" "C:\Progr...

Note: The first item in any list will be the default tool.

4. Click on **Tools** on the left hand side and choose, '**NesC-TinyOS**' from the drop-down for Scheme. Double click each of `**shell**`, and **Edit**. This will bring up "Edit Tools Properties" dialog box shown below.



Name: shell

Command: C:\Program Files\Crossbow\MoteWorks S

Folder:

Parameters: "%d" "C:\Program Files\Crossbow\MoteV

Shortcut: F6

Save: None

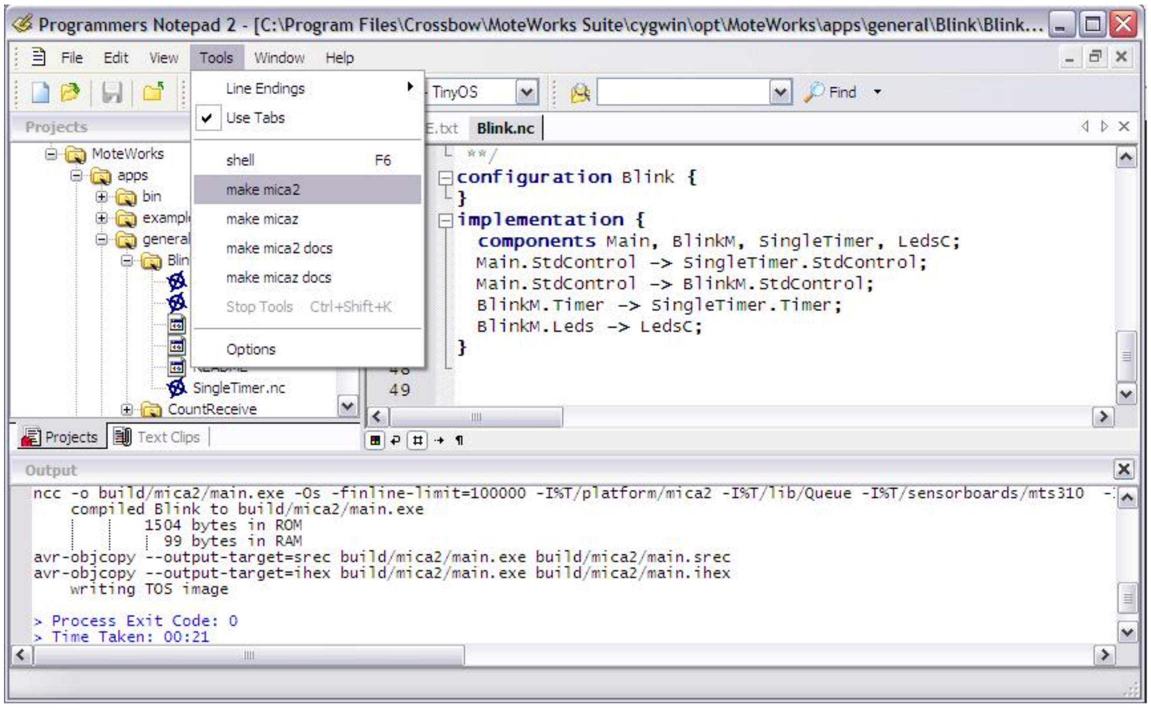
Special Symbols:

Text	Meaning	Example
%f	File Name	mainfrm.cpp
%n	File Name (no ext)	mainfrm
%l	Current Line Number	232
%?	Ask for parameters	(?)
%p	Current Project File	pn.pnproj
%d	Path of File	c:\source\pn\test\
%c	Column	12

5. If your MoteWorks Suite was installed under a directory different from default
   - Change Command: to point to correct Programmer's Notepad directory.
   - Change Parameters: to point to correct MoteWorks directory.

   Repeat the above step for other Tools (eg **make mica2**, **make micaz** etc.)

6. Open a nesC file within an application directory (eg. *Blink.nc*), and click on **Tools > make mica2** or **make micaz.** You can also execute the shell commands by clicking on **Tools > shell** and then typing the command in the dialog box.



```
configuration Blink {
}
implementation {
  components Main, BlinkM, SingleTimer, LedsC;
  Main.StdControl -> SingleTimer.StdControl;
  Main.StdControl -> BlinkM.StdControl;
  BlinkM.Timer -> SingleTimer.Timer;
  BlinkM.Leds -> LedsC;
}
```

```
ncc -o build/mica2/main.exe -Os -finline-limit=100000 -I%T/platform/mica2 -I%T/lib/Queue -I%T/sensorboards/mts310  -:
    compiled Blink to build/mica2/main.exe
            1504 bytes in ROM
              99 bytes in RAM
avr-objcopy --output-target=srec build/mica2/main.exe build/mica2/main.srec
avr-objcopy --output-target=ihex build/mica2/main.exe build/mica2/main.ihex
    writing TOS image

> Process Exit Code: 0
> Time Taken: 00:21
```

7. Double click any errors in the Output window displayed in purple to warp to file and line number.

◀ **NOTE:** You need to be in the .nc of the app file you want to compile and program before you can execute shell commands from Programmer's Notepad.

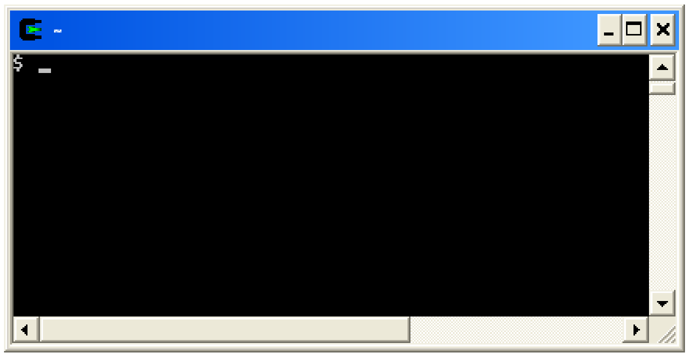
3.2 Cygwin

Cygwin is a Unix/Linux emulation environment for Microsoft Windows. It consists of two parts:

1. A DLL (cygwin1.dll) which acts as a Linux API emulation layer providing substantial Linux API functionality.

2. A collection of tools, which provide a Linux look and feel.

The Cygwin tools are ports of the popular GNU development tools for Microsoft Windows. Cygwin is an optional user interface for compiling and downloading Mote applications in *MoteWorks*. The Cygwin shell can be started by double clicking on the icon located on your desktop. You should see a new command prompt window similar to the following.



```
$ _
```

More details on Cygwin are provided in Appendix A.

3.3 Setting Aliases

Once you have successfully installed *MoteWorks*, it is recommended that you setup aliases to commonly used commands and accessed directories. Aliases are to be edited at the bottom of the filed called *profile* which is located in ***<install dir> /cygwin/etc/***.

These aliases are useful for quickly changing to commonly used directories while in the *Cygwin* shell. Although some the aliases appear as two lines, all are written as one line.

```
alias cdMoteWorks="cd <install dir>/cygwin/opt/MoteWorks"
alias cdtools="cd <install dir>/cygwin/opt/MoteWorks/tools"
alias cdapps="cd <install dir>/cygwin/opt/MoteWorks/apps"
```

NOTE: If the *<install dir>/* is the folder *Program Files*, then you must enter in the text **Program\ Files** to correctly handle the space between the two words when changing directories in *Cygwin*. To go to the root of the Cygwin directory, just type ***/opt*** instead of the complete path.

To create your own aliases, use the format shown in the examples above.

3.4 Compiling *MoteWorks* Applications

The syntax for compiling (building) application code in a Cygwin window is of the form:

```
make <platform>
```

The name to be used for ***<platform>*** can be found in Table 7-1.

Table 3-1. Listing of Hardware Platforms (*<platform>*)

Processor/Radio Platform	For ***<platform>*** use
MICAz (MPR2400 series)	**micaz**
MICA2 (MPR4x0 series)	**mica2**
MICA2DOT (MPR5x0 series)	**mica2dot**

3.5 Programming Boards

The *MoteWorks* development environment supports a variety of programming tools. The ones that are mentioned or described in this Guide are.

1. The MIB510CA serial port programming board
2. The MIB520CA USB port programming board
3. The MIB600CA Ethernet port programming board.

Table 3-2. Listing of Mote Interface Board ("MIB") Programming Boards (`<programmer>`)

MIB Board	For *`<programmer>`* use
MIB510	**`mib510`**
MIB520	**`mib520`**
MIB600	**`eprb`**

The standard programming software used in *MoteWorks* is the Micro (the Greek letter "µ") In-System Programmer or UISP. This program takes various arguments according to the programmer hardware and the particular programming action desired (erase, verify, program, etc.). To simplify using this tool, the *MoteWorks* environment invokes UISP with the correct arguments whenever you issue an **`install`** or **`reinstall`** command. You also need to specify the type of device you are using and how to communicate with it. This is done using environment variables.

3.5.1 MIB510/Serial Port Programmers

Append the default command line with **`mib510,com<x>`** where **`<x>`** is the serial port number where the MIB510 is attached. Before running this command check your system for available ports.

☑ EXAMPLE—Command Line Entry for MIB510

This example is for programming a MICAz from a MIB510 that is connected to a PC's serial port COM1.

```
make micaz install mib510,com1
```

NOTE: If your computer does not have a DB9 serial port and are using a USB to DB9 serial port converter, you must know what port (COM) number your computer has assigned to the USB port. Use that COM port number when doing the above command. However, there are cases where your computer will issue a COM port number but is not what *Cygwin* will communicate through. That is, by trial and error you will have to try different numbers for the COM port.

3.5.2 MIB520 USB Programmers

MIB520 uses the FTDI FT2232C to use the USB port as a virtual COM port. Hence you need to install FT2232C VCP drivers.

- When you plug a MIB520 into your PC for the first time, Windows detects and reports it as a new hardware. Please select "Install from a list or specific location (Advanced)" and browse to "MIB520 Drivers" folder of the *MoteWorks* CDROM. The install shield wizard will guide you through the installation process.

- When the drivers are installed, you will see two serial ports added under the Control Panel>System>Hardware>Device Manager>Port. Make a note of the assigned COM port numbers.
- The two virtual serial ports for MIB520 are com$_x$ and com$_{(x+1)}$; com$_x$ is for Mote programming and com$_{(x+1)}$ is for Mote communication.

Append the default command line with **`mib520,com<x>`** where **`<x>`** is the COM port number to which the MIB520 is attached. Before running this command check and verify your PC to see which ports are available.

☑ EXAMPLE—Command Line Entry for MIB520

This example is for programming a MICAz from a MIB520 that is connected to a PC's serial port COM7.

```
make micaz install mib520,com7
```

3.5.3 MIB600 Ethernet Programmers

You can (re)program Motes through a LAN by using the MIB600 Ethernet programming board. As the previous sentence suggests, the MIB600 is also known as the "eprb" (Ethernet program board).

Prior to using to using the MIB600, you either need to know or to assign an IP address to it. (Every device connected to an IP network must have a unique IP address.) This address is used to reference the specific unit. Every TCP (Transmission Control Protocol) and UDP (User Datagram Protocol) connection is defined by a destination IP address and a port number.

1. Install Lantronix device installer (*DeviceInstaller36.zip*) from the CD ROM under *MIB600 Device Installer* folder.
2. Connect the MIB600 to the network using RJ-45 Ethernet cable and plug-in the power supply that was included in the packaging. Make sure the Power Switch SW2 is in "5V" position.
3. Click the Start button on the Task Bar and select **Start > Programs > Lantronix > Device Installer > Device Installer.** The *Device Installer* window will open.
4. Click on **Search** button and you will see a list of devices that were found with the IP address and corresponding Hardware address.
5. Select the device that matches the hardware address of your MIB600 board (e.g., 00-20-4A-63-47-31). Click on "Assign IP" and follow the instructions. Note down the IP address.
6. Once you have assigned the IP address of the MIB600, the *Cygwin* command line to program a Mote is

   ```
   make <platform> install eprb,<IP_Address_of_MIB600>
   ```

☑ EXAMPLE—Command Line Entry for MIB600

The following command is for programming a MICA2 Mote on an MIB600 assigned with IP address 192.168.100.123.

```
make mica2 install eprb,192.168.100.123
```

3.6 Installing *MoteWorks* Applications into a Mote

The programming tools also include a method of programming unique node addresses without having to edit the source code directly. To set the node address/ID during program load, the general syntax for installing is:

```
make <platform> re|install,<n> <programmer>,<port>
```

where `<programmer>,<port>` the name of the programmer the port ID or address or number of the host PC to which the programmer is attached, `,<n>` is an optional number (in decimal) to set the node ID or address, and `<platform>` is the type of Mote processor/radio hardware platform.

The difference between **`install`** and **`reinstall`** is explained below.

> **`install`**`,<n>`—compiles the application for the target platform, sets the node ID/address and programs the device (Mote).
>
> **`reinstall`**`,<n>`—sets the node ID/address and downloads the pre-compiled program (into the Mote) **only** and does not recompile. This option is significantly faster.

Assigning a node ID by using the "`,<n>`" is optional and is discussed further in the next subsection.

3.7 Setting the Group ID and Node Address for the Mote Network

The Mote messages contain a group ID in the header, which allows multiple distinct groups of Motes to share the same radio channel. If you want to separate multiple groups of Motes that are on the same radio channel, you need to set the group ID to a unique 8-bit value to filter out those messages. The default group ID is `0x7d`. You can set the group ID by defining the preprocessor symbol `DEFAULT_LOCAL_GROUP` in a *MakeXbowlocal* file which is located in */MoteWorks/apps/* directory. Section 3.8 has information about how to edit a *MakeXbowlocal* file. In addition, the message header carries the destination node number, which is a 16-bit value.

IMPORTANT: Except for decimal numbers **`126`** (the `TOS_UART_ADDR 0x007E)` and **`255`** (the `TOS_BCAST_ADDR 0xFFFF)`, all other values between 0 and 65535 are permissible. The number 0 is **typically** reserved for the base station Mote.

Setting the node address is important when programming Motes for a sensor network (as in Section 3.6. The node address/ID of your Mote is set when you download the application into the Mote. The command line entry is

```
make <platform> re|install,<n> <programmer>,<port>
```

☑ EXAMPLE—MIB510: Assigning a node address/ID of 38 to a MICA2. The MIB510 is on the PC's COM1 serial port.

```
make mica2 install,38 mib510,com1
```

☑EXAMPLE— MIB520: Assigning a node address/ID of 38 to a MICA2. The Virtual COM port of the MIB520 on the PC are COM3 and COM4.

```
make mica2 install,38 mib520,com3
```

☑ EXAMPLE—MIB600: Assigning a node address/ID of 38 to a MICA2. The MIB600's IP address is: 10.1.1.248.

```
make mica2 install,38 eprb,10.1.1.248
```

3.8 The *MakeXbowlocal* file

The *MakeXbowlocal* file provides a convenient way for users to change the local group ID, channel (RX/TX frequency) and RF transmission power.

To use it, double-check that the *Makefil*e in a particular application's top-level directory has the following line:

```
include ../MakeXbowlocal
```

By adding this line in your applications *Makefile* will cause the compiler to include the *MakeXbowlocal* file.

NOTE: The MoteConfig does not read and use the parameters defined in *MakeXbowlocal* and hence they need to be set separately while using MoteConfig.

☑ EXAMPLE

Portions of the *MakeXbowlocal* file located under ***/MoteWorks/apps/***

```
##########################################################################
#
# MakeXbowlocal - Local Defines related to apps in contrib/xbow directory
#
# $Id: MakeXbowlocal,v 1.5 2006/03/29 23:45:49 mturon Exp $
##########################################################################

##########################################################################
# Settings for the the Mote Programmer,
#   If you are using MIB510 and it is connected to COM1
#   of your PC use the following setting
#   For MIB600 use "eprb" setting and provide the hostname/IP address
###########################################################################
#DEFAULT_PROGRAM=mib510
#DEFAULT_PROGRAM=mib520
#DEFAULT_PROGRAM=eprb
#MIB510=COM1
#MIB520=COM5
#EPRB=10.1.1.238
```

Programming Board Option

```

# Automatically add certain command-line goals:
# GOALS += basic
# GOALS += group,125
# GOALS += freq,903

###########################################################################
# set Mote group id
# - default mote group
###########################################################################
#DEFAULT_LOCAL_GROUP=0x7D
```

Group ID Selection

```
###########################################################################
# set radio channel (freq)
#   -Uncomment ONLY one line to choose the desired radio operating freq.
#   -Select band based on freq label tag on mote (916,433..)
#    (i.e. 433Mhz channel will not work for mote configured for 916Mhz)
###########################################################################
#
# 916 MHz Band
#
# CHANNEL_00 - 903 MHz     CHANNEL_02 - 904 MHz     CHANNEL_04 - 905 MHz
# CHANNEL_06 - 906 MHz     CHANNEL_08 - 907 MHz     CHANNEL_10 - 908 MHz
# CHANNEL_12 - 909 MHz     CHANNEL_14 - 910 MHz     CHANNEL_16 - 911 MHz
# CHANNEL_18 - 912 MHz     CHANNEL_20 - 913 MHz     CHANNEL_22 - 914 MHz
# CHANNEL_24 - 915 MHz     CHANNEL_26 - 916 MHz     CHANNEL_28 - 917 MHz
# CHANNEL_30 - 918 MHz     CHANNEL_32 - 919 MHz     CHANNEL_34 - 920 MHz
# CHANNEL_36 - 921 MHz     CHANNEL_38 - 922 MHz     CHANNEL_40 - 923 MHz
# CHANNEL_42 - 924 MHz     CHANNEL_44 - 925 MHz     CHANNEL_46 - 926 MHz
# CHANNEL_48 - 927 MHz
#
```

```
#  Original Channels defined by TinyOS 1.1.0
# CHANNEL_100 - 914.077 MHz     CHANNEL_102 - 915_988 MHz
#
#-----------------------------------------------------------------------
#RADIO_CLASS   = 916                  RF Band Selection
#-----------------------------------------------------------------------
#RADIO_CHANNEL = 00
#RADIO_CHANNEL = 02
#RADIO_CHANNEL = 04
……                                    RF Channel Selection
……
……
#RADIO_CHANNEL = 102
#--------------------------------------------------------------------------


#--------------------------------------------------------------------------
# 868 MHz Band
#
# CHANNEL_00 - 869 MHz     CHANNEL_02 - 870 MHz
#
#
#--------------------------------------------------------------------------
#RADIO_CLASS   = 868
#--------------------------------------------------------------------------
#RADIO_CHANNEL = 00
#RADIO_CHANNEL = 02
#--------------------------------------------------------------------------



#--------------------------------------------------------------------------
# 433 MHz Band
#
# CHANNEL_00 - 433.113 MHz     CHANNEL_02 - 433.616 MHz
# CHANNEL_04 - 434.108 MHz     CHANNEL_06 - 434.618 MHz
#
#  Original Channels defined by TinyOS 1.1.0
# CHANNEL_100 - 433.002 MHz    CHANNEL_102 - 434.845 MHz
#
#--------------------------------------------------------------------------
```

```
#RADIO_CLASS   = 433
#---------------------------------------------------------------------------
#RADIO_CHANNEL = 00
#RADIO_CHANNEL = 02
#RADIO_CHANNEL = 04
#RADIO_CHANNEL = 06
#RADIO_CHANNEL = 100
#RADIO_CHANNEL = 102
#---------------------------------------------------------------------------

#---------------------------------------------------------------------------
# 315 MHz Band
#
# CHANNEL_00 - 315 MHz
# Original Channels co-efficients defined by TinyOS 1.1.0
# CHANNEL_100 - 315.178 MHz
#---------------------------------------------------------------------------
#RADIO_CLASS   = 315
#RADIO_CHANNEL = 00
#RADIO_CHANNEL = 100
#---------------------------------------------------------------------------

###########################################################################
# MICA2 Family Radio Power
#  - Radio transmit power is by a value (RTP) between 0x00 and 0xFF
#  - RTP = 0 for least power; =0xFF for max transmit power
#--------------------------------------------------------------------------
#  For Mica2 and Mica2Dot
#  Freq Band:  Output Power(dBm) RTP
#  916 Mhz     -20               0x02
#              -10               0x09
#               0 (1mw)          0x80
#               5                0xFF
#  433 Mhz     -20               0x01
#              -10               0x05
#               0 (1mw)          0x0F
#               10               0xFF
#
# Uncomment the line for the required Power Setting
```

RF Power Selection

```
##########################################################################
#RADIO_POWER=0xFF
#RADIO_POWER=0x0F
#RADIO_POWER=0x09
#RADIO_POWER=0x05
#RADIO_POWER=0x02
#RADIO_POWER=0x01
#########################################################
#
# Zigbee Channel Selection
# CHANNEL_11 - 2405 MHz    CHANNEL_12 - 2410 MHz    CHANNEL_13 - 2415 MHz
# CHANNEL_14 - 2420 MHz    CHANNEL_15 - 2425 MHz    CHANNEL_16 - 2430 MHz
# CHANNEL_17 - 2435 MHz    CHANNEL_18 - 2440 MHz    CHANNEL_19 - 2445 MHz
# CHANNEL_20 - 2450 MHz    CHANNEL_21 - 2455 MHz    CHANNEL_22 - 2460 MHz
# CHANNEL_23 - 2465 MHz    CHANNEL_24 - 2470 MHz    CHANNEL_25 - 2475 MHz
# CHANNEL_26 - 2480 MHz
#
# 15, 20, 25 & 26 seem to be non-overlapping with 802.11
#########################################################
#RADIO_CHANNEL=11
#RADIO_CHANNEL=12
……
……
……
#RADIO_CHANNEL=24
#RADIO_CHANNEL=25
#RADIO_CHANNEL=26

##############################################
#
# MICAZ RF Power Levels
#
#TXPOWER_MAX      TXPOWER_0DBM
#TXPOWER_0DBM     0x1F   //0dBm
#TXPOWER_M1DBM    0x1B   //-1dBm
#TXPOWER_M3DBM    0x17   //-3dBm
#TXPOWER_M5DBM    0x13   //-5dBm
#TXPOWER_M7DBM    0x0F   //-7dBm
#TXPOWER_M10DBM   0x0B   //-10dBm
```

```
#TXPOWER_M15DBM   0x07   //-15dBm
#TXPOWER_M25DBM   0x03   //-25dBm
#TXPOWER_MIN      TXPOWER_M25DBM
##########################################

#RADIO_POWER=TXPOWER_MAX
#RADIO_POWER=TXPOWER_M0DBM
#RADIO_POWER=TXPOWER_M3DBM
#RADIO_POWER=TXPOWER_M5DBM
#RADIO_POWER=TXPOWER_M10DBM
#RADIO_POWER=TXPOWER_M15DBM
#RADIO_POWER=TXPOWER_M25DBM
#RADIO_POWER=TXPOWER_MIN
```

3.9 Radio Frequencies

The radio transceivers on the MICAz, MICA2, and MICA2DOT support multiple frequencies. Units are delivered at a pre-defined channel in 315 MHz, 433 MHz, 915 MHz, or 2.4 GHz ISM bands. All of the coefficients for radio tuning for the MICA2 and MICA2DOT are contained in the TinyOS file *CC1000Const.h* located in ***/MoteWorks/tos/platform/mica2/***.

Users must compile in the correct base radio frequency to prevent radio communication failure. The best and safest way to make sure you're compiling for the correct frequency for any Mote platform is to edit the *MakeXbowlocal* file (described in Section 3.8 above).

3.10 Automated Build Tools

MoteWorks offers several automated tools to simplify the compilation process.

3.10.1 build

This command is similar to make, but filters out the compile output to highlight only error messages and warnings.

```
      $ build micaz
          compiling Blink to a micaz binary
          compiled Blink to build/micaz/main.exe
                  1546 bytes in ROM
                    99 bytes in RAM
```

3.10.2 Buildall

This command performs an automated build of all applications under that application folder.

```
      $ buildall -?
      $Id: buildall,v 1.8 2006/02/11 02:11:57 mturon Exp $
      Usage: buildall [OPTION]...

       --cvs      Updates latest source code from cvs.
       --docs     Runs nesdoc in addition to normal build.
```

```
        --summary  Shows running summary.
```

3.11 Mote Programming Tools

MoteWorks also offers several automated tools to simplify the Mote programming process.

3.11.1 flash

This command flashes an image onto the Mote. The image filename must be specified in the first argument. The Node ID and COM port arguments are optional, and default to node id 1 and COM1. It only works with MIB510 and MIB520 programming interface boards.

```
       $ flash
         Usage: flash [image] [nodeid] [port]

       $ flash main.exe 1 /dev/ttyS0
       FLASH main.exe as node 1 to /dev/ttyS0

       avr-objcopy --output-target=srec build build
       avr-objcopy: build: File format not recognized

       set-mote-id build build-1 1

      uisp -dprog=mib510 -dpart=ATmega128 -dserial=/dev/ttyS0 --wr_fuse_h=0xd9 --wr_fu
       se_e=ff  --erase --upload if=build-1
```

3.11.2 flashall

This command flashes an image onto a test bed of Motes. It works with MIB510, MIB520, or MIB600 interface boards.

```
       $ flashall
       Usage:        flashall image_file < port_list
       Description:
           Will flash [image_file] to all ports passed in [port_list] file.
           [port_list] is a text file where each line is one of:
                /dev/tty# or /dev/ttyS#, or ip ###.###.###.###
           First line will be assigned node id == 0.
           All remaining lines will be assigned node id == ###.
```

3.11.3 fuses

This command allows the user to read or write the fuse settings of the Mote on the programming interface board.

```
       $ fuses

       fuses Ver:$Id: fuses,v 1.1 2005/03/01 17:24:19 jprabhu Exp $

         Usage: fuses [command] [port] [args]

           read     = read fuses

           clkint   = set to internal oscillator

           clkext   = set to external oscillator

           jtagen   = enable JTAG

           jtagdis  = disable JTAG

        Command  Flag

        -------  ------------------------------------------------------------

         clkext  --wr_fuse_l=0xff
         clkint  --wr_fuse_l=0xc4
        jtagdis  --wr_fuse_h=0xd9
         jtagen  --wr_fuse_h=0x19
           read  --rd_fuses
```

3.11.4 motelist

This command lists MIB520 and Telos devices attached to the USB port.

3.12 TinyOS Interoperability and Tree Management

Users can interoperate between the prior versions of TinyOS (such as 1.1.10) and *MoteWorks*. Several commands are provided to conveniently switch back and forth between TinyOS and *MoteWorks* trees.

3.12.1 gettos

This command allows the user to see how their current TinyOS environment is configured.

```
$ gettos
TOSDIR=/opt/MoteWorks/tos
TOSROOT=/opt/MoteWorks
MAKERULES=/opt/MoteWorks/make/Makerules
total 1
drwx------+  2 mturon  0 Feb  3 13:15 CVS
-rwx------+  1 mturon 77 Feb  3 13:15 README.txt
drwx------+  9 mturon  0 Jan 27 08:45 apps
drwxr-xr-x+  3 mturon  0 Feb  8 12:14 doc
drwx------+  8 mturon  0 Feb  3 15:51 make
drwx------+ 12 mturon  0 Feb 14 17:34 tools
drwx------+ 10 mturon  0 Jan 12 01:21 tos
```

3.12.2 settos

The user can switch to a new MoteWorks tree by changing the symbolic link. Both trees maintain the same ***/opt/MoteWorks*** root, but the users can maintain two versions, the 2.0 Standard release and a 2.1 Enterprise developer tree for example. The first time you run this command, it will rename your current MoteWorks tree to the specified version.

```
$ settos 2.0
 Warning: /opt/MoteWorks directory moved to /opt/MoteWorks.2.0
 Warning: /opt/MoteWorks will be made into a symbolic link
 Set TinyOS tree to: /opt/MoteWorks.2.0

 $ settos 2.1
 Set TinyOS tree to: /opt/MoteWorks.2.1
```

3.12.3 usetos

This command allows the users to switch between *MoteWorks* and a legacy TinyOS 1.x environment.

`usetos`	- switch to MoteWorks

`usetos tinyos`	- switch to TinyOS 1.x
`usetos tinyos-2.x`	- switch to TinyOS 2.x

The following command shell session shows switching to a TinyOS 2.x environment, and back into *MoteWorks*.

```
$ `usetos tinyos-2.x`

$ gettos
TOSDIR=/opt/tinyos-2.x/tos
TOSROOT=/opt/tinyos-2.x
MAKERULES=/opt/tinyos-2.x/support/make/Makerules
total 5
drwx------+  2 mturon    0 Feb 16 23:50 CVS
-rwx------+  1 mturon  156 Feb 16 23:49 README
drwx------+ 12 mturon    0 Feb 16 23:50 apps
drwx------+  7 mturon    0 Feb 16 23:49 doc
-rwx------+  1 mturon 2635 Mar  9  2005 overall-todo.txt
drwx------+  5 mturon    0 Jan 20 12:13 support
drwx------+  6 mturon    0 Feb 16 23:50 tools
drwx------+ 11 mturon    0 Feb 16 23:50 tos

$ `usetos`

$ gettos
TOSDIR=/opt/MoteWorks/tos
TOSROOT=/opt/MoteWorks
MAKERULES=/opt/MoteWorks/make/Makerules
lrwxrwxrwx  1 mturon 18 Feb 17 17:52 /opt/MoteWorks -> /opt/MoteWorks.2.1
```

3.13 Compiling Utilities

MoteWorks offers several compilation utilities.

3.13.1 make

This command allows users to compile their nesC code with several options directly from the command line (such as *XMesh* power mode, group ID, radio frequency).

```
make <platform>
       <route,hp|lp|elp>
       <group,125>
       <freq,315|433|433.5|434|434.5|903|904|926|2405|2420|2445>
```

3.13.2 mote-mem

This utility displays memory usage of compiled firmware by module. Usage is broken down by Program ROM, Constants RAM, and Heap RAM.

```
$ mote-mem build/micaz/main.exe
Module Memory Usage: AVR binary file "build/micaz/main.exe"

 1542 bytes of Program ROM allocated
 1340 bytes of Program ROM used
  202 bytes of Program ROM wasted
usage by module:
     164  HPLPowerManagementM
      62  TOS_post
     518  TimerM
       4  __nesc_atomic_end
       8  __nesc_atomic_start
     176  __vector_15
     408  main
```

```
          4 bytes of Constants RAM allocated
          4 bytes of Constants RAM used
          0 bytes of Constants RAM wasted
      usage by module:
             1  HPLPowerManagementM
             1  TOS_DATA_LENGTH
             1  TOS_PLATFORM
             1  TOS_ROUTE_PROTOCOL

         95 bytes of Heap RAM allocated
         95 bytes of Heap RAM used
          0 bytes of Heap RAM wasted
      usage by module:
             4  HPLClock
             1  LedsC
             1  PotM
            64  TOSH_queue
             1  TOSH_sched_free
             1  TOSH_sched_full
             1  TOS_BASE_STATION
            22  TimerM
```

3.13.3 treediff

This utility displays source differences between two different applications.

3.14 XSniffer

XSniffer is a Crossbow-developed tool that allows users to monitor multi-hop communication over *XMesh*. This program runs on a PC and uses a MICA2 or MICAz Mote to monitor the RF packet traffic. The following applications are required to run *XSniffer*:

1. *XSniffer* TinyOS code: This code can be built for either a MICA2 or MICAz running on a Crossbow MIB510 or MIB520 base station. The source code is located under

   /MoteWorks/apps/general/XSniffer
2. *XSniffer* GUI which installs and runs on the PC. The executables are installed in ***C:/ Crossbow/XSniffer***.

NOTE: *XSniffer* is set for a group ID=0 and TOS_LOCAL_ADDRESS = 0xff00 so that it will never return an acknowledgement for any radio packet meant for another mote.

3.14.1 Building and Starting XSniffer

In the ***/MoteWorks/apps/general*** directory, build and install the application for the correct platform. For a MICAz and a MIB510 the command would be

```
make install micaz mib510,/dev/ttyS0
```

⚠ **WARNING:** *XSniffer* does not run *XMesh*. Do not use route,hp2 or route,lp2 variables when building. *XSniffer* uses TOSH_DATA_LENGTH = 64 which should accommodate the largest user data packets.

Open the *XSniffer* GUI, select the correct COM port and START. Network messages should appear in the Log tab.

3.14.2 Using XSniffer

XSniffer can be used to monitor the behavior of the mesh. It will display all radio messages overheard within its radio range. Use *XSniffer* to:

- Check to see if a mote has joined the mesh. When this happens the health and data packets will change from a broadcast address to either the base station address or the address of another parent.
- Monitor the packet sequence numbers of individual mote radio packets.
- Monitor downstream radio communication from the base station.
- Monitor radio message retries.
- Monitor route update and time synchronization messages.

For more details on *XSniffer*, refer to *XMesh* User's manual.

4 Introduction to TinyOS and nesC

In this chapter you will be introduced to:

- Introduction to TinyOS and programming philosophy
- Introduction to nesC language

4.1 TinyOS

TinyOS is an open-source operating system designed for wireless embedded sensor networks. It features a component-based architecture, which enables rapid innovation and implementation while minimizing code size as required by the severe memory constraints inherent in sensor networks. TinyOS's component library includes network protocols, distributed services, sensor drivers, and data acquisition tools—all of which can be used as-is or be further refined for a custom application. TinyOS's event-driven execution model enables fine-grained power management yet allows the scheduling flexibility made necessary by the unpredictable nature of wireless communication and physical world interfaces.

TinyOS is not an operating system ("OS") in the traditional sense; it is a programming framework for embedded systems and set of components that enable building an application-specific OS into each application. The reason for this is to ensure that the application code has an extremely small memory foot print. In addition TinyOS is designed to have no file system, supports only static memory allocation, implement a simple task model, and provide minimal device and networking abstractions.

TinyOS has a component-based programming model (codified by the nesC language). Like other operating systems, TinyOS organizes its software components into layers. The lower the layer the closer it is to the hardware; the higher the component, the closer it is to the application. A complete TinyOS application is a graph of components, each of which is an independent computational entity.

Components have three computational concepts: 1) commands, 2) events, and 3) tasks. Commands and events are mechanisms for inter-component communication, while tasks are used to express intra-component concurrency. A command is typically a request to a component to perform a service. A typical example is starting a sensor reading. By comparison, an event would signal the completion of that service. Events may also be signaled asynchronously, for example, due to hardware interrupts or message arrival. From a traditional OS perspective, commands are analogous to downcalls and events to call backs. Commands and events cannot block. However, a request for a service is split-phase in that the request for service (the command) and the completion signal (the corresponding event) are decoupled. The command returns immediately and the event signals completion at a later time.

Rather than performing a computation immediately, commands and event handlers may post a task, a function executed by the TinyOS scheduler at a later time. This allows commands and events to be responsive, returning immediately while deferring extensive computation to tasks. While tasks may perform significant computation, their basic execution model is run-to-completion, rather than to run indefinitely; this allows tasks to be much lighter-weight than threads. Tasks represent internal concurrency within a component and may only access state information within that component. The TinyOS scheduler uses a non-preemptive, first in, first out ("FIFO") scheduling policy.

A developer composes an application by writing components and wiring them to other TinyOS components that provide implementations of the required services. How developers write components and wire them in nesC is discussed later in this document.

4.1.1 TinyOS Programming philosophy

The TinyOS operating system, libraries, and applications are all written in nesC, a new structured component-based language. The nesC language is primarily intended for embedded systems such as sensor networks. The nesC has a C-like syntax, but supports the TinyOS concurrency model, as well as mechanisms for structuring, naming, and linking together software components into robust network embedded systems. The principal goal is to allow application designers to build components that can be easily composed into complete, concurrent systems, and yet perform extensive checking at compile time.

TinyOS also defines a number of important concepts that are expressed in nesC. A brief summary is provided here.

Table 4-1. Description of the Main TinyOS/nesC Concepts

TinyOS/nesC Concept	Description
Application	A TinyOS/nesC application consists of one or more components, linked ("wired") together to form a run-time executable
Component	Components are the basic building blocks for nesC applications. There are two types of components: *modules* and *configurations*. A TinyOS component can provide and use interfaces.
Module	A component that *implements* one or more interfaces.
Configuration	A component that *wires* other components together, connecting interfaces used by components to interfaces provided by others. (This is called **wiring**.) The idea is that a developer can build an application as a set of modules, wiring together those modules by providing a configuration. Furthermore, every nesC application is described by a top-level configuration that specifies the components in the application and how they invoke one another.
Interface	An interface is used to provide an abstract definition of the interaction of two components. This concept is similar to Java in that an interface should not contain code or wiring. It simply declares a set of functions that the interface's provider must implement—commands—and another set of functions the interfaces' requirer must implement—events. In this way it is different than Java interfaces which specify one direction of call. NesC interfaces are bi-directional. For a component to call the commands in an interface it must implement the events of that interface. A single component may require or provide multiple interfaces and multiple instances of the same interface. These interfaces are the *only* point of access to the component.

The nesC also defines a **concurrency model**, based on **tasks** and **hardware event handlers**, and detects **data races** at compile time. When looking at the files in an application directory, you can identify the nesC files because it uses the extension "`.nc`" for all source files—interfaces, modules, and configurations.

4.1.2 Concurrency Model

TinyOS executes only one program consisting of selected system components and custom components needed for a single application. There are two threads of execution: **tasks** and **hardware event handlers**. Tasks are functions whose execution is deferred. Once scheduled, they run to completion and do not preempt one another. Hardware event handlers are executed in response to a hardware interrupt and also run to completion. Unlike a task, it may preempt the execution of a task or other hardware event handler. Commands and events that are executed as part of a hardware event handler must be declared with the *async* keyword.

Because tasks and hardware event handlers may be preempted by other asynchronous code, nesC programs are susceptible to certain race conditions. Races are avoided either by accessing shared data exclusively within tasks, or by having all accesses within **atomic** statements. The nesC compiler reports potential **data races** to the programmer at compile-time. It is possible the compiler may report a false positive. In this case a variable can be declared with the **norace** keyword. The norace keyword should be used with extreme caution.

NesC programming has concepts and keywords which are similar to other languages, notably the C programming language and to some degree Java. This chapter will introduce the underlying concepts and the keywords used to implement those concepts

4.2 The nesC Language

The nesC (network embedded systems C) is an extension to C designed to embody the structuring concepts and execution model of TinyOS. The basic concepts behind nesC are:

4.2.1 Separation of construction and composition

Programs are built out of components, which are assembled ("wired") to form whole programs. Components define two scopes, one for their specification (containing the names of their interface instances) and one for their implementation. Components have internal concurrency in the form of tasks. Threads of control may pass into a component through its interfaces. These threads are rooted either in a task or a hardware interrupt.

4.2.2 Specification of component behavior in terms of set of interfaces

Interfaces may be provided or used by the component. The provided interfaces are intended to represent the functionality that the component provides to its user, the used interfaces represent the functionality the component needs to perform its job.

4.2.3 Interfaces are bidirectional

Interfaces specify a set of functions to be implemented by the interface's provider (commands) and a set to be implemented by the interface's user (events). This allows a single interface to represent a complex interaction between components (e.g. registration of interest in some event, followed by a callback when that event happens). This is critical because all lengthy commands in TinyOS (e.g. send packet) are non-blocking; their completion is signaled through an event (send done). By specifying interfaces, a component cannot call the send command unless it provides an implementation of the `sendDone` event. Typically commands call downwards, i.e., from application components to those closer to the hardware, while events call upwards. Certain primitive events are bound to hardware interrupts (the nature of this binding is system-dependent, so is not described further in this reference manual)

4.2.4 Components are statically linked to each other via their interfaces

This increases runtime efficiency, encourages robust design, and allows for better static analysis of programs.

4.2.5 Use of whole-program compilers

NesC is designed under the expectation that code will be generated by whole-program compilers. This allows for better code generation and analysis. An example of this is nesC's compile-time data race detector.

4.2.6 Tasks and interrupt handlers

The concurrency model of nesC is based on run-to-completion tasks, and interrupt handlers which may interrupt tasks and each other. The nesC compiler signals the potential data races caused by the interrupt handlers.

For more details on TinyOS and nesC programming concepts, refer to the "TinyOS/nesC Reference Manual" by Phil Levis included on the *MoteWorks* CD.

5 First Steps in nesC Programming

In this chapter you will learn:

- The basics of nesC and TinyOS programming
- How to use the Timer and LED components
- How to compile and download an application to a Mote

This first application is called *MyApp*. As the name suggests it uses one of the timers on the ATmega128L Mote. The timer will be set to *fire* continuously every second and the Mote red LED will toggle on and off to show this visually. So why go through the trouble of this program? To help the developer unfamiliar with TinyOS, nesC & Motes gain more confidence in embedded programming concepts before tackling more complex applications.

The steps that you'll take to build the application will be as follows:

- Enter in all necessary code and auxiliary files
- Build (compile) and download the application
- Take a closer look at the code and auxiliary files

5.1 Hardware Requirements

This chapter requires the following hardware:

- One MICA Mote: standard editions of MICA2 (MPR4x0) or MICAz (MPR2400) or OEM editions of MICA2 or MICAz
- One gateway / programming board: MIB510, MIB520, or MIB600 and the associated hardware (cables, power supply) for each
- A Windows PC with *MoteWorks* installed

5.2 A simple nesC program: MyApp

To get started the first thing to do is to create the application folder (directory) where all your application code and other files will be stored.

1. Change into the directory ***/MoteWorks/apps/tutorials/*** and create a new subfolder (subdirectory) that should have the name as your application is to be called. In this first lesson the application will be called MyApp.

2. You have two options to create the source files. You can copy, paste, and rename the subdirectory ***/lesson_1*** found in the ***/tutorials*** subdirectory and avoid some typing. If you choose to do this you can go straight to the compiling and installation step or follow these instructions and learn along the way.

Within the MoteWorks framework a minimum of five files will be in any application's directory:

1. *Makefile* (section 5.2.1)
2. *Makefile.component* (section 5.2.2)
3. Application's configuration written in nesC

4. Application's module written in nesC
5. README (optional)

The *Makefile* and *Makefile.component* are created next.

5.2.1 Makefile

The first step in creating an application is to type in the *Makefile*. Alternatively you can copy and paste this file from the subdirectory ***/lesson_1*** into ***/MyApp*** (both of which are in the ***/tutorials*** subdirectory).

To create the *Makefile*, enter the following text into a new document in Programmer's Notepad:

```
include Makefile.component
include $(TOSROOT)/apps/MakeXbowlocal
include $(MAKERULES)
```

When finished save the file with **File > Save As...** using the following parameters:

File name	Makefile
Save as type	All files (".")
File format	No change to file format

5.2.2 Makefile.component

The next step is to create the *Makefile.component* file. This file describes the top level application component, *MyApp* and the name of the sensorboard we are going to use. The sensorboard reference tells the compiler we want to use the pre-built nesC components for accessing the sensor devices on that board. Each sensorboard has its own set of pre-built nesC sensor components, also referred to as drivers.

To create the *Makefile.component* file, enter the following text into a new document in Programmer's Notepad:

```
COMPONENT=MyApp
SENSORBOARD=mts310
```

When finished save the file with **File > Save As...** using the following parameters:

File name	Makefile.component
Save as type	All files (".")
File format	No change to file format

5.2.3 Create the Top-Level Configuration

The application's configuration is located in the *MyApp.nc* file. The `StdControl` interface must always be implemented as the bare minimum for an application. The `StdControl` interface provides the basic functionality for the TinyOS application to be initialized, started and stopped.

To create the application's configuration, enter the following text into a new document in Programmer's Notepad:

```
/**
 * This configuration shows how to use the Timer and LED components
**/
configuration MyApp {
}
implementation {
  components Main, MyAppM, TimerC, LedsC;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;

  MyAppM.Timer -> TimerC.Timer[unique("Timer")];
  MyAppM.Leds -> LedsC.Leds;
}
```

The last two lines in the configuration wire the `TimerC` and `LedsC` components to the application's module. The module can then control the Timer and LED devices by calling functions in the `TimerC` and `LedsC` components. The concept of component wiring will be fully explained in a later chapter dedicated to NesC/ TinyOS programming concepts.

When finished save the file with **File > Save As...** using the following parameters:

File name	MyApp.nc
Save as type	All files (".")
File format	No change to file format

NOTE: When you do save or save as and use the ".nc" file extension, Programmers Notepad will use the default text coloring and highlighting scheme.

5.2.4 Create the Module

The application's module is located in the *MyAppM.nc* file. The module file is where the application programming code is entered. This is where we type in programming code to start the Timer and toggle the red LED on the Mote.

To create the application's module, enter the following text into a new document using Programmer's Notepad:

```
/**
 * This module shows how to use the Timer and LED components
**/
module MyAppM {
  provides {
    interface StdControl;
  }
  uses {
    interface Timer;
    interface Leds;
  }
}
```

```
implementation {

  /**
   * Initialize the components.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.init() {
    call Leds.init();
    return SUCCESS;
  }

  /**
   * Start things up.  This just sets the rate for the clock
   * component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.start() {
    // Start a repeating timer that fires every 1000ms
    return call Timer.start(TIMER_REPEAT, 1000);
  }

  /**
   * Halt execution of the application.
   * This just disables the clock component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.stop() {
    return call Timer.stop();
  }

  /**
   * Toggle the red LED in response to the <code>Timer.fired</code>
   * event.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  event result_t Timer.fired()
  {
    call Leds.redToggle();
    return SUCCESS;
  }
}
```

When finished save the file with **File > Save As...** using the following parameters:

File name	MyAppM.nc
Save as type	All files (“.”)
File format	No change to file format

5.2.5 Compile and Install the Code in a Mote

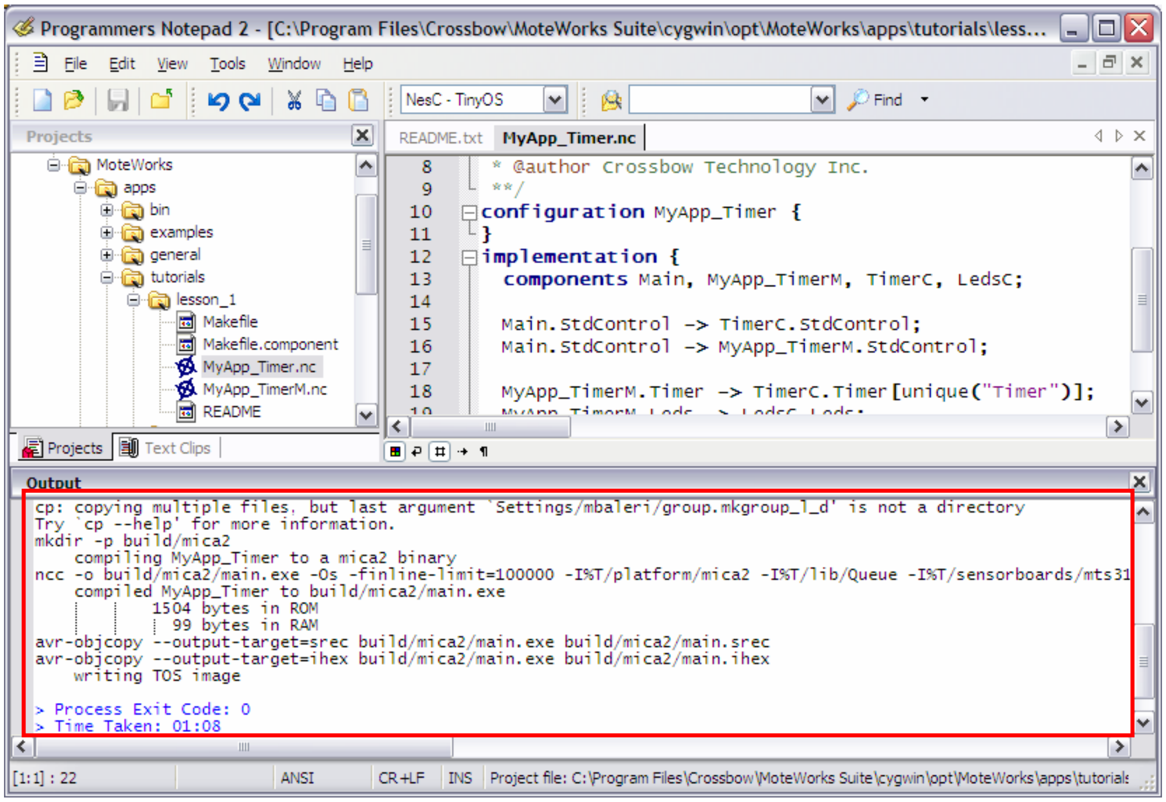
Now that you have edited all the application files or copied over from the ***/lesson_1*** folder, we can proceed with the compilation and installation steps.

> **NOTE:** You need to be in the .nc of the app file you want to compile and program before you can execute shell commands from Programmer's Notepad.

You can compile your nesC application code from Programmer's Notepad.

To compile your application:

- Select **Tools > make mica2** (or **make micaz** or **make mica2dot**)
- The "Output" section of the Programmers Notepad will print the compiling results to the screen:


Programmers Notepad 2 - [C:\Program Files\Crossbow\MoteWorks Suite\cygwin\opt\MoteWorks\apps\tutorials\less...
File Edit View Tools Window Help
NesC - TinyOS
Find
Projects
MoteWorks
apps
bin
examples
general
tutorials
lesson_1
Makefile
Makefile.component
MyApp_Timer.nc
MyApp_TimerM.nc
README
Projects
Text Clips
README.txt
MyApp_Timer.nc
Output
[1:1] : 22
ANSI
CR+LF
INS
Project file: C:\Program Files\Crossbow\MoteWorks Suite\cygwin\opt\MoteWorks\apps\tutorials

```
 * @author Crossbow Technology Inc.
 **/
configuration MyApp_Timer {
}
implementation {
  components Main, MyApp_TimerM, TimerC, LedsC;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyApp_TimerM.StdControl;

  MyApp_TimerM.Timer -> TimerC.Timer[unique("Timer")];
```

```
cp: copying multiple files, but last argument `Settings/mbaleri/group.mkgroup_l_d' is not a directory
Try `cp --help' for more information.
mkdir -p build/mica2
    compiling MyApp_Timer to a mica2 binary
ncc -o build/mica2/main.exe -Os -finline-limit=100000 -I%T/platform/mica2 -I%T/lib/Queue -I%T/sensorboards/mts31
    compiled MyApp_Timer to build/mica2/main.exe
            1504 bytes in ROM
              99 bytes in RAM
avr-objcopy --output-target=srec build/mica2/main.exe build/mica2/main.srec
avr-objcopy --output-target=ihex build/mica2/main.exe build/mica2/main.ihex
    writing TOS image

> Process Exit Code: 0
> Time Taken: 01:08
```

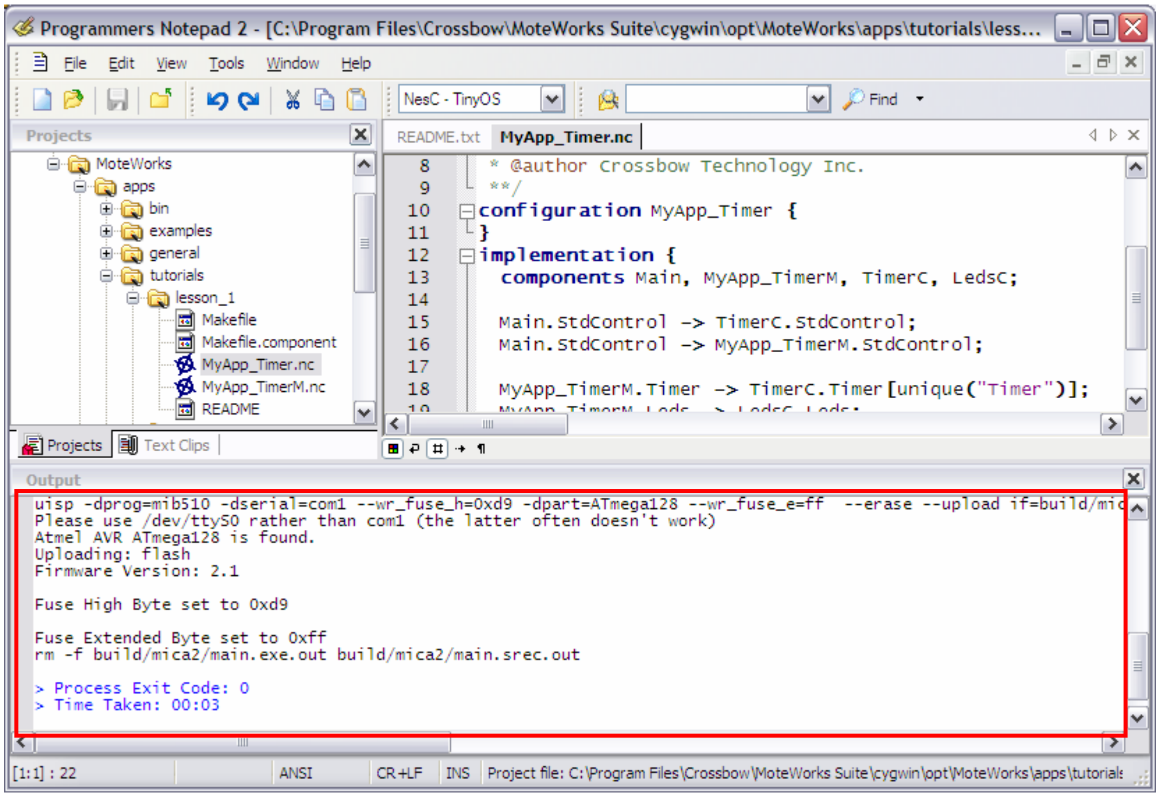
- After the compilation has completed you should see "writing TOS image" as the last line in the Output window. If you don't see this then you have made an error typing in one of your files. Verify your files against the files provided for you in the ***/lesson_1*** folder. Copy them over from the ***/lesson_1*** folder into your folder if you get stuck. Make sure you have success compiling your application before proceeding.

You can also install your application to a Mote plugged into your programming board using Programmer's Notepad. To install your application:

- Select **Tools > shell**. When prompted for parameters, type in **`make mica2 reinstall mib510,com1`** (or **`make micaz reinstall`** or **`make mica2dot reinstall`**)

> **NOTE:** This example assumes you are using an MIB510 programming board connected to your PC using the COM1 serial port. Please make the necessary adjustments if using a different programming board and/or serial port.

- The “Output” section of the Programmers Notepad will print the installation results to the screen:



```
 * @author Crossbow Technology Inc.
 **/
configuration MyApp_Timer {
}
implementation {
  components Main, MyApp_TimerM, TimerC, LedsC;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyApp_TimerM.StdControl;

  MyApp_TimerM.Timer -> TimerC.Timer[unique("Timer")];
```

```
uisp -dprog=mib510 -dserial=com1 --wr_fuse_h=0xd9 -dpart=ATmega128 --wr_fuse_e=ff  --erase --upload if=build/mic
Please use /dev/ttyS0 rather than com1 (the latter often doesn't work)
Atmel AVR ATmega128 is found.
Uploading: flash
Firmware Version: 2.1

Fuse High Byte set to 0xd9

Fuse Extended Byte set to 0xff
rm -f build/mica2/main.exe.out build/mica2/main.srec.out

> Process Exit Code: 0
> Time Taken: 00:03
```

- Make sure you see the “Uploading: flash” line complete without errors. You should then see the red LED on the Mote blinking on and off every second.

Congratulations, you have just written, compiled and installed your first TinyOS embedded application using *MoteWorks*!

5.3 A Closer Look at MyApp

The reason for the distinction between modules and configurations is to allow a developer to quickly "snap together" applications using pre-build components without additional programming. For example, a developer could provide a configuration that simply wires together one or more pre-existing modules. The idea is for developers to provide a set of “library” components that can be re-used in a wide range of applications.

5.3.1 *Makefile and Makefile.component*

What are the *Makefile* and *Makefile.component*? Why do I need to use them? The Makefile is a file containing the dependencies (other files) your application uses during the compilation step. Within *MoteWorks* all Makefiles within a particular application subdirectory (***/xmesh***, ***/xsensor***, ***/examples***, /general, ***/tutorials***) have the same contents. The *Makefile.component* is simply a

MoteWorks convention to describe the particular dependencies for a particular application. The *Makefile.component* is included into the *Makefile* at build time.

5.3.2 Comments

Comments make your code more readable. They help explain your code to others, and can be a reminder to yourself when you need to modify the code. nesC programming supports the following type of comments. If you use Programmers Notepad to edit nesC code, you'll find that these comments are highlighted in green text.

`/* text */`

The compiler ignores everything from the opening `/*` to the closing `*/`.

`/** documentation */`

This style indicates a documentation comment that is used by automatic documentation utilities such as *GraphViz*. As with the first kind of comment, the compiler ignores all the text in the comment.

`// text`

The compiler ignore everything from the // to the end of the line.

The green parts in the following code are comments:

```
configuration MyApp {
   // This configuration provides no interfaces
}

implementation {
   components Main, My App_TimerM, TimerC;

   Main.StdControl -> MyAppM.StdControl;
   Main.StdControl -> MyAppC.StdControl;
   MyApp.Timer -> TimerC.Timer[unique("Timer")];
}
```

5.3.3 Defining an Application's Configuration

The nesC compiler, ncc, compiles an application when given the file containing the top-level configuration. The *Makefile* in the applications directory invokes nesC with appropriate options or dependencies on the application's top-level configuration.

All applications require a top-level configuration file, which is typically named after the application itself. In this case `MyApp.nc` is the configuration for the *MyApp* application and the source file that the nesC compiler uses to generate an executable file. On the other hand `MyAppM.nc` actually provides the functionality of the *MyApp* application. As you might guess, *`MyApp.nc`* is used to wire the *MyAppM.nc* module to other components that are required by the *MyApp* application.

Let's examine the initial lines of the *MyApp* application. The first thing to notice is the key word `configuration` (in **`boldface`**) which indicates that this is a nesC configuration (as opposed to a nesC module)

```
configuration MyApp {
```

```
// this module does not provide any interface
}

implementation {
 …
```

These lines simply state that the name of the configuration is called `MyApp`. A *configuration* is one of two types of components defined by nesC. The general form for a configuration is shown in the code example below.

```
configuration ComponentName {
       //Configuration definition block which may or may not have
       //interfaces.

}
```

The interfaces that are used or provided are enclosed by the braces that begin and end the configuration definition block.

NOTE: Since the `MyApp` configuration doesn't provide or use any interfaces, there is no text (other than perhaps a comment).

As the name suggestions a configuration is an assembly of other components that are connected together using a symbolic syntax that defines how components are related to one another. This is commonly called component *wiring* where one component is wired to another.

Let's take a look at the lines below the configuration code block.

```
…
implementation {
  components Main, MyApp;

  Main.StdControl -> MyAppM.StdControl;

}
```

The next keyword to note is `implementation`. As implied the code block defined by implementation defines the wiring of components. The "connecting points" for the wiring is defined by a component's interface, which will be discussed in more detail later. Following the keyword `component` is a list of nesC components that are referenced by the configuration. In this example the components are `Main` and `MyAppM.`

The line

```
 Main.StdControl -> MyAppM.StdControl;
```

wires the `StdControl` interface in `Main` to the `StdControl` interface in `MyAppM`. `MyAppM.StdControl.init()` will be called by `Main.StdControl.init()`. The same rule applies to the `start()` and `stop()` commands.

Concerning `used` interfaces, it is important to note that subcomponent initialization functions must be explicitly called by the using component. For example, the `MyAppM` module uses the interface `Leds`, so `Leds.init()` is called explicitly in `MyAppM.init()`.

The nesC uses arrows to determine relationships between interfaces. Think of the right arrow "->" as "binds to". The left side of the arrow binds an interface to an implementation on the right side. In other words, the component that **uses** an interface is on the left, and the component **provides** the interface is on the right.

The line

```
MyAppM.Timer -> TimerC.Timer[unique("Timer")];
```

is used to wire the `Timer` interface used by `MyAppM` to the `Timer` interface provided by `TimerC.` `MyAppM.Timer` on the left side of the arrow is referring to the *interface* called Timer (***/MoteWorks/tos/interfaces/Timer.nc***), while `TimerC.Timer` on the right side of the arrow is referring to the *implementation* of Timer. Remember that the arrow always binds interfaces (on the left) to implementations (on the right). The `unique("Timer")` statement makes certain we are using a timer instance not used anywhere else in the application – more on that later.

nesC supports multiple implementations of the same interface. The `Timer` interface is such an example. The `TimerC` implements multiple timers using timer id as a parameter.

Wirings can also be implied. For example,

```
MyAppM.Leds -> LedsC;
```

is really shorthand for

```
MyAppM.Leds -> LedsC.Leds;
```

In this example, the interface named `Leds` was not explicitly listed. Since no interface name is given on the right side of the arrow, the nesC compiler by default tries to bind to the same interface as on the left side of the arrow.

5.3.4 *The component* `main:` *The scheduler*

Conceptually a TinyOS application is a collection of components and a scheduler called `Main`. The components typically provide some computation or function and the scheduler runs the tasks created by those components. The code for `Main` is shown below.

```
configuration Main {
  uses interface StdControl;
}
implementation
{
  components RealMain, PotC, HPLInit;

  StdControl = RealMain.StdControl;
  RealMain.hardwareInit -> HPLInit;
  RealMain.Pot -> PotC;
}
```

`Main` is a component that is executed first in a TinyOS application. To be precise, the `Main.StdControl.init()` command is the first command executed in TinyOS followed by `Main.StdControl.start()`. Therefore, a TinyOS application must have the `Main` component in its configuration. `StdControl` is a common interface used to initialize and start TinyOS components.

5.3.5 The MyAppM module

In the minimum case, an applications module looks something like this:

```
module ModuleName {
   provides {
      interface StdControl;
   }
}

implementation {
   command result_t StdControl.init() {
      return SUCCESS;
   }
   command result_t StdControl.start() {
      return SUCCESS;
   }
   command result_t StdControl.stop() {
      return SUCCESS;
   }
}
```

While this module is not very useful, we'll use it for instructional purposes. Let's have a look at the `StdControl` interface (in ***/MotwWorks/tos/interfaces/StdControl.nc***) before going back to discussing the rest of the application, as it is a very common interface in nesC programming.

```
interface StdControl {
  command result_t init();
  command result_t start();
  command result_t stop();
}
```

We see that `StdControl` defines three commands: `init()`,`start()`, and `stop()`. `init()` is called when a component is first initialized, and `start()` when it is started, that is, actually executed for the first time. `stop()` is called when the component is stopped, for example, in order to power off the device that it is controlling. `init()` can be called multiple times but will *never* be called after either `start()` or `stop()` are called. Specifically, the valid call patterns of `StdControl` are `init`*(`start` | `stop`)*. All three of these commands have "deep" semantics; calling `init()` on a component must make it call `init()` on all of its subcomponents.

Now let's look further into the module `MyAppM.nc`. In many nesC applications, it is common to call a function periodically. The realization of that function is done by means of a timer. The name for the interface for a timer is, conveniently enough `Timer`.

```
**
 * Implementation for MyApp application. This is
 * just a shell of an application that wires in the Timer
 * module.
 **/
```

```
module MyAppM {
  provides {
    interface StdControl;
  }
  uses {
    interface Timer;
  }
}
```

The first part of the code states that this is a module called `MyAppM` and declares the interfaces which are prefaced by the keywords `provides` and `uses`. The `MyAppM` module provides the interface `StdControl`. This means that `MyAppM` must implement the `StdControl` interface. As explained above, this is necessary to get the `MyApp` component initialized and started.

The `MyAppM` module may call any command declared in the interfaces it uses and must also implement any events declared in those same interfaces.

`Timer.nc` is a little more interesting than `StdControl`:

```
interface Timer {
  command result_t start(char type, uint32_t interval);
  command result_t stop();
  event result_t fired();
```

Here we see that `Timer` interface defines the `start()` and `stop()` commands, and the `fired()` event. The nesC word `result_t` is the data type of the status value returned by the command or event. This returned status value can have one of two values: `SUCCESS` or `FAIL`.

The `start()` command is used to specify the type of the timer and the interval at which the timer will expire. The unit of the interval argument is millisecond. The valid types are `TIMER_REPEAT` and `TIMER_ONE_SHOT`. A one-shot timer ends after the specified interval, while a repeat timer goes on and on until it is stopped by the `stop()` command.

How does an application know that its timer has expired? The answer is when it receives an event. The `Timer` interface provides an event:

```
  event result_t fired();
```

An `event` is a function that the implementation of an interface will signal when a certain event takes place. In this case, the `fired()` event is signaled when the specified time interval has passed. This is an example of a **bi-directional interface**: an interface not only provides `commands` that can be called by *users* of the interface, but also signals `events` that call handlers *implemented by the user*. You can think of an `event` as a callback function that the implementation of an interface will invoke. A module that **uses** an interface must implement the events that this interface uses.

Let's look at the rest of *MyAppM.nc* to see how this all fits together:

```
implementation {
  command result_t StdControl.init() {
    call Leds.init();
    return SUCCESS;
  }
  command result_t StdControl.start() {
    return call Timer.start(TIMER_REPEAT, 1000) ;
  }

  command result_t StdControl.stop() {
    return call Timer.stop();
  }

  event result_t Timer.fired()
  {
    call Leds.redToggle();
    return SUCCESS;
  }
}
```

This is simple enough. As we see the `MyAppM` module implements the `StdControl.init()`, `StdControl.start()`, and `StdControl.stop()` commands, since it provides the `StdControl` interface. It also implements the `Timer.fired()` event, which is necessary since `MyAppM` must implement any event from an interface it uses.

The `init()` command in the implemented `StdControl` interface simply initializes the `Leds` subcomponent with the call to `Leds.init()`. The `start()` command invokes `Timer.start()` to create a repeat timer that expires every 1000 ms. `stop()` terminates the timer. Each time `Timer.fired()` event is triggered, the `Leds.redToggle()` toggles the red LED.

5.4 Generating the Component Structure Documentation

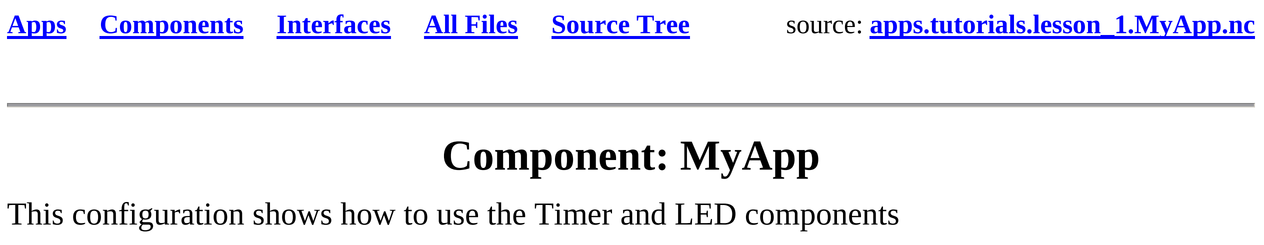
You can view a graphical representation of the component relationships within an application. TinyOS source files include metadata within comment blocks that ncc—the nesC compiler—uses to automatically generate html-formatted documentation.

To generate the documentation, use the following command:

```
make <platform> docs
```

The resulting documentation will have the filename generated in the file ***/MoteWorks/doc/nesdoc/<platform>.docs/nesdoc/<platform>/index.html***. This is the main index to all documented applications.

The directory index takes you to an html file that looks like the diagram shown below.



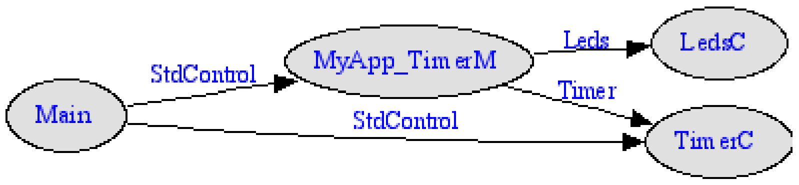
Apps **Components** **Interfaces** **All Files** **Source Tree** source: **apps.tutorials.lesson_1.MyApp.nc**

Component: MyApp

This configuration shows how to use the Timer and LED components

Author: Crossbow Technology Inc.

Component Graph (text version, help)



Apps Components Interfaces All Files Source Tree

6 A Simple Sensing Application

In this chapter you will learn:

- How to create a simple Mote firmware application that reads light sensor data from your sensor board
- How to send a message containing the sensor data through the Mote serial port connected directly to the programming board
- How to send a message containing the sensor data over the Mote radio (single-hop network) to another Mote plugged into the programming board
- Using *XServe* to parse packets on a PC
- Using *XSniffer* to display the sensor data message on a PC.

6.1 Hardware Requirements

This chapter requires the following hardware:

- Two MICA Motes: standard editions of MICA2 (MPR4x0) or MICAz (MPR2600) or OEM editions of MICA2 or MICAz
- One sensor or data acquisition board: MDA100, MTS300 or MTS310
- One gateway board: MIB510, MIB520, or MIB600 and the associated hardware (cables, power supply) for each
- A Windows PC with *MoteWorks* installed

6.2 A Simple Sensing Application: MyApp

A simple sensing application that samples the light sensor on a sensor board, packetizes, and sends the data back to the base station is presented here to help further familiarize you with nesC programming and TinyOS messaging.

The following enhancements will be made to the simple Timer application presented in Chapter 5:

- Take light readings using one of the following sensors boards: MTS300/310 or MDA100
- Use the Mote serial port (UART) and radio to send sensor data to the base station
- Blink the yellow LED when the sensor is sampled
- Blink the green LED when the sensor data message is successfully sent to the base station
- Compile and debug if necessary

To get started the first thing to do is to create the application folder (directory) where all your application code and other files will be stored.

1. Change into the directory ***/MoteWorks/apps/tutorials/*** and create a new subfolder named after your application. In this first lesson the application will be called *MyApp*.

2. Once again you have two options to create the source files. You can copy, paste, and rename the subdirectory ***/lesson_2*** found in the ***/tutorials*** subdirectory and avoid some typing. If you choose to do this you can go straight to the compiling and installation step or follow these instructions and learn along the way.

The *Makefile* and *Makefile.component* are exactly the same as the *MyApp* application presented in Chapter 5 so we will move along to the configuration and module files. Just copy the *Makefile* and *Makefile.component* files created in Chapter 5.

6.2.1 Create the Top-Level Configuration

The application's configuration is located in the `MyApp.nc` file. This new configuration differs from the `MyApp.nc` file in that it adds two more components that were not present in the previous application: `Photo` and `GenericComm`. The `Photo` component is used to actuate the sensorboard light sensor device. The `GenericComm` component is used to send messages over the serial port and radio.

To create the application's configuration, enter the following text into a new document in Programmer's Notepad:

```
includes sensorboardApp;

/**
 * This module shows how to use the Timer, LED, ADC and Messaging 
components.
 * Sensor messages are sent to the serial port
 *
 * @author Crossbow Technology Inc.
 **/
configuration MyApp {
}
implementation {
  components Main, MyAppM, TimerC, LedsC, Photo, GenericComm as Comm;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;
  Main.StdControl -> Comm.Control;

  MyAppM.Timer -> TimerC.Timer[unique("Timer")];
  MyAppM.Leds -> LedsC.Leds;
  MyAppM.PhotoControl -> Photo.PhotoStdControl;
  MyAppM.Light -> Photo.ExternalPhotoADC;

  MyAppM.SendMsg -> Comm.SendMsg[AM_XSXMSG];
}
```

When finished save the file with **File > Save As...** using the following parameters:

File name	MyApp.nc
Save as type	All files (".")
File format	No change to file format

6.2.2 Create the Module

The application's module is located in the `MyAppM.nc` file. This new module differs from the `MyAppM.nc` module in that it adds the functionality of sampling the light sensor when the timer fires and then sends a sensor message through the Motes serial (UART) port when the sampling is complete.

To create the application's module, enter the following text into a new document in Programmer's Notepad:

```
includes sensorboardApp;

/**
 * This module shows how to use the Timer, LED, ADC and Messaging components
 * Sensor messages are sent to the serial port
 *
 * @author Crossbow Technology Inc.
 **/
module MyAppM {
  provides {
    interface StdControl;
  }
  uses {
    interface Timer;
    interface Leds;
   interface StdControl as PhotoControl;
   interface ADC as Light;
   interface SendMsg;
  }
}
implementation {
  bool sending_packet = FALSE;
  TOS_Msg msg_buffer;
  XDataMsg *pack;

  /**
   * Initialize the component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.init() {
    call Leds.init();
   call PhotoControl.init();

    // Initialize the message packet with default values
    atomic {
      pack = (XDataMsg *)&(msg_buffer.data);
      pack->xSensorHeader.board_id = SENSOR_BOARD_ID;
      pack->xSensorHeader.packet_id = 2;
      pack->xSensorHeader.node_id = TOS_LOCAL_ADDRESS;
      pack->xSensorHeader.rsvd = 0;
   }

    return SUCCESS;
  }

  /**
   * Start things up.  This just sets the rate for the clock component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.start() {
    // Start a repeating timer that fires every 1000ms
    return call Timer.start(TIMER_REPEAT, 1000);
  }

  /**
   * Halt execution of the application.
   * This just disables the clock component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.stop() {
    return call Timer.stop();
  }

  /**
   * Toggle the red LED in response to the <code>Timer.fired</code> event.
   * Start the Light sensor control and sample the data
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  event result_t Timer.fired()
  {
    call Leds.redToggle();
   call PhotoControl.start();
   call Light.getData();

    return SUCCESS;
  }

  /**
    * Stop the Light sensor control, build the message packet and send
   **/
  void task SendData()
  {
    call PhotoControl.stop();

    if (sending_packet) return;
    atomic sending_packet = TRUE;

   // send message to UART (serial) port
   if (call SendMsg.send(TOS_UART_ADDR,sizeof(XDataMsg),&msg_buffer) !=
SUCCESS)
     sending_packet = FALSE;

    return;
  }

 /**
   * Light ADC data ready
   * Toggle yellow LED to signal Light sensor data sampled
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  async event result_t Light.dataReady(uint16_t data) {
   atomic pack->xData.datap1.light = data;
  atomic pack->xData.datap1.vref = 417; // a dummy 3V reference voltage,
1252352/3000 = 417
  post SendData();
   call Leds.yellowToggle();

    return SUCCESS;
  }

 /**
   * Sensor data has been sucessfully sent over the UART (serial port)
   * Toggle green LED to signal message sent
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  event result_t SendMsg.sendDone(TOS_MsgPtr msg, result_t success) {
   call Leds.greenToggle();
   atomic sending_packet = FALSE;

     return SUCCESS;
  }
```

When finished save the file with **File > Save As...** using the following parameters:

File name	MyAppM.nc
Save as type	All files (“.”)
File format	No change to file format

6.2.3 Compile and Install the Code in a Mote

Please Refer to section 5.2.5 to compile and install this application on a Mote plugged into the programming board.

When the application is installed and running on the Mote you should see the red, green and yellow LED’s blinking every second. Each LED is used to indicate the progression of firing the timer, sampling the light sensor and then sending the message back to the base station.

NOTE: Make sure you have connected a sensorboard (MTS300, MTS310 or MDA100) to the underside of the MIB510 programming board. This will allow the application to sample the light sensor. The application will run if you don’t connect the sensorboard however the light value will not be valid when we display the sensor message on the PC.

Table 6-1. Mote LED Status

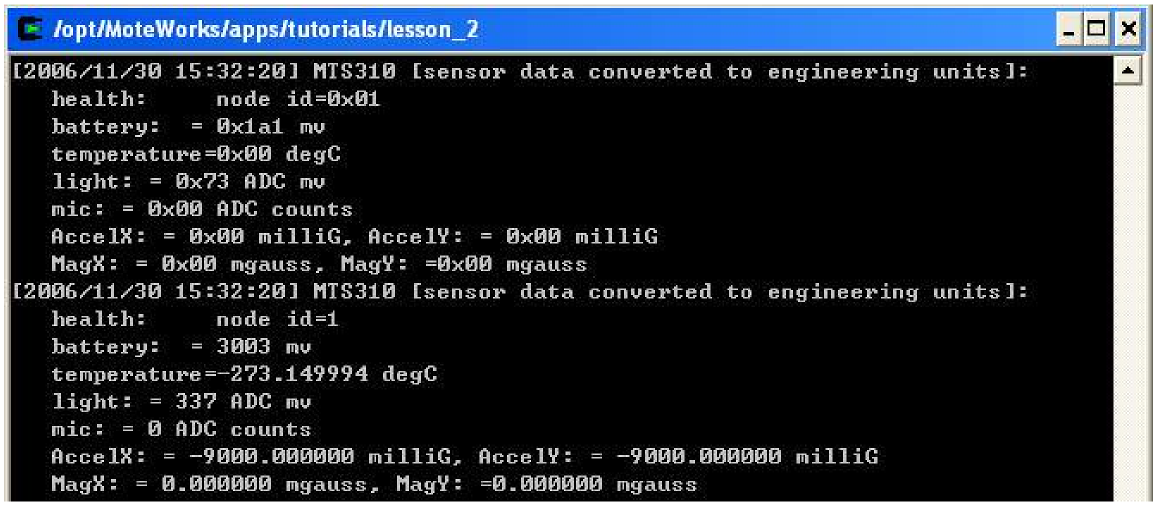
LED Toggle	Indication
Red	1 second timer event fired
Yellow	Light sensor has been sampled
Green	Sensor message has been sent back to base station

6.2.4 Parsing Message Packets on PC using XServe

The next part of the tutorial involves displaying the sensor message packet contents as they arrive on the PC over the serial port. The tool we use for this is called *XServe*. *XServe* is an application that installs with *MoteWorks* for this purpose. *XServe* has many other features including automatic logging of sensor messages to a database such as PostgreSQL.

1. *XServe* is a program that runs within a Cygwin command prompt window. The first step is to open a Cygwin command prompt by double clicking on the icon located on your desktop.

2. Type **`xserve -device=COM1`** at the command prompt and hit enter, you should see output similar to the following when the sensor message packets arrive over the serial port and are displayed by *XServe*:


/opt/MoteWorks/apps/tutorials/lesson_2

```
[2006/11/30 15:32:20] MTS310 [sensor data converted to engineering units]:
   health:     node id=0x01
   battery:  = 0x1a1 mv
   temperature=0x00 degC
   light: = 0x73 ADC mv
   mic: = 0x00 ADC counts
   AccelX: = 0x00 milliG, AccelY: = 0x00 milliG
   MagX: = 0x00 mgauss, MagY: =0x00 mgauss
[2006/11/30 15:32:20] MTS310 [sensor data converted to engineering units]:
   health:     node id=1
   battery:  = 3003 mv
   temperature=-273.149994 degC
   light: = 337 ADC mv
   mic: = 0 ADC counts
   AccelX: = -9000.000000 milliG, AccelY: = -9000.000000 milliG
   MagX: = 0.000000 mgauss, MagY: =0.000000 mgauss
```

NOTE: Substitute your specific COM port for COM1 above according to your particular hardware setup.

You may notice that the message packet contains data fields for other sensors that we are not using with our sensing application – all set to 0. You should see a valid light value however – this is the part of the message that our application is filling in. The reason the other fields are present in the packet is because we are using a standard packet format that *XServe* knows about.

6.2.5 Sending Sensor Data over the Radio

With a slight modification this application can be altered to send the message packet over the Mote radio to another Mote plugged into the base station instead of directly through the serial port (UART). The only change needed is a single line of code in the *MyAppM.nc* file:

From

```
   if (call SendMsg.send(TOS_UART_ADDR,sizeof(XDataMsg),&msg_buffer) !=
SUCCESS)
```

To

```
   if (call SendMsg.send(TOS_BCAST_ADDR,sizeof(XDataMsg),&msg_buffer) !=
SUCCESS)
```

The `SendMsg.send` command uses the first parameter to decide where the message packet should be sent. Changing from `TOS_UART_ADDR` to `TOS_BCAST_ADDR` tells the communications component to send the message through the radio instead of the UART. Setting this parameter to `TOS_BCAST_ADDR` actually sends the message to any Mote within range, i.e. broadcast the message. If we want to send the message specifically to the base station we can set this parameter value to 0. The Mote plugged into the base station always has a node id of 0.

This modification is provided for you in the ***/lesson_3*** folder.

6.2.6 Using XSniffer to View Sensor Data Sent Over the Radio

MoteWorks includes a tool named *XSniffer* that can be used to eavesdrop on messages sent over the Mote radios. We will use the *XSniffer* tool to monitor the messages sent from our modified sensing application from section 6.2.5.

First, install the modified sensing application located in the ***/lesson_3*** folder onto a Mote. You can compile and install the application in a single step using Programmer's Notepad as follows:

- Load the *MyApp.nc* file from /lesson_3 into Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type in **`make mica2 install,1 mib510,com1`** (assuming MICA2 Mote)

Remove the Mote from the programming board, plug one of the sensorboards (MDA100, MTS300 or MTS310) onto the Mote, make sure it has batteries and turn it on. You should see all three LEDs blinking every second.

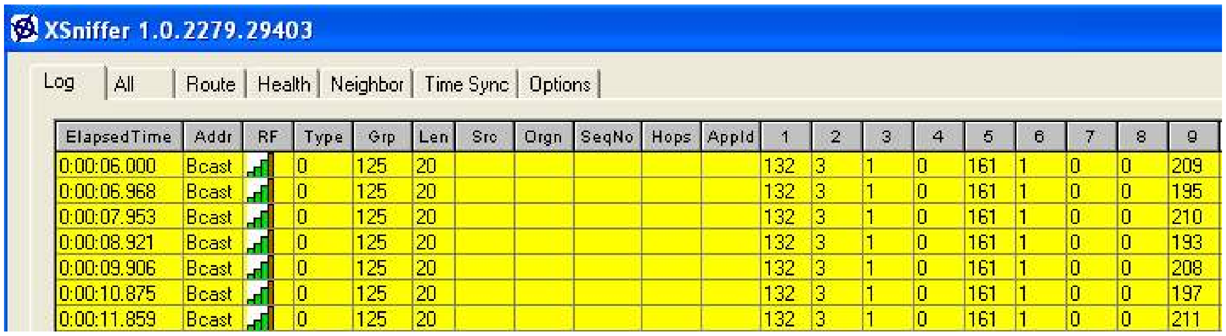
Next, install the *XSniffer* application onto another Mote that remains plugged into your programming board (base station). This application is located in the ***/MoteWorks/apps/general/XSniffer*** folder. Install this application with a node id of 2 using Programmer's Notepad:

- Load the *TOSBase.nc* file from ***/MoteWorks/apps/general/XSniffer*** into Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,2 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1)

Now, keep the Mote you just programmed plugged into the programming board and start the *XSniffer* application by double clicking on the icon located on your desktop.

Click on the "**Options**" tab within *XSniffer* and select the "**General Packet Type**" radio button. Go back to the Log tab, select the COM port that is connected to the programming board and then click on Start to begin "sniffing" the radio traffic. After a short time you should see message packets displayed in *XSniffer* similar to Figure 6-1.

NOTE: If you are in the Run mode, you need to **Pause** the XSniffer before you can change any of the parameters in Options tab and then click on **Continue** to make the changes take effect.



ElapsedTime	Addr	RF	Type	Grp	Len	Src	Orgn	SeqNo	Hops	AppId	1	2	3	4	5	6	7	8	9
0:00:06.000	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	209
0:00:06.968	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	195
0:00:07.953	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	210
0:00:08.921	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	193
0:00:09.906	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	208
0:00:10.875	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	197
0:00:11.859	Bcast	📶	0	125	20						132	3	1	0	161	1	0	0	211

Figure 6-1. *XSniffer* Log Screen Display

You can see from the elapsed time the messages are begin sent about 1 second apart – each time the LEDs blink you should see a new message captured by *XSniffer*.

6.3 A Closer Look at MyApp

The *MyApp* application developed in this chapter builds on the basic *MyApp* application from Chapter 5. There are two additional features incorporated into this application. First, we are sampling the sensorboard light sensor. Second, we are building a message packet that includes this light sensor value and sending it back to the base station either directly through the UART or over the radio.

6.3.1 Using a Sensorboard

The first thing we need to do when building a sensing application is to specify the sensorboard we want to use. For the *MyApp* application this is specified in the *Makefile.component* file as follows:

```
SENSORBOARD=mts310
```

This line in the Makefile.component file tells the nesC compiler to link in all the TinyOS components required to access the sensors on the MTS310 sensorboard. The components for the MTS310 sensorboard are located in the ***/MoteWorks/tos/sensorboards/mts310*** folder. There are similar components for other sensorboards located in subfolders under ***/MoteWorks/tos/sensorboards***.

6.3.2 Sampling the Light Sensor

In order to sample the light sensor on the MTS310 sensorboard we need to include a component named `Photo` in our configuration file. The `Photo` component implements the `StdControl` interface for turning on and off the light sensor and the `ADC` interface for sampling the sensor value through the hardware ADC port.

Here is part of the implementation section from the *MyApp.nc* configuration file:

```
implementation {
  components Main, MyAppM, TimerC, LedsC, Photo, GenericComm as Comm;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;
  Main.StdControl -> Comm.Control;

  MyAppM.Timer -> TimerC.Timer[unique("Timer")];
  MyAppM.Leds -> LedsC.Leds;
  MyAppM.PhotoControl -> Photo.PhotoStdControl;
  MyAppM.Light -> Photo.ExternalPhotoADC;

…
```

You can see we are connecting the `MyAppM.PhotoControl` (StdControl interface) to the `Photo.PhotoStdControl` (StdControl interface for the light sensor) and the `MyAppM.Light` (ADC interface) to the `Photo.ExternalPhotoADC` (ADC interface for light sensor).

We have seen the `StdControl` interface before, so let's take a closer look at the `ADC` Interface:

```
interface ADC {
  async command result_t getData();
  async command result_t getContinuousData();
  async event result_t dataReady(uint16_t data);
}
```

The `ADC` interface is specified with two commands: `getData` and `getContinuousData` and one event `dataReady`. Quite simply when we want to sample the current light value we call the `getData` command. This will start a process of sampling the light sensor through the processor hardware ADC interface. At some later time this process will complete and we will receive the current light sensor value through the `dataReady` event.

Here are the excerpts from the *MyAppM.nc* module where we sample the light sensor and then receive the callback event with the sampled value:

```
  event result_t Timer.fired()
  {
    call Leds.redToggle();
    call PhotoControl.start();
    call Light.getData();
…
  async event result_t Light.dataReady(uint16_t data) {
     atomic pack->xData.datap1.light = data;
     atomic pack->xData.datap1.vref = 417; // a dummy 3V reference voltage,
1252352/3000 = 417
     post SendData();
     call Leds.yellowToggle();
…
```

First, we can see that in the `Timer.fired` event function we first turn on the light sensor by calling the `start` command through the `StdControl` interface. Next we call the `getData` command through the `ADC` interface to start the process of sampling the current light value. At some time in the near future when the sampling has completed we then receive a callback in the form of a `dataReady` event. The `dataReady` event passes the 16-bit (10 significant bits) light sensor value that we store in our message packet for sending later.

The last thing we do is to post a task to send a message containing the sensor data – this is discussed next.

6.3.3 Sending a Message Packet

In order to send a message containing the sensor data back to the base station we need access to the TinyOS communication component named `GenericComm`. `GenericComm` is able to send messages through the UART port or over the radio depending on the destination node address specified.

```
implementation {
  components Main, MyAppM, TimerC, LedsC, Photo, GenericComm as Comm;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;
  Main.StdControl -> Comm.Control;
…
  MyAppM.SendMsg -> Comm.SendMsg[AM_XSXMSG];
…
```

If we take another look at the *MyApp.nc* configuration file we can see that `GenericComm` (aliased as `Comm`) is connected through its `Comm.Control` (`StdControl`) interface and that the `MyAppM` module connects to one instance of the `Comm.SendMsg` interface. The `AM_XSXMSG` identifies the active message type. This value is used to distinguish between multiple messages you may wish to send.

Let's take a closer look at the `SendMsg` interface:

```
interface SendMsg
{
  command result_t send(uint16_t address, uint8_t length, TOS_MsgPtr msg);
  event result_t sendDone(TOS_MsgPtr msg, result_t success);
}
```

The `SendMsg` interface specifies one command named `send` and one event named `sendDone`. When we want to send a message we simply call the `send` command with the correct parameters. We receive the `sendDone` event after the message has been sent.

Each message that is sent using the `SendMsg` interface is defined by a data structure named `TOS_Msg`:

```
typedef struct TOS_Msg
{
  /* The following fields are transmitted/received on the radio. */
  uint16_t addr;
  uint8_t type;
  uint8_t group;
  uint8_t length;
  int8_t data[TOSH_DATA_LENGTH];
}

typedef TOS_Msg *TOS_MsgPtr;
```

Where:

addr – the destination address

type – the active message type (`AM_XSXMSG` for this application)

group – group id specified during programming

length – the payload length

data – variable length payload area (sensor data)

The data region in the `TOS_Msg` is where we place our application specific payload. The following excerpt is from the *MyAppM.nc* module that shows how we initialize the payload area of the `TOS_Msg` for our specific sensor application:

```
  command result_t StdControl.init() {
…
    // Initialize the message packet with default values
    atomic {
      pack = (XDataMsg *)&(msg_buffer.data);
      pack->xSensorHeader.board_id = SENSOR_BOARD_ID;
      pack->xSensorHeader.node_id = TOS_LOCAL_ADDRESS;
      pack->xSensorHeader.rsvd = 0;
   }
…
```

Here are the excerpts from the *MyAppM.nc* module where we send the message containing the sensor data and then receive the callback event:

```
  void task SendData()
  {
    call PhotoControl.stop();

    if (sending_packet) return;
    atomic sending_packet = TRUE;

// broadcast message over radio
   if (call SendMsg.send(TOS_BCAST_ADDR,sizeof(XDataMsg),&msg_buffer) !=
SUCCESS)
     sending_packet = FALSE;
…
  event result_t SendMsg.sendDone(TOS_MsgPtr msg, result_t success) {
   call Leds.greenToggle();
   atomic sending_packet = FALSE;
…
```

Notice first how the `SendData` task calls the `stop` command for the light sensor component. This is done in order to save power when we are not using the sensor. Next you can see that if we are currently in the process of sending a message (`sending_packet == TRUE`) we just return. This means the `sendDone` event has yet to be called and we must wait.

Finally we call the `SendMsg.send` command passing the destination node address, in this case `TOS_BCAST_ADDR` and a pointer to the actual message packet we wish to send.

Finally the `SendMsg.sendDone` event is called notifying us the packet has been sent. We are now ready to start the whole process over again the next time the timer fires.

6.4 *XSensor* Applications Supported in *MoteWorks*

All of Crossbow's sensor and data acquisition boards are supported with *XSensor* enabled applications. *XSensor* applications are test applications for Crossbow's sensor and data acquisition boards. They allow the user to quickly and easily test sensor and data acquisition boards when attached to Mote. *XServe* is connected to these applications through a base station running the *TOSBase* application. *XSensor* applications send data over one hop so all test Motes must be within RF range of the base station. The Table 6-2 below provides a summary of the *XSensor* applications and their corresponding sensor boards.

Table 6-2. Sensor and data acquisition boards and the corresponding *XSensor* application

Sensor and Data Acquisition Boards	Application Name	Location of Driver Folder
MDA100	XSensorMDA100	/MoteWorks/apps/XSensor/ XSensorMDA100
MDA300	XSensorMDA300	/MoteWorks/apps/XSensor/XSensorMDA300

MDA320	XSensorMDA320	/MoteWorks/apps/XSensor/XSensorMDA320
MDA325	XSensorMDA325	/MoteWorks/apps/XSensor/XSensorMDA325
MDA500	XSensorMDA500	/MoteWorks/apps/XSensor/XSensorMDA500
MEP410	XSensorMEP410	/MoteWorks/apps/XSensor/XSensorMEP410
MEP510	XSensorMEP510	/MoteWorks/apps/XSensor/XSensorMEP510
MTS101	XSensorMTS101	/MoteWorks/apps/XSensor/XSensorMTS101
MTS300/310	XSensorMTS300	/MoteWorks/apps/XSensor/XSensorMTS300
MTS400/420	XSensorMTS400	/MoteWorks/apps/XSensor/XSensorMTS400
MTS410	XSensorMTS410	/MoteWorks/apps/XSensor/XSensorMTS410
MTS450	XSensorMTS450	/MoteWorks/apps/XSensor/XSensorMTS450
MTS510	XSensorMTS510	/MoteWorks/apps/XSensor/XSensorMTS510

7 XMesh enabled Sensing Application

In this chapter you will learn:

- How to enhance the sensing application developed in the last chapter with the *XMesh* multi-hop networking service
- Using *XServe* to parse packets on a PC
- Using *XSniffer* to display the sensor data message on a PC
- Using *MoteView* to display the sensor data message on a PC

7.1 Hardware Requirements

This chapter requires the following hardware:

- Three MICA Motes: standard editions of MICA2 (MPR4x0) or MICAz (MPR2400) or OEM editions of MICA2 (MPR600) or MICAz (MPR2600)
- One sensor or data acquisition board: MDA100, MTS300 or MTS310
- One gateway/programming board: MIB510, MIB520, or MIB600 and associated accessories (cables, power supply) for each
- A Window's PC with *MoteWorks* & *MoteView* installed

7.2 An XMesh enabled Sensing application: MyApp

A simple sensing application that samples the light sensor on a sensor board, packetizes, and sends the data back to the base station using the *XMesh* multi-hop networking service is presented here to help further familiarize you with nesC programming and TinyOS messaging.

The following enhancements will be made to the simple Sensor application presented in Chapter 6:

- Use the Mote radio to send sensor data to the base station using the *XMesh* multi-hop networking service.
- Compile and debug if necessary

To get started the first thing to do is to create the application folder (directory) where all your application code and other files will be stored.

1. Change into the directory ***/MoteWorks/apps/tutorials/*** and create a new subfolder (subdirectory) named after your application. In this lesson the application will be called *MyApp*.
2. Once again you have two options to create the source files. You can copy, paste, and rename the subdirectory ***/lesson_4*** found in the ***/tutorials*** subdirectory and avoid some typing. If you choose to do this you can go straight to the compiling and installation step. Or you can follow these instructions and learn along the way.

7.2.1 Makefile

The first step in creating an application is to type in the *Makefile*. Alternatively you can copy and paste this file from the subdirectory ***/lesson_4*** into ***/MyApp*** (both of which are in the ***/tutorials*** subdirectory).

To create the *Makefile*, enter the following text into a new document in Programmer's Notepad:

```
include Makefile.component
include $(TOSROOT)/apps/MakeXbowlocal
GOALS += basic freq route
include $(MAKERULES)
```

When finished save the file with **File > Save As...** using the following parameters:

File name	Makefile
Save as type	All files (".")
File format	No change to file format

7.2.2 Makefile.component

The next step is to create the *Makefile.component* file. This file describes the top level application component, *MyApp* and the name of the sensorboard we are going to use.

To create the *Makefile.component* file, enter the following text into a new document in Programmer's Notepad:

```
COMPONENT=MyApp
SENSORBOARD=mts310
```

When finished save the file with **File > Save As...** using the following parameters:

File name	Makefile.component
Save as type	All files (".")
File format	No change to file format

7.2.3 Create the Top-Level Configuration

The application's configuration is located in the `MyApp.nc` file. This new configuration differs from the `MyApp.nc` file from the subdirectory ***/lesson_3*** in that it adds two more components that were not present in the previous application: `MULTIHOPROUTER` and `GenericCommPromiscuous`. The `MULTIHOPROUTER` component is the *XMesh* multi-hop routing service. The `GenericCommPromiscuous` component is used by the `MULTIHOPROUTER` service to provide the basic radio communications functions – it's included here for initialization only. You may remember the `MyApp.nc` file from the last chapter had a component named

`GenericComm`. `GenericCommPromiscuous` is similar in functionality but provides other features required by *XMesh* such as the ability to "snoop" on radio conversations.

To create the application's configuration, enter the following text into a new document in Programmer's Notepad:

```
#include "appFeatures.h"
includes sensorboardApp;

/**
 * This configuration shows how to use the Timer, LED, ADC and XMesh
 * components.
 * Sensor messages are sent multi-hop over the RF radio
 *
**/
configuration MyApp {
}
implementation {
  components Main, GenericCommPromiscuous as Comm, MULTIHOPROUTER, MyAppM,
TimerC, LedsC, Photo;

(still using older version of the wiring – see xmesh manual)

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;
  Main.StdControl -> Comm.Control;
  Main.StdControl -> MULTIHOPROUTER.StdControl;

  MyAppM.Timer -> TimerC.Timer[unique("Timer")];
  MyAppM.Leds -> LedsC.Leds;
  MyAppM.PhotoControl -> Photo.PhotoStdControl;
  MyAppM.Light -> Photo.ExternalPhotoADC;

  MyAppM.RouteControl -> MULTIHOPROUTER;
  MyAppM.Send -> MULTIHOPROUTER.MhopSend[AM_XMULTIHOP_MSG];
  MULTIHOPROUTER.ReceiveMsg[AM_XMULTIHOP_MSG]
                                   ->Comm.ReceiveMsg[AM_XMULTIHOP_MSG];
}
```

When finished save the file with **File > Save As...** using the following parameters:

File name	MyApp.nc
Save as type	All files (".")
File format	No change to file format

7.2.4 Create the Module

The application's module is located in the `MyApp.nc` file. This new module differs from the `MyApp.nc` module from the subdirectory ***/lesson_3*** in that it sends the sensor message over the Mote radio using the *XMesh* routing service.

To create the application's module, enter the following text into a new document in Programmer's Notepad:

```
#include "appFeatures.h"
includes MultiHop;
//includes sensorboard;

/**
 * This module shows how to use the Timer, LED, ADC and XMesh
 * components.
 * Sensor messages are sent multi-hop over the RF radio
 **/
module MyAppM {
  provides {
    interface StdControl;
  }
   ses {
    interface Timer;
    interface Leds;
   interface StdControl as PhotoControl;
   interface ADC as Light;
   interface MhopSend as Send;
   interface RouteControl;
  }
}
implementation {
  bool sending_packet = FALSE;
  TOS_Msg msg_buffer;
  XDataMsg *pack;

  /**
   * Initialize the component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.init() {
    uint16_t len;
    call Leds.init();
   call PhotoControl.init();

    // Initialize the message packet with default values
    atomic {
      pack = (XDataMsg*)call Send.getBuffer(&msg_buffer, &len);

      pack->board_id = SENSOR_BOARD_ID;
      pack->packet_id = 4;
   }

    return SUCCESS;
  }

  /**
   * Start things up.  This just sets the rate for the clock component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.start() {
    // Start a repeating timer that fires every 1000ms
    return call Timer.start(TIMER_REPEAT, 1000);
  }
  /**
   * Halt execution of the application.
   * This just disables the clock component.
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  command result_t StdControl.stop() {
    return call Timer.stop();
  }

  /**
   * Toggle the red LED in response to the <code>Timer.fired</code> event.
   * Start the Light sensor control and sample the data
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  event result_t Timer.fired()
  {
    call Leds.redToggle();
   call PhotoControl.start();
   call Light.getData();

    return SUCCESS;
  }

  /**
    * Stop the Light sensor control, build the message packet and send
   **/
  void task SendData()
  {
    call PhotoControl.stop();

    if (sending_packet) return;
    atomic sending_packet = TRUE;

   // send message to XMesh multi-hop networking layer
    pack->parent = call RouteControl.getParent();
    if (call
Send.send(BASE_STATION_ADDRESS,MODE_UPSTREAM,&msg_buffer,sizeof(XDataMsg)) !
= SUCCESS)
     sending_packet = FALSE;

    return;
  }

 /**
   * Light ADC data ready
   * Toggle yellow LED to signal Light sensor data sampled
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  async event result_t Light.dataReady(uint16_t data) {
   atomic pack->light = data;
  atomic pack->vref = 417; // a dummy 3V reference voltage, 1252352/3000 =
417
    post SendData();
   call Leds.yellowToggle();
```

```
    return SUCCESS;
  }

 /**
   * Sensor data has been sucessfully sent through XMesh
   * Toggle green LED to signal message sent
   *
   * @return Always returns <code>SUCCESS</code>
   **/
  event result_t Send.sendDone(TOS_MsgPtr msg, result_t success) {
    call Leds.greenToggle();
    atomic sending_packet = FALSE;

    return SUCCESS;
  }
}
```

When finished save the file with **File > Save As...** using the following parameters:

File name	MyAppM.nc
Save as type	All files (“.”)
File format	No change to file format

7.2.5 Compile and Install the Code in a Mote

Before proceeding you should have all the application files typed in and saved using Programmer’s Notepad or copied over from the ***/lesson_4*** folder.

This application will require two Motes and one sensorboard (MDA100, MTS300 or MTS310). One Mote will function as the sensor node with the sensorboard plugged into it and a second Mote will function as the base station plugged into the programming board and connected to your PC. The Mote that functions as the sensor node will need to have batteries plugged into it. The Mote that functions as the base station does not require batteries.

Plug the Mote that will function as the sensor node into the programming board. To compile and install the `MyApp` application onto the sensor node:

- Select the `MyApp.nc` file in Programmer’s Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,1 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1)

Next, plug the Mote that will function as the base station into the programming board. This Mote will be programmed with a special application named `XMeshBase` located in the ***/MoteWorks/apps/xmesh/XMeshBase*** folder. To compile and install the *XMeshBase* application onto the base station node:

- Select the `XMeshBase.nc` file in Programmer’s Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,0 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1).

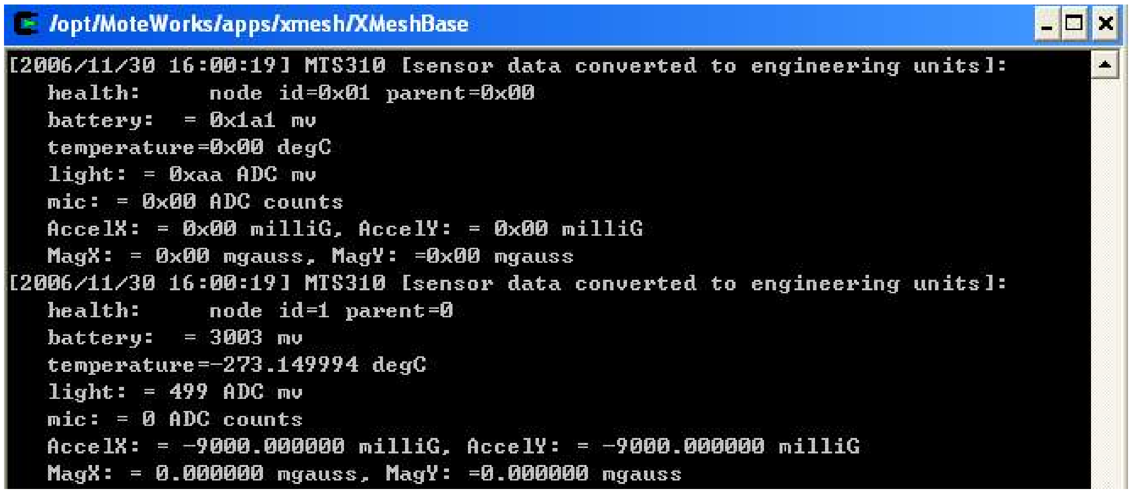
NOTE: The Mote that functions as the base station is always programmed with node id of 0.

Keep the base station Mote plugged into the programming board and turn on the sensor node Mote – making sure the sensorboard is plugged into the sensor node Mote first. You should see the LEDs flashing on the sensor node Mote every second. Refer to section 6.2.3 for an explanation of the LED status.

7.2.6 Parsing Message Packets on PC using XServe

The next step is to verify that messages are being received at the base station by running the *XServe* application on your PC to display the packets.

1. *XServe* is a program that runs within a Cygwin command prompt window. The first step is to open a Cygwin command prompt by double clicking on the icon located on your desktop.
2. At the command prompt type **`xserve –device=COM<x>`**, where **`<x>`** is the serial port to which your MIB510 or MIB520 is connected, and hit enter. You should see output similar to the following when the sensor message packets arrive over the serial port and are displayed by *XServe*:



```
[2006/11/30 16:00:19] MTS310 [sensor data converted to engineering units]:
   health:     node id=0x01  parent=0x00
   battery:  = 0x1a1 mv
   temperature=0x00 degC
   light: = 0xaa ADC mv
   mic: = 0x00 ADC counts
   AccelX: = 0x00 milliG, AccelY: = 0x00 milliG
   MagX: = 0x00 mgauss, MagY: =0x00 mgauss
[2006/11/30 16:00:19] MTS310 [sensor data converted to engineering units]:
   health:     node id=1 parent=0
   battery:  = 3003 mv
   temperature=-273.149994 degC
   light: = 499 ADC mv
   mic: = 0 ADC counts
   AccelX: = -9000.000000 milliG, AccelY: = -9000.000000 milliG
   MagX: = 0.000000 mgauss, MagY: =0.000000 mgauss
```

If you compare the *XServe* output with this application vs. the non *XMesh* application in section 6.2.4 you will notice the addition of the parent field. The parent field is part of the multi-hop networking information and it tells us that sensor node 1 is routing its packets directly to the base station (node id 0). The base station forwards the message packets from the sensor nodes through the serial port where they are processed by *XServe*.

NOTE: The multi-hop mesh network must form before you see any packets displayed by *XServe*. This may take a few minutes.

Congratulations, you have just deployed your first multi-hop sensor network!

7.2.7 Using XSniffer to View Sensor Data Sent through the Network

We will now use the *XSniffer* tool to monitor the messages being sent from the sensor node. Remove the *XMeshBase* programmed Mote from the programming board and set aside before continuing.

NOTE

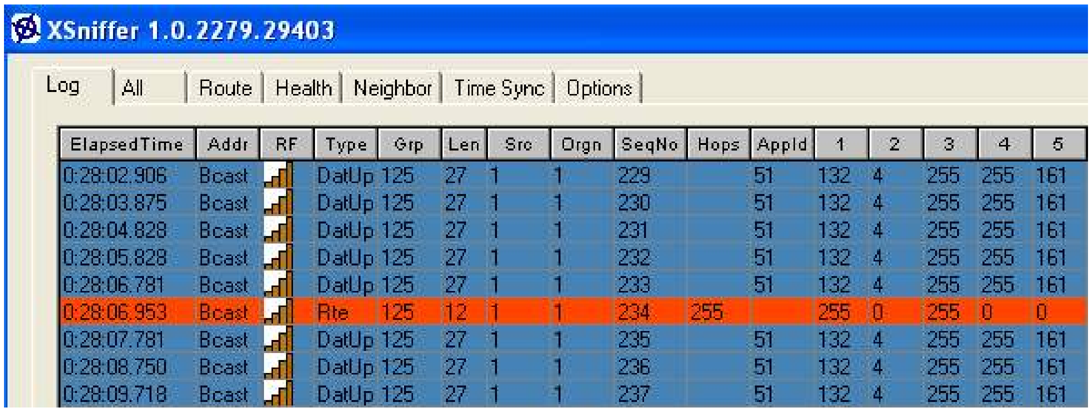
XSniffer currently does not support the MIB600 programming board. *XSniffer* tool will work only while using *XMesh*–based applications in the tutorial lessons.

Install the *XSniffer* application onto a third Mote that you will plug into your programming board (base station). This application is located in the ***/MoteWorks/apps/general/XSniffer*** folder. Install this application with a node id of 2 using Programmer's Notepad:

- Open the *TosBase.nc* file from ***/MoteWorks/apps/general/XSniffer*** using Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,2 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1)

Now, keep the Mote you just programmed plugged into the programming board and start the *XSniffer* application by double clicking on the icon located on your desktop.

Click on the **Options** tab within *XSniffer* and select the *XMesh* Packet **Type** radio button. Go back to the **Log** tab, select the COM port that is connected to the programming board and then click on Start to begin "sniffing" the radio traffic. After a short time you should see message packets displayed in *XSniffer* similar to Figure 7-1.



ElapsedTime	Addr	RF	Type	Grp	Len	Src	Orgn	SeqNo	Hops	AppId	1	2	3	4	5
0:28:02.906	Bcast		DatUp	125	27	1	1	229		51	132	4	255	255	161
0:28:03.875	Bcast		DatUp	125	27	1	1	230		51	132	4	255	255	161
0:28:04.828	Bcast		DatUp	125	27	1	1	231		51	132	4	255	255	161
0:28:05.828	Bcast		DatUp	125	27	1	1	232		51	132	4	255	255	161
0:28:06.781	Bcast		DatUp	125	27	1	1	233		51	132	4	255	255	161
0:28:06.953	Bcast		Rte	125	12	1	1	234	255		255	0	255	0	0
0:28:07.781	Bcast		DatUp	125	27	1	1	235		51	132	4	255	255	161
0:28:08.750	Bcast		DatUp	125	27	1	1	236		51	132	4	255	255	161
0:28:09.718	Bcast		DatUp	125	27	1	1	237		51	132	4	255	255	161

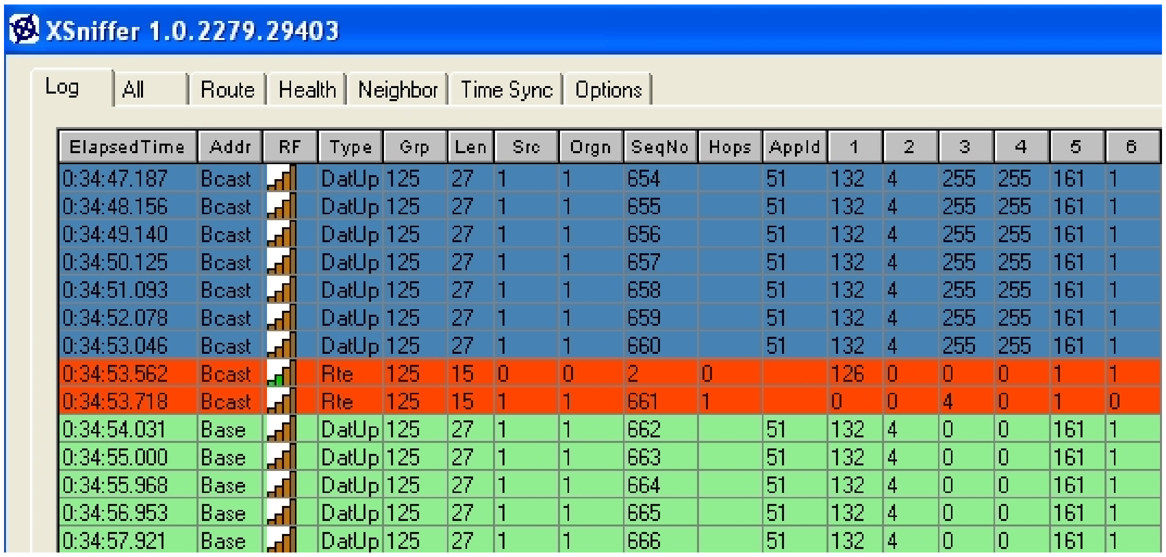
Figure 7-1. *XSniffer* Log Screen Display

You can see from the elapsed time the messages are begin sent about 1 second apart – each time the LEDs blink you should see a new message captured by *XSniffer*.

There are a couple of interesting things to note. First, look at the destination address field *Addr*. The value for this field is **Bcast** which means the sensor node id 1 (*Src* column) is broadcasting its packet to all nodes. This is the initial state of *XMesh* until the multi-hop network has formed efficient routes. Second, you can see there are two types of messages being sent by the sensor node (identified by *Type* field). Message type *DatUp* identifies a message as a data message sent upstream from the sensor node to the base station. Message type *Rte* designates a route update message. Route update messages are periodically sent by all nodes in a mesh network for the purpose of updating each other's routing tables.

So far we can see the messages from one sensor node. Remember we removed the *XMeshBase* Mote from the programming board – without a base station Mote, *XMesh* cannot form the multi-hop network. Now find the *XMeshBase* Mote we set aside earlier, make sure it has batteries and then turn it on.

As the messages flow into *XSniffer*, you should begin to see some interesting things.



XSniffer 1.0.2279.29403

Log | All | Route | Health | Neighbor | Time Sync | Options

ElapsedTime	Addr	RF	Type	Grp	Len	Src	Orgn	SeqNo	Hops	AppId	1	2	3	4	5	6
0:34:47.187	Bcast	📶	DatUp	125	27	1	1	654		51	132	4	255	255	161	1
0:34:48.156	Bcast	📶	DatUp	125	27	1	1	655		51	132	4	255	255	161	1
0:34:49.140	Bcast	📶	DatUp	125	27	1	1	656		51	132	4	255	255	161	1
0:34:50.125	Bcast	📶	DatUp	125	27	1	1	657		51	132	4	255	255	161	1
0:34:51.093	Bcast	📶	DatUp	125	27	1	1	658		51	132	4	255	255	161	1
0:34:52.078	Bcast	📶	DatUp	125	27	1	1	659		51	132	4	255	255	161	1
0:34:53.046	Bcast	📶	DatUp	125	27	1	1	660		51	132	4	255	255	161	1
0:34:53.562	Bcast	📶	Rte	125	15	0	0	2	0		126	0	0	0	1	1
0:34:53.718	Bcast	📶	Rte	125	15	1	1	661	1		0	0	4	0	1	0
0:34:54.031	Base	📶	DatUp	125	27	1	1	662		51	132	4	0	0	161	1
0:34:55.000	Base	📶	DatUp	125	27	1	1	663		51	132	4	0	0	161	1
0:34:55.968	Base	📶	DatUp	125	27	1	1	664		51	132	4	0	0	161	1
0:34:56.953	Base	📶	DatUp	125	27	1	1	665		51	132	4	0	0	161	1
0:34:57.921	Base	📶	DatUp	125	27	1	1	666		51	132	4	0	0	161	1

Figure 7-2. *XSniffer* Log Screen Display

After turning on the *XMeshBase* Mote you will start to see *Rte* (route update) messages being generated for node 0 – the base station. The sensor node Mote will see these Rte messages and will eventually add the base station Mote as its parent. Once this happens you will see the *DatUp* (data messages upstream to base) from node 1 being sent directly to the base station node 0 instead of being broadcast. The base station id 0 is denoted as **Base** in the *Addr* field.

You have just witnessed a two node multi-hop mesh network being formed using *XSniffer*!

7.2.8 Viewing your Sensor Network with MoteView

As valuable as the *XServe* and *XSniffer* tools are for monitoring sensor networks, we are now going to focus on a more feature rich client application named *MoteView*.

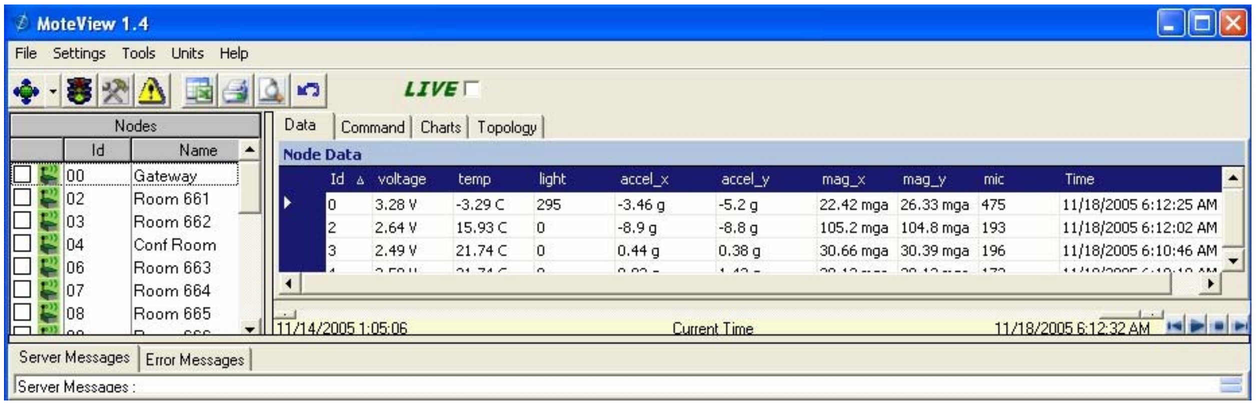
The *MoteView* application is installed separately from *MoteWorks* and may be downloaded free from the Crossbow web site. Make sure you also download the *MoteView* User's Manual.

Please download and install *MoteView* before continuing.

We are now going to use *MoteView* to view our two node sensor network. Double click on the icon located on your desktop. You should see something similar to the Figure 7-3 when *MoteView* loads.

NOTE

MoteView is only supported and can be used as monitoring tool for the tutorial ***lesson_4 lesson_5*** and ***lesson_6***, which use *XMesh* feature.



	Id	Name
☐	00	Gateway
☐	02	Room 661
☐	03	Room 662
☐	04	Conf Room
☐	06	Room 663
☐	07	Room 664
☐	08	Room 665

Id	voltage	temp	light	accel_x	accel_y	mag_x	mag_y	mic	Time
0	3.28 V	-3.29 C	295	-3.46 g	-5.2 g	22.42 mga	26.33 mga	475	11/18/2005 6:12:25 AM
2	2.64 V	15.93 C	0	-8.9 g	-8.8 g	105.2 mga	104.8 mga	193	11/18/2005 6:12:02 AM
3	2.49 V	21.74 C	0	0.44 g	0.38 g	30.66 mga	30.39 mga	196	11/18/2005 6:10:46 AM

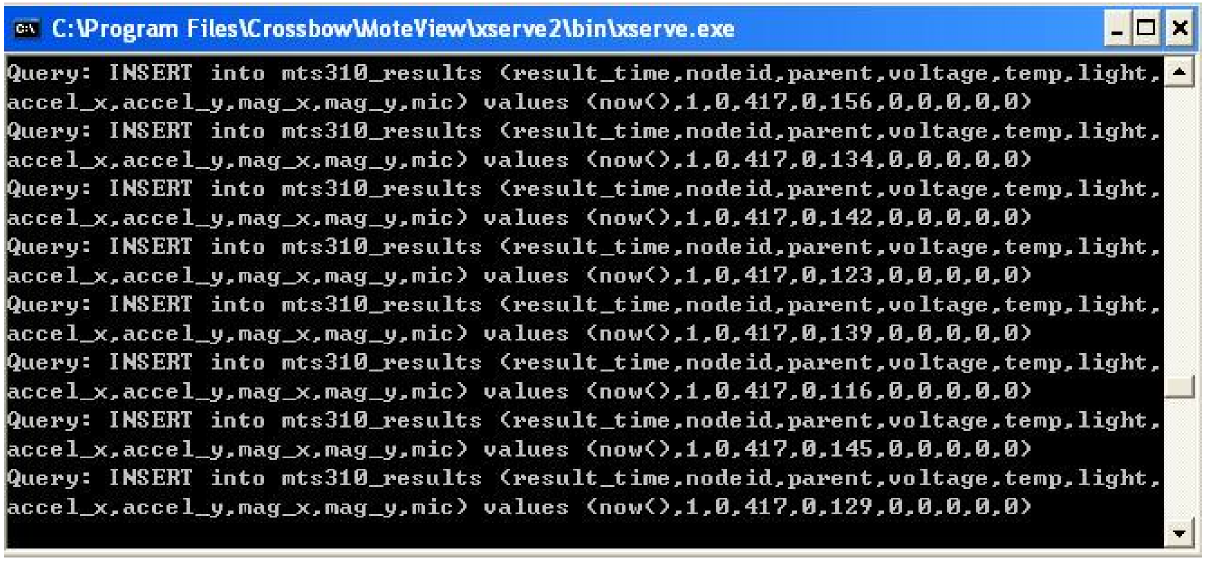
11/14/2005 1:05:06 Current Time 11/18/2005 6:12:32 AM

Figure 7-3. *MoteView* GUI Display

To view the sensor network data using *MoteView* perform the follow steps:

- Remove the *XSniffer* Mote from the programming board and plug the *XMeshBase* Mote (base station) back into the programming board
- From the *MoteView* main menu select **File > Connect > Connect to Database**
- Select **mts310_results** in the table name drop down list and click on **Apply**
- From the MoteView main menu select **File** > **Connect** > **Connect to MIB510/MIB520/MIB600/Stargate**.
  - Set the COM port value to the correct value for your setup
  - Select the **XMTS310** application from the *XMesh* Application drop down list
  - Select the **Advanced** tab. In **Data Logging Options** menu, check the box for **Spawn Separate Shell**.
- Click on **Start**. You will see *XServe* start-up enabled to log sensor data to the database

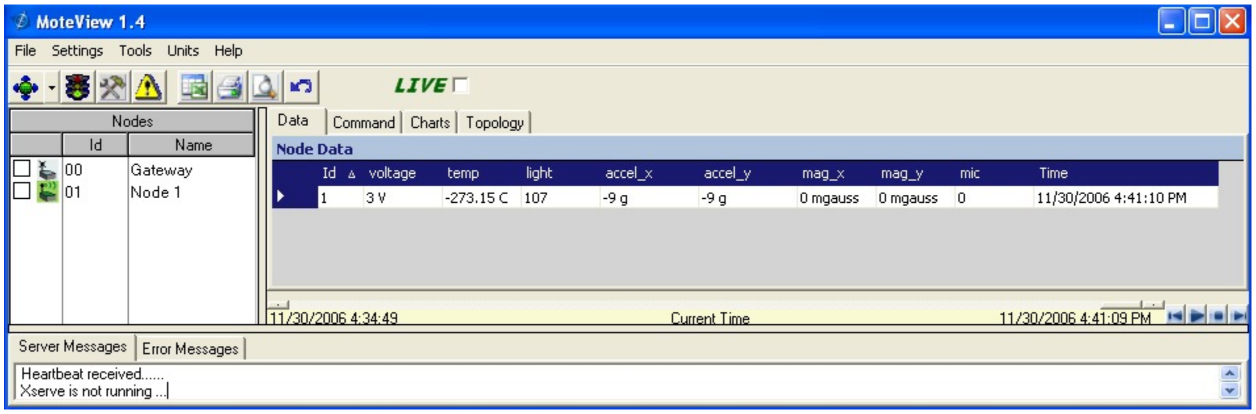
After a few minutes you should see *XServe* logging sensor data to the database similar to Figure 7-4.



```
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,156,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,134,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,142,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,123,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,139,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,116,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,145,0,0,0,0,0)
Query: INSERT into mts310_results (result_time,nodeid,parent,voltage,temp,light,
accel_x,accel_y,mag_x,mag_y,mic) values (now(),1,0,417,0,129,0,0,0,0,0)
```

Figure 7-4. *XServe* Log Screen Display

Now move back to the main *MoteView* window and you should see the sensor data from node 1 displayed in the data view similar to Figure 7-5.



Nodes	
Id	Name
00	Gateway
01	Node 1

Node Data

Id	voltage	temp	light	accel_x	accel_y	mag_x	mag_y	mic	Time
1	3 V	-273.15 C	107	-9 g	-9 g	0 mgauss	0 mgauss	0	11/30/2006 4:41:10 PM

11/30/2006 4:34:49 Current Time 11/30/2006 4:41:09 PM

```
Heartbeat received......
Xserve is not running ...
```

Figure 7-5. *MoteView* GUI Displaying Sensor Data

Congratulations, you have now deployed a complete end-to-end multi-hop sensor network solution!

7.3 A Closer Look at MyApp

Let's examine the specific differences between the *MyApp* application we developed in Chapter 6 and the *MyApp* application we have developed in this chapter. The significant difference is the communication service we are using to send the sensor data messages.

The *MyApp* application from the subdirectory ***/lesson_3*** used the basic `GenericComm` component for sending a message either directly through the UART port or over the radio – broadcasted or to a specific node address. The *MyApp* application in this chapter uses the *XMesh* networking service to multi-hop messages back to the base station. The *XMesh* service ultimately uses the `GenericComm` service for sending individual messages but special routing information is added – this is hidden from the application.

To summarize:

GenericComm – single hop, point-to-point communication service

XMesh – multi-hop mesh networking service

Let's take a closer look at the *MyApp.nc* configuration file:

```
configuration MyApp {
}
implementation {
  components Main, GenericCommPromiscuous as Comm, MULTIHOPROUTER, MyAppM,
TimerC, LedsC, Photo;

  Main.StdControl -> TimerC.StdControl;
  Main.StdControl -> MyAppM.StdControl;
  Main.StdControl -> Comm.Control;
  Main.StdControl -> MULTIHOPROUTER.StdControl;

  MyAppM.Timer -> TimerC.Timer[unique("Timer")];
  MyAppM.Leds -> LedsC.Leds;
  MyAppM.PhotoControl -> Photo.PhotoStdControl;
  MyAppM.Light -> Photo.ExternalPhotoADC;

  MyAppM.RouteControl -> MULTIHOPROUTER;
  MyAppM.Send -> MULTIHOPROUTER.MhopSend[AM_XMULTIHOP_MSG];
  MULTIHOPROUTER.ReceiveMsg[AM_XMULTIHOP_MSG] -
>Comm.ReceiveMsg[AM_XMULTIHOP_MSG];
}
```

The first thing you notice is that we have added a component named `MULTIHOPROUTER`. This is the actual component that implements *XMesh*. The other difference is that the `GenericComm` component has been replaced by `GenericCommPromiscuous`. `GenericCommPromiscuous` adds special radio "snooping" capabilities required by *XMesh*.

The other thing that looks different is the component wiring. You can see the `MyAppM` is now using the `MhopSend` interface instead of the `SendMsg` interface. *XMesh* implements the `MhopSend` interface which looks a little bit different:

```
interface MhopSend {
  command result_t send(uint16_t dest, uint8_t mode, TOS_MsgPtr msg,
                        uint16_t length);
  command void* getBuffer(TOS_MsgPtr msg, uint16_t* length);
  event result_t sendDone(TOS_MsgPtr msg, result_t success);
}
```

Specifically the `send` command adds a mode parameter. This parameter specifies the *XMesh* communication transport mode. In this example we use the `MODE_UPSTREAM` transport which sends a message in the direction of the base station.

Let's now take a look at the specific differences in the *MyAppM.nc* module for sending sensor data messages:

```
  command result_t StdControl.init() {
    uint16_t len;
    call Leds.init();
   call PhotoControl.init();

    // Initialize the message packet with default values
    atomic {
      pack = (XDataMsg*)call Send.getBuffer(&msg_buffer, &len);

      pack->board_id = SENSOR_BOARD_ID;
      pack->packet_id = 4;
   }
…
```

The first change we see is a different message packet being initialized in the `StdControl.init` function. We call the *XMesh* `Send.getBuffer` command which returns a pointer to the payload area in the `msg_buffer`. We then initialize the standard MTS310 packet with the default values.

```
  void task SendData()
  {
…
   // send message to XMesh multi-hop networking layer
    pack->parent = call RouteControl.getParent();
    if (call Send.send(BASE_STATION_ADDRESS,
                       MODE_UPSTREAM,
                       &msg_buffer,
                       sizeof(XDataMsg)) != SUCCESS)
…
```

The next difference we see is that the packet must include the current routing parent; this is obtained by making a call to the *XMesh* `RouteControl.getParent` command.

We then send the message using the `Send.send` command specifying the base station as the destination and the transport mode as `MODE_UPSTREAM`.

```
  event result_t Send.sendDone(TOS_MsgPtr msg, result_t success) {
    call Leds.greenToggle();
    atomic sending_packet = FALSE;
…
```

Finally similar to the *MyApp* application in Chapter 6 we receive the `Send.sendDone` event that notifies that the message has been sent.

7.4 *XMesh* Applications Supported in *MoteWorks*

All of Crossbow's sensor and data acquisition boards are supported with *XMesh* enabled applications. *XServe* is connected to these applications through a base station running the *XMeshBase* application. The Table 7-1 below provides a summary of the *XMesh* applications and the corresponding sensor boards.

Table 7-1. Sensor and data acquisition boards and the corresponding *XMesh* application

Sensor and Data Acquisition Boards	Application Name	Location of Driver Folder
MDA100CA	XMDA100	MoteWorks/apps/XMesh/XMDA100
MDA100CB	XMDA100CB	MoteWorks/apps/XMesh/XMDA100CB
MDA300	XMDA300	MoteWorks/apps/XMesh/XMDA300
MDA320	XMDA320	MoteWorks/apps/XMesh/XMDA320
MDA325	XMDA325	MoteWorks/apps/XMesh/XMDA325
MDA500	XMDA500	MoteWorks/apps/XMesh/XMDA500
MEP410	XMEP410	MoteWorks/apps/XMesh/XMEP410
MEP510	XMEP510	MoteWorks/apps/XMesh/XMEP510
MSP410	XMSP410	MoteWorks/apps/XMesh/XMSP410
MTS101	XMTS101	MoteWorks/apps/XMesh/XMTS101
MTS300CA/310CA	XMTS310	MoteWorks/apps/XMesh/XMTS310
MTS300CB/310CB	XMTS310CB	MoteWorks/apps/XMesh/XMTS310CB
MTS410	XMTS410	MoteWorks/apps/XMesh/XMTS410
MTS400/420	XMTS420	MoteWorks/apps/XMesh/XMTS420
MTS450	XMTS450	MoteWorks/apps/XMesh/XMTS450
MTS4510	XMTS510	MoteWorks/apps/XMesh/XMTS510

8 XMesh Advanced Features

In this chapter you will learn:

- How to use some advanced features of the *XMesh* multi-hop networking service
    - o How to use the *XMesh* end-to-end acknowledgment message transport service
    - o How to send downstream commands from the base station to individual Motes

8.1 Hardware Requirements

This chapter requires the following hardware:

- Two MICA Motes: standard editions of MICA2 (MPR4x0) or MICAz (MPR2400) or OEM editions of MICA2 (MPR600) or MICAz (MPR2600)
- One gateway board: MIB510, MIB520, or MIB600 and the associated hardware (cables, power supply) for each
- A Windows PC with *MoteWorks* installed

8.2 End-to-End Acknowledgements: MyApp from the subdirectory */lesson_5*

In this section we will look at an example application, *MyApp* from the subdirectory ***/lesson_5*** that shows how to use the XMesh end-to-end acknowledgement message transport service.

The following enhancements have been made to the *XMesh* application presented in Chapter 7:

- Code modified to use the `MOTE_UPSTREAM_ACK` transport mode to request an acknowledgement back from the base station
- Yellow LED toggles when an acknowledgement message is received back from the base station

There is a class of sensor network applications that requires a 100% reliable delivery of messages to the base station. *XMesh* implements a special networking transport service that sends acknowledgement messages back to the originating node when the sensor messages arrive at the base station. It is then a simple task of resending the sensor message from the originating node if the acknowledgement is not received back within a certain time.

8.2.1 Compile and Install the Code in a Mote

The *MyApp* application is located in the ***/MoteWorks/apps/tutorial/lesson_5*** folder. This application will be installed on two motes. One Mote will function as the sensor node and the other will function as the base station. The sample application is installed on both Motes due to the use of the `MODE_UPSTREAM_ACK` transport mode used. This is a different transport mode than the one used by the *XMeshBase* application used earlier.

Plug the Mote that will function as the sensor node into the programming board. To compile and install the `MyApp` application onto the sensor node:

- Select the `MyApp.nc` file in Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,1 mib510,com1`** (assuming MICA2 Mote assigned with Node ID 1 and PC connected to COM1)

NOTE: A sensorboard is not required to be plugged into the sensor node Mote.

Next, plug the Mote that will function as the base station into the programming board. This Mote will be programmed with the same *XMeshBase* application as follows:

- Select the `XMeshBase.nc` file in Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 reinstall,0 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1)

Leave the base station Mote plugged into the programming board.

Make sure you have batteries plugged into the sensor node Mote – the one programmed with id 1 and then turn it on. You should see the red and green LEDs flashing until the mesh network is formed. Once the sensor node has joined the network with the base station (a couple minutes or sooner) you should see the yellow LED flash on the sensor node.

The flashing yellow LED on the sensor node indicates that an acknowledgement message has been received from the base station!

You can also run *XServe* (see section 7.2.6) or *MoteView* to display the incoming packets on the PC.

8.3 A Closer Look at MyApp

The *MyApp* application in this chapter has very minimal changes when compared to the *MyApp* application developed in Chapter 7.

First, let's look at the *MyApp.nc* configuration file:

```
…
  MyAppM.RouteControl -> MULTIHOPROUTER;
  MyAppM.Send -> MULTIHOPROUTER.MhopSend[AM_XMULTIHOP_MSG];
  MyAppM.ReceiveAck -> MULTIHOPROUTER.ReceiveAck[AM_XMULTIHOP_MSG];

  MULTIHOPROUTER.ReceiveMsg[AM_XMULTIHOP_MSG] -
>Comm.ReceiveMsg[AM_XMULTIHOP_MSG];
…
```

The only change to the configuration file is the addition of the `ReceiveAck` interface wiring. The `ReceiveAck` interface is required to implement an event callback function that will be generated by *XMesh* when the acknowledgment message has arrived from the base station.

Let's now look at the *MyAppM.nc* module file:

```
  void task SendData() {
…
    if (call Send.send(BASE_STATION_ADDRESS,
                       MODE_UPSTREAM_ACK,
                       &msg_buffer,
                        sizeof(XDataMsg)) != SUCCESS)
…
  event TOS_MsgPtr ReceiveAck.receive(TOS_MsgPtr pMsg, void* payload,
                                      uint16_t payloadLen) {
    call Leds.yellowToggle();
…
```

The first change is the transport mode of `MODE_UPSTREAM_ACK`. This tells *XMesh* to send an acknowledgement message back to the message originator when the message is received at the base station.

The second change is the addition of the `ReceiveAck.receive` event function. This is the event called by *XMesh* when the acknowledgement message has arrived from the base station for the most recently sent message. The yellow LED is toggled upon receiving this acknowledgment message.

8.3.1 Enhancements for Reliable Message Delivery

This example application shows the basic mechanism for using the *XMesh* `MODE_UPSTREAM_ACK` message transport. For a robust real world application it is also necessary to implement a message re-send strategy for cases where the acknowledgment message is not received due to a network problem. The easiest way to do this is to use another timer set to fire after the maximum acknowledgement waiting period – determined by the developer. If the acknowledgement is received before the timer *fires* you just stop the timer. Otherwise the timer fires indicating you should resend the message. You also want to have a maximum number of message retries before giving up.

NOTE: It is important to remember the `MODE_UPSTREAM_ACK` transport mode does not guarantee message delivery – this is the responsibility of the application developer.

8.4 Downstream Command Processing: MyApp from the subdirectory */lesson_6*

In this section we will look at an example application named *MyApp* from the subdirectory ***/lesson_6*** that shows how to implement command processing in Motes. We will also show how to send commands to individual Motes using the *MoteWorks XServeterm* application.

The following enhancements have been made to the *XMesh* application presented in Chapter 7.

- Code modified to use the `XCommand` component to intercept and process downstream commands

8.4.1 Compile and Install the Code in a Mote

The *MyApp* application is located in the ***/MoteWorks/apps/tutorial/lesson_6*** folder. This application will require two Motes. One Mote will function as the sensor node and a second Mote will function as the base station plugged into the programming board and connected to your PC. The Mote that functions as the sensor node will need to have batteries plugged into it. The Mote that functions as the base station does not require batteries.

Plug the Mote that will function as the sensor node into the programming board. To compile and install the `MyApp` application onto the sensor node:

- Select the `MyApp.nc` file in Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,1 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1)

Next, plug the Mote that will function as the base station into the programming board. This Mote will be programmed with a special application named `XMeshBase` located in the ***/MoteWorks/apps/xmesh/XMeshBase*** folder. To compile and install the *XMeshBase* application onto the base station node:

- Select the `XMeshBase.nc` file in Programmer's Notepad
- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,0 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1).

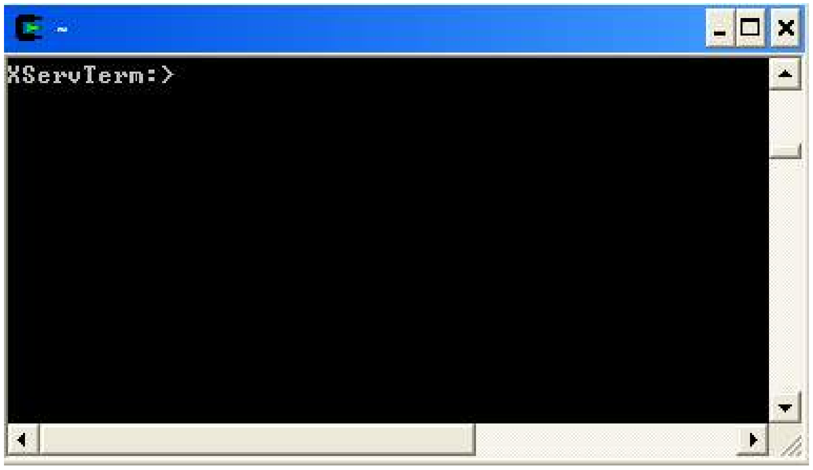
Keep the base station Mote plugged into the programming board and turn on the sensor node Mote.

8.4.2 Sending Commands to a Mote using XServeterm

MoteWorks includes a utility named *XServeterm* that provides a terminal interface for a running instance of *XServe*. *XServeterm* provides many commands for monitoring and configuring your sensor network. We are going to use it to send commands to our sensor node to demonstrate the downstream command capabilities of *XMesh*.

The next step involves running *XServe* and *XServeterm* on your PC.

1. *XServe* is a program that runs within a Cygwin command prompt window. The first step is to open a Cygwin command prompt by double clicking on the icon located on your desktop.
2. Type **`xserve –device=COM1`** at the command prompt and hit enter.
3. Open another Cygwin command prompt window and then type **`xserveterm –group 125`** you should see output similar to Figure 8-1.

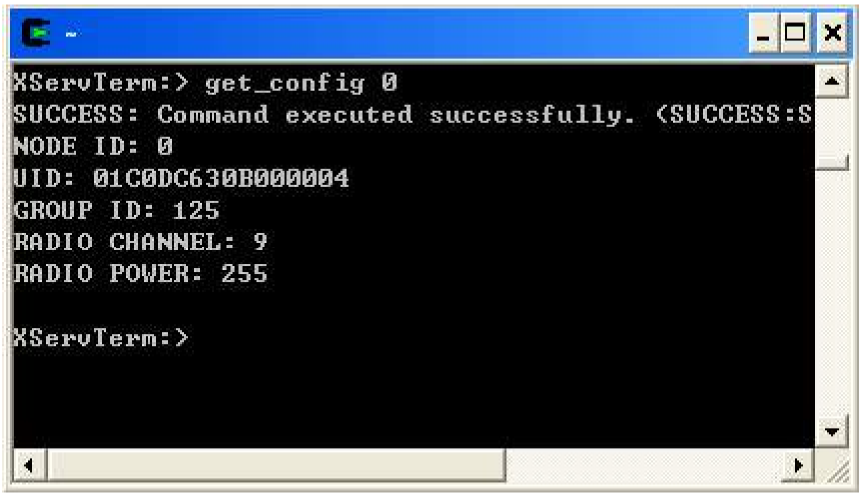


```
XServTerm:>
```

Figure 8-1. *XServeterm* Console Output

The first command we will try is the **`get_config`** command. The `get_config` command returns the current configuration parameters for a Mote – similar to the `ping` command.

Let's check the current configuration of the base station Mote. From the *XServeterm* window type in **`get_config 0`** and hit enter, you should see output similar to Figure 8-2.



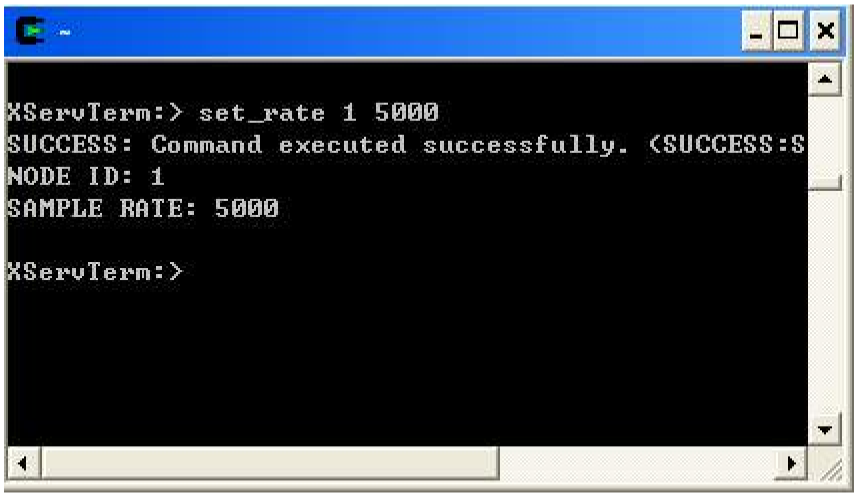
```
XServTerm:> get_config 0
SUCCESS: Command executed successfully. (SUCCESS:S
NODE ID: 0
UID: 01C0DC630B000004
GROUP ID: 125
RADIO CHANNEL: 9
RADIO POWER: 255

XServTerm:>
```

Figure 8-2. *XServeterm* `get_config` Command Output

Now try the same `get_config` command for node 1 – the sensor node. Type in **`get_config 1`** and hit enter. If you get a time-out error, node 1 has not yet joined the network. You must get a valid response from node 1 before continuing.

Now that you have communication with node 1, you can try issuing some other commands.

The next command is named **`set_rate`** and it's used to change the Mote sensor sampling rate. The current sampling rate for our sensor node is 1000 msec. Lets change the sampling rate to 5000 ms – type in **`set_rate 1 5000`** and hit enter. The command parameters are the *node id* followed by the *sampling rate* in msec. You should see output similar to Figure 8-3.



```

XServTerm:> set_rate 1 5000
SUCCESS: Command executed successfully. (SUCCESS:S
NODE ID: 1
SAMPLE RATE: 5000

XServTerm:>
```

Figure 8-3. *XServeterm* `set_rate` Command Output

You should now notice that the LEDs on node 1 are blinking much slower than before – every 5000 ms. This means the light sensor is now being sampled and reported every 5 seconds instead of the original 1 second.

The other command that we can try is to control the state of the LEDs. The LEDs are controlled using the **`actuate`** command as follows:

```
actuate <destination address> <device> <state>
                device ids              states
                ----------              ------
                green led       0       off     0
                yellow led      1       on      1
                red led         2       toggle  2
                all leds        3
                sounder         4
                relay1          5
                relay2          6
                relay3          7
```

Toggle the yellow LED on node 1 by typing **`actuate 1 1 2`**.

8.5 A Closer Look at MyApp

The *MyApp* application from the subdirectory ***/lesson_6*** is also based on the *MyApp* application developed in Chapter 7. Minimal changes are required for implementing command processing.

Let's look at the changes for the *MyApp.nc* configuration file:

```
configuration MyApp {
}
implementation {
  components Main, GenericCommPromiscuous as Comm, MULTIHOPROUTER, MyAppM,
TimerC, LedsC, Photo, XCommandC;
…
  MyAppM.RouteControl -> MULTIHOPROUTER;
  MyAppM.Send -> MULTIHOPROUTER.MhopSend[AM_XMULTIHOP_MSG];
  MyAppM.XCommand -> XCommandC;
  MULTIHOPROUTER.ReceiveMsg[AM_XMULTIHOP_MSG] -
>Comm.ReceiveMsg[AM_XMULTIHOP_MSG];
…
```

The first change you will notice is the addition of the `XCommandC` component. This is the component that provides the basic functionality for processing downstream commands.

Next you will notice that `XCommandC` is wired to `MyAppM` module through the *XCommand* interface.

Here is the definition for the *XCommand* interface:

```
interface XCommand {
  event result_t received(XCommandOp *op);
}
```

The `XCommand` interface provides one single event named `received` which must be implemented in your application module – in this case *MyAppM.nc*. The `received` event is signaled when a command arrives for the node.

Here are the changes made to the *MyAppM.nc* module file:

```
  event result_t XCommand.received(XCommandOp *opcode) {
    uint16_t timer = 0;

    switch (opcode->cmd) {
      case XCOMMAND_SET_RATE:
        // Change the data collection rate.
        timer = opcode->param.newrate;
        call Timer.stop();
        call Timer.start(TIMER_REPEAT,timer);
        break;
…
```

The only required change is to implement the `XCommand.received` event function. Handling the LED actuation is handled implicitly by *XCommand*. For this application `set_rate` command is the only other command implemented locally.

9 Data Logging Application

In this chapter you will learn:

- How to write and read data from external flash on a Mote.

9.1 Hardware Requirements

This chapter requires the following hardware:

- One MICA Motes: standard editions of MICA2 (MPR4x0) or MICAz (MPR2400) or OEM editions of MICA2 (MPR600) or MICAz (MPR2600)
- One gateway board: MIB510, MIB520, or MIB600 and the associated hardware (cables, power supply) for each
- A Windows PC with *MoteWorks* installed

9.2 Using the external flash: MyApp from the subdirectory */lesson_7*

In this section we will look at an example application, *MyApp* from the subdirectory ***/lesson_7*** that shows how to write to and read from the mote's external flash.

The following enhancements have been made to the *MyApp* application presented in Chapter 6:

- Code modified to use the `ByteEEPROM` component to request memory allocation in the external flash, write to and read from this allocated memory.
- Green LED toggles when data read from external flash is sent to the base station through the UART.

There are some sensor network applications that require data logging to the external flash. The component `ByteEEPROM` enables memory allocation to the application and read/write operations at the external flash. In the *MyApp* application we log certain number of light sensor readings in the external flash. When a new reading is reported by the sensor, it replaces the stalest reading in the external flash. Once the new reading is written to the external flash, the entire logged data is read back from the flash, inserted into a data packet and sent to the PC over the UART.

9.2.1 Compile and Install the Code in a Mote

The *MyApp* application is located in the ***/MoteWorks/apps/tutorial/lesson_7*** folder. This application will be installed on to a single Mote that will run the application and also function as the base station. We therefore install the application on the Mote with node id as 0.

Plug the Mote into the programming board. To compile and install the `MyApp` application onto the sensor node:

- Select the `MyApp.nc` file in Programmer's Notepad

- Select **Tools > shell**. When prompted for parameters, type **`make mica2 install,0 mib510,com1`** (assuming MICA2 Mote and PC connected to COM1). Node id is assigned to be 0 since it sends data packets directly over the UART.

NOTE: A sensorboard is may be plugged into the programming board if mib510 is used.

Leave the Mote plugged into the programming board.

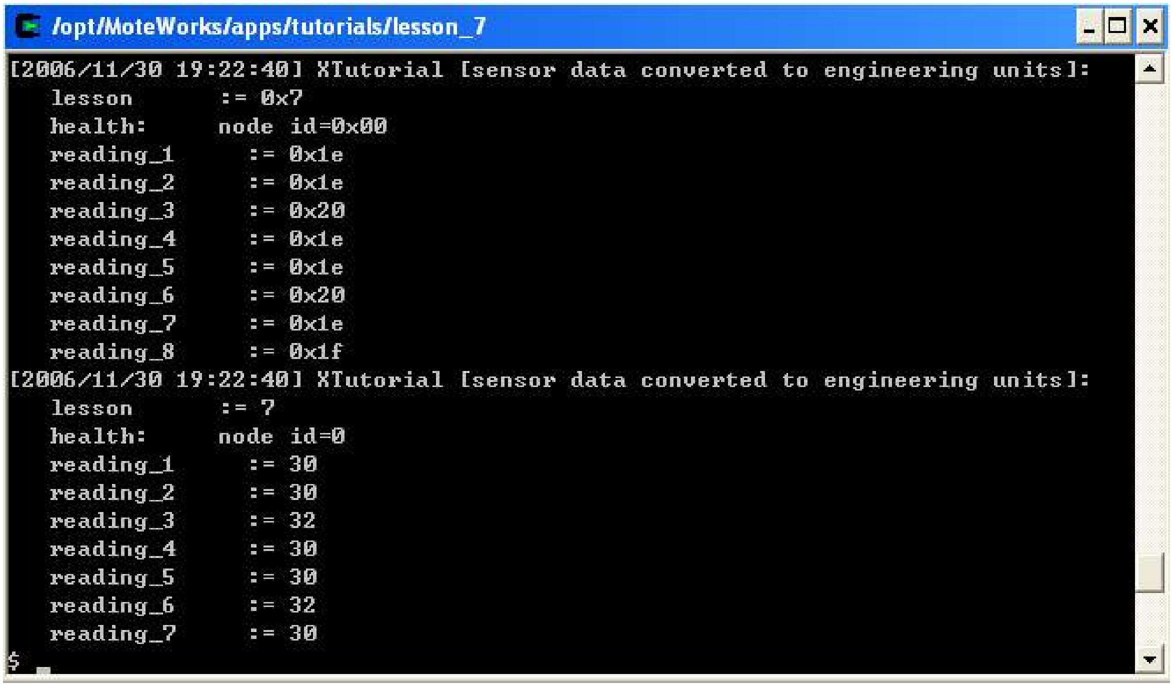
The flashing green LED on the mote indicates that a data packet has been sent to the UART.

You can now run *XServe* to display the incoming packets on the PC.

9.2.2 Receiving data on the XServe

We now run *XServe* on the PC to view the contents of the data packets.

1. The first step is to open a Cygwin command prompt by double clicking on the icon located on your desktop.
2. Type **`xserve -device=COM1`** at the command prompt and hit enter, you should see output similar to the following when the data packets filled using the external flash arrive over the serial port and are displayed by *XServe*:



```
[2006/11/30 19:22:40] XTutorial [sensor data converted to engineering units]:
   lesson       := 0x7
   health:      node id=0x00
   reading_1      := 0x1e
   reading_2      := 0x1e
   reading_3      := 0x20
   reading_4      := 0x1e
   reading_5      := 0x1e
   reading_6      := 0x20
   reading_7      := 0x1e
   reading_8      := 0x1f
[2006/11/30 19:22:40] XTutorial [sensor data converted to engineering units]:
   lesson       := 7
   health:      node id=0
   reading_1      := 30
   reading_2      := 30
   reading_3      := 32
   reading_4      := 30
   reading_5      := 30
   reading_6      := 32
   reading_7      := 30
$ _
```

Figure 9-1. XServe Output for MyApp in lesson 7

NOTE: Please note that this application cannot be used together with XOtap since both share the external flash memory.

9.3 A Closer Look at MyApp

The *MyApp* application in this chapter has the following changes when compared to the *MyApp* application developed in Chapter 6.

First, let's look at the *MyApp.nc* configuration file:

```
…
  Main.StdControl -> ByteEEPROM;


  MyAppM.AllocationReq -> ByteEEPROM.AllocationReq[BYTE_EEPROM_ID];
  MyAppM.ReadData->ByteEEPROM.ReadData[BYTE_EEPROM_ID];
  MyAppM.WriteData->ByteEEPROM.WriteData[BYTE_EEPROM_ID];

…
```

The change to the configuration file is the addition of the `ByteEEPROM` component wiring. The `ByteEEPROM` component is required to request memory in the external flash and carry out read write operations on the allocated memory in the external flash.

The interface `AllocationReq` requests a byte section of the flash. This request must be made at the time `ByteEEPROM` is initialized. The interface `ReadData` reads a line from the EEPROM where each line is 16 bytes. The interface `WriteData` writes a line to the EEPROM where each line is 16 bytes.

Let's now look at the *MyAppM.nc* module file:

```
  module MyAppM {
  …

  uses {
    …

   interface AllocationReq;
   interface WriteData;
   interface ReadData;
  }
}

command result_t StdControl.init() {
…
    call AllocationReq.request(PhotoLogCount*sizeof(uint16_t));
…


  event result_t AllocationReq.requestProcessed(result_t success) {
    // Allocation must succeed
    if (success){
      ready = TRUE;
      }
    return SUCCESS;
  }

event result_t Timer.fired()
  {
   if(ready)
  {
  call PhotoControl.start();
  call Light.getData();
  }
…

async event result_t Light.dataReady(uint16_t data) {
  atomic pack->xData.datap1.light[0] = data;
  lightData[0]=data;
  if(call ReadData.read(0,(uint8_t*)(&lightData[1]),(PhotoLogCount-
1)*2)==FAIL)
  {
  call Leds.redToggle();
  }
…

  event result_t ReadData.readDone(uint8_t *buffer, uint32_t
numBytesRead, result_t success)
  {

    call Leds.greenToggle();
    if(numBytesRead==((PhotoLogCount-1)*2))
    {
    memcpy((uint8_t*)(pack->Data.datap1.light)+2,
              (uint8_t*)(&lightData[1]),(PhotoLogCount-1)*2);
    call WriteData.write(0,(uint8_t*)(&lightData[0]),
              PhotoLogCount*2);
    }
    return SUCCESS;
 }

event result_t WriteData.writeDone(uint8_t *data, uint32_t
numBytesWrite, result_t success)
  {

  post SendData();
  return SUCCESS;

  }
```

All the changes are related to using the interfaces `AllocationReq`, `ReadData` and `WriteData` of `ByteEEPROM` component.

The first interface used is `AllocationReq.request(PhotoLogCount*sizeof(uint16_t))` during the `StdControl` initialization. This is used to request memory allocation in the external flash where the size of memory is specified with the request command. The value of PhotoLogCount is defined in the file `SensorboardApp.h`. In this example value of PhotoLogCount is 8. We thus store 8 light sensor readings each of size 2 bytes in the external flash.

Once the allocation request is processed, the event `AllocationReq.requestProcessed (result_t success)` is signaled. If the outcome of the event is a `SUCCESS`, then the `ready` flag is set as true. The purpose of the `ready` flag is to start sampling of the light sensor. If the state of `ready` flag is true, when the periodic timer fires then the light sensor is sampled.

When the event `Light.dataReady(uint16_t data)` is signaled; the data packet is filled in with the new reading. Then the `ReadData` interface is used to read the data from the flash where the address of the memory buffer to be read and the size of data to be read is specified in the arguments of the command `ReadData.read()`. As a result of this command the event `ReadData.readDone(int8_t *buffer, uint32_t numBytesRead, result_t success)` is signaled. The green LED toggles to denote that `ReadData.readDone()` event has been signaled. In this event, the last seven readings read from the external flash are copied to the data packet. Therefore the data packet consists of the last seven readings and the eighth reading is the latest reading from the light sensor. The `WriteData` interface is then used to write these eighth readings to the external flash using command `WriteData.write()`. As a result of the command `WriteData.write()`, the event `WriteData.writeDone(uint8_t *data, uint32_t numBytesWrite, result_t success)` is signaled which returns the data and number of bytes written and whether write command was successfully executed.

Hence, the data is logged in a circular buffer, such that the stalest reading is pushed out of the buffer, each time a new reading is generated by the light sensor. When this event is signaled we post the task `sendData()` to send the data packet consisting of the latest eighth light readings through the UART.

When the event `SendMsg.sendDone()` is signaled then green LED toggles to indicate that data was sent successfully.

9.4 Conclusion

This example application shows the basic mechanism for using the interfaces of `ByteEEPROM` component to access the mote's external flash message transport. For a real world application it is necessary to know how to use the Mote's external flash for data logging. The Mote's internal flash is not sufficient to fulfill the data logging requirements of real world application. User may want to log several readings of sensor data as illustrated in the example application described in this chapter. User may also require logging of data related to mote health, application specific data structures or Mote configuration parameters. But accessing external flash consumes Mote's battery power hence this operation should be used with discretion.

10 Appendix A: Cygwin Command Reference

Cygwin is a Unix/Linux emulation environment for Microsoft Windows. The Cygwin tools are ports of the popular GNU development tools for Microsoft Windows. Cygwin is a means to providing a stable, mature, useful, and usable, command-line environment on Microsoft Windows platforms. It is an optional user interface for compiling and downloading Mote applications in *MoteWorks*.

Some useful Cygwin commands are listed in Table 10-1 below.

Table 10-1. Some Useful Cygwin Commands

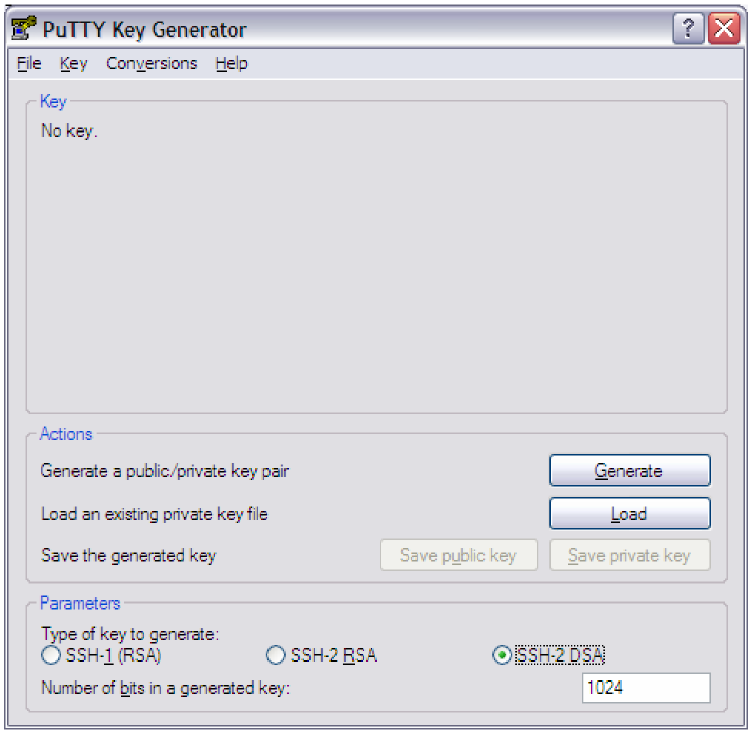
Description	Cygwin Command
Move up a directory	`../`
Move up two directories	`../../`
Go to a sub-directory called “mydirectory”	`cd mydirectory`
List all files and directories	`ls`
Where is the executable?	`which <executable>`
Show all environment variables	`set`
Add a environment variable	`export MYHOME=c:/mydev/apps`
Show an environment variable	`echo $MYHOME`
Remove an environment variable	`unset MYHOME`
Compile for MICA2	`make mica2`
Compile and install for MICA2	`make mica2 install`
Compile and install for MICA2 with node ID=0	`make mica2 install,0`
Install a pre-compiled app into MICA2	`make mica2 reinstall`
generate HTML format component structure diagrams	`make mica2 docs`

11 Appendix B: Accessing Crossbow CVS

MoteWorks Enterprise Edition subscribers can access the http://cvs.xbow.com server to get updates to the stable release source code. Instructions on how to connect to cvs.xbow.com using either Cygwin or WinCVS clients are available online when logged in as a valid CVS user.

11.1 Generate Key with PuTTY

1. Open PuTTYgen from **Start>Programs>PuTTY>PuTTYgen.**
2. Select **SSH-2 DSA.**



No key.

Generate a public/private key pair

Load an existing private key file

Save the generated key

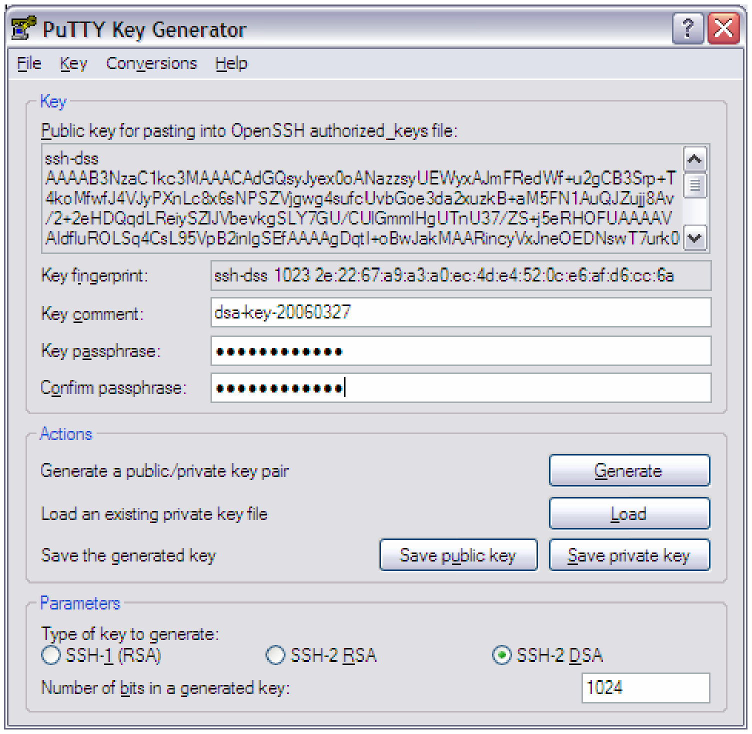
Type of key to generate: SSH-1 (RSA) SSH-2 RSA [✓ SSH-2 DSA]

Number of bits in a generated key: 1024

3. Click on **Generate.**

4. Move around mouse on black area to generate randomness.

5. Enter **passphrase** and **confirm.**



PuTTY Key Generator

Public key for pasting into OpenSSH authorized_keys file:

```
ssh-dss
AAAAB3NzaC1kc3MAAACAdGQsyJyex0oANazzsyUEWyxAJmFRedWf+u2gCB3Srp+T
4koMfwfJ4VJyPXnLc8x6sNPSZVjgwg4sufcUvbGoe3da2xuzkB+aM5FN1AuQJZujj8Av
/2+2eHDQqdLReiySZlJVbevkgSLY7GU/CUlGmmlHgUTnU37/ZS+j5eRHOFUAAAAV
AldfluROLSq4CsL95VpB2inlgSEfAAAAgDqtI+oBwJakMAARincyVxJneOEDNswT7urk0
```

Key fingerprint: ssh-dss 1023 2e:22:67:a9:a3:a0:ec:4d:e4:52:0c:e6:af:d6:cc:6a

Key comment: dsa-key-20060327

Key passphrase: •••••••••••••

Confirm passphrase: •••••••••••••

Actions

Generate a public/private key pair — Generate

Load an existing private key file — Load

Save the generated key — Save public key — Save private key

Parameters

Type of key to generate: SSH-1 (RSA) SSH-2 RSA [✓ SSH-2 DSA]

Number of bits in a generated key: 1024

6. Click **Save public key** as key.pub.

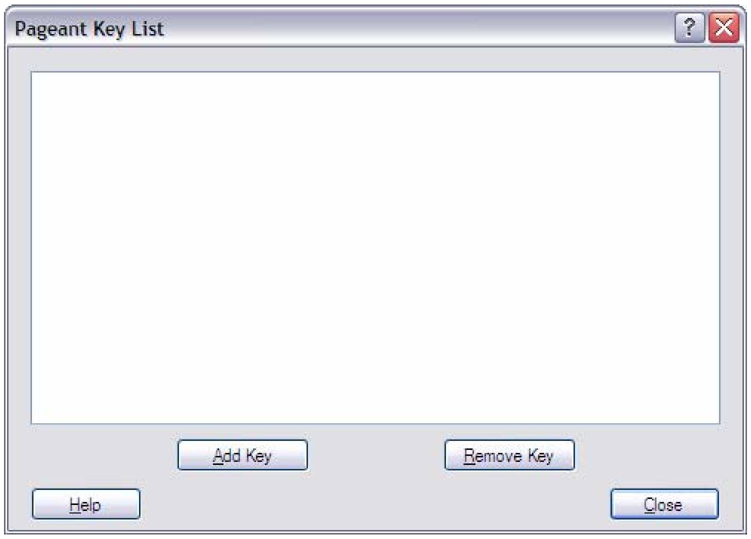
7. Click **Save private key** as key.ppk.

8. Close PuTTYgen.

9. Open Pageant from **Start>Programs>PuTTY>Pageant.**

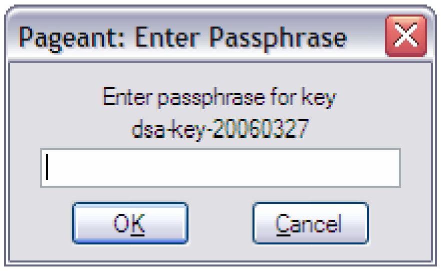
10. Double-click on Pageant icon on lower right task bar (Computer with Hat)

11. Click on **Add Key**

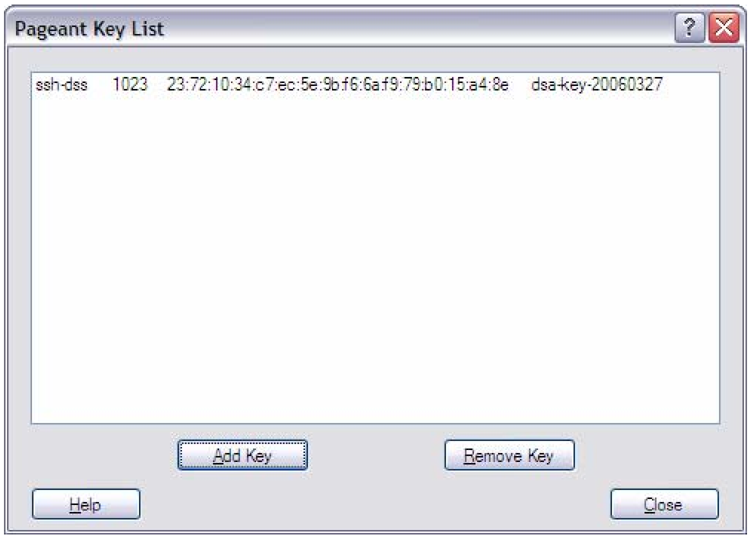


12. Browse to and select key.ppk private key that was generated in Step 7.

13. Enter your passphrase from Step 5 and click on **OK**.



14. Verify that the key is added and click on **Close**.



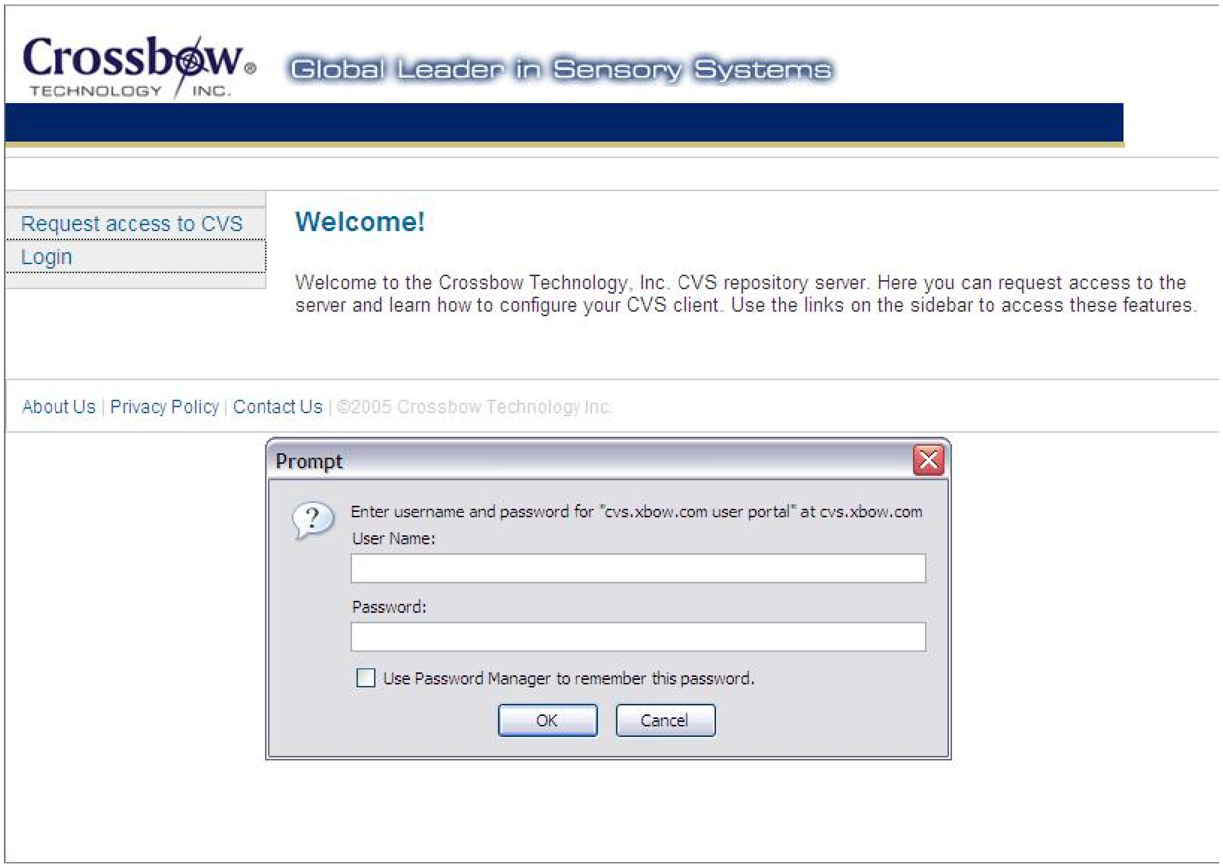
```
ssh-dss   1023   23:72:10:34:c7:ec:5e:9b:f6:6a:f9:79:b0:15:a4:8e   dsa-key-20060327
```

11.2 Upload public key to CVS server

The next step is to transfer your public key to the CVS server.

1. Open a browser and go to http://cvs.xbow.com/
2. Click on **Login.**
3. Enter your *MoteWorks* User name and password (different from Key Passphrase).

NOTE: You should contact the Crossbow Support team to obtain login and password for CVS access. Refer to Appendix C for details.


Global Leader in Sensory Systems

Request access to CVS
Login

Welcome!

Welcome to the Crossbow Technology, Inc. CVS repository server. Here you can request access to the server and learn how to configure your CVS client. Use the links on the sidebar to access these features.

About Us | Privacy Policy | Contact Us | ©2005 Crossbow Technology Inc.

Prompt

Enter username and password for "cvs.xbow.com user portal" at cvs.xbow.com

User Name:

Password:

Use Password Manager to remember this password.

4. At the CVS Server – User Portal page, click on **Upload an SSH Key.**

5. Click on **Browse** and point to the public key file "key.pub" generated in Step 7 of Section 11.1.

6. Click on **Upload Key.**

7. If the upload is successful, you should see "Operation Succeeded".

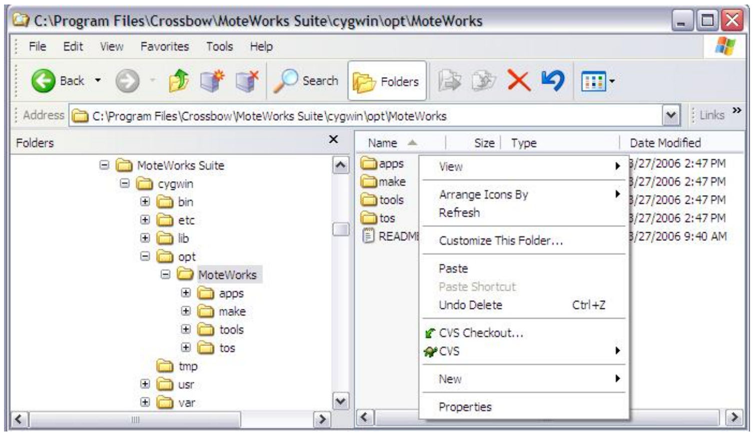
11.3 Configure TortoiseCVS client and check out code

Next, we will configure the TortoiseCVS client application to access the remote CVS repository.

1. Open a Windows File explorer.

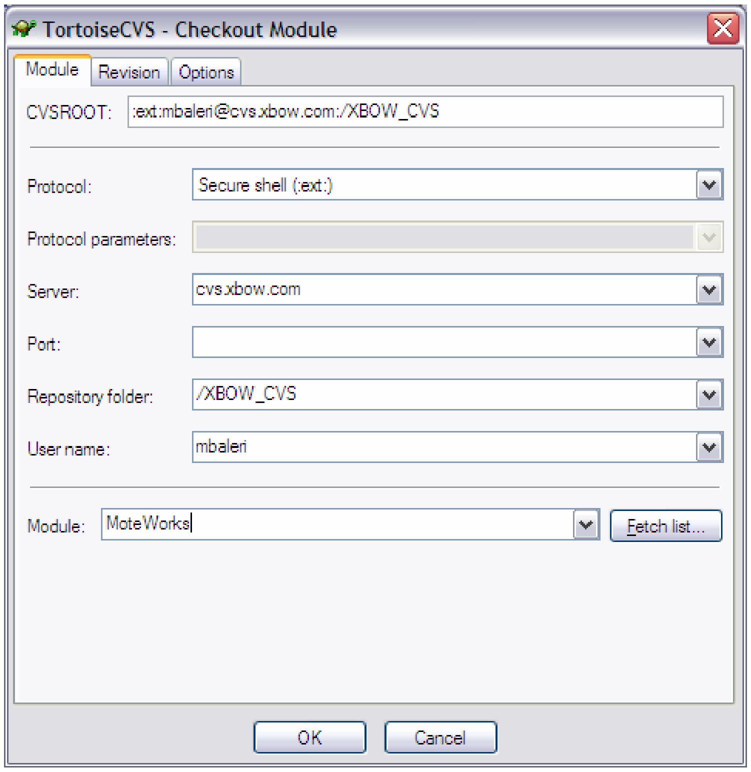
2. Go to the *MoteWorks* directory that you want to update and initiate a pop-up menu with a right-click of the mouse.

3. Select **CVS Checkout.**



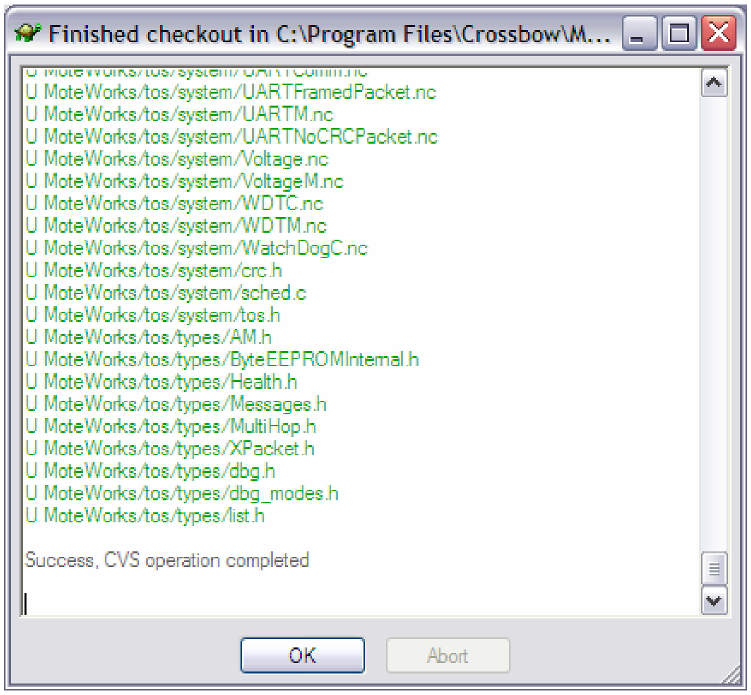
4. Fill in CVSROOT, server, module:
   a. Protocol: Secure shell (:ext:)
   b. Server = cvs.xbow.com
   c. Repository folder = /XBOW_CVS
   d. User name = Your user name
   e. Module = MoteWorks

   Click on **OK**.



CVSROOT: :ext:mbaleri@cvs.xbow.com:/XBOW_CVS
Protocol: Secure shell (:ext:)
Protocol parameters:
Server: cvs.xbow.com
Port:
Repository folder: /XBOW_CVS
User name: mbaleri
Module: MoteWorks

5. You can now right click in the MoteWorks tree and use TortoiseCVS commands:
   - update
   - commit
   - diff (only appears for files that have been modified)



```
U MoteWorks/tos/system/UARTComm.nc
U MoteWorks/tos/system/UARTFramedPacket.nc
U MoteWorks/tos/system/UARTM.nc
U MoteWorks/tos/system/UARTNoCRCPacket.nc
U MoteWorks/tos/system/Voltage.nc
U MoteWorks/tos/system/VoltageM.nc
U MoteWorks/tos/system/WDTC.nc
U MoteWorks/tos/system/WDTM.nc
U MoteWorks/tos/system/WatchDogC.nc
U MoteWorks/tos/system/crc.h
U MoteWorks/tos/system/sched.c
U MoteWorks/tos/system/tos.h
U MoteWorks/tos/types/AM.h
U MoteWorks/tos/types/ByteEEPROMInternal.h
U MoteWorks/tos/types/Health.h
U MoteWorks/tos/types/Messages.h
U MoteWorks/tos/types/MultiHop.h
U MoteWorks/tos/types/XPacket.h
U MoteWorks/tos/types/dbg.h
U MoteWorks/tos/types/dbg_modes.h
U MoteWorks/tos/types/list.h

Success, CVS operation completed
```

NOTE: Make sure you have Pageant running on your before performing a CVS update.

IMPORTANT: If your PC is to host both the server and client layer functions, then running the *PostgreSQL* database service is required to use *MoteView*. However, if you are accessing a server or Stargate that is running *XServe/PostgreSQL*, then you don't need to run the service on your PC.

IMPORTANT: If you installed MoteWorks Standard and then updated to an Enterprise tree from CVS, your tools may not work fully. "Make install" may not work for example.

This is because the permissions on two directories are not preserved in CVS. To correct this, you may run the following commands in Cygwin window:

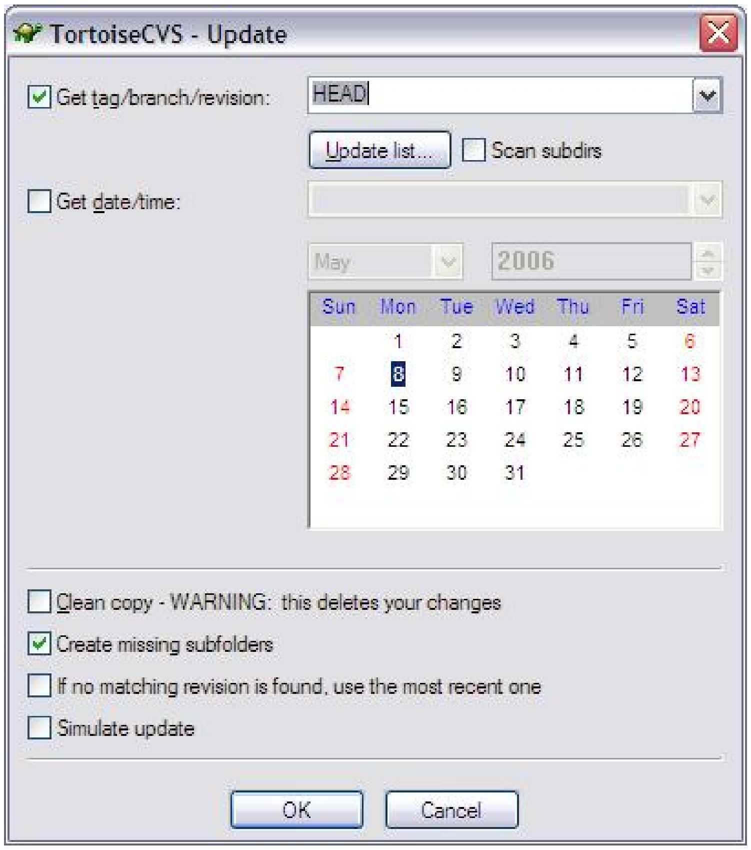
```
chmod +x /opt/MoteWorks/tools/bin/*
chmod +x /opt/MoteWorks/make/scripts/*
```

11.3.1 Checking out multiple code branches from CVS

The CVS access allows MoteWorks Enterprise users to download the code not only from released and supported tree, but also from development/unreleased and unsupported tree. To do this, follow these steps:

1. Open a Windows File explorer.
2. Go to the *MoteWorks* directory that you want to update and initiate a pop-up menu with a right-click of the mouse.

3. Select **CVS > Update Special…** The window shown on the right-hand side would appear. Check on **Get tag/branch/revision** and click on **Update List.**



TortoiseCVS - Update

[✓] Get tag/branch/revision: HEAD

Update list... [ ] Scan subdirs

[ ] Get date/time:

May 2006

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

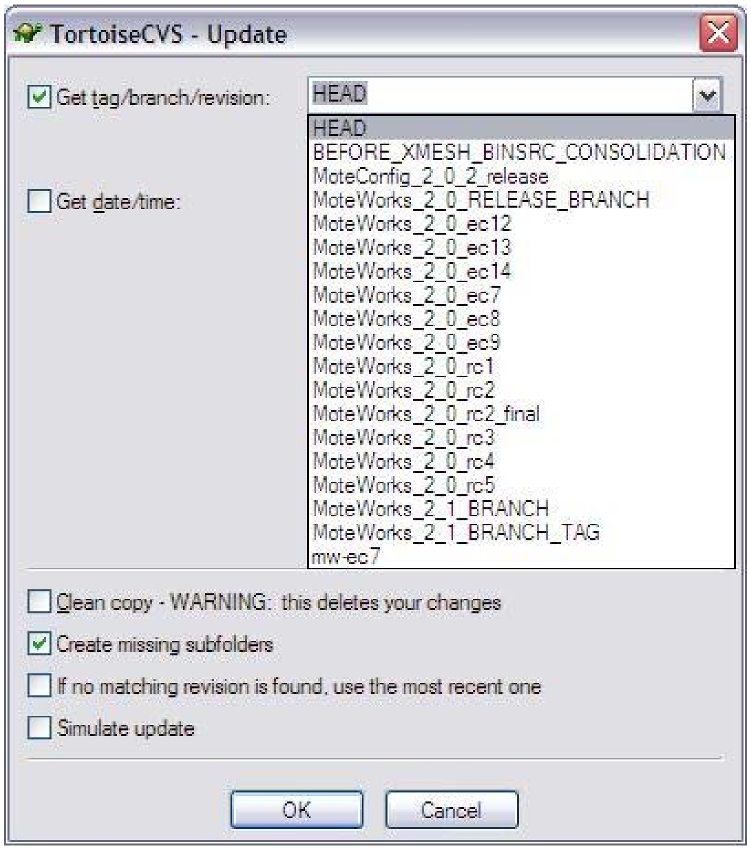
[ ] Clean copy - WARNING: this deletes your changes

[✓] Create missing subfolders

[ ] If no matching revision is found, use the most recent one

[ ] Simulate update

4. From the dropdown box, select the branch you want to download and click on **OK.**



TortoiseCVS - Update

[✓] Get tag/branch/revision: HEAD

[ ] Get date/time:

HEAD
BEFORE_XMESH_BINSRC_CONSOLIDATION
MoteConfig_2_0_2_release
MoteWorks_2_0_RELEASE_BRANCH
MoteWorks_2_0_ec12
MoteWorks_2_0_ec13
MoteWorks_2_0_ec14
MoteWorks_2_0_ec7
MoteWorks_2_0_ec8
MoteWorks_2_0_ec9
MoteWorks_2_0_rc1
MoteWorks_2_0_rc2
MoteWorks_2_0_rc2_final
MoteWorks_2_0_rc3
MoteWorks_2_0_rc4
MoteWorks_2_0_rc5
MoteWorks_2_1_BRANCH
MoteWorks_2_1_BRANCH_TAG
mw-ec7

[ ] Clean copy - WARNING: this deletes your changes

[✓] Create missing subfolders

[ ] If no matching revision is found, use the most recent one

[ ] Simulate update

IMPORTANT: Although you see multiple tree and branches in the dropdown, the only ones that might be of relevance to you are listed below.

1. **MoteWorks_2_x_y_RELASE** – Released and Supported tree
2. **MoteWorks_2_x_RELEASE_BRANCH –** Most up-to-date but unreleased tree.
3. **HEAD –** Stable, Unreleased and Unsupported Development Tree

If you want to work with a stable, released and supported tree, we strongly recommend that you choose Option 1 above with the latest revision of y.

12 Appendix C: Registration and Support

12.1 Support Policy

Your MoteWorks license is provided with 1 year of free support. Please go to http://www.xbow.com/Support/MoteWorksSupport.aspx to register for your support login and password. Your license key is required for support registration.

For the Standard edition, the support registration will give you access to all updates, patches, and documentation releases during the support period. In addition, you may submit your support requests at http://www.xbow.com/Support/Waskaquestion.aspx once you have registered.

For the Enterprise edition, the support registration will give you access to all updates, patches, and documentation releases during the support period. In addition, you may submit your support requests at http://www.xbow.com/Support/Waskaquestion.aspx or call the phone number provided on your welcome letter once you have registered. Enterprise level support requests are guaranteed a response within 1 full business day.

A copy of the Support Policy in its entirety is located on the *MoteWorks* CD.

12.2 Source Code Access:

Your Enterprise license includes access to our source code via CVS server. Once you have registered for support you will receive an email with your CVS login and password. This login is separate from your support login and password.

12.3 Code under Development

We are pleased to provide you with access to our development tree via the CVS server login. We hope that you will appreciate the opportunity to view our developers' work in process. Please understand that this code is not included in the support coverage, and that features you encounter in the development tree may never be included in the released version of the software.

12.4 Known Issues

Please read the README.txt file that is included on your CD for a list of known issues in the software.

Crossbow

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