RangeNet User Guide

TDSR UWB Radios

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1. Introduction

RangeNet consists of two components:

- Embedded code running on a TDSR P400 series Ultra Wideband (UWB) platform
- A Microsoft Windows-based Graphical User Interface (GUI) program that runs on a Host PC and connects to any P400 series device

The RangeNet code embedded in the P400 performs all of the range measurements, operates the network, and computes the location of units in the network.

The RangeNet GUI uses Serial, USB, or Ethernet communications to monitor and control the operation of the attached P400 platform. Key parameters displayed include:

- Range measurements, statistics, and their constituent waveforms
- Network status including range measurements, range quality metrics, and system ranging rates
- 2D or 3D location of any node in the system

RangeNet operates on any member of the P400 family of platforms. This currently includes the P400, P410, P412, and P440. This family is expected to grow with time. For purposes of this discussion, the various P400 series devices will be referred to jointly as a P4xx. Where specific differences exist, the platforms will be referred to by their specific names.

In the course of this discussion several supplementary documents will be referenced. All of these documents can be found on the software delivery disk.

It is important to note that the Host-based RangeNet GUI operates as a window into the connected P4xx. It is a window in that the user can define configuration parameters and display status. When operating as a network all range calculations, all scheduling of network activities, and all computation of node locations are performed by the processor in the attached P4xx. This significantly offloads the responsibilities of the Host. Some applications may not require a Host processor.

The RangeNet GUI communicates with the P4xx through a standard and well documented Application Programming Interface (API). This interface consists of a few dozen commands and acknowledgments, all of which are described in detail in the document *320-0313 RangeNet API Specification*. The RangeNet GUI executes all of these commands, such that the system developer can use RangeNet to gain familiarity and experience with the interfaces and system operation. This experience will aid the system integrator in porting the desired RangeNet GUI functionality to other Host platforms. Typical single board computers include platforms as small as a Raspberry Pi and even peripheral interface controllers (PICs).

To aid in jumpstarting such integration efforts, TDSR also provides sample C and MATLAB code to illustrate how communication through the API can be independently implemented.

- 150-0103 Ranging C Sample Applications
- 150-0104 Ranging MATLAB Sample Apps
- 150-0117 RangeNet C Sample Apps
- 150-0118 RangeNet MATLAB Sample Apps

RangeNet is available in two versions. RangeNet Lite is a node-limited version capable of handling up to 10 nodes while RangeNet is an unrestricted version. The Lite version is provided to all users and is intended for evaluation and test. Those interested in reselling units or systems which incorporate RangeNet Lite should contact TDSR directly for further information on purchase or license options.

1.1 Overview: UWB, Ranging, Networks, and Localization

UWB: The P4xx modules coherently transmit and receive UWB pulses. These pulses are transmitted over RF frequencies between 3 and 5 GHz and have an RF bandwidth of approximately 1.4 GHz. The pulses are transmitted at a nominal repetition rate of 10 MHz. Because the transmissions are coherent, the energy of multiple pulses can be integrated and used to increase the received signal strength. (SNR will increase by 3 dB each time the integration rate is doubled.) Pseudo-random encoding of transmissions (either by flipping the polarity of the pulse, varying the pulse repetition rate, or using pulse position modulation) allows the creation of independent channels. This allows multiple units to be operated on different channels in the same area, at the same time, with a minimum of mutual interference.

Depending on how the pulses are transmitted and received, the units can be used as a range measurement device, a low rate data link (maximum data rate of approximately 600 kbps), an impulse transceiver for channel modeling, a monostatic radar, a bistatic radar, a multistatic radar, or some combination of the above. The device's operating mode is software-defined. RangeNet uses UWB pulses to measure range and to communicate. Other TDSR software packages use UWB pulses for radar and channel modeling. More information on these capabilities can be found at www.tdsr-uwb.com.

UWB Ranging: UWB ranging is normally performed using Two-Way Time-of-Flight (TW-TOF) distance measurement. With this approach, a packet is sent from one UWB platform (the requester) to a second unit (the responder). The responder then transmits a carefully timed response packet which is received by the requester. By knowing the speed of light, the exact time when the request packet was sent, the time it took the responder to send the return packet, and the time when the response packet was received, it is possible to measure the range with sub-centimeter accuracy. (Using averaging, some customers have reported accuracy of 2 mm.) Such measurements are also called Precision Range Measurements (PRMs).

The P4xx units also measure the signal strength of the first arriving energy. Since the strength of a signal is inversely proportional to the square of the distance, the signal strength can be used to estimate distance. Because signal strength is also a function of other factors, this estimate is rather coarse and is therefore referred to as a Coarse Range Estimate (CRE). A CRE can be calibrated with periodic Precision Range Measurements to form a Filtered Range Estimate (FRE).

Since a transmission from one unit can be heard from many units, CREs are effectively a broadcast in that every transmission will result in a CRE produced at each receiving unit. This technique can be used to increase the system capacity.

Networks: While it is useful to measure the range between two lone devices, it is often more valuable to take measurements from a system of devices and use that information to compute not just the range between two units but the actual device location in three dimensions.

Control and coordination of such a system of units will require a network. In principle, such a network can be implemented using a wired solution (based on Ethernet or USB) or a wireless solution such as Wi-Fi. However, these types of networks have a serious limitation in that they are designed to maximize data throughput using one-way packets. While that approach is a logical and reasonable approach for handling data, it is not well-suited for handling range measurements. This is due to the way in which range is measured. The range measurement process requires the transmission of two carefully timed packets acting as a single conversation. Therefore, the network must be designed to handle conversations and not just simple one-way transmissions.

RangeNet has been specifically designed and optimized to handle networks of UWB ranging devices. While RangeNet can transport data, the associated data rates and throughput are of secondary interest and are normally limited to rates consistent with command and control functions.

RangeNet (embedded and GUI) provides the user with the ability to:

- Measure inter-device range with either Precision Range Measurements (based on Two-Way Time-of-Flight measurements) or Filtered Range Estimates (one-way Coarse Range Estimates updated with periodic Precision Range Measurements).
- Transmit data between nodes.
- Operate P4xx nodes in Ranging Mode on a standalone basis without the benefit of a network.
- Operate P4xx nodes in Networking Mode as part of a network.
- Operate P4xx nodes in a Network and determine the location of units in the network.
- Operate the network either as a random access clock-less ALOHA network or as a synchronized TDMA network.
- Transition back and forth between operation as a standalone device or as part of a network.
- Enable a node to enter or exit a network.
- Define a schedule by which a node will share airtime with other units in the network.
- Manually define an average rate at which the node will source a transmission.
- Automatically throttle the ranging rate as a function of the total number of system nodes.
- Exclude specific units from range requests.
- Limit some P4xx nodes such that they cannot initiate a range request.
- Define in each P4xx a Neighbor Database (NDB) which includes, for example, important data such as the ranges to each Neighbor, the rate of approach/withdrawal, and other useful information.
- Allow the user to monitor the contents of the NDB, either on a demand basis or as part of a routine schedule.
- Allow the user to limit the amount of information transmitted from the P4xx to the user.
- Allow the user to monitor communications statistics.
- Allow the user to identify a default communications path that does not rely on an established Host connection.
- Define and save configuration parameters.

Localization: Since the ultimate goal of a network-based ranging system is to determine the location of Mobile nodes relative to Anchor (Reference) nodes, TDSR has added a localization layer to RangeNet. All of the computations and commands associated with collecting and converting range measurements to locations are executed in the P4xx. Nodes are therefore responsible for computing and reporting their positions. The localization interface is captured in a fully documented, user-accessible API.

While the Localization capabilities of RangeNet provide an excellent example of how UWB can be used to determine location of fixed and moving units, this capability can be fragile in some environments. This sensitivity can be largely eliminated by fusing the UWB signals with other sensor types such as Inertial Measurement Units (IMUs) or odometry. This fusing is not available in RangeNet. Those interested in fused systems should contact TDSR directly.

It is also important to note that while the RangeNet GUI is primarily used to configure, control, and monitor the system, it also is responsible for performing the Autosurvey function. When operating in Autosurvey mode, the references range to each other and automatically compute their relative location and thereby establish a frame of reference. To be clear, while Autosurvey has been implemented in the RangeNet GUI, it makes use of the standard API messages.

These capabilities transform the P4xx platforms from individual ranging devices into a complete system of platforms which can be used for high level system performance analysis, rapid prototyping, and even in final products.

More specifically, the localization layer allows the user to:

- Use either the ALOHA or TDMA network to compute the location of a system of P4xx platforms in either 2D (X and Y) or 3D (X, Y, and Z) dimensions.
- Operate the system of platforms in three different modes: Idle (all units awaiting instruction), Autosurvey (Anchors range to each other until their locations are known to a requisite accuracy), and Tracking (locations of all nodes are reported to all units and to the RangeNet GUI).
- Configure each node and transition the entire system of nodes from one operating mode to another on command. The command is initiated though the RangeNet GUI but uses the UWB network and a P4xx-based flood routing algorithm to ensure that all units are properly configured and operational.
- The Autosurvey mode has been designed to work with 3 or 4 Anchors and in benign environments can be expanded procedurally. Alternatively, the user is free to bypass the Autosurvey capability and manually determine and enter X, Y, and Z locations for the Anchors.
- Computation of the locations is based on a user tunable Kalman filter or a Geometric solver. Additional filtering options are also provided.
- Once in Tracking mode, the location of the Mobiles is displayed on the GUI in real time. A variety of tools are provided to show the instantaneous and historical tracks of Mobiles as well as actual ranges.
- Location data is provided with the associated variance and covariance data. An estimate of Geometric Dilution of Precision (GDOP) is also provided.
- Define any number of reference Waypoints against which the accuracy of the ranging/localization system can be compared.
- Bypass the RangeNet GUI and use the localization API to develop a user-specific interface.

1.2 Installing and Operating RangeNet

The RangeNet GUI comes as an installation executable (.exe) which, when unbundled, will create default directories, load the software, load the USB drivers, load sample configuration files, and create a link on the user's PC Desktop. The RangeNet GUI operates under the following Windows operating systems: Windows 7 (32 and 64 bit), Windows 8 (32 and 64 bit), and Windows 10 (32 and 64 bit). For instructions on the installation and initial use, please see the *320-0314 RangeNet Quick Start Guide*.

The default location for RangeNet is in the directory:

C:/Program files (x86)/Humatics/RangeNet220

These directories will contain the drivers, default files and the program file.

Five sample configuration files are provided for the P400 platforms:

- One provides configuration settings for a sample 5-node ALOHA network.
- One provides configuration settings for a sample 5-node TDMA network.
- One provides configuration settings for a 2D Localization network consisting of 3 Anchors (references) and 2 Mobiles using a geometric solver.
- One provides configuration settings for a 3D Localization network consisting of 4 Anchors and 1 Mobile using a geometric solver.
- One provides configuration settings for a 3D Localization network consisting of 4 Anchors and 1 Mobile using a Kalman solver.

More than one copy of the RangeNet GUI can be run on the same PC. Each copy can be connected to a different P4xx module through Ethernet, USB, or Serial connections.

2. Before You Begin

Make sure that the P4xx is powered up and that the board-mounted LEDs are blinking properly. While each board has several LEDs, there is normally only one LED that needs to be considered. When connected to a P440, the blue LED should be blinking once every 2 seconds. When connected to a P410, the green LED should be blinking at approximately 5 Hz. (See the relevant data sheet for a definition of proper operation of all LEDs).

Choose which interface you want to use: USB, Serial, or Ethernet. USB is the easiest interface to use and is reasonably robust. Serial is very slow and because of this should be avoided. Ethernet requires initial setup but is fast and robust. If you are new to RangeNet, then start with USB. Once you are comfortable with the basic operation you are well advised to use Ethernet.

When using the USB interface, simply connect the USB cable to both the P4xx and the Host computer.

The Serial interface requires a special custom cable and the connection point varies from one P4xx platform to another. For details on the serial interface, cable type and connection points, see the document *320-0287 Using the USB and Serial Interfaces*.

When using Ethernet, you should first verify the TCP/IP properties of your PC and then determine the IP address of the radio you wish to connect with. While this is simple in principle, it can be complicated in practice. See **Appendix A: Connecting with Ethernet** for details on how to connect via Ethernet.

3. Connecting

To start the RangeNet GUI, double-click on the RangeNet icon shown on the left side of **Figure 3-1**. This will launch the Connect display shown on the right side of **Figure 3-1**.

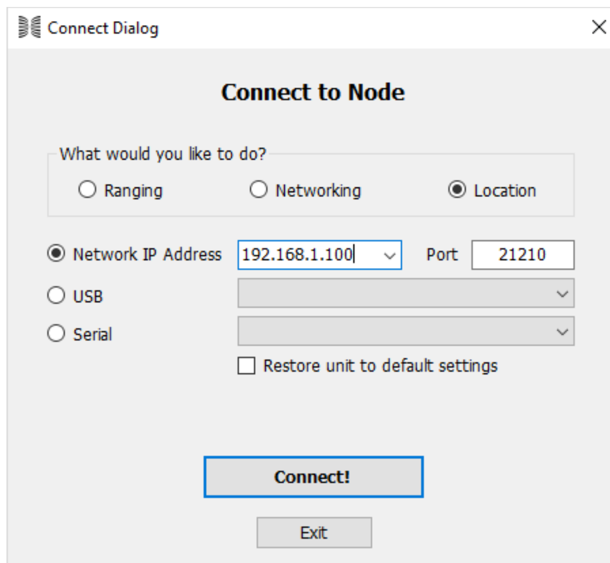

Fig. 3-1: RangeNet Icon (left), Initial RangeNet Connect display (right)

The user will then have three decisions to make:

1. **What aspect of RangeNet's capabilities would you like to exercise? Ranging? Networking? Or Location?**

   This allows the user to limit the number of control screens available and thereby limit operation to only those functions which are of interest. Clicking the Ranging button will provide access to just the range-related control tabs and force the mode of operation of the unit to Ranging Mode. Clicking the Network button will provide access to the range and network-related tabs. Clicking Location will give access to all tabs.

   We recommend that you start by selecting Location.

2. **Would you like to restore the default settings?**

To restore the connected P4xx to the factory parameters stored in the P4xx, connect the Host to the P4xx through the desired physical interface (USB, Ethernet, or Serial), select the appropriate communications technique, click the box named “Restore unit to default settings,” and then click the **Connect!** button. A prompt will appear reminding you that the changes are final. At this point you can either abort or continue.

This capability is useful for a few reasons. First, if you are developing your own code, then it is possible that your code may, in error, load registers with invalid numbers. Normally this isn’t an issue but occasionally such an error will prevent you from ever reconnecting to the P4xx. In the past, the only remedy was to return the unit to the factory to be reset. The capability to reload the defaults allows reset of the unit without returning it to the factory.

Second, when upgrading to a new version of code, it is possible that prior values will not be compatible with the new version. For example, we have observed that connecting the 2.1 version of RangeNet to a P440 operating with an older installed version of the code can generate a Comms error [Index was outside the bounds of the array]. Restoring the defaults clears the error.

Third, when testing a system in the field, one can sometimes lose track of what parameters have been used. (This normally happens when the weather is bad or late in the day when the operator may be tired and more likely to make mistakes.) Reloading the defaults is normally a quick and easy way to return operation to a common state.

Resetting the default configuration will also reset the GPIOs, Serial baud rates, CAN bus parameters but not the units IP address or Node ID.

3. **How do you want to connect to the P4xx?**

   This allows the user to select which physical interface (USB, Ethernet, or Serial) will be used to connect to the P4xx.

3.1 Connecting with Ethernet

The RangeNet GUI assumes that the units have been configured with Static IP addresses and that the Host computer has been set up to use Static IP addresses and not Dynamic Host Configuration Protocol (DHCP). If you aren’t sure how the Host computer has been configured, then please see **Appendix A: Connecting with Ethernet** for configuration instructions.

The IP address of units delivered with TDSR Development Kits or Lab is 192.168.1.xxx, where “xxx” is the number written on the top of the Ethernet connector. Units delivered as standalone units are sent normally set with the IP address set to 192.168.1.100. The RangeNet GUI will allow you to manually change the IP address or set the unit for DHCP.

To connect the P4xx to the Host computer, click the button to the left of the “Network IP Address” and enter the unit’s IP address in the drop-down to the right. See example shown in **Figure 3-2**. If you have previously connected to the unit, click the drop-down box. You will likely see your IP address and can click on it directly. Each time you add a new IP address, the RangeNet GUI will automatically add it to the drop-down. When it reaches 15 entries it will stop adding entries. To delete an entry from the drop-down window, highlight the entry you want deleted and press the “Del” or “Delete” key. The RangeNet GUI will also automatically search for other units on the network. If another IP address is discovered, then it will be added to the drop-down list. This is handy when you are connected to an Ethernet network containing many P440s.

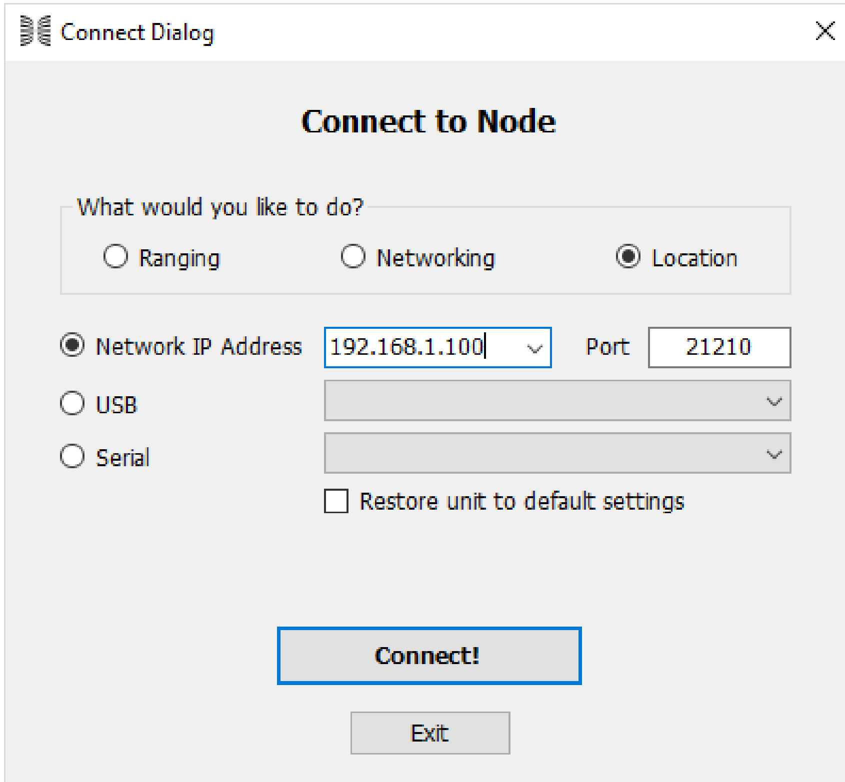

Fig. 3-2: Connecting with Ethernet

If the Host PC is properly connected, then clicking on **Connect!** will transition to either the RangeNet Configuration Tab or the last tab used.

If the connection is successful, then the window will display the P4xx operating mode (Ranging, Network, or Location) in the bottom left corner, the Node ID of the connected P4xx in the bottom left center as well as in the Title Bar, and the unit type (P400, P410, P412, P440) in the lower right corner. Controls are now enabled, allowing the user to send commands to the P4xx. If unsuccessful, then a message will appear in the Action Area indicating "Unable to Connect. Giving up." and the unit will show as disconnected. **Figure 3-3** illustrates a successful connection on the top and an unsuccessful one on the bottom.

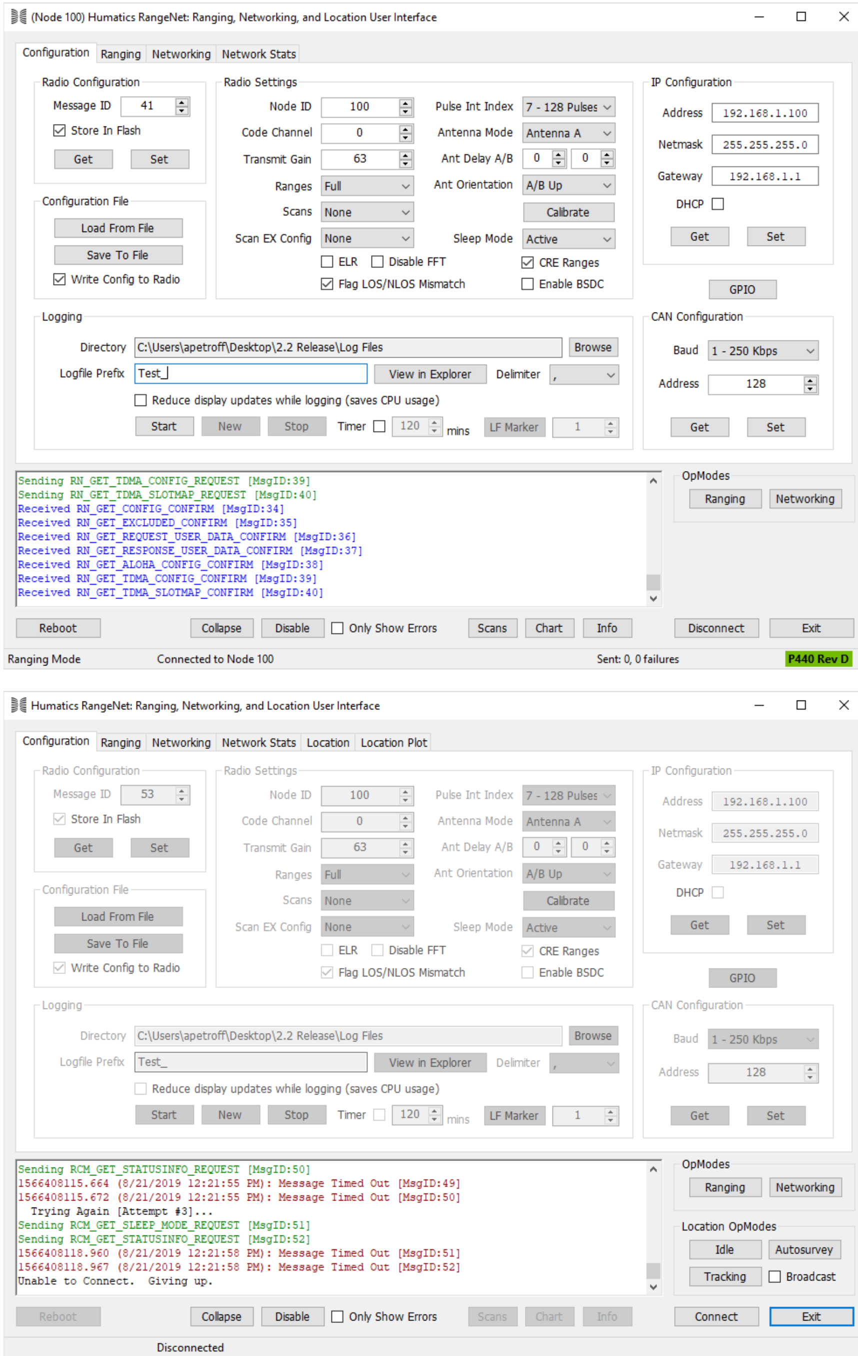

Fig. 3-3: Successful connection (top), unsuccessful connection (bottom)

3.2 Connecting with USB

To connect to a P4xx via USB connection, first connect the USB cable to the P4xx and Host, click the function (Ranging, Network, or Location) that you are interested in exercising, click the USB button and select the COM port/unit serial number from the drop-down window. See **Figure 3-4** for an example. If more than one P4xx is connected via USB to the Host, then click on the drop-down window and connect to the unit of your choice. (Remember that it takes about 10 seconds for a P440 to boot. So if you power a unit that is connected to the Host, you will not see a COM port until the unit has booted and the driver has been identified.)

If the Host PC is properly connected, then clicking on **Connect!** will transition to either the RangeNet Configuration Tab or the last tab used. If the connection is successful, then the window will display the P4xx operating mode (Ranging, Network, or Location) in the bottom left corner, the Node ID of the connected P4xx in the bottom left center as well as in the Title Bar, and the unit type (P400, P410, P412, P440) in the lower right corner. Controls are now enabled, allowing the user to send commands to the P4xx. If unsuccessful, then a message will appear in the Action Area indicating "Unable to Connect. Giving up." and the unit will show as disconnected. **Figure 3-3** illustrates a successful connection on the top and an unsuccessful one on the bottom.

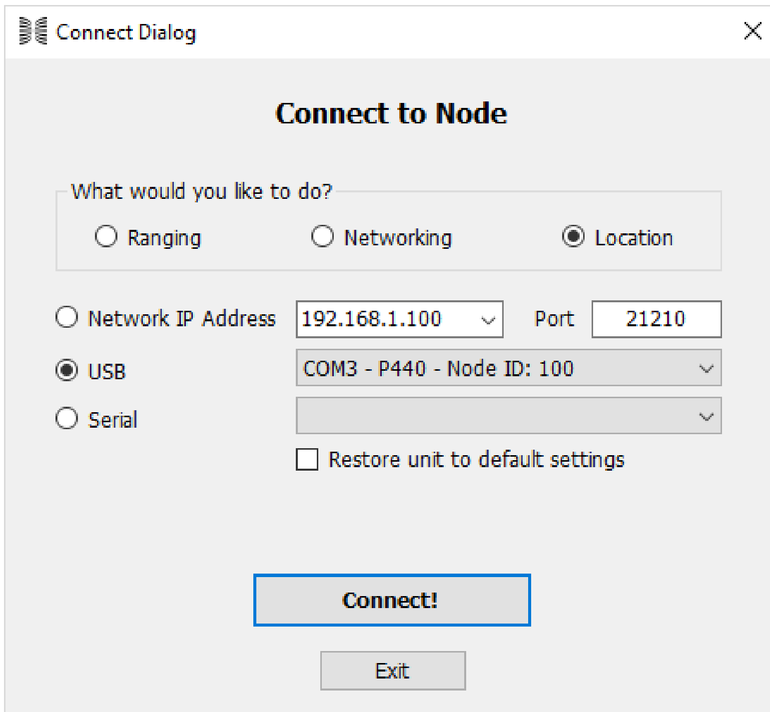

Fig. 3-4: Connecting with USB

3.3 Connecting with Serial

To connect via Serial to a P4xx, use a serial-to-USB cable to connect the P4xx to the Host, then select the function (Ranging, Network, or Location) that you are interested in exercising, click the Serial button and select the COM port/unit serial number from the drop-down window. If more than one P4xx is connected via USB to the Host, then click on the drop-down window and connect to the unit of your choice. **Figure 3-5** shows the Serial connection point for a P440 on the left and an example of the Connect screen on the right. The Serial connector cable used must be a serial-to-USB cable. These are available from many suppliers including FTDI (part number TTL-232R-3v3) or Digikey (part number 768-1015-ND, www.digikey.com).

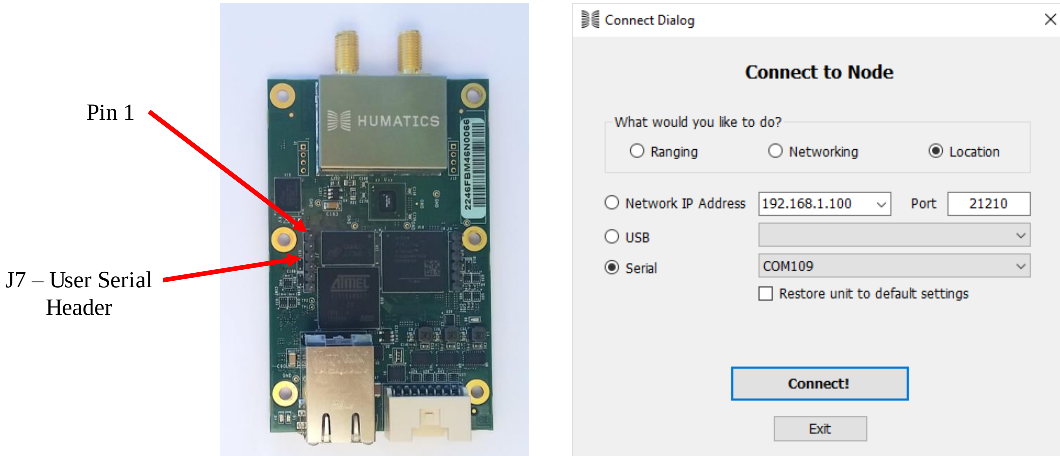

Fig. 3-5: Connecting with Serial

If the Host PC is properly connected, then clicking on **Connect!** will transition to either the RangeNet Configuration Tab or the last tab used. If the connection is successful, then the window will display the P4xx operating mode (Ranging, Network, or Location) in the bottom left corner, the Node ID of the connected P4xx in the bottom left center as well as in the Title Bar, and the unit type (P400, P410, P412, P440) in the lower right corner. Controls are now enabled, allowing the user to send commands to the P4xx. If unsuccessful, then a message will appear in the Action Area indicating "Unable to Connect. Giving up." and the unit will show as disconnected. **Figure 3-3** illustrates a successful connection on the top and an unsuccessful one on the bottom.

3.4 Failure to Connect

The RangeNet GUI will attempt to verify connectivity to the P4xx by sending an RCM_GET_CONFIG_REQUEST to that address. This message will be sent up to three times. If the P4xx does not respond after the third attempt, then the RangeNet GUI will indicate that the connection was unsuccessful and the connection status will show as disconnected. At this point, the user should verify that the cabling is correct, the proper COM port or IP address was selected, and that the P4xx is powered on and the LEDs are properly illuminated. (See **Section 2** for details.)

3.5 Issues with USB or Serial connection

If there are still connection issues with either USB or Serial, then open the Device Manager (Start button/Control Panel/Device Manager) and confirm that the computer actually registers connection to your USB Host port. The screen shot shown on the left side of **Figure 3-6** confirms that the UWB radio on the COM13 port is actually connected to the computer. The screen shot on the right indicates that no connection exists between the Host and the radio. Once these parameters are verified, the user can attempt to connect by selecting the **Connect!** button.

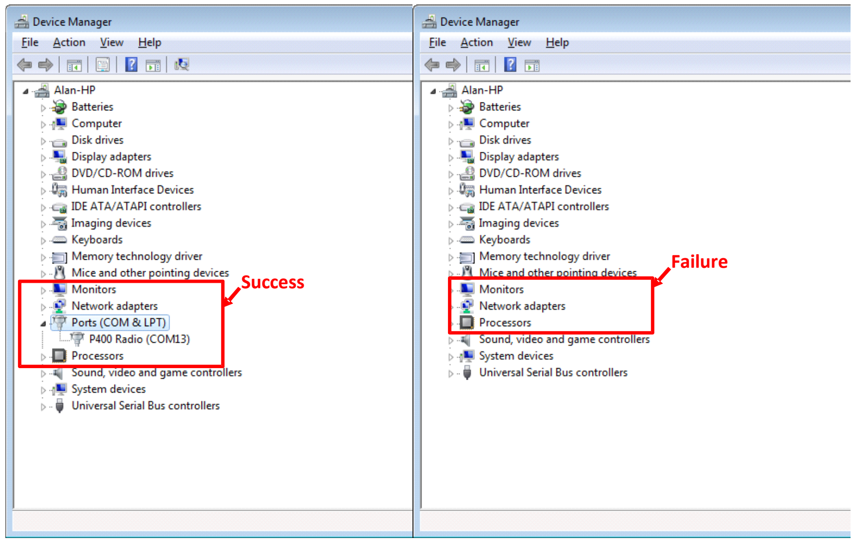

Fig. 3-6: Successful connection (left), unsuccessful connection (right)

Note: The connection from the P4xx to Host through the USB connector (whether connecting with a USB cable or with a Serial cable) is generally very reliable. However, there are times when the Windows operating system does not handle COM port assignment in a robust and reliable manner. It can become confused if the P4xx is disconnected or power-cycled during execution of a RangeNet command. A wobbly USB connector can also cause issues. These issues will manifest themselves in one of two ways. Either (1) the RangeNet GUI shows that the P4xx is connected when it is not, or (2) the RangeNet GUI shows that the P4xx is not connected when it clearly is. If this should happen, then disconnect the P4xx, cycle its power, and try to reconnect. If this fails, disconnect and power-cycle the P4xx and reboot the Host computer. Additional information is provided in **Appendix B: Issues with USB and Microsoft Windows**.

4. Display Organization

The RangeNet GUI displays are divided into six general areas shown in **Figure 4-1**. While these areas are common to all tabs, the contents of the P4xx Control and Status areas will vary depending on the tab selected. The description of the Control and Status areas for each of the individual tabs will be described in subsequent sections on a tab-by-tab basis.

- **Title Bar:** Displays the Logo, the Node ID of the connected node, the program name and provides access to Status Information.
- **Tabs:** This collection of tabs allows the user to select the type of operation to monitor and control.
- **P4xx Control & Status:** This area contains all of the P4xx Control and Status fields relevant to the selected tab. Selecting a different tab will bring up a different Control and Status area. The other five areas are common to all tabs.
- **Action Area:** This area contains a scrolling text of every message sent to and received from the P4xx and any errors that occur. Errors will be displayed with two timestamps. The left timestamp is in the same time format as the logfile while the right timestamp (month/day/year) is human readable.

- **P4xx Mode Control:** This area provides the controls needed to transfer the P4xx between each of the operating modes. Those modes are Ranging Mode, Networking Mode, and Location Mode. Note that the Location Mode has several sub-modes.
- **GUI Control & Status:** This area provides control and status information relative to operating the GUI. Additionally, it allows the display of waveform scans with the Scans button, plots of reported ranges using the Chart button, as well as Echo Last Range (ELR), Echo Last Location (ELL), and Beacon messages using the Info button. Status information displayed includes: operating mode, P4xx node number, node type, and various information or error messages.

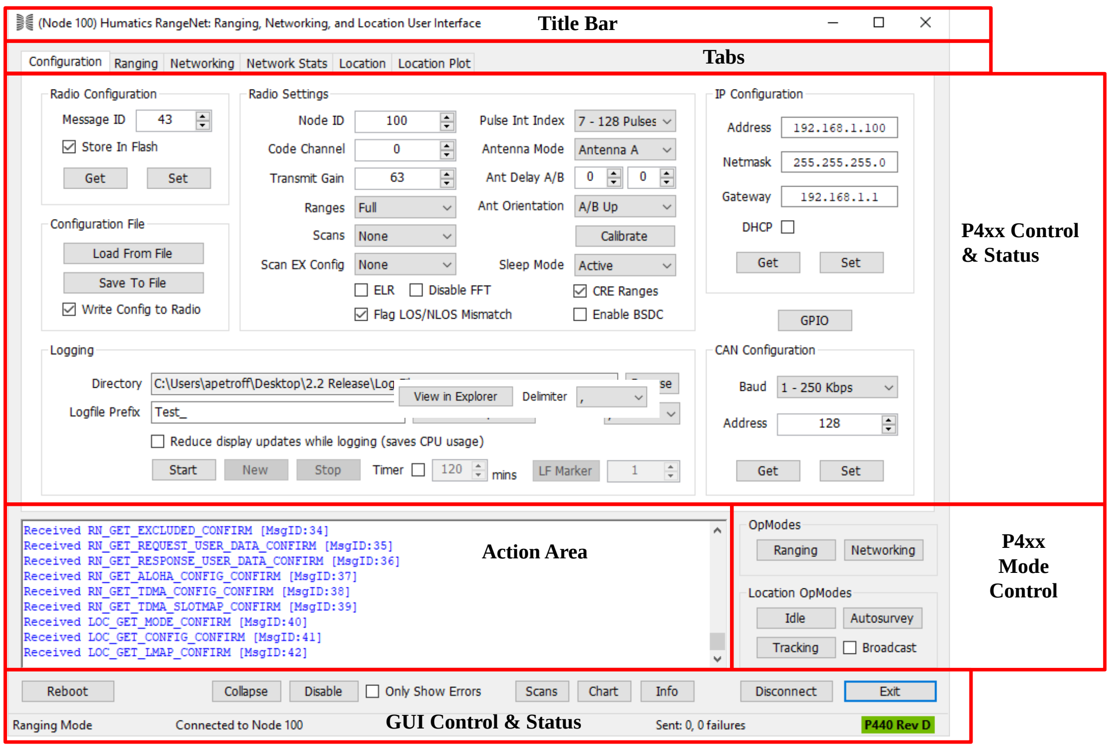

Fig. 4-1: Display layout convention

The following sections define and describe all of the fields and controls common to all of the displays.

4.1 Title Bar and Status Info

The Title Bar displays the RangeNet Logo, the Node ID of the P4xx currently connected to the RangeNet GUI, and the name of this program (RangeNet). Right-clicking on the Title Bar will display the drop-down window shown in **Figure 4-2.**

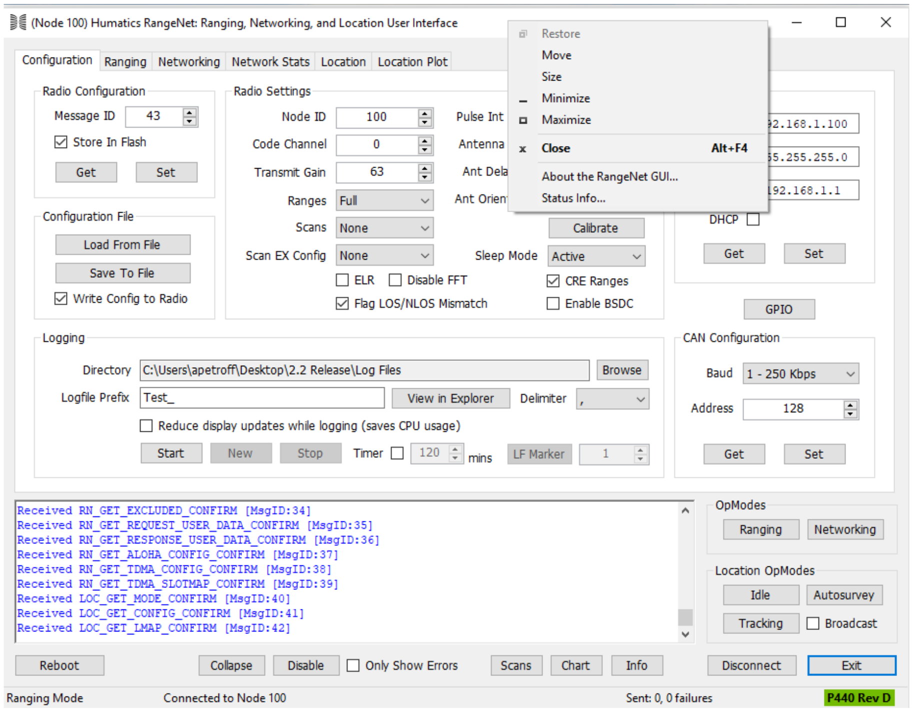

Fig. 4-2: Title Bar drop-down window

Clicking “About the RangeNet GUI” will display the RangeNet GUI version number and a link to the Humatics website. An example is shown in **Figure 4-3**. Please disregard this as TDSR has recently picked up the UWB Kit and radio business from Humatics.

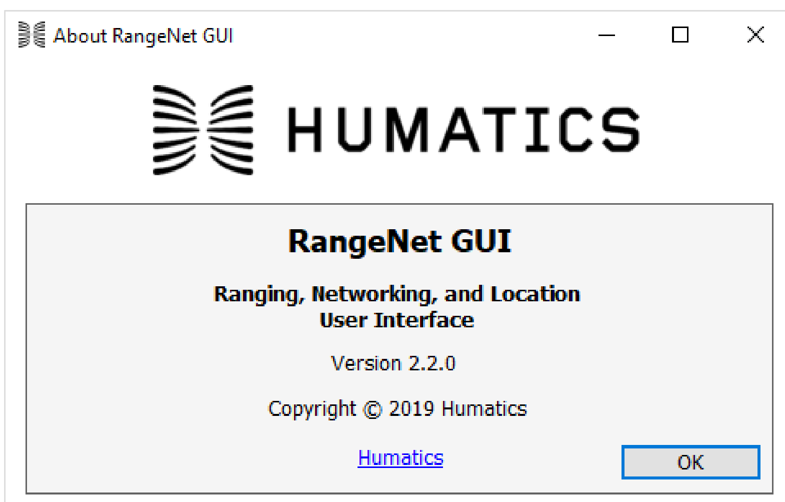

Fig. 4-3: About RangeNet GUI

Clicking the “Status Info” field will open a window (shown in **Figure 4-4**) which shows the information specific to the connected P4xx. This data is valuable for debug purposes. If your P4xx should malfunction, then the TDSR product support team will likely ask for a screenshot of this window.

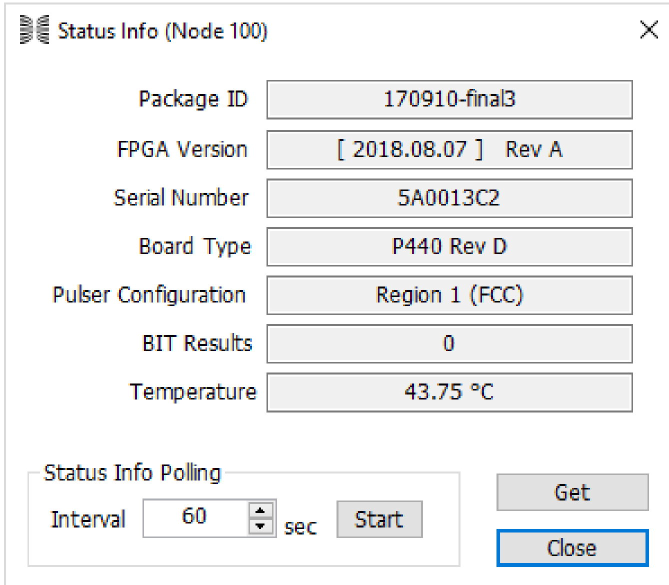

Fig. 4-4: Status Info window

The key fields of note are:

Package ID: This is the version number of the code embedded in the P4xx. The version number also contains the release date (yymmdd-final). The version number may also have the suffix "RL." If this is present, then this node is operating with RangeNet Lite and will be limited to operating nodes with 10 nodes or less. If this is absent, then the connected radio is operating with an unrestricted license.

FPGA Version: This field can be ignored. It is only of use for factory checkout.

Serial Number: This is the serial number of the board (in hexadecimal format) and is stored in the P4xx's flash memory. Units not delivered with kits will have a Node ID (in decimal format) equivalent to this value. The board serial number is not the same as the printed bar code placed on the top side of the board. However, the numbers are paired in a factory database such that knowing one will allow the factory to determine the other.

Board Type: This will indicate the Board type (P400, P410, P412, P440) and the revision level of the board.

Pulser Configuration: The suffix "FCC" indicates that UWB transmissions from the connected P4xx are intended for those countries which comply with the U.S. Federal Communications Commission (FCC) regulations. The suffix "EU" indicates that UWB transmissions are intended for those countries which comply with the European Union's European Telecommunications Standards Institute (EU ETSI) regulations. TDSR refers to the first (FCC) as Region 1 and the second (EU) as Region 2. The third type of pulser configuration is High Power. These units have an onboard power amplifier which increases the RF emissions by up to 20 dB (See relevant data sheet for details.) Note that as of the publishing of this manual, the P440s have been certified for compliance with the FCC regulations. While the transmitted waveform is consistent with EU ETSI regulations, the Region 2 P440s have not been through a formal EU certification process. The Region 2 units are also certified for operation in the US.

BIT Results: BIT (Built-in-Test) is performed when the unit boots. If the unit passes the internal tests then the BIT Result will be 0. Any non-zero number indicates some sort of failure.

Temperature: This is the temperature of the P4xx as measured by an onboard temperature sensor mounted near the hottest point on the board. This is *not* the ambient air temperature. Because the P4xx generates heat, the board will run hotter than the ambient. Operating the P4xx at temperatures greater than 85°C or below -40°C (as measured by this onboard sensor) exceeds the specifications of most of the parts on the P4xx and therefore should be avoided.

Get: Clicking this button will update the screen. This capability is most useful for monitoring the temperature.

Close: The button closes the window. Note that you can move this window anywhere on your desktop and continue using RangeNet.

The Status Info Polling block allows you to automatically update the Status Info window.

Interval: This field allows you to define the rate at which the Status Info window will be updated.

Start: This button allows you to start the automatic update. Once clicked, it will change to a Stop button and thereby allow you to halt the update.

4.2 Tabs

All of the RangeNet controls and displays are accessible by clicking one of the following tabs. Operation of the tabs is summarized below and is described in detail in subsequent sections.

Configuration Tab: This tab provides access to all controls and displays necessary to:

- Get configuration info from the P4xx or set/download parameters to the P4xx
- Load the configuration parameters from or save to file
- Set and/or display the configuration parameters (Node ID, code channel, transmit power, pulse integration, antenna selection, antenna delay calibration information)
- Define the amount of scan data which will be reported by the P4xx and the compression used
- Calibrate the P4xx antenna delay
- Set the sleep mode
- Enable/Disable Echo Last Range, FFT, Coarse Range Estimates, Flag LOS/NLOS Mismatch, and Enable BSDC
- Log messages, data, and markers sent to (or received from) the P4xx to a logfile
- Display the logfile
- Set the IP and CAN Configurations
- Set or monitor the GPIO pins

Ranging Tab: This tab provides all controls and displays necessary to:

- Initiate and stop range measurements
- Send and receive data
- Display range measurements, range measurement statistics, and error messages
- Filter received range information

- Set the units of choice (millimeters, meters, feet)

Networking Tab: This tab provides all controls and displays necessary to:
- Download to and upload from the P4xx all the communications protocols (ALOHA vs. TDMA) and protocol-related parameters such as ALOHA transmit rates, TDMA slot maps, flags, etc.
- Send and receive data
- Define default communications
- Define the type of data, quantity of data, and rate at which the data in the P4xx Neighbor Database is uploaded to the RangeNet GUI

Network Stats Tab: This tab provides all controls and displays necessary to:
- Display the Neighbor Database and statistics
- Display the Network performance statistics for the attached unit
- Set various controls such as the units of measurement (millimeters, meters, feet) used to display data

Location Tab: This tab provides all controls and displays necessary to:
- Define units as Anchors or Mobiles as well as define other details of behavior
- Save to or load from file these definitions
- Automatically survey the location of the Anchor nodes and control the level of accuracy with which these locations are computed

Location Plot: Display graphically and in real-time the X, Y, and Z locations of Anchor (Reference) nodes, Mobile nodes, and Waypoints as well as various location statistics, metrics, and identifiers.

4.3 Action Area

The Action Area contains scrolling text of every message sent to and received from the P4xx as well as any errors that occur. Errors will be displayed with two timestamps. The left timestamp is in the same time format as the logfile while the right timestamp (month/day/year) is human readable.

In Ranging Mode the user has the ability to instruct the P4xx to range continuously or for a fixed number of attempts. At the conclusion of these ranges, the RangeNet GUI will compute statistics and display the results in this area. See **Section 6.7 - Range Statistics for Repeat Function** for details.

4.4 P4xx Mode Control Area

The buttons in this area allow the user to control the operating mode (OpMode) of the connected P4xx unit. These modes have the following characteristics:

Ranging Mode: This is intended for users interested in operating without the benefits (and complexity) of network operation. Units in Ranging Mode will only respond to units in Ranging Mode. They will receive range requests and data from units in other modes, but these requests will be ignored. The reverse is not true. Units in Ranging Mode can range to units in Networking Mode. However, such communications are not reliable because the ranging P4xx will not be complying with the rules associated with the ALOHA or TDMA protocol. This is not recommended behavior both for reliability reasons and because the ranging P4xx will likely interfere with operation of the network.

Networking Mode: This is intended for users who are operating a system of ranging radios or who require the fastest possible range measurements.

Location Mode: This is intended for users who want to be able to:

- Configure a localization system
- Automatically survey (Autosurvey) the location of Anchor nodes
- Compute and display location information for the various units operating in an area
- Distribute configuration information through the UWB network to all of the units in the system

.

While clicking any of the OpMode buttons will cause the unit to change to that operational mode, this setting change will not survive a reboot unless (a) the Store in Flash box is checked, and (b) the user clicks the Set button. As a reminder, anytime the OpMode buttons are clicked, the color of the Set button will change from gray to yellow. This is a reminder to click the Set button if you wish the operational mode to survive a reboot or power cycling the unit.

The current operating mode will be displayed in the lower left hand corner.

4.5 GUI Control & Status Area

This area consists of two lines shown below in **Figure 4-5**. The top line is the Control Line and the bottom line is the Status Line.

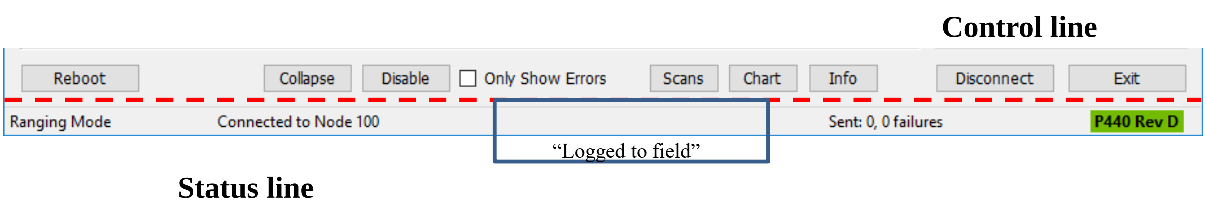

Fig. 4-5: GUI Control and Status Area

The Control Line commands are described below, moving from the left corner to the right:

Reboot: This button allows the user to reboot the connected P4xx without disconnecting power to the device.

Collapse: Clicking this button hides the Action Area and the Mode Control Area. It also renames the button to Expand. Clicking the Expand button will cause the Action Area and Mode Control Area to reappear.

Disable: This button will display the Action Area but will not post any new messages. This can be useful in that the GUI will run faster if it doesn't need to update the Action Area. When running in the Location Mode it is ***strongly*** recommended that the user either disable the Action Area or set to only display errors. This will minimize the chance that the flood of messages being sent from the P4xx will overwhelm the communications interface. Disabling the display does not interfere with the logging of messages to disk files.

Only Show Errors: Selecting this checkbox will filter the messages reported in the Action Area and display only those messages which have errors. Doing so does not interfere with the logging of messages to disk file.

Scans: Clicking this button will allow the user to see actual received waveforms. This will be discussed in detail in **Section 6.4 - Scan Button**.

Chart: Clicking this button will allow the user to plot range measurements vs. time. This will be discussed in detail in **Section 6.5 - Chart Button**.

Info: Clicking this button will allow the user to display all of the miscellaneous information packets sent by the attached P4xx. This will be discussed in **Section 6.6 - Info Button**.

Disconnect: This button disconnects the currently connected P4xx and returns the user to the Connect screen.

Exit: This button disconnects the connected P4xx and exits the RangeNet GUI.

The Status Line indicators in **Figure 4-5** are described below. Moving from the left corner to the right are the following:

Mode indication: This field indicates in which mode (Ranging, Network or Localization) the unit is currently operating.

Connected to Node x: This field indicates the Node ID of the currently connected P4xx. Double-clicking on the Node ID number will change the display from decimal representation to hexadecimal. Subsequent double-clicks will toggle between decimal and hex. If there is no unit connected, then this field will indicate "Disconnected." **Note:** If the P4xx is connected using Ethernet, then physically disconnecting the P4xx from the Host will not result in the unit being flagged as Disconnected. The only indication that you will receive is that the unit will not respond to any messages. From that you will need to deduce that something is wrong. This is less than ideal but is dictated by the constraints of the physical interface.

Logged to (__): This field indicates the name of the file currently being logged. If logging is not engaged, then this field will be blank. For more information on Logging see **Section 5.4 – Logging Block**.

Sent: This field provides statistics on the ranging success rate. This field is generated whenever the operator initiates ranging requests. This field is only relevant when operating in Ranging Mode. For more information see **Section 6.7 - Range Statistics for Repeat Function**.

Unit type: This field indicates the model number and revision level of the connected P4xx. Double-clicking on this field will open the Status Info window previously shown and described in **Figure 4-4**.

5. Configuration Tab

Clicking the Configuration Tab will display all of the ranging configuration parameters and allow the user to:

- View configuration information
- Make modifications to the radio settings and download them to the P4xx
- Load and save configurations from or to file
- Define operation status for the 5 control buttons ELR, Disable FFT, CRE, Flag LOS/NLOS Mismatch, and Enable BSDC
- View messages and control how they are logged to file
- Set the IP address, mask
- Control and monitor GPIOs
- Set the CAN configuration parameters

All of these controls are in the Control & Status Area shown in **Figure 5-1.** The Control & Status Area for this tab is divided into seven sub-blocks, all of which are described in the following subsections:

- Radio Configuration
- Radio Settings
- Configuration File
- Logging
- IP Configuration
- GPIO
- CAN Configuration

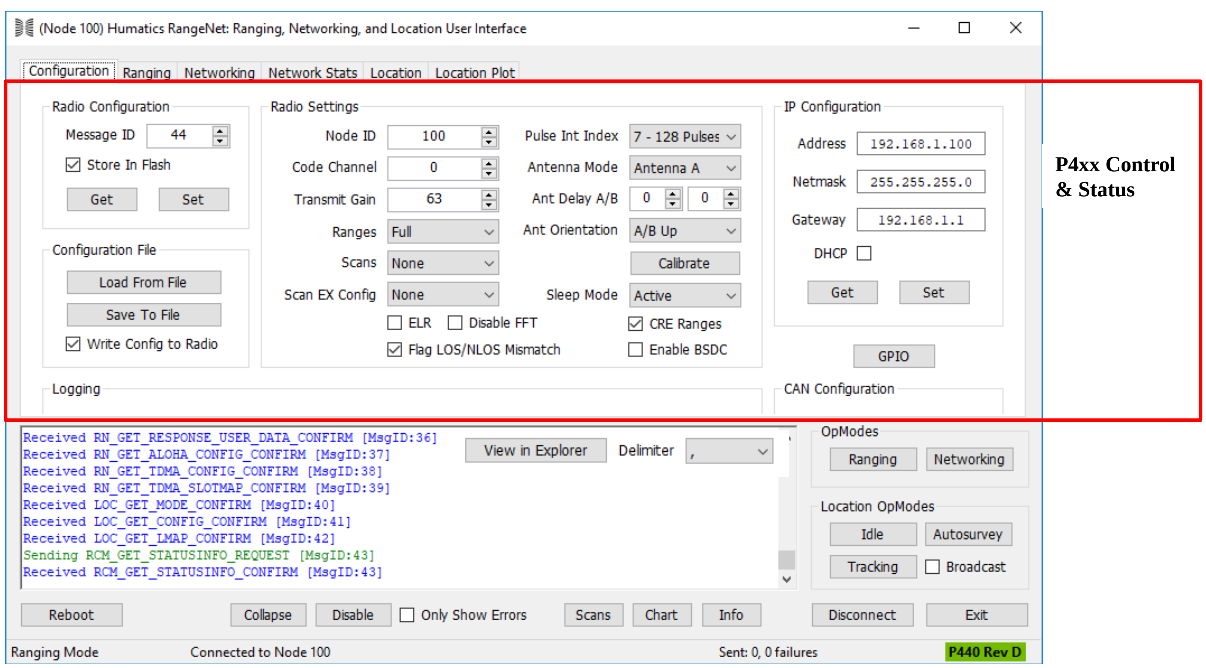

Fig. 5-1: Configuration Controls and Status Area

5.1 Radio Configuration Block

This block provides the means for viewing and configuring the P4xx units for radio operation.

Get: Clicking this button will upload the parameters currently stored in the connected P4xx to the RangeNet GUI. (This command is automatically executed when the RangeNet GUI first connects to the unit.)

Set: Clicking this button will download the parameters currently defined in the RangeNet GUI to the connected P4xx. Note that changing any one of the key parameters in the Radio Settings Block will change the color of the Set button to yellow. This changing of color is a reminder to the user that the Set button must be clicked before the parameter changes will be downloaded to the connected P4xx.

Store In Flash: If this box is checked, then the P4xx will store the changed parameters to its onboard flash memory. If this box is not checked, then the changed parameters are in stored in volatile memory only. Turning off power to the unit or rebooting it will result in the loss of any changes and the connected unit will revert to the previous settings.

Message ID: This field contains the number of the next message which will be sent from the Host to the P4xx. Whenever a message is sent, the RangeNet GUI will increment the value currently shown and send this identification number with the message. Message ID is a 16-bit value. When the maximum is reached, the next value will be 0. The RangeNet GUI will start with message ID 0, but the user can reset this number to any 16-bit number at any time.

A message may cause other messages to be initiated. If so, then those subsequent messages will have the same Message ID values. For example, when the Host requests that the P4xx issue a range request message, the Message ID of that Host-sourced range request will appear in:

- The message sent to the P4xx
- The confirmation message returned by the P4xx
- The RF packet sent by the P4xx to the responding P4xx
- The info message issued by the responding P4xx to its attached Host
- The message from the P4xx reporting the measured range.

This mechanism provides a convenient way of tracking messages recorded in logfiles of multiple units.

However, when operating in Networking Mode, the P4xx is responsible for initiating various messages. For example, it will issue range request messages to other units and it will send periodic database updates messages to the Host. All of these messages will also have Message ID numbers. Since the messages are initiated by the P4xx and not by the Host, these Message ID numbers are independently calculated by the P4xx. In other words, a message initiated by the P4xx will have a Message ID number that is not related to or affected by the current value of “Message ID.” The number used by the P4xx will be set to 0 when the P4xx is either powered up or rebooted. It will be incremented whenever the P4xx sources a message. The Message ID number is a 16-bit value and once it has reached the maximum value it will return to 0. Unlike the Message ID field, the user does not have a means of changing the starting point of P4xx-sourced messages.

5.2 Radio Settings Block

This block contains the key parameters which define radio ranging operation.

Node ID: The identification number of the specific P4xx connected to the RangeNet GUI. This is the identifier by which the unit is referenced by other P4xx units. The user is free to choose this number as he or she wishes and can set the value between 1 and (2^32)-2. P4xx received with kits will be preset with a value between 100 and 119. Units not received in kits will have a Node ID preset to be equal to the serial number shown in the Status Info screen. The value shown in the Status Info screen is in hexadecimal format, while the value shown Node ID field is in decimal format.

Code Channel: This is the communications channel over which the unit transmits and receives. This is analogous to channel numbers on a UHF radio or on a television. Units operating on different channels will not be able to communicate. While other numbers can be entered, the only valid values are 0 through 10.

Transmit Gain: This controls the magnitude or strength of transmitted pulses. When used with a standard TDSR Broadspec antenna, an entry of 63 will produce an output signal equal to the maximum transmit power allowed under either the Region 1 (FCC) or Region 2 (EU/ETSI standard) rules. Setting this value to 0 will reduce the transmit power by up to 30 dB. The settings have been calibrated at 63 but not at other settings. For a P440, settings between 0 and 63 are monotonic but are not necessarily linear. For example, a setting of 40 on one unit will not necessarily produce the same signal strength as a 40 on a different unit. (See the respective data sheet for more information.)

Ranges: This drop-down menu determines whether the connected P4xx will return range information using the RCM_FULL_RANGE_INFO or the RCM_SMALL_RANGE_INFO messages. Since the "Full" range info packet is much larger than the "Small" range info packet, it will consume more of the Host P4xx communications bandwidth. Some network and slow serial applications are frequently communications bandwidth-limited and require use of the RCM_SMALL_RANGE_INFO message. We recommend that the user start with Full range info messages and switch to Small if required.

Scans & ScanEX Config: In order to produce a range measurement it is necessary that the P4xx capture an image of a received waveform. Viewing the waveform can be very useful as it provides insight into the performance of the RF channel. However, transmitting this information from the connected P4xx to the RangeNet GUI can consume a significant amount of the data bandwidth. This volume of data can overwhelm the USB, Ethernet, and most certainly the low speed Serial interface. When the interface is overwhelmed, the RangeNet GUI will drop packets and it will not provide any warning that the packets are being dropped. The only way dropped packets can be detected is by logging the data and checking to see if either (a) the number of requested scans were properly logged or (b) checking to see if the Message IDs are all present and accounted for.

The Scans drop-down allows the user to select how much of the scan data will be automatically transferred from the P4xx to the Host computer. The choices are:

- None: No scan data will be transferred.
- Scan: 350 waveform measurement points will be reported. Since measurements are taken every 61 picoseconds (ps), this equates to measuring waveforms approximately ~22

nanoseconds (ns) long with half of the waveform occurring before the arrival of the pulse and the rest afterwards.

- Full Scan: 1632 measurements will be reported. This corresponds to a waveform 99.5 ns long with ~90 ns prior to the pulse and 10 ns after the pulse.
- Full Scan EX: This will transfer 1632 measurements, but the 32 bit readings will be compressed using the compression algorithm selected in the Scan Ex Config drop-down. There are currently only two choices:
  - None – no compression will be used
  - 16-Bit – In this operation the highest two bytes are deleted. For PII 8, the data is divided by 2 before the top bytes are deleted. For PII 9, the data is divided by 4 before the top bytes are deleted.

Pulse Int Index drop-down menu: This drop-down selection is used to set the number of pulses which will be coherently integrated to form a single symbol. Each time the Pulse Integration Index (PII) is increased by 1 step, the number of pulses per symbol will be doubled. This has two effects. First, the transmitted packet will take twice as long to send. Second, the received signal strength will increase by 3 dB. Units operating with different PIIs will not be able to communicate.

Antenna Mode drop-down menu: This drop-down window controls which antenna port will be used to transmit and which will be used to receive. There are 4 choices:

- Transmit on A, Receive on A
- Transmit on B, Receive on B
- Transmit on A, Receive on B
- Transmit on B, Receive on A

Antenna Delay A & B: These two fields define the amount of time (in picoseconds) that it takes the pulse to be produced in the UWB ASIC and travel through the circuitry and connectors up to the feed point of the antenna. This value is important because it will be subtracted from the distance reported by the range measurement. When Antenna Delay A & B is set to zero (the default), then range measurements taken with standard P4xx modules (using Broadspec antennas and right-angle SMA adapters) will be accurate within a few centimeters (assuming the units are not operating in saturation). If the antenna is attached directly to the antenna port (without the right-angle connector) then the antenna delay will be shorter by a few centimeters. If this difference is important to your application, then when operating without the right antenna the Ant Delay a/b fields should be set to -91. Adding a cable between the antenna and P4xx antenna port or changing to a different type of antenna will change this value. To recalibrate the sensor see **Appendix C: Calibrating Ranging Bias**.

Ant Orientation: Those interested in the best accuracy possible should be aware that the orientation of the antenna (pointing up vs. pointing down) can change the bias by 4 cm. If the antennas on the requester and responder are both pointed in the same direction (both up or both down) then there will be no change in bias. However, if one antenna is pointing up and the other is pointing down, then the pulse being transmitted is actually inverted in phase. This will cause the 4 cm change in bias. If such a difference is important to your application, then the solution is to set the Ant Orientation field to reflect how the antenna will be mounted. The default is A/B up.

For example, in some situations it may be advisable to mount a unit high on a wall or pole with the antenna pointed down. Such a mounting maximizes the energy pointed downward so the operation with ground-based units can benefit from the strongest signal strength possible. In this case, the wall-mounted units should be set with Ant Orientation set to the down positon.

Insuring that the antenna orientations are properly set will also have a minor, but beneficial, effect on the standard deviation of the range measurements.

Calibrate: This control allows the user to calibrate (set the Antenna Delay) such that it will have a bias of 0 cm. See **Appendix C: Calibrating Ranging Bias** for instructions on how to calibrate a unit. Since the unit to unit bias variation is only about 1 cm, it is not normally necessary to calibrate a unit. Calibration is necessary only when either (a) a cable is inserted between the P440 antenna port and the antenna or (b) the user is attempting to achieve accuracies better than 1cm.

Sleep Mode: Each member of the P4xx family supports various sleep modes. The advantage of sleep modes is that they allow the unit to power off different parts of circuitry to save energy. Not all P4xx units support all of the sleep mode states. To determine which states a given P4xx platform supports, please refer to the relevant data sheet. Because the power savings achieved by employing the Sleep mode are quite modest and because either (a) most applications require fast update of ranges such that there is no opportunity of using the Sleep Mode or (b) are powered by main, the Sleep Mode is not normally a useful control mechanism.

ELR (Echo Last Range): If this box is checked, then the next time the P4xx requests a range measurement, it will also transmit as data the last range measurement information it has taken. This information includes the range measurement as well as the Node IDs of the requester and responder associated with that range measurement. Any P4xx units that receive this request message and have their ELR box checked will report this last range measurement information. This information can be viewed by clicking on the Info button. See **Section 6.6 - Info Button**. When multiple units are in use in the same area at the same time, this mechanism will allow range information to propagate through all of the units and thereby increase the system capacity.

Disable FFT: This box allows the user to disable the range waveform FFT.

The 170330-Final release adds the capability of performing an FFT on a received waveform scan, thereby increasing the SNR of the received waveform by approximately 6-7 dB. This means that the range measurements have a lower standard deviation and, because the FFT is less likely to produce occasional range outliers, will have more robust operation. The only disadvantages are minor. The user may see an increase in the number of SNR Mismatch errors received from virtually zero to approximately 1 in 10,000 ranges. Also, the computation of SNR from received waveforms becomes a bit more complex. See **Appendix E: Noise, Signal, and SNR** for details.

TDSR recommends the use of the FFT and has set that as the default. Users who would rather not use the FFT can click the Disable FFT box.

This feature is not available on any units prior to the P440, such as the P400, P410, or P412. This is due to the fact that the FFT is implemented in the FPGA and units prior to the P440 do not have enough capacity to support this new feature. Therefore, when connected to units older than the P440, this control box will not appear on the RangeNet GUI.

In addition, FFTs are not performed when the received signal is compressed, or when Region 1 units (P440s which comply with FCC rules) communicate with Region 2 units (P440s which comply with EU emission rules).

CRE Ranges: This checkbox controls whether or not the unit will compute Coarse Range Estimates. For more information on CREs, see **Appendix F: CRE Demonstration Exercise**. However, CRE Ranges have proven to be of limited value. In some cases, they are demonstrably wrong. Future versions of RangeNet will not support CRE ranging at all.

Flag LOS/NLOS Mismatch: When this box is checked, the system will flag as invalid any range reading in which the requester and responder disagree as to whether the RF channel is Line-of-Sight or Non-Line-of-Sight. Such mismatches normally result in outlier (incorrect) range measurements. When operating outside, checking the box will help, but when operating in complex environments it will hurt more often than it helps. Therefore, TDSR recommends that this box not be checked.

Enable BSDC: When this box is checked, BSDC (Both Sides Delta Check) will compare the requester and responder received waveforms and confirm if they are reasonably similar. If the waveforms fail this check then the reading will be flagged as an invalid number.

BSDC has shown to be an effective method of reducing outliers, reducing standard deviation of range readings to less than 5 mm and minimizing range quantization. (A range quantization error occurs when the range algorithm is uncertain as to which lobe in the received waveform is representative of the earliest arriving energy. This uncertainty will cause reading-to-reading variations of 38 mm).

The biggest disadvantage is that the algorithm can, in some situations, discard up to 80% of the readings. This can happen in environments characterized by low SNR and/or complex characteristics.

TDSR believes that BSDC is a valuable tool for users interested in achieving the highest accuracy possible and who can afford occasions where the range measurement rate is degraded. These users should check the Enable BSDC box; all others should leave the box unchecked.

Note that BSDC is not active in certain situations:

- To be used, both requester and responder must have FFT enabled (no check in the Disable FFT box) and Enable BSDC must be checked.
- BSDC is not operational when either unit is in saturation.
- Region 1 units (P440s compliant with FCC regulations) will not use BSDC when operating with Region 2 units (P440s compliant with EU regulations).
- BSDC is not supported on high power units.

When connected to units older than the P440 (such as the P400, P410 or P412) the BSDC control box will not appear. This is due to the fact that the FFT required by BSDC is not supported on older units.

5.3 Configuration File Block

Load from File: Clicking the "Load from File" button will load configuration information stored in an XML file to the RangeNet GUI. Selecting the file is accomplished through the standard

Windows File-Open dialog window. The configuration information includes ranging parameters, network parameters, and localization parameters. This configuration file or "config file" can be created by clicking the Save to File button. **Note:** Previous versions of RangeNet provided a default parameters file with the GUI. Since the default parameters are now stored in the P4xx there is no need to provide this file.

The ability to load a configuration from file is generally a great asset. However, there are times when one should be careful. For example, there are several parameters which could be specific to a particular unit. Loading a "standard" file into a unit which needs specific settings would effectively ruin its configuration. While this would not harm the unit, it could make life frustrating when integrating a large system of nodes. For example, suppose some units require an antenna up configuration and other an antenna down configuration. Loading a specific configuration file into all the units would incorrectly set the direction of the antennas of some of the units. Other examples include:

- Custom antenna configurations
- Unit specific antenna delay calibrations
- GPIO settings
- Unit specific TDMA slot maps

In these cases it is advisable to create node-specific config files.

<u>Save to File:</u> Clicking the "Save to File" button will create an XML file where the configuration data will be saved. The RangeNet GUI will prompt the user with a standard Windows File-Open dialog window. The sample configuration files provided with RangeNet are write protected.

<u>Write Config to Radio:</u> If this box is checked, then clicking the Load From File button will not only load the RangeNet GUI with the parameters, but it will also automatically download the parameters to the attached P4xx platform.

There is one detail associated with loading and saving a configuration file which may cause confusion. When you connect to the unit you have the option to limit the number of tabs which are active. You can use just ranging screens or ranging plus network or ranging plus network plus location tabs. If you pick a subset and then load from file or save to file, the parameters saved will have an extension matched to the subset you picked. For example:

- If ranging is set, then save operations will store configurations to a .rng file.
- If networking is set, then save operations will store configurations to a .rnn file.
- If location is set, then save operations will store configurations to a .rnl file.

When loading configuration files, the default extension will be either .rng, .rnn or rnl, depending on which subset of screens were selected. However, the user can load using any extension. This is illustrated in **Figure 5-2**.

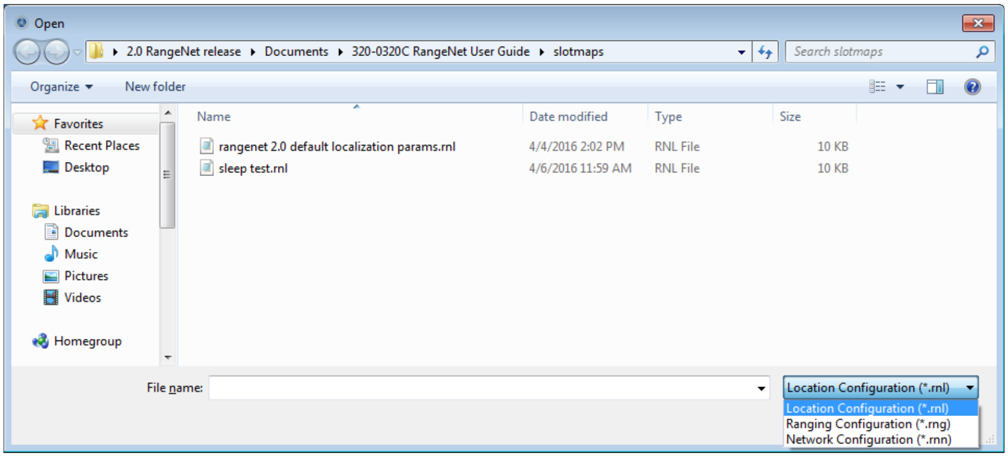

Fig. 5-2: User can load configuration files using any legal extension (.rng, .rnn, .rnl)

5.4 Logging Block

The controls in this block allow the user to log all message flow between the Host and the attached P4xx platform to a comma-separated variable (.csv) ASCII text file in a folder/directory of the user's choice. This capability allows the user to monitor and review in detail the behavior of a unit over extended periods of time and to log data for post-processing. Operation of the various control fields is described below:

Directory/Browse: These two fields allow the user to select or create the target directory in which the logfile will be stored.

Logfile Prefix: This is the prefix of the name of the log file. The user may select the default or change it to any arbitrary name. The RangeNet GUI will append to this prefix an incremented zero-filled number. Each time the log file is closed and opened, the RangeNet GUI will automatically increment the number. For example, given the default prefix of RangeNet_Log_, the first logged file would be RangeNet_Log_000. The second would be RangeNet_Log_001 and so on. Picking a new prefix will zero the number. If the prefix has already been used, then the next available number will be selected.

View in Explorer: Clicking this button will allow the user to view any log file in the log directory. If the selected file is currently in use, then the file will be opened with read-only privileges.

Delimiter: All data logged to file will be stored using a delimiter specified by the user. The user can chose the desired delimiter by selecting one from the dropdown box associated with this field. If a comma is selected then the log file will be save as a .csv file (comma separated variable file) otherwise the log file will be saved as a .txt file.

Reduce display updates while logging (saves CPU usage): If this box is checked during logging, then all messages will be logged but the scan display will not update and messages will not be shown in the Action Area. This reduces the processing load of the Host computer.

Start: Starts the logging of data to the named file.

New: Clicking this button will close the existing file and open a new file which has an incremented file number. If clicked in the process of logging data, no data will be lost.

Stop: This stops the logging of data to the named file and closes the file.

LF Marker: Each time this button is pressed, a new entry will be added to the log file. This entry will be the number shown to the right of the LF Marker button. This entry will have three fields; the date, an entry indicating this is a Logfile Marker message, and the Logfile Marker number. When taking large data sets, this is a handy way of adding an easily locatable marker to indicate a notable section of data.

5.5 IP Configuration Block

These controls allow the user to display and modify the IP configuration information for the attached P4xx.

If the DHCP button is checked, then the attached P4xx is using dynamically assigned IP addresses. Note that in order for your Host computer to communicate using DHCP, it must be set up with a DHCP server.

If the DHCP button is not checked then the attached P4xx is using static IP addresses and the current values are displayed on the screen.

To change the operational mode (DHCP or Static IP Addresses), click the DHCP button. To change any part of the IP address (Address, Netmask, and/or Gateway), enter the desired changes. Any changes to the IP address information will change the color of the Set button. This is a reminder to the user to download the values by clicking the Set button. Once clicked, the Set button will return to its regular color after it receives a successful confirmation. This will take several seconds. During this time it is critical that the user must not disconnect power from the P440. Doing so will corrupt the memory and the unit will need to be returned to the factory and reset. During this period of vulnerability the following warning message will be prominently displayed.

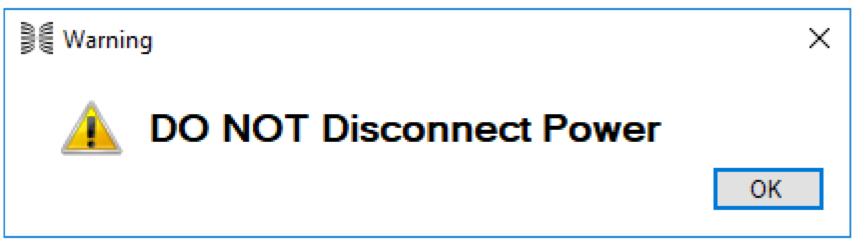

Fig. 5-3: Critical warning. Do not remove power from the P440 while this message is displayed.

Note that these changes will not actually take effect until the P4xx is either rebooted or power to the unit has been cycled.

Clicking the Get button will upload the IP configuration information from the P4xx to the Host computer.

Warning: While changing the last three digits of the static IP Address is easy and frequently useful, changing either the Netmask or the Gateway addresses needs to be done carefully by someone familiar with the IT ramifications of the changes. When in doubt, consult your network manager. Also, while it is possible to set the last field of the IP address to 0 or 255 this is not recommended because these two addresses frequently have special network uses. Therefore, unless you are really knowledgeable about the Ethernet network ramifications you should avoid using 0 or 255.

5.6 GPIO Block

5.6.1 Overview

This block allows the user to define, monitor, and control the 15 GPIO pins provided with the P440. This capability is limited to P440 units operating at a revision level equal to or more recent than 170330-final. Earlier members of the P400 family such as the P400, P410, and P412 do not support GPIOs. In fact, the GPIO control button will not appear unless you are connected to a P440 which is at a suitable revision level.

Clicking the GPIO button will activate the GPIO screen shown in **Figure 5-4**.

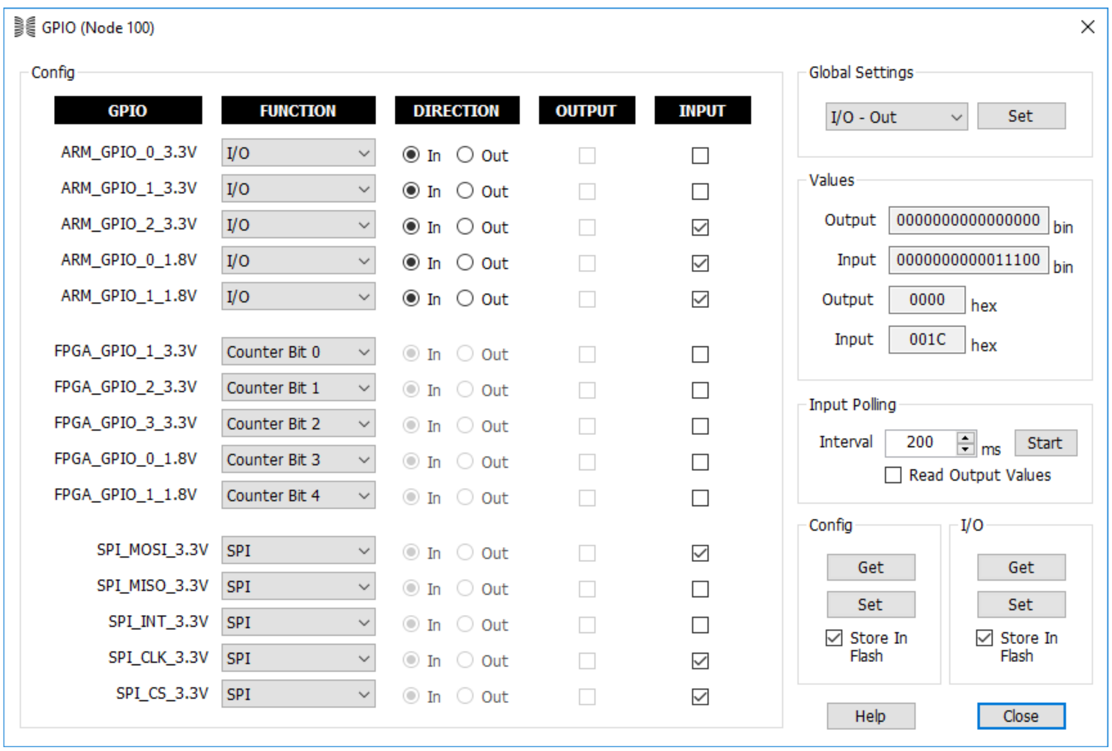

Fig. 5-4: GPIO control window

There are several different types of GPIOs. Some are literally input or output pins while others have special functions. Some functions, such as the SPI and Counter Bits special functions, span multiple GPIOs. Every GPIO can be configured as one of 4 different functions. Some functions are reserved for the addition of future capabilities.

The GPIOs have different electrical and mechanical characteristics. Some are controlled by the P440 ARM processor and others by the FPGA. ARM GPIOs are slower and with higher jitter than FPGA based GPIOS. Some operate at 3.3 volts and others at 1.8 volts. While the GPIOs are provided with antistatic protection, the user should be very careful not to reverse-connect the pins or drive them with voltages higher than 3.3 or 1.8 volts or lower than Digital Ground. The GPIOs are scattered between the Locking, User, Factory, and Ethernet Mezzanine connectors. Some GPIOs are available on more than one connector.

For pins available on multiple connectors, it is the responsibility of the user to insure that each GPIO connected in a rational manner. For example, consider GPIO number 1 (ARM_GPIO_0_3.3V). This GPIO is mechanically connected to both the Locking and User Mezzanine connectors. Defining GPIO 1 as an input and then connecting Locking Connector Pin 11 to ground and User Mezzanine Pin 11 to +3.3 would be a terrible mistake. Doing so would create a dead short which would likely evaporate copper traces on either the P440 or the board driving it.

The entire configuration, mechanical, electrical, and functional operations for the GPIOs can be viewed by clicking the Help button on the GPIO control display. The help screen is shown in **Figure 5.5**. Functions highlighted in yellow show the default configuration. Those in light gray are reserved for future use.

GPIO Help

#	GPIO	Source	Voltage	Connectors*	Function 0	Function 1	Function 2	Function 3
0	ARM_GPIO_0_3.3V	µProc	3.3	LC 11, UM 11	I/O	Counter Bit 0	Reserved	Slot 0 Edge
1	ARM_GPIO_1_3.3V	µProc	3.3	UM 15	I/O	Counter Bit 1	Reserved	Reserved
2	ARM_GPIO_2_3.3V	µProc	3.3	FM 20	I/O	Counter Bit 2	Reserved	Reserved
3	ARM_GPIO_0_1.8V	µProc	1.8	EM 17	I/O	Counter Bit 3	Reserved	Slot 0 Edge
4	ARM_GPIO_1_1.8V	µProc	1.8	EM 18	I/O	Counter Bit 4	Reserved	Reserved
5	FPGA_GPIO_1_3.3V	FPGA	3.3	LC 4, UM 6	I/O	Counter Bit 0	Reserved	Reserved
6	FPGA_GPIO_2_3.3V	FPGA	3.3	LC 6, UM 8	I/O	Counter Bit 1	Reserved	Reserved
7	FPGA_GPIO_3_3.3V	FPGA	3.3	LC 15	I/O	Counter Bit 2	Reserved	Reserved
8	FPGA_GPIO_0_1.8V	FPGA	1.8	FM 18	I/O	Counter Bit 3	Reserved	Reserved
9	FPGA_GPIO_1_1.8V	FPGA	1.8	FM 12	I/O	Counter Bit 4	Reserved	Reserved
10	SPI_MOSI	FPGA	3.3	LC 1, UM 1	I/O	Counter Bit 0	Reserved	SPI
11	SPI_MISO	FPGA	3.3	LC 3, UM 3	I/O	Counter Bit 1	Reserved	SPI
12	SPI_INT	FPGA	3.3	LC 2, UM 4	I/O	Counter Bit 2	Reserved	SPI
13	SPI_CLK	FPGA	3.3	LC 7, UM 7	I/O	Counter Bit 3	Reserved	SPI
14	SPI_CS	FPGA	3.3	LC 9, UM 9	I/O	Counter Bit 4	Reserved	SPI

* **LC** - Locking Connector - J11; **UM** - User Mezzanine - J10, **EM** - Ethernet Mezzanine - J8; **FM** - Factory Mezzanine - J6

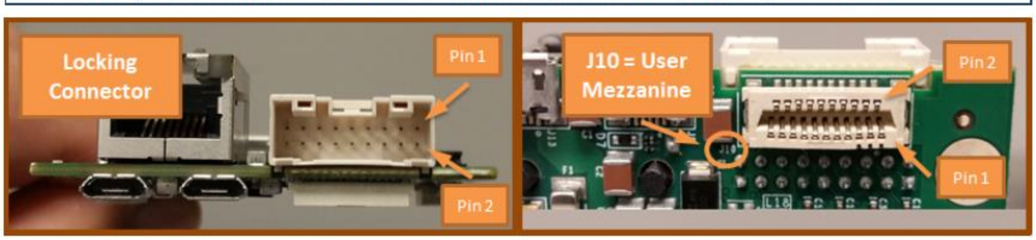

Fig. 5-5: Summary of GPIO electrical, mechanical, and functional characteristics

5.6.2 GPIO Types

There are currently 4 types of GPIOs. They are described below. More will be added in the future.

I/O: These are single Inputs and Outputs. The state of the current inputs and outputs can be monitored either manually or automatically.

Counter Bits 1 through 5: These output bits currently only have meaning when the P440 is operating as a radar sensor. It currently has no purpose when the P440 is operating as a ranging radio or when it is communicating data. When selected, the output counter will be set to the current message ID number and the result will be output to the Counter GPIOs. Each time a radar scan is completed, the Counter Bits will be incremented and output to the Counter GPIOs.

SPI: These pins are used to implement a SPI interface. The SPI interface is described in the *320-0317 P440 Data Sheet*.

Slot 0 Edge: This output pin only has meaning when the radio is operating in a TDMA network. For details on TDMA and TDMA Slot Maps, see **Section 7.5 Behavior as a TDMA Network** and **Section 8.5 TDMA Slot Map**. When operating a TDMA network, the airtime is shared between multiple units. Each unit is allocated a specific time, or slot, when it can communicate. These slots are numbered and RangeNet supports up to 32 slots. When every unit has had a turn, the sequence restarts at slot 0. Time is synchronized such that all of the units in the system will transition from one slot to another with an accuracy of approximately 1 μs.

The Slot 0 Edge function will drive a GPIO pin low approximately 1 μs after the network transitions from the last slot to slot 0. The GPIO pin will be set high approximately 1 μs after the transition to the final slot. This is illustrated in **Figure 5.5**.

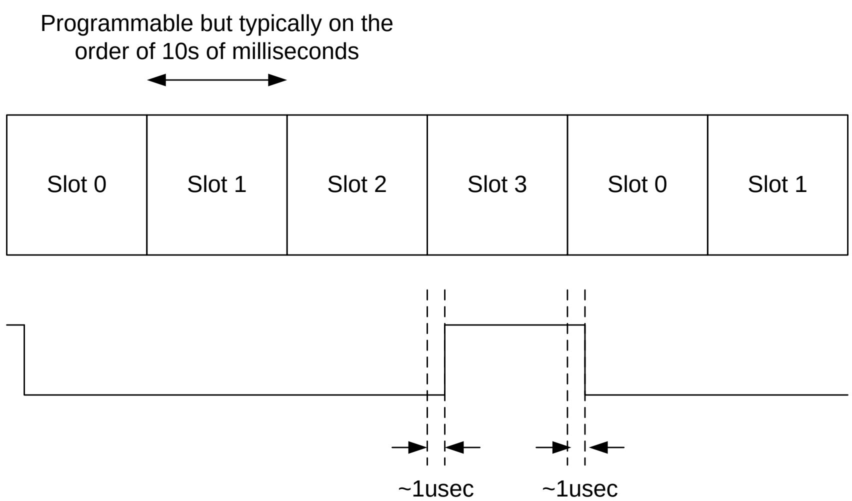

Fig. 5-5: Timing Diagram for Slot 0 Edge GPIO pin

5.6.3 Operation of the GPIO Window

The GPIO Window is divided into several sections: Config, Global Settings, Values, Input Poling, Config, & I/O.

Config: This section is dived into several columns. The GPIO column provides a name for each of the 15 GPIOs. These names correspond to the ones used in the *320-0317 P440 Data Sheet*. The Help button provides a visual display of the pin and connector numbers.

- Function: Each pin has been defined to support one of up to 4 functions. The drop-down allows the user to assign a particular function to a particular GPIO. The assignment will be complete when the user clicks the Set button in the Config block.

- Direction: This column allows the user to define whether an I/O is an output or an input. Special functions are predefined and the user will not be able to override the designated direction. The definition will be complete when the user clicks the Set button in the Config block.

- Output: If the GPIO is an output, the user can set the bit by clicking the corresponding Output checkbox. However, the change will not take place until the user clicks the Set button in the I/O block.

- Input: If the GPIO is an input, then the checkbox will be set if the input is a 1 or unchecked if the input is a 0. The status of the GPIO is updated whenever the I/O Get button is clicked.

Global Settings: This control block allows you to set all of the outputs at once. The user can select the desired setting from the drop-down and then click the Global Setting Set button. This configuration information is downloaded to the P440 when the Config Set button is clicked.

Values Block: The block displays the current Output and Input values as either a binary or hex value.

Input Polling: This control block allows the user to cause the GUI to periodically poll the status of the inputs. The Interval entry allows the user to set the polling rate. Clicking the Start button will cause the polling to begin. Once started, the Start Button will become a Stop button.

Config: Clicking the Get button will upload the GPIO configuration from the P440 to the GUI. Clicking the Set button will download the Configuration from the RangeNet GUI to the P440. If the Store if Flash box is checked, then the configuration information will be written to the P440's non-volatile memory. If the Flash box is not checked, then the configuration will be lost when the unit reboots or powers down.

I/O: Clicking the Get button will upload the GPIO input and output values from all 15 GPIOS in the P440 to the GUI. Clicking the Set button will download the GPIO output values of just I/O pins from RangeNet GUI to the P440. If the Store if Flash box is checked, then the output values of I/O pins will be written to the P440's non-volatile memory. If the Flash box is not checked, then the output value will be lost when the unit reboots or powers down.

5.7 CAN Configuration Block

This block allows the user to set or upload the CAN baud rates and address to or from the P4xx. Changing the values on the GUI will change the color on the Set button in the CAN Configuration Block. This is to remind the user that the change will not take place until the Set button is clicked.

Baud: This drop-down allows the user to set the CAN baud rate for the connected unit. Note that it is the users responsibility to ensure that all units on the CAN bus communicate at the same baud rate. Also, remember that the maximum achievable baud rate is a function of the length and type of cable used for the CAN bus as well as the characteristics of the line drivers. These are all dependent on the implementation details of your system. However, in general, high speed communications requires short cables and low speed operation functions.

Address: This allows the user to set the CAN address of the connected P4xx. Note that it is the user's responsibility to ensure that all nodes on a given bus have unique addresses. The default address is 128 and the user can set the address to any number between 0 and 255. However, the user should avoid addresses 0 and 255 because some CAN systems reserve these addresses for special functions. When in doubt, consult with your CAN system manager.

Set: This button allows the user to download the Baud Rate and Address settings to the connected P4xx. The new parameters will take effect when the unit is power cycled or rebooted.

Get: This button allows the user to upload the Baud Rate and Address settings from the connected P4xx.

6. Ranging Tab

When operating in Ranging Mode, the P4xx will neither initiate a range measurement request nor send a data-only packet unless commanded to do so by the Host. If the unit is in Ranging Mode and not initiating a range measurement request, it will be actively receiving. It will respond to any range request or data packet it may receive from other units in Ranging Mode but it will not respond to units in Networking Mode. It will maintain this behavior even if no Host is attached to the unit.

The Ranging Tab (see **Figure 6-1**) provides the user with an easy means of transmitting ranging and data packets and displaying received information. Range measurement produces three types of information: a distance measurement, a received waveform scan from which the distance is computed, and various statistics which describe the range measurements and received scan. (The scan is basically the received impulse response of the RF channel.)

The Ranging Tab Control and Status Area is divided into three main sections and three buttons.

- Ranging commands (on the left) control the transmissions
- Received statistics (shown in the middle) display range and signal quality information
- Ranges, range filter controls, and data are displayed on the right
- The Scans button allows the display of received scans
- The Chart button allows the user to produce a strip chart plot of range vs. time for any units within ranging distance
- The Info button displays any Echoed Last Ranges (ELRs), Echoed Last Locations (ELLs) and Beacon messages

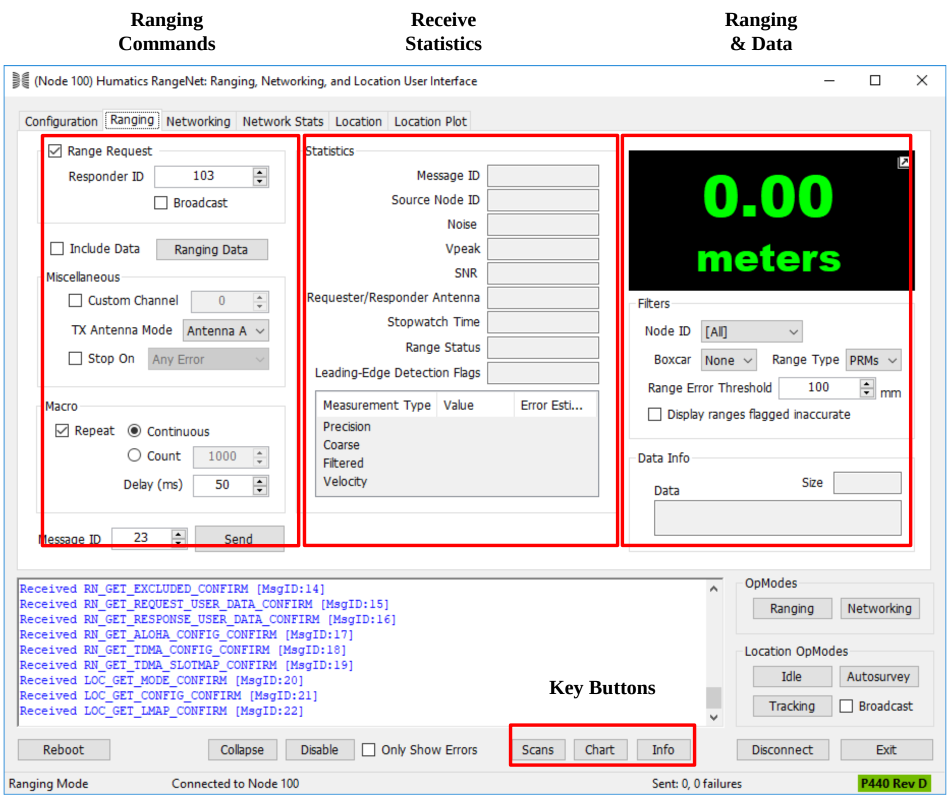

Fig. 6-1: Ranging Tab Control and Status Area

6.1 Ranging Commands

Range Request Block & Data

Range measurement is performed using either Two-Way Time-of-Flight (TW-TOF) ranging or Coarse Range Estimation. TW-TOF produces extremely accurate range measurements also called Precision Range Measurements (PRMs). Coarse Range Estimates (CREs) are based on the measurement of the received signal strength of the first arriving energy. They have (relatively) low accuracy and only operate out to 100 meters. In some cases, they are demonstrably wrong. CRE Ranges have proven to be of limited value and are not supported when operating in Network mode. Future versions of RangeNet will not support CRE ranging at all. For more information, see **Section 1.1 - Overview: UWB, Ranging, Networks, and Localization** as well as **Appendix F: CRE Demonstration Exercise.**

There are two types of user-generated transmit packets: range requests and data-only. Range request packets can optionally contain data, but data-only packets do not result in a range measurement.

The data can also be automatically sent in a response packet. This offers two separate opportunities for data transmission. Two different transmit buffers are provided for these purposes. The Request Buffer is intended for transmission with data-only or request packets. The Response Buffer is intended for transmission with Response packets.

Range Request: Checking the Range Request box instructs the attached P4xx to prepare to send a range request. If this box is not set, then the P4xx will only send data packets.

Responder ID**:** Range requests can be directed at an individual responder or broadcast to any units in the area. The unit initiating the request is the "Requester" the unit responding is called the "Responder". To direct to a particular Responder, enter the desired Node ID in the Responder ID field.

Broadcast: Alternatively, if the responder ID is unknown, the user may select the Broadcast checkbox to command any P4xx listening in Ranging Mode to respond. Selecting the Broadcast checkbox will set the Responder ID to 0xFFFFFFFF. Note that if multiple P4xx modules respond then (a) they can interfere with each other such that no response is received or (b) one Responder (normally the closest strongest transmitter) will be received by the Requester.

Include Data: Checking the Include Data box will cause data in the Request Data Buffer to be transmitted with the range request.

Ranging Data: Clicking this window will open the display shown in **Figure 6-2**. These fields allow the user to enter data into the Requester and/or Response Data Buffers. Data entered in the Requester buffer will be sent in next available ranging messages (if the Include Data flag is set) or in data-only packets. Data entered in the Response buffer will be sent when the P4xx sends a response packet. The data in these buffers will be transmitted each time a transmission is sent. In other words, sending a transmission does not reset the buffer. The maximum amount of user data that can be sent in a single message is 1000 bytes. However, when operating in Location mode the maximum is 900bytes. These bytes are actually transferred in 4 byte words. Consequently, the P4xx will up-fill to a 4 byte (word) boundary. For example, if the user loads 3 bytes in the response buffer, the P4xx will actually send four bytes. The GUI allows the user to send readable ASCII text, but the underlying API can handle any characters.

Clicking the *Cancel* button clears the buffers. Clicking *Ok* sets the buffers.

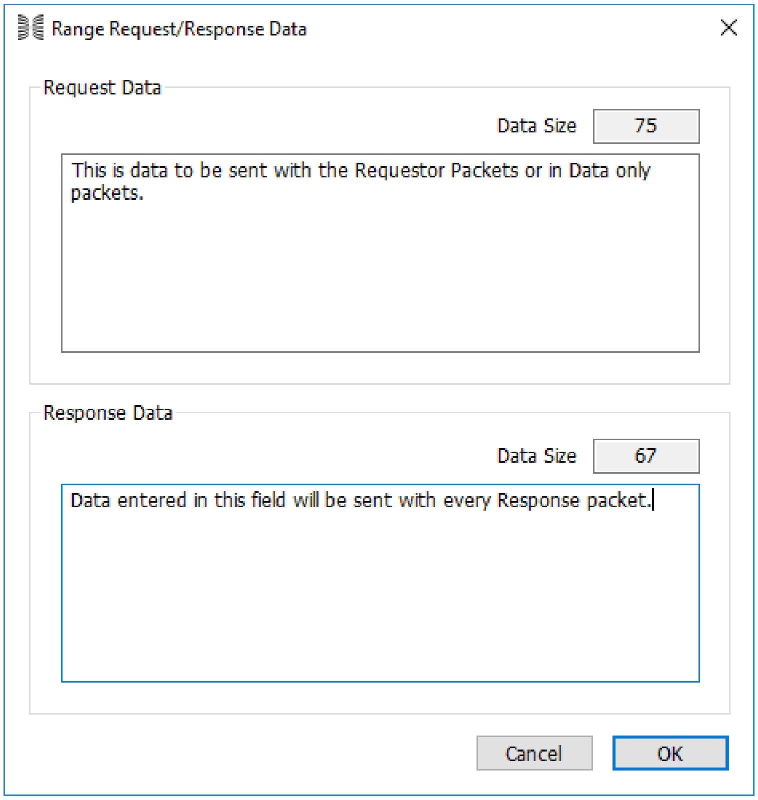

Fig. 6-2: Data buffers for Request (top) and Response (bottom) packets

Miscellaneous

This box allows the user to modify the radio's choice of antennas and communications codes and to automatically stop the ranging process if a condition is set.

Normally, the radio will send and receive using the antenna and communications code selected on the Configuration Tab. Occasionally, it is useful to define a different antenna and or communications code for transmissions. This is useful if the requester needs to range to two separate units as fast as possible. While this function could also be accomplished by making the change on the Configuration Tab, doing so would require the user to execute two API commands. The first would send an API command to set the radio to a new code, and the second would reset it back to the original value. These two steps would take many milliseconds (ms) to execute and will reduce the ranges taken per unit of time. In contrast, using the Custom Channel does not add any measureable amount of time to the process and thereby maximizes ranging throughput.

The next two commands provide this capability. Once the data has been sent or the range/response transaction has completed, the communications channel and antenna mode will revert to the configuration selected on the Configuration Tab.

Custom Channel: If the Custom Channel button is checked, then the Code Channel for the entire requested range conversation will be changed from the code channel indicated on the Configuration Tab to the one indicated in the Custom Channel drop-down menu.

TX Antenna Mode: This drop-down menu allows the user to select a different antenna to use for transmissions.

Automatically stopping ranges:

Stop On: Clicking this box will cause stop transmissions on either (a) any error or (b) on the first range error as defined in the associated *Any Error* drop-down menu. This is useful if you are sending many (hundreds to millions) of range packets and are interested in only the first range that fails.

Macro, Message ID and Send

Send: Clicking this button will order the attached P4xx to transmit packets as defined in the previous parameters. The frequency and number of packets sent is defined in the Macro box. Once clicked, the name of the button will change to Stop and will remain renamed until the user clicks Stop or the Host has sent the requested number of packets.

Repeat: If this box is not set then the Host will order the attached P4xx to transmit one (and only one) packet when the Send button is clicked. If this box is set then the other controls take effect.

Continuous/Count: Selecting one of these two buttons will deselect the other. Selecting the *Count* button will cause the unit to transmit a user-defined number of packets, while clicking *Continuous* will send packet after packet until the Stop button is clicked.

Delay: The time interval between successive transmissions is set by the value entered in the *Delay* field. If sending ranging packets with or without data, then this is the time between reception and processing of the range Response packet and transmission of the next Request packet. If a data-only packet is being sent, then this represents the time between the end of one data packet and the transmission of the next data packet.

Message ID: This field contains the number of the next message which will be sent from the Host to the P4xx. For a detailed description of Message ID fields and a discussion of their use, see the Message ID field description in **Section 5.1 - Radio Configuration Block**.

6.2 Ranging Statistics

These statistics are reported by the attached P4xx through the Range Info API command. If the user has selected “Small” in the Ranges field in the Configuration Tab, then the P4xx will report only key range information such as the range, the Node ID of the unit ranged to, the Range Status, and the Message ID. If the user has select “Full” then all the fields on this screen will report information.

The following is a description of each of the fields in the Ranging Statistics block as well as a discussion of the Scan, Chart, and Info buttons. To aid in this discussion, a typical range measurement is shown in **Figure 6-3.**

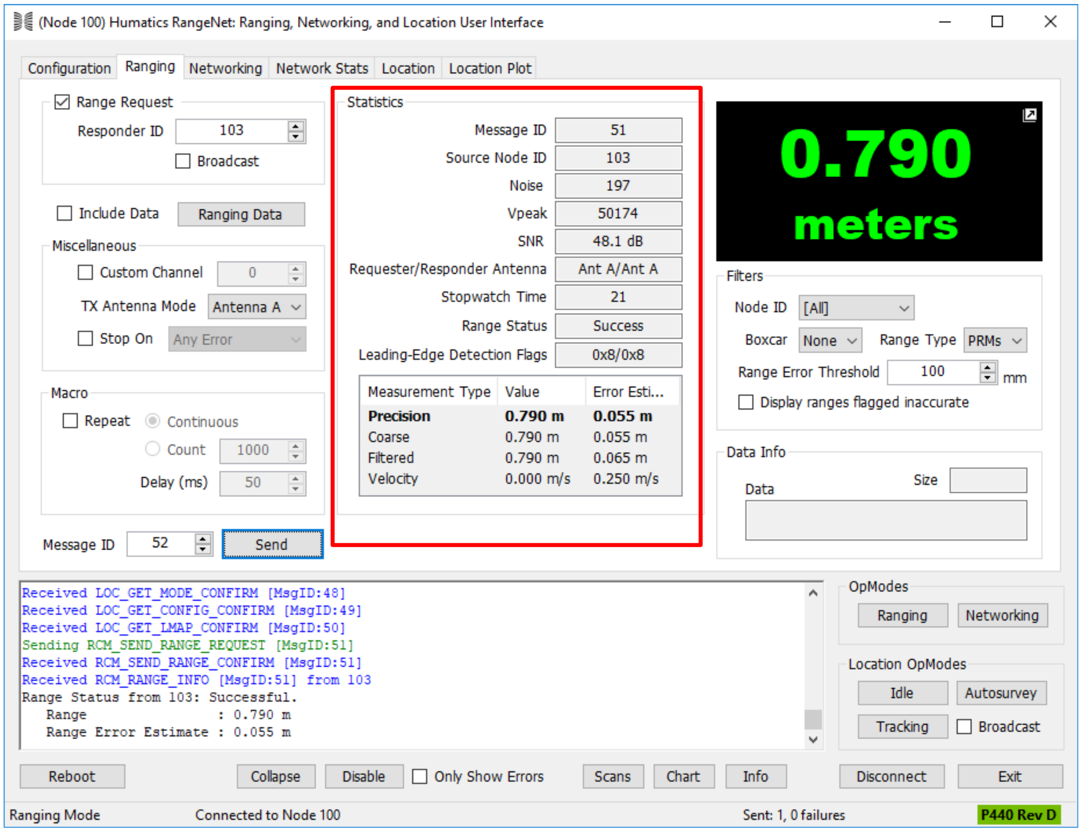

Fig. 6-3: Example range measurement with statistics section highlighted

Statistics Block

Message ID: This is the ID of the P4xx API message which contained this information.

Source Node ID: This is the ID of the node which responded.

Noise: This is a scaled estimate of the received noise as measured by the P4xx. The unscaled noise can be computed using the following formula:

Unscaled noise = noise * (2^PII)/512

Vpeak: This is the scaled estimate of the maximum received signal in the leading edge as measured by the P4xx. The unscaled signal can be computed using the following formula:

Unscaled signal = Vpeak * (2^PII)/512

SNR: This is an estimate of the Signal-to-Noise Ratio (SNR) of the received signal. It is computed from the waveform scan using the following formula:

SNR = 20*log10(Vpeak/Noise)

Noise, Signal/Vpeak, and SNR are discussed in greater detail in **Appendix E: Noise, Signal, and SNR**.

Requester/Responder Antenna: The position to the left of the slash indicates the antenna used by the Requester and the position to the right indicates the antenna used by the Responder.

Stopwatch Time: This is an indication of the amount of time in milliseconds required to take a single range measurement.

Range Status: This field indicates whether or not the range measurement requested was successfully completed. See Table 3-2 in the API documentation for an enumeration of the possible responses.

Leading-Edge Detection Flags: These flags convey information about the nature of the received signal. If the received signal is a clean Clear Line-of-Sight (CLOS) channel and the signal was not saturated, then a 0x8 will be displayed. Any other values indicate an issue with the signal. The flag values are indicated in the API and can be seen by hovering one's mouse over the field for a few seconds. A description is provided in **Figure 6-4**.

Bit	Meaning	Valid reading?	Interpretation
Bit 0 - 001 hex	Saturated	Yes	Units are too close. Signal is being clipped. Expect small degradation in precision and small shift in range bias.
Bit 1 - 002 hex	Scan window too short	Invalid. See API Range Info Table 3-2, Code Flags 2,4 or 6	Unable to find valid leading edge. Likely operating in dense multipath.
Bit 2 - 004 hex	SNR too low	Invalid. See API Range Info Table 3-2, Code Flags 2,4 or 6	SNR is unrealistically low or unable to find valid leading edge.
Bit 3 - 008 hex	Line-of-sight	Yes	Link is line-of-sight. This is the normal situation. Expect fine range measurements.
Bit 4 - 010 hex	Non-line-of-sight	Generally valid. Read the interpretation.	Link is blocked and range measurement is likely determined by multipath reflection and not the first arriving signal. High probability that the range is much too long. Requester will compare the responder's Bit 4 with its own Bit 4. A difference indicates a channel mismatch. Depending on the state of the user defined LOS/NLOS checkbox, this will either be kept as valid or discarded.

Bit 5 - 020 hex	Line-of-sight peak mismatch	Yes	Link is operating in area with sufficient multipath that the range measurement might be suspect. It is more likely that the reading is valid and accurate.
Bit 6 - 040 hex	Reserved and not currently used.	Not used	Currently reserved. Was used in older (obsolete) releases. Recommend upgrading the P4xx to the most recent release.
Bit 7 - 080 hex	Internal RMS LED metric exceeded	Marginal	This reading is marginally valid. It will produce a valid reading but the localizer will not use the value to compute a location.
Bit 8 - 100 hex	Internal Residual LED metric exceeded	Marginal	This reading is marginally valid. It will produce a valid reading but the localizer will not use the value to compute a location.

Fig. 6-4: Interpretation of LED flag bits

These are bit-based flags. For example, if one were to receive a LED flags of 0189h it would indicate that Bits 8, 7, 3 and 1 are set. This would be a very unusual indication. A more common reading would be 009h. This indicates that you have a clear line-of-sight but that the signal is compressed.

Precision: This is the Precision Range Measurement (PRM) taken using the Two-Way Time-of-Flight (TW-TOF) ranging technique. To the right of that is an estimate of the range accuracy.

Coarse: This is the range measurement taken using the Coarse Range Estimation (CRE) technique. To the right of that field is an estimate of the error in the range accuracy. The error estimate is predicted using an algorithm that has been tuned for predicting range error for use with relatively slow moving vehicles operating in an open environment. When operating in other environments the error estimate can be overly pessimistic.

You may notice that taking a PRM always generates a CRE. That is because the response packet associated with TW-TOF also meets the definition of a CRE. Demonstrating CREs can be a bit frustrating for a first time user. **Appendix F: CRE Demonstration Exercise** provides a quick overview and example exercise which illustrates the operation of CREs.

Finally, note that the CRE is only valid if the communications channel is determined to be Line-of-Sight (LOS), the link is not in compression, the range is less than 100 meters, and the Responder is not on the far side of a Fresnel cancellation area.

Filtered: This is the Filtered Range Estimate (FRE). It is an estimate of the range based on a combination of the CRE, PRM, and a linear motion model. If CREs are not used, then the FRE will be based on the PRM and a Kalman linear motion model. To the right of that is an estimate of the error in the filtered range estimate. This is the FREE (Filtered Range Estimate Error). Invalid values of CRE (compression or >100 m operation) are excluded from this filtering process.

FREs can provide higher update rates when used in a network. The increase in update rate comes at the cost of higher range error and increased latency. This is an advanced feature which may benefit some networks. However, we strongly recommend that users focus on using PRMs and avoid FREs.

Velocity: This is an estimate of the rate at which the two devices are approaching or receding from each other. A negative value indicates that the units are approaching. A positive value indicates that the units are separating. To the right of that is an estimate of the error associated with the velocity estimate.

6.3 Range Measurements

This tab section (see **Figure 6-5**) describes the range display, a filter control box, and the data info box.

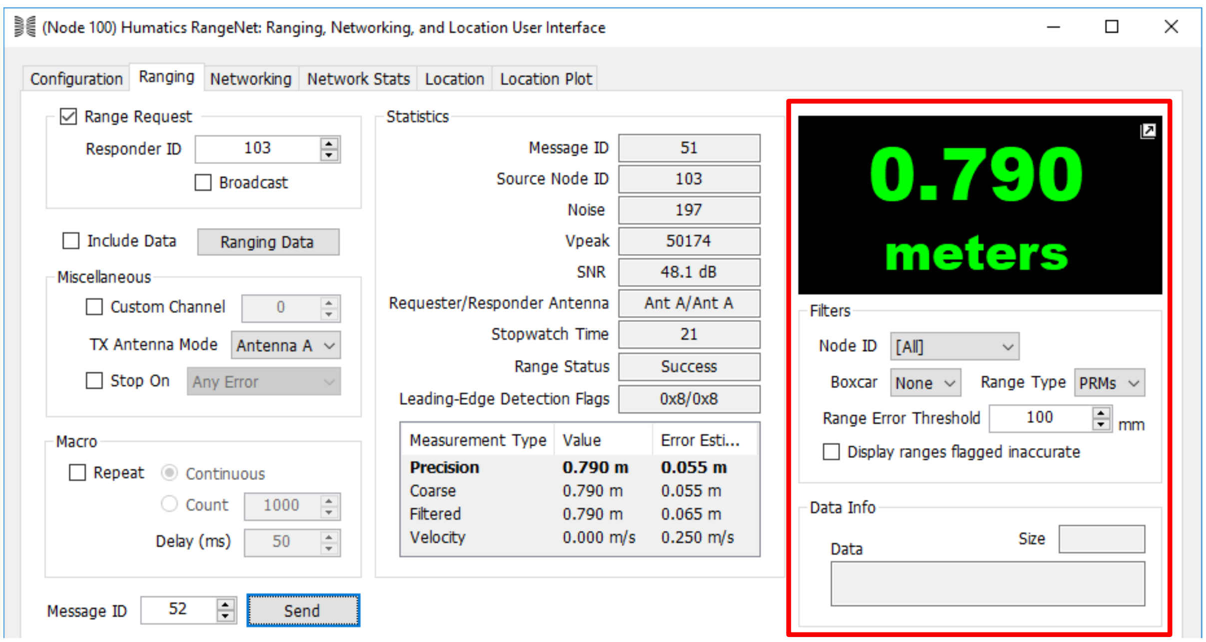

Fig. 6-5: Ranging Tab with Ranging and Data section highlighted in red

Range Display

The Range Display shows the value of the current range measurement. This display has several useful properties.

- The display enables adjustment of the units of measure. Double-clicking the display will change the display's units such that it is possible to display the measurement in feet, meters, or millimeters. (Changing units on one tab will be reflected on all tabs where units are displayed.)

- The range can be displayed in a larger format. Clicking the arrow in the upper right-hand corner will cause a much larger display to appear and provide access to the Show SNR checkbox. If this box is checked, then the SNR of the received signal will also appear. This window will remain displayed until the Close button is clicked. This allows the user to monitor the range measurement and SNR while using other control tabs.

- Range measurement values are color coded. Colors are coded as follows:

  - Green numbers indicate successful ranges (RangeStatus=0).
  - As long as the Range Error Threshold is >0, then yellow numbers indicate range readings which have range error estimates greater than the threshold.
  - Blue numbers denote CREs.
  - Red numbers indicate unsuccessful ranges (RangeStatus >0). For instance, a RangeStatus=1 indicates a TIMEOUT condition. This indicates that the responder is either out of range, in an invalid configuration, or inoperable. In the case of a TIMEOUT, the display will indicate a red zero “0.” Red numbers will only be reported if the “Display ranges flagged inaccurate” button is set.

Filter Control Box

This box allows the user to filter the data presented on the display in various ways.

Node ID: This drop-down menu will allow the user to control which ranges are displayed. If set to [All] then the Range Tab will display the range information from any received range conversation. When set to a particular Node ID, the display will only show the range information from that particular node. If the selected node does not respond, then the Range Tab will be entirely blank. This feature is very valuable when operating in Network mode.

Boxcar: This drop-down menu offers four choices as to how the range values can be displayed. The user can select “None” in which the readings will be displayed as they are taken. The user can also average the last N readings using a Boxcar filter. The choices for N are Boxcar 5, Boxcar 10, and Boxcar 20.

While the box car filters are handy, the user should be careful when using Boxcar filtering while operating in Network mode. In these cases, box car filtering will average ALL of the node ranges and thereby produce the average distance separating the nodes. This is generally not useful. The user should either turn Boxcar filtering off, or set Node ID to the node of interest.

Range Type: This drop-down menu offers two choices: PRMs (Precision Range Measurements) or FRMs (Filtered Precision Range Measurements).

Once again, note that if the communications channel is in compression or the channel is not line-of-sight, then Coarse Range Estimates (CREs) (and consequently filtered ranges) will not be calculated. At present, TDSR recommends not using FRMs.

Range Error Threshold: This field is the user adjustable threshold setting for the Precision Range Measurement Error Estimate (PRME). The PRME is an estimate of the error of the PRM. The P4xx determines this error estimate based on a heuristic algorithm that incorporates SNR and the shape of the received waveform.

The RangeNet GUI will compare the PRME with the Range Error Threshold. If the PRME is greater than the threshold, then the range measurement will be displayed in yellow. When using the Repeat Function (see **Section 6.7 – Range Statistics for Repeat Function**), PRMs which have a PRME in excess of the threshold will be excluded in the computation of summary statistics.

This threshold check does not affect any data stored in the logfiles.

The PRME threshold is relatively insensitive. Small changes to the Range Error Threshold do not have an appreciable effect. Based on field tests, a value of 100 has proven to be a useful number.

Setting the Range Error Threshold to 0 will disable the thresholding function.

Display range measurements flagged as inaccurate: If this box is checked, then the unit will display readings in red if the Range Status is something other than 0 or 64 (where 0=success and 64 designates the range is a CRE).

Data Info Block

Any data received by the attached P4xx will be displayed in the Data box. The box will also display the number of characters received in the transmission.

6.4 Scans Button

Clicking the Scans button will display a plot of the received waveform as reported in the Range Info message sent by the P4xx. An example is shown in **Figure 6-6.** The length of time from start to finish of the received waveform is defined by the user's entry in the Scans field on the Configuration Tab. Those options are:

- None: in which case no scan is shown
- Scan: in which case a scan of about 22 ns (350 measurements) is shown
- Full Scan & Full Scan EX: in which case a scan of approximately 100 ns (1632 measurements) is shown

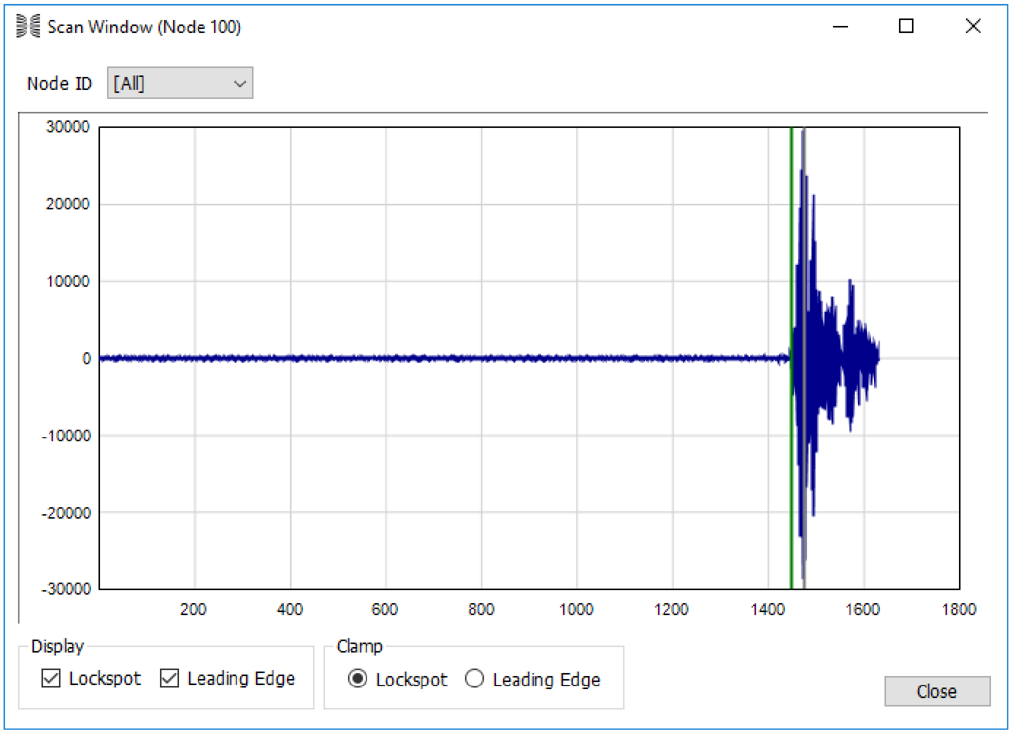

Fig. 6-6: Example of a received waveform

The plot shows the magnitude of the waveform as a function of time. The vertical axis is the sum of all of integrated analog to digital measurements taken by the radio for the specific measurement point. The Y-axis units are volts, not power, and are not calibrated such that the values can be converted from counts to volts. The horizontal axis is time in increments of approximately 61.0 ps.

The radio lock point is the zero crossing closest to the strongest signal which the radio found. It is indicated by a gray vertical line and, in this example, is at approximately point 1475. The scan waveform is relative to the lock point. While the radio has been programmed to lock on the strongest signal that it finds, there is no guarantee that the radio will always lock on the strongest signal. In fact, there will be occasions at which the radio will lock on a comparatively weak signal.

The green line indicates the point on the waveform that the radio believes is the leading edge. Since the ranging measurement is based on finding the leading edge of the transmitted impulse (also knowns as the first arriving energy), the waveform capture has been biased to show more of the waveform prior to the lock spot than after.

Changing Scales: The scales can be adjusted in several ways:

- Double-clicking the right mouse button will auto-scale the magnitude and set the time scale to either 1632 (if “Full Scan” was selected) or 350 (if “Scan” was selected).
- Holding the left mouse button down and shifting the mouse to the left will move the plot to the left, shifting the mouse to the right will move the plot to the right.
- Holding the right mouse button down and shifting to the right will magnify or expand the scale. Shifting to the left will collapse the scale.
- Holding the right mouse button down and shifting up will increase the scale (make the plot smaller), while shifting down will decrease the scale.

Using these controls and the normal Windows click and drag controls, it is possible to magnify different areas of interest. **Figure 6-7** shows an expanded view of the waveform in **Figure 6-6**.

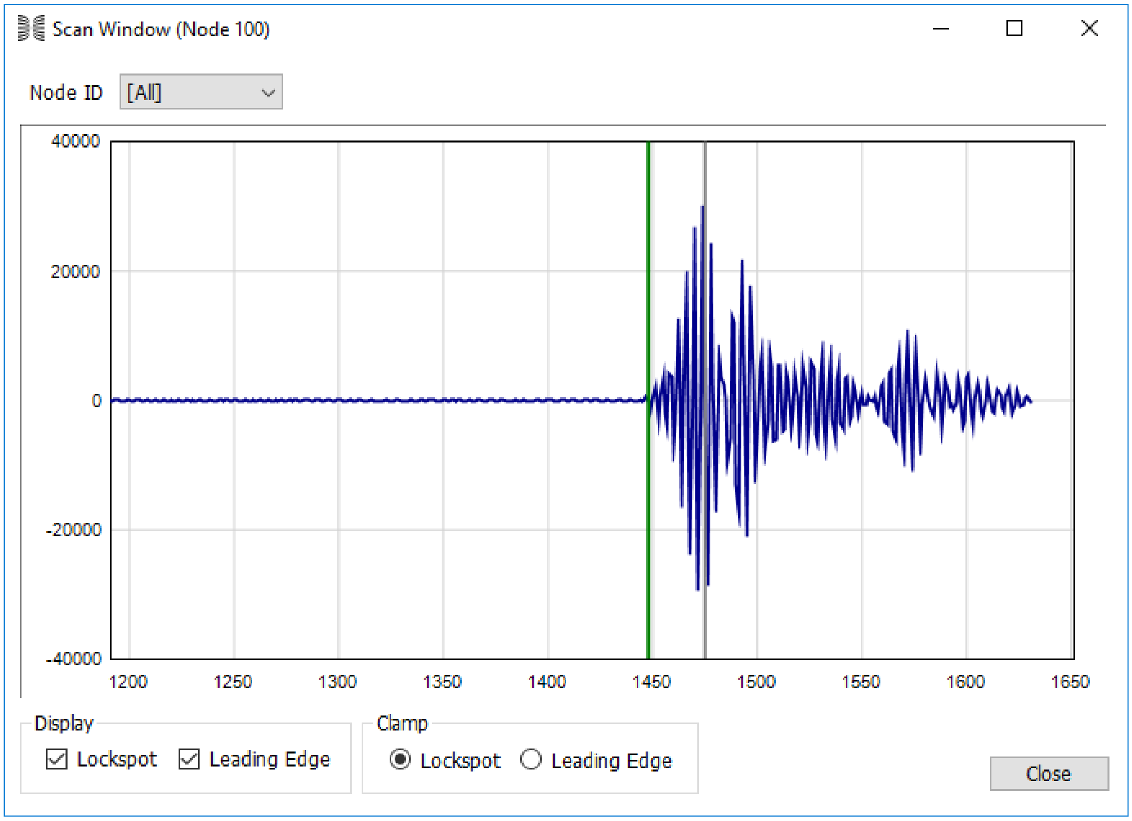

Fig. 6-7: Expanded view of received waveform. Green line at ~1455 indicates the leading edge of waveform, gray line indicates radio lock point at ~1475.

This window is also provided with a number of controls.

<u>Node ID:</u> This drop-down allows the user to filter which scans should be displayed. The user can select a particular Node ID in which case only scans from the Node ID will be displayed. Selecting [All] will display any received waveform scan. This capability is very useful when operating in a Network mode.

<u>Lockspot:</u> If this box is checked, then the gray line will be displayed.

<u>Leading Edge:</u> If this box is checked, then the green line will be displayed.

<u>Clamp:</u> This control will synchronize the waveform display either to the lockspot or the leading edge.

The Scan window will remain displayed until the Close button is clicked. This allows the user to monitor the scans while using other control tabs. The scan window can also be maximized to fill the entire monitor display.

6.5 Chart Button

The Chart button allows the user to plot range measurements as a function of time. See example shown in **Figure 6-8**. Once clicked, this window will remain displayed until the Close button is clicked. This allows the user to monitor ranges while using other control tabs.

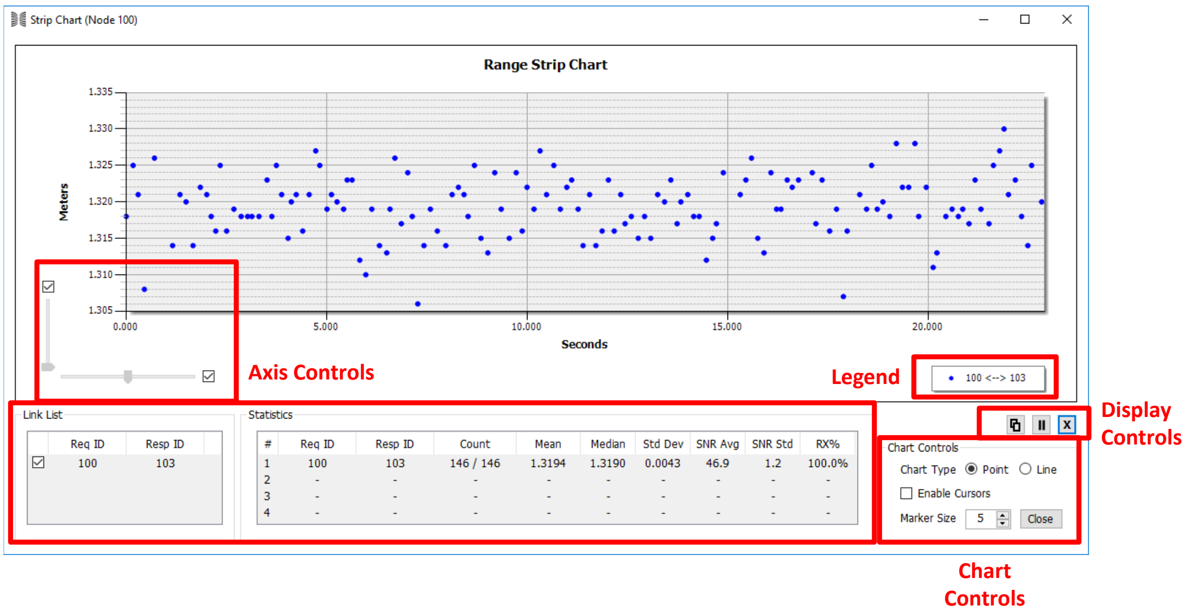

Fig. 6-8: Example of a typical range measurement strip chart. Plot of range measurements vs time (sec)

In addition to the plot of range measurements vs. time this chart also provides the following additional controls and information: Axis Controls, Display Controls, Link List, Legend, Statistics and Chart controls. These are described below.

<u>Axis Controls:</u> These controls allow the user to modify the axis of the displayed data. Each axis has a checkbox and a slide bar.

- X-axis checkbox and slide bar: If clicked, this button will set the X-axis such that it is scaled to show all of the collected data. It will also rescale as new data is collected.

  If unclicked, the user can control how much data is to be displayed using the slide bar. The slide bar can be adjusted such that the time scale shows all of the data collected (slid all the way to the right) or as little of the time scale as one value (slid all the way to the left). Unclicking the slide bar also causes a second slide bar to appear under the strip chart. This slide bar uses the current x scale and, by moving the bar, allows the user to different parts of the strip chart. These two controls give the user the capability to zoom in on any particular part of the X-axis.

- Y-axis checkbox and slide bar: if clicked, this button will set the Y-axis such that it is scaled to show all of the collected data.

If unclicked, the minimum of the Y-axis will be set to be equal to the shortest range measurement and the user has the freedom to adjust the maximum Y-axis using the slide bar. If multiple ranges are being displayed such that the range of distance measurements is large, then a second slide bar will appear on the Y-axis. These two controls give the user the capability to zoom in on any particular part of the Y-axis.

Display Controls: These consist of the following three control buttons:

- Double Rectangle button: Clicking this button will copy the display to a buffer such that the chart window can be pasted into a document.

- Play/Pause button: This operates in the same fashion as a YouTube video display. Clicking the Play button (a right-pointing triangle) will start the strip chart (this is the default position). Once clicked, the Pause button (two vertical lines) will appear. Clicking the Pause button will halt the display and the Play button will appear again. Any ranges collected while the Pause button is active will be lost from the strip chart.

- X button: Resets the strip chart and the displayed statistics.

Link List: This is a list of all of the range links (Requester ID to Responder ID) which can be displayed. Since it is possible that the unit is operating as part of a network and since other units in the area may be using ELR (Echo Last Range), it is possible that the unit connected to the RangeNet GUI will be reporting ranges to multiple units as well as the ranges of other units to each other. Checking the box to the left of the Requester ID allows the user to display only those ranges of interest.

Legend: The legend provides a color code for interpreting which set of data is produced by which range link.

Statistics Box: This box displays a table which provides statistics on the data collected. Besides the Req and Resp IDs, this table displays:

- Count: A running count of the number of ranges displayed for that range link. The left value indicates how many range measurements were successful, and the right value indicates how many range measurements were attempted.
- Mean: Average of all readings
- Median: Median value of displayed ranges
- STD Dev: Standard deviation of the mean readings
- SNR Avg: The average SNR of the response messages
- SNR Std: The standard deviation of average SNRs
- RX%: The Count parameter expressed as a percentage

These statistics are reset when the user clicks the X button and resets the chart.

Chart Controls: This set of controls allows the user to define characteristics of the plot and allows the user to inspect individual measurements.

- Chart Type: This control allows the user to choose between displaying the measurement points as individual points (the default) or by connecting the points with a line.
- Enable Cursors: Clicking this button displays a blue crosshair. Positioning the cursor over a specific measuring point and then clicking either the left or right mouse will result in the display of the message ID number that produced the reading, the time at which the

measurement occurred relative to the strip chart, and the actual range measurement. See example shown in **Figure 6-9.**

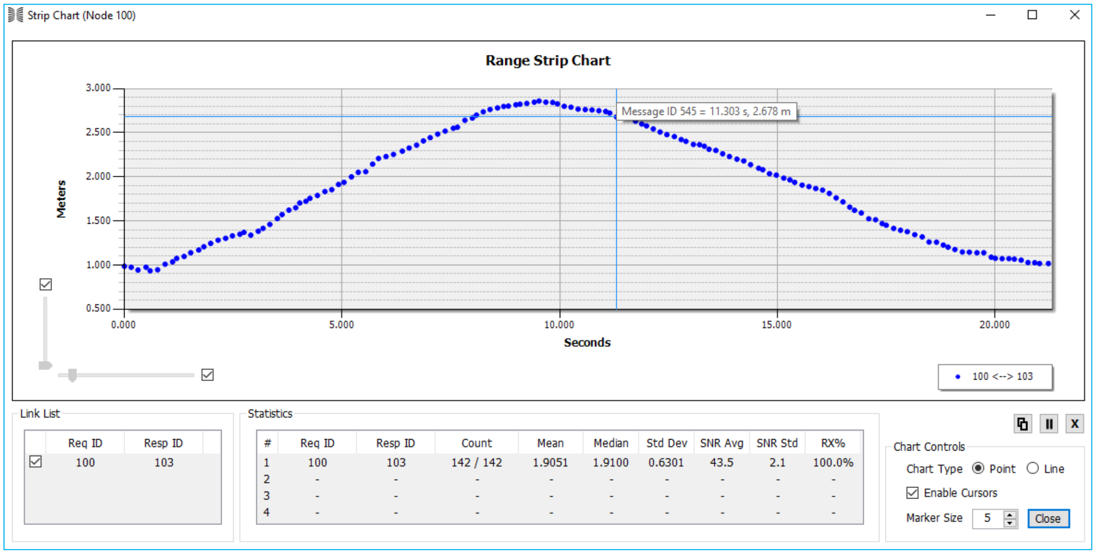

Fig. 6-9: Displaying the numerical data of individual data points

<u>Marker Size:</u> This control allows the user to change the size of the font used to display the range measurement data points.

<u>Close:</u> Clicking this button will terminate this window.

To change the units (meters, feet, or millimeters), move the cursor over the chart area and double click the mouse.

When operating multiple units, keep the following in mind:

- When operating in Networking Mode, be sure to set the Range Info drop-down box on the Networking tab to either All or Successful. This will allow ranges to be plotted.
- If ELR is selected on all units in a network, then it is possible to plot the ranges measured between units other than the one you are connected to.
- The ELR message does not include SNR information, so SNR Avg and SNR Std fields will be blank.
- The Link List will display the links in view. This number will vary with time as units enter or leave the area. This Link List does not have a fixed limit and will accommodate all the units in the area.
- The user can display up to 4 links by clicking the box next to the Link List rows of interest.
- Be aware that operating the strip chart with many units will generate a very large amount of data. At some point the number of units in the system will generate so much data that it will overwhelm the ability capacity of the GUI and computer memory to maintain a reasonable update rate. In these cases there will be a significant lag between when the range was measured and when that change appears on the chart.

6.6 Info Button

Clicking this button will reveal the Info window. An example is shown in **Figure 6-10**. This window will display any Echo Last Range (ELR), Echo Last Location (ELL), Beacon, and OTA Ack messages which the P4xx sends to the Host computer. The ELR function is described in the ELR portion of **Section 5.2 - Radio Settings Block**. ELL is described in **Section 11.1 - Location Map** and Beacons are described in **Section 7.1 - Networks are Simple**.

The user is provided with the ability to change the units displayed to either feet, meters, or millimeters. Changing units on one tab will be reflected on all tabs. Two other controls are provided.

> <u>Freeze:</u> Clicking this button will suspend the display of received Info messages and change the name of the button to *Unfreeze* (which provides the opposite function). Freezing the screen makes it possible to conveniently use the scroll bar to view previous messages.
>
> <u>Clear:</u> Clicking this button will clear the screen of entries.

The Info window will remain displayed until the Close button is clicked. This allows the user to monitor the Info window while using other control tabs.

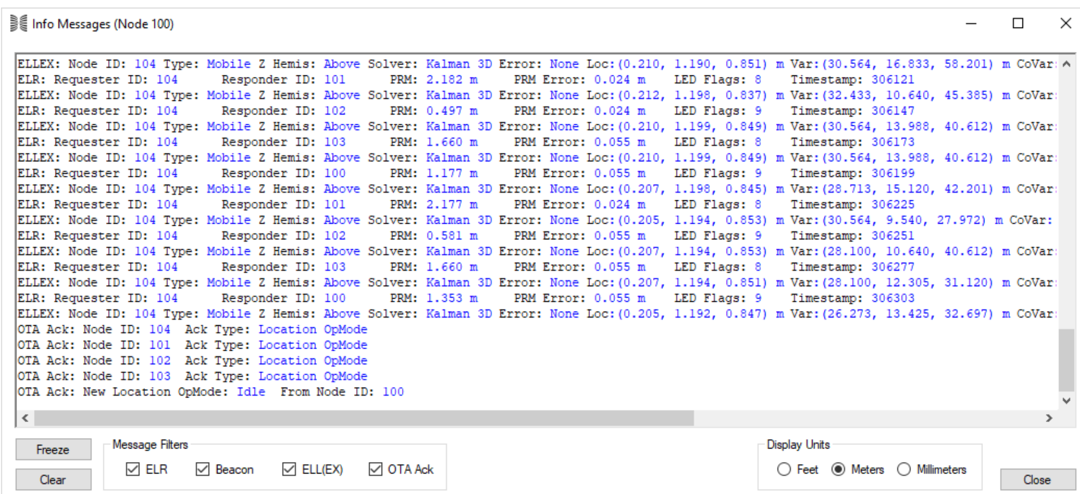

Fig. 6-10: Example Info display

6.7 Range Statistics for Repeat Function

When the user selects the Repeat button (see **Section 6.1 – Ranging Commands**) the RangeNet GUI will order the attached P4xx to take multiple range measurements. This offers the opportunity to compute the statistics of the range measurements. The computation will take two forms.

First, the RangeNet GUI will display a running count at the bottom of the screen of the number of range packets that have been sent in the current test, the total number to be sent, and the number of ranging transactions that have failed.

Second, the RangeNet GUI will compute various statistics. When the test has concluded, either in the course of normal operation or by the user clicking the Stop button, then the RangeNet GUI will summarize these range statistics and display the following information in the Action Area:

- Number of ranges successfully completed vs. the number sent
- Success percentage rate
- Mean of the readings
- Standard deviation of the range measurements
- Mean of SNR
- Standard deviation of the SNR
- SNR Mean (linear)
- SNR Standard Deviation (linear)

In addition, the RangeNet GUI will also filter the readings based on the PRME threshold set on the Filter Control Box. Basically any range reading which has a PRME greater than the threshold will be discarded and accounted for as being unsuccessful. The statistics for the remaining readings will then be displayed.

This statistics and error reporting feature is illustrated in **Figure 6-11**. In the left column, the ranges will be either the Precision Range Measurements or the Filtered Range Measurements as selected on the Range Tab (see **Section 6.2 – Ranging Statistics**). In the right column, the ranges (either Precision Range Measurements or Filtered Range Measurements) will be filtered according to the Range Error Threshold selected on the Range Tab.

Note that the mean SNR and standard deviation are reported in two different ways:

- Mean is reported as Mean of SNR and SNR Mean (linear)
- Standard Deviation is reported as the Standard deviation of the SNR and SNR Standard Deviation (linear)

There is a subtle mathematical difference between the two computations. Mean and Standard Deviation of SNR are computed on the set of SNRs collected. In the case of **Figure 6-10**, this would mean that the statistics were computed for the set of SNRs as reported by the P4xx.

Some feel that this is not accurate, because computing the standard deviation of an exponential lacks meaning. In this case, it is better to determine the average of the SNRs before performing the logarithmic operation and then convert to dB. Consequently the linear version of the mean and standard deviation statistics are computed as follows:

- Each SNR is converted to a linear value using the equation SNRlinear = 10^(SNRdB/10).
- The SNR Mean linear is computed by taking the average of SNRlinear values and then converting to log format by 10*Log10(average of SNRlinear).

Use the version you feel most comfortable with and take comfort in the fact that there is almost no difference between the results produced by the two methods.

Finally, the SNR summary values shown in the Action Area are computed based on information sent by the Range Info message. If, on the Configuration Tab, the user sets the Range Info tab to “Small” instead of “Full,” then the P4xx will not report the information necessary for computation of SNR and no value will be reported for SNR.

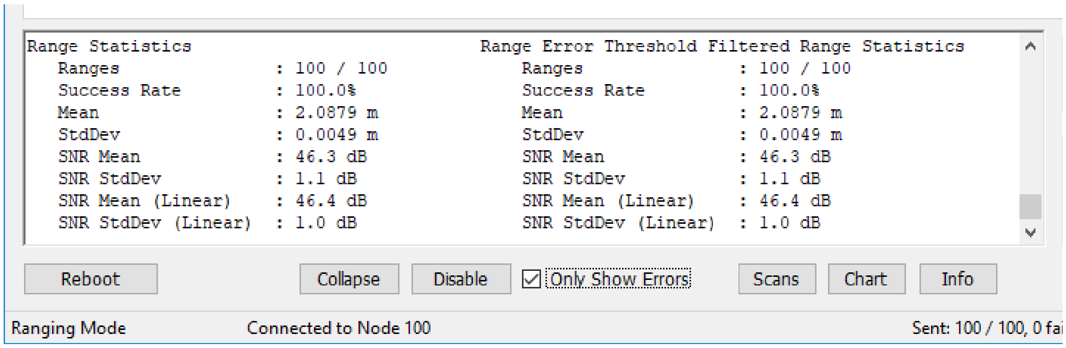

Fig. 6-11: Example of range statistics

In the case shown in **Figure 6-11**, the link was strong enough there were no errors or discarded values.

7. Network Principles

In principle, networks are simple. In practice, they can be as simple or as complex as the application requires. This section discusses both aspects.

7.1 Networks are Simple

RangeNet is a very simple network.

- RangeNet resides on the P4xx platforms and not on the Host computer. The RangeNet GUI is resident on the Host and allows the user to monitor and control operation of RangeNet.
- Each P4xx platform maintains a database of the distances/ranges to neighboring P4xx units as well as other information. This is called the Neighbor Database (NDB).
- The P4xx units each have a scheduler which initiates range requests to neighbors.
- The scheduler operates using your choice of either (a) the ALOHA protocol (random access, simple but relatively inefficient) or (b) a TDMA protocol (time slot setup requires a bit more effort,but is very efficient).
- Both protocols have provisions for dealing with neighbors who leave or join the network.
- With ALOHA, there are provisions for dealing with:
  - neighbors who need less frequent range measurements
  - neighbors to whom one never ranges
  - neighbors who send periodic beacons but do not initiate range conversations
  - neighbors who request that they not be ranged to
  - neighbors who are ranged to based on a round-robin selection
- With TDMA, the system maintains the network synchronization and the user is able to define and optimize the definitions of which units communicate with which others, when, and how.

That is all there is to RangeNet, two protocol choices, six simple principles and some software knobs with which the user can define and customize operation.

The control knobs are accessed through the Networking Tab. All monitoring of the network is done on the Network Stats Tab. The Networking Tab allows the user to:

- Define the general control parameters
- Configure ALOHA-specific network parameters
- Configure TDMA-specific network parameters
- Load the transmit buffers with data
- Define the default communications link to the Host

The Network Stats Tab allows the user to:

- Monitor and display the contents of the P4xx Neighbor Database
- Control the rate at which the Neighbor Database is uploaded from the P4xx
- Monitor statistics on unit operation, network performance, and ranging failure rates

Moreover, when operating in Networking Mode with either the ALOHA or TDMA protocols the responsibility of the Host computer is limited to loading the Network data buffers with any information it may wish to share with others, receiving any data which might be directed to it, and being informed of whatever portion of the Neighbor Database it might be interested in receiving at whatever rate it wishes to be updated. Not only does this free the processor for other purposes, but it also maximizes the rate at which range measurements can be taken. For example, the ranging rates achieved in Ranging mode are much slower than the ranging rates achieved in Network mode. This is due to the fact the RangeNet GUI adds considerable overhead in Ranging mode which is not present when operating Network mode.

It should also be noted that while most ALOHA networks have a network efficiency of approximately 18%, TDSR's ALOHA effectively operates on a slotted basis and thereby enjoys a network efficiency of 35%.

7.2 Networks are Complicated

The complexity in a network becomes apparent when the user attempts to tune or optimize network operation for a particular application. The ideal network would allow a near infinite number of P4xx platforms to operate in a very large area with near instantaneous updates while at the same time many existing P4xx platforms exit the network and new ones join. Such broad system requirements are difficult to accommodate.

The user will need to balance the application requirements against the limitation that an individual range request requires a finite amount of time to complete. For example, the shortest duration range measurement is produced with PII 4. At this PII, a range measurement will be produced in 6.5 ms. This 6.5 ms does not include any additional data the user might want to send with the range measurement. PII 4 has a maximum operating range of about 66 meters. This range can be extended by increasing the integration from PII 4 to PII 5. In general, each increase in PII by one will double the amount of time it takes to produce a reading and increase the range distance by 40%. Increasing PII by 2 will double the range and quadruple the measurement time. For details see the *320-0317 P440 Data Sheet.*

Most users will likely use PII 7. At this integration rate, the system will produce a range measurement in 21 ms. This means that an ideal system would allow approximately 50 range measurements per second. ALOHA is a random scheduling system which does not try to coordinate when units range but rather counts on infrequent operation reducing the number of conflicts/collisions to an acceptable level. At PII 7, the user should not count on more than 18 ranges per second. This range capacity needs to be shared between the neighbors in the system.

For many applications this ranging rate is sufficient and these constraints are manageable. However, there will be times when additional capacity is required. For this reason the ALOHA protocol has been provided with the ability to exclude certain neighbors. It is also possible to make use of the fact that multiple channels can be used to support multiple networks. While this adds capacity, it also adds complexity, operational overhead, and increased (albeit modest) amounts of co-channel interference.

When needs outgrow the capacity provided, the user can switch to the TDMA protocol. This protocol divides time into slots such that each radio is assigned a specific time slot for ranging. This collection of slots that defines when units are able to communicate is called a Slot Map.

The system automatically synchronizes timing so that all units operate only in the correct time slot. Configuration of the slots requires some effort, but the efficiency of the end result is quite good. The user can expect efficiencies on the order of 99.5%. When the application requires even more capacity, the user can also use multiple code channels and add a CDMA layer to the TDMA backbone. This adds complexity in that most units will require custom and unique Slot Maps.

As the complexity of the system grows, the user (or Host application) will take on additional coordination responsibilities. At that point, RangeNet will begin to feel less like a network and more like a MAC layer.

7.3 Behavior in Ranging Mode

When operating in Ranging Mode, the P4xx will respond to any range request or data transmission from any other unit which is in Ranging Mode. It will do so automatically and regardless of whether or not it is connected to a Host. In Ranging Mode, it will initiate transmissions (either range requests or data transmissions) only when commanded to do so by the Host.

7.4 Behavior as an ALOHA Network

The ALOHA network protocol is a totally asynchronous means of allowing an arbitrary and variable number of P4xx units to communicate with a minimum of mutual interference. It allows units to announce their presence to the general community of devices and to learn who else is in the area. It also has processes for dealing with units which enter or leave the neighborhood. The ALOHA network is good for networks in which the total number of units in the network are unknown and those units join and leave the network at unpredictable times.

The behavior is based on the following basic rules:

1. A unit will start by listening.
2. If it hasn't recently received a message, then it will broadcast a Beacon message. This message announces its presence to the community of devices.

3. If the unit does receive a packet, even one not directed specifically to it, then it will (a) enter the Node ID of the transmitting unit into its database of neighbors (also referred to as the Neighbor Database) and (b) respond if the received message was directed toward it. If the received message was a range request, then it will reply with a range response packet and transmit any data which might be in the Network Response Data buffer. Once a neighboring unit's Node ID has been entered into the Neighbor Database, RangeNet will periodically check to see if it has heard from that unit recently. If it hasn't received a message from the unit in a user programmable amount of time, then it will assume that the unit has left the neighborhood and it will delete that Node ID from the Neighbor Database.
4. If it is aware of units in the area, it will wait a random amount of time before it attempts to send data or issue a range request. The upper and lower bounds of this waiting period are user-selectable, but are normally controlled by an Automatic Congestion Control (ACC) algorithm. Basically if there are a lot of neighbors in the area, the algorithm will increase the mean period between transmission attempts. Conversely, if there are a small number, the algorithm will reduce that time between transmission attempts.
5. Once it has performed its transmission it will wait for any expected response, update the Neighbor Database with the range measurement and other useful information, and at a polling rate set by the Host it will report the contents of the Neighbor Database to the Host.
6. It will then return to Step 1.

RangeNet also allows the user to place additional restrictions on the behavior. These restrictions will be described in detail in later sections, but for now, be aware that the user can:

- Prohibit some units from ranging to specific units. This behavior ensures that units don't waste time issuing range requests to irrelevant units.
- Designate some units as being Beacon-only units. Beacon-only units will send periodic Beacon messages to announce their presence and will respond to Range Requests, but will never transmit a Range Request message. This behavior makes them excellent for use as fixed References or network Anchors.

Notice that the ALOHA protocol does not place any restrictions on when units can communicate. It is therefore possible for two units to transmit at the same time. That will result in a collision and there is an excellent chance that neither unit will be successful in reaching the intended receiver. The trick then is to optimize the rate at which the units attempt to communicate with the collisions. If there are too many collisions, then everyone will attempt less frequently with the understanding that all units will suffer some loss of service but will at least be able to communicate.

The ALOHA protocol is tremendously efficient in that it allows an arbitrary number of units to communicate. But it is inefficient in that collisions will happen and the random waiting times are long enough that there will be times when all units are waiting and none are transmitting.

One way to measure efficiency would be to compute the number of successful range measurements a system of units takes vs. the number of range measurements a pair of units could take if they ranged continuously. For example, consider the case of a network of N units operating at PII 6. At this integration rate, a complete range conversation will require 13.7 ms. If one were to range as fast as possible this would yield 73 range measurements per second. Experiments have demonstrated that the efficiency of the RangeNet ALOHA protocol is about 35%. Therefore you can expect a network of units operating at PII 6 to successfully range 73*35% or about 25 ranges per second. These 25 successful measurements would be allocated evenly between the N members of the network.

This is excellent in two regards. First, without making any limitations on the number of units in a network or any knowledge of when they may join or leave the system, the ALOHA protocol takes this chaos and operates at 35% efficiency. Second, the RangeNet implementation is operating at twice the efficiency of a standard ALOHA network. Standard ALOHA achieves about 18%, while RangeNet is operating at the efficiency of a Slotted ALOHA system.

On the other hand, there are many applications where 35% will yield disappointing results. In these cases one should consider TDMA, which runs at 99.5% efficiency, or a combination of TDMA and CDMA which can run at 400% efficiency or higher. This operation is discussed in the next section.

7.5 Behavior as a TDMA Network

A Time Division Multiple Access (TDMA) network operates by defining specific time windows (slots) in which specific units may communicate with specific units or with all units. This type of network is most useful when the number of units participating in the network is both known and fixed. Each slot contains the definition of the means of communication (PII, code channel, antenna) and the type of message sent (ranging or data). More specifically, for each time slot the user can define:

- Which unit will transmit and which unit(s) will receive
- What PII and code channel will be used for the message
- Which antenna configuration will be used
- Whether the transmitted packet is a ranging or data packet
- Whether and how much data will be transmitted
- Whether the unit will enter a sleep mode when not participating in the current slot

Typically there will be one set of slots for all units in the system. This collection of slots is called a Slot Map. When in Networking Mode, the P4xx will cycle through the Slot Map starting with Slot 0 and upon reaching the last slot, it will return to Slot 0 and repeat.

The big advantage of this approach is that it uses every possible moment of time for communications and thereby achieves almost 100% utilization of the system. This is in contrast to the ALOHA-based network which normally achieves only 35% efficiency. Because it utilizes airtime more efficiently, the TDMA protocol offers higher network capacity.

The big disadvantage of this protocol lies in the fact that the user has gained capacity at the cost of increased complexity. After all, it is now the user’s responsible to define the Slot Map, to distribute the Slot Map to all units, and to guarantee that units not defined in the Slot Map are prohibited from operating. These system limitations are controllable but add to the overall management complexity. In contrast, an ALOHA-based network is very simple to operate. It offers simplicity at the cost of network capacity.

7.5.1 System Synchronization

TDMA has one important limitation in that the units must be well-synchronized. Fortunately, the TDMA network has been designed so that it will automatically maintain system-wide clock synchronization with an accuracy of approximately 1 μs.

Synchronization is accomplished in the following manner. The requester in Slot 0 is the Clock Master to whom all units in the system will be synchronized. Any message which the Clock Master transmits will have an embedded clock synchronization signal. All units in the listening area that can receive this transmission will synchronize their clock to the transmitted sync signal. When it is their turn to transmit, they will resend this sync signal. Any units which have not heard the Clock Master will synchronize their clock to this repeated sync signal. In this manner clock synchronization can be distributed through an entire system, even if an outermost unit needs to be synchronized through several intermediate units. Given the accuracy of the oscillators in the P4xx units, there is no practical limit to the size of the area over which a clock can be distributed.

When the TDMA network first starts, the Clock Master will broadcast the clock signal in Slot 0 and the other units will not start transmitting until they have received the clock signal either directly from the Clock Master or a unit that has been synchronized by the Clock Master and it is their turn to initiate a transmission.

7.5.2 Increasing Network Capacity with a Hybrid TDMA/CDMA system

Code Division Multiple Access (CDMA) is a technique for allowing multiple units to operate on different communications channels, simultaneously, without significantly interfering with each other. This capability is supported within the RangeNet TDMA Network. While the increase in capacity depends on several factors, including how many channels are used and the number of units, TDSR has designed Slot Maps which increase the network capacity by a factor of four. Once again this increase in system capacity comes at the cost of increased complexity. Such a system is more complex because each unit needs to have a slightly different Slot Map reflecting which communications channel is used in which slot for each unit. Furthermore, care needs to be taken to ensure that:

- The total Slot Map times line up such that (a) all slots for a given time start and end at the same time and (b) the time required for the total Slot Map is the same for all units.
- Units that share a slot agree on the length of the slot
- All units are synchronized by the Clock Master

For example, consider a system that consists of 3 Anchors (units at a fixed location that do not initiate range requests) and 3 Mobiles (units that move and determine their location based on range measurements to the Anchors). In this system, each Mobile will need to range to each Anchor and one Anchor will need to send a data packet in Slot 0 to maintain the network clock. Assuming that the PII is set to 6 and communications channel 2 is used, then it will take 130 ms to cycle through the entire Slot Map once.

In contrast, consider the following system in which 3 communications channels are used simultaneously by the Mobiles:

- **Slot 0:**
  Anchor 1 sends a data packet on Channel 2 to all units such that the network clock can be maintained.

- **Slot 1:**
  Mobile 1 ranges to Anchor 1 on Channel 2
  Mobile 2 ranges to Anchor 2 on Channel 3
  Mobile 3 ranges to Anchor 3 on Channel 4

- **Slot 2:**
  Mobile 2 ranges to Anchor 1 on Channel 2
  Mobile 3 ranges to Anchor 2 on Channel 3
  Mobile 1 ranges to Anchor 3 on Channel 4

- **Slot 3:**
  Mobile 3 ranges to Anchor 1 on Channel 2
  Mobile 1 ranges to Anchor 2 on Channel 3
  Mobile 2 ranges to Anchor 3 on Channel 4

- Repeat

This Slot Map approach will cycle through once every 47 ms, or about 2.8 times faster than the single code channel approach. Note, however, that once again increasing capacity has increased complexity in that with this approach each of the units in the 6 node system will have a different, but consistent, slot map.

8. Networking Tab

Selecting this tab will bring up the display shown in **Figure 8-1**. This display provides the user with access to all of the controls necessary to configure and operate the P4xx in a network. These controls are divided into the following blocks:

- Configuration
- Settings
- Reporting Parameters
- ALOHA Parameters
- TDMA Slot Map

These controls are described in the following subsections.

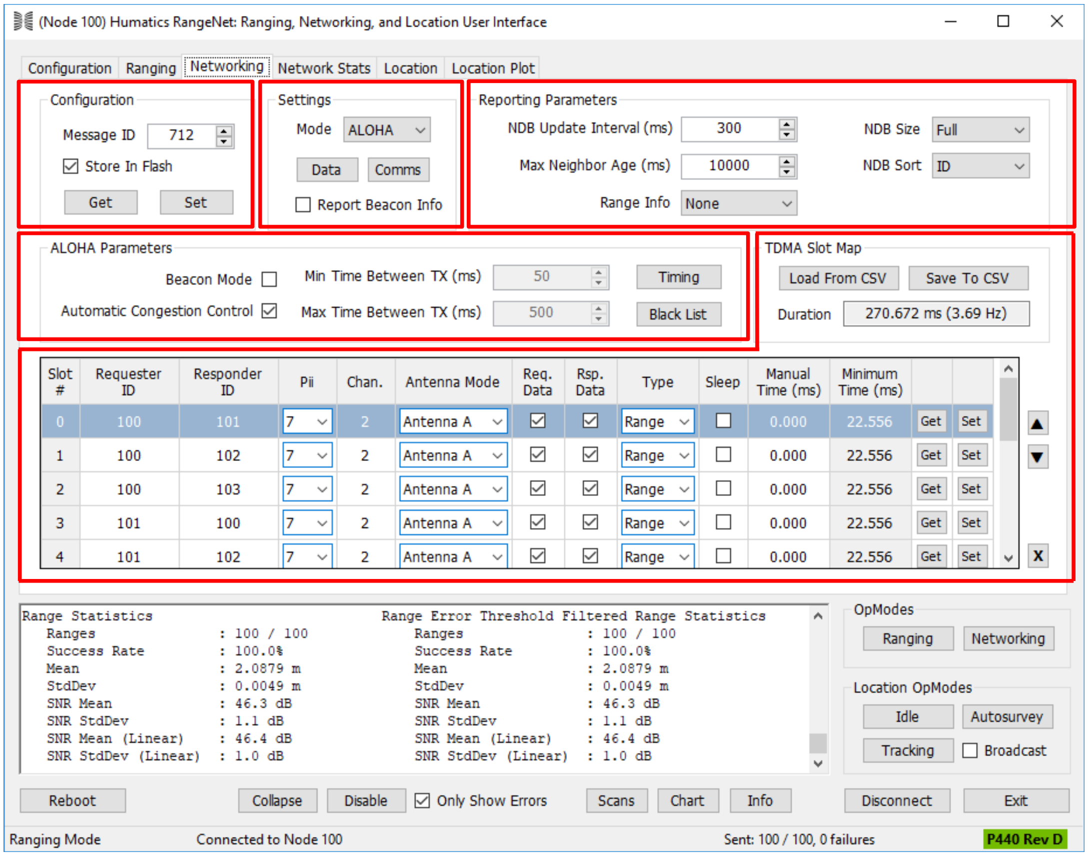

Fig. 8-1: Networking Tab with the five control blocks marked in red

8.1 Configuration

This block allows the user to download and retrieve the network configuration parameters from the P4xx. Note that this control affects only the network parameters and not the ranging or localization parameters.

Get: Clicking this button will retrieve the current network parameters from the connected P4xx. This also includes the ALOHA parameters and the TDMA Slot Map.

Set: This button will download the current Network, ALOHA and TDMA Slot Map information from the RangeNET GUI to the connected P4xx. This button will be turned yellow whenever the user modifies any of these parameters. This serves as a reminder to the user to click the Set button and store values in the P4xx.

Store In Flash: Clicking this button will cause the P400 to store the Network parameters in the P4xx's non-volatile memory. This ensures that the parameter changes will survive through the power-down of the attached P4xx.

Message ID: This field contains the number of the next message which will be sent from the Host to the P4xx. For a detailed description of Message ID fields and a discussion of their use, see the message ID field discussion in **Section 5.1 - Radio Configuration Block**.

8.2 Settings

This block allows the user to select the network protocol to be used, set the network request and response buffers, and select the Beacon info box.

Mode: Allows the user to select whether the unit will use either the TDMA or ALOHA network protocols.

Data: This button provides access to the Network Request and Response Data buffers. See **Figure 8-2** for an example. Note that the Network Data buffers are separate and distinct from the Ranging Request and Response Data buffers and are controlled by the RangeNet program resident in the P4xx. While the user can control what data is loaded into these buffers, the RangeNet program controls when the buffers are sent.

This button also allows the user to set the maximum size of the buffers. Since this value will affect the amount of time in a Slot Map, one must ensure that this value is the same in all Slot Maps in the system.

The user can type in any alphanumeric characters into the buffers up to the maximum. (When using the API directly, the user can enter any value into the buffers.) A count of the number of bytes entered is displayed by the RangeNet GUI for the benefit of the user and compared against the maximum size allowed. If the user enters more characters than is allowed, the GUI will give the user the opportunity to correct the discrepancy. It can be corrected either by increasing the maximum size or reducing the number of bytes to be sent. If the discrepancy is not corrected, the user will not be able to update the buffer.

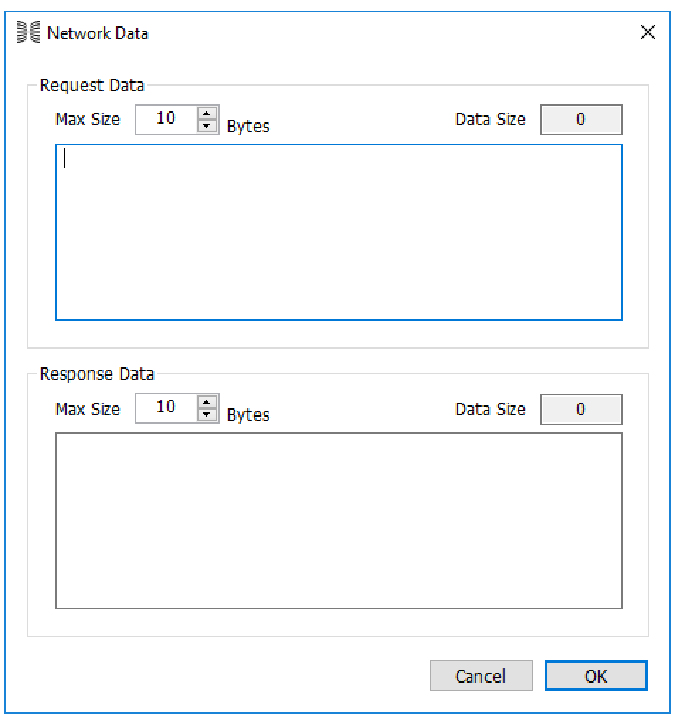

Fig. 8-2: Network Data window allows user to load the Network Request and Response Data buffers, set the maximum buffer length, and monitor the size of any buffers being loaded

The user may select any value between 0 and 1000. Any data sent by the user will increase the time it takes to produce a range measurement. Be aware that while the user selects bytes, the P4xx will send 32-bit words. While the user can select any number of bytes up to 1000, if the number is not divisible by 4, then RangeNet will add bytes to fill up to the boundary. (Note that the 1000 byte limit is no valid when operating in Location mode. In Location mode the limit is 900bytes.) The additional time required to send data is defined by the following equation:

Additional time (ms) = (Roundup(Number of Bytes/4))*32*(2^PII)*0.0001

At PII 7, a 10-byte data transfer will add 1.2288 ms to the 20 ms required to take a range measurement. This equation is an approximation. It will vary depending on the code channel selected, but the approximation is accurate to within a few percent.

<u>Comms:</u> This menu allows the user to define a default communications port. (See **Figure 8-3**) This ability bridges an important gap. When operating in Ranging Mode, the P4xx will never generate a message unless the unit is specifically polled by the Host computer. When operating in Networking Mode, the P4xx is responsible for initiating conversations and will therefore generate Range Info and Scan Info packets automatically. If the P4xx is operating in RangeNet mode and power fails, it will reboot and resume operation in Networking Mode. However, the power-down will break the communications link with the Host computer. This means that packets sent by the P440 might be sent over the wrong link. Therefore, this menu is used to set the default communications port for the period between boot-up and restoration of the P4xx-Host communications link. Once the link is restored, the P4xx will send all Range Info and Scan Info packets to the Host via the restored link defined by this parameter.

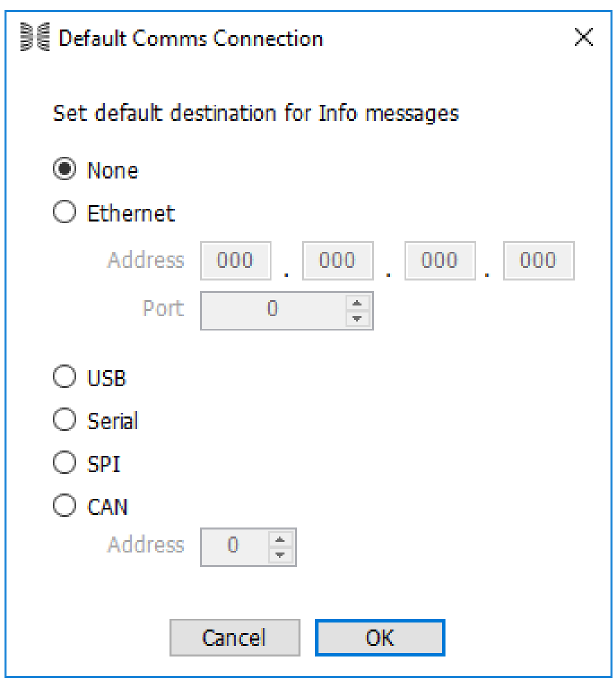

Fig. 8-3: The Comms Connection window is used to set the default P4xx Host communication path

This window will allow the user to select a communications path from among the valid choices. Invalid choices are gray and cannot be selected. The following is a breakdown of valid choices:

P400: Ethernet, USB, Serial
P410: USB, Serial
P412: USB, Serial, CAN
P440: Ethernet, USB, Serial, SPI, CAN

The Cancel button will reject any changes which were made and return the user to the Networking screen. The OK button accepts any changes and returns the user to the Networking screen.

Note that "None" is also a selection. If "None" is selected, then no messages will be issued by the P4xx until the Host initiates a connection.

Report Beacon Info: Nodes designated as Beacon nodes will periodically transmit a short data message. Basically, their function is to announce their presence and thereby initiate networking behavior with units in the area. Any unit which has the Report Beacon Info box checked will report the Beacon Info packet to the connected Host. This is a useful mechanism for observing operation of the network.

8.3 Reporting Parameters

NDB (Neighbor Database) Update Interval (ms): This is the rate at which the Neighbor Database is uploaded from the P4xx to the RangeNet GUI. This parameter is passed as a 16-bit binary number and, in principle, can be set to any value between 0 and 2^{16}-1. In practice, the P4xx limits its reporting rate such that it is difficult to overrun the interface. The Ethernet, USB, Serial, SPI, and CAN interfaces have been limited to a 10 Hz update rate.

If the user attempts to load the Update Interval with too small a value, then the RangeNet GUI will automatically substitute the entered value with the highest rate possible for the given interface.

Even so, the user should be aware that the P4xx can produce a lot of data and it is possible for the user to request enough data to flood the communications port. If this happens, then packets arriving at the Host can be dropped and packets sent from the Host to the P4xx may have trouble getting through.

Max Neighbor Age (ms): This parameter defines what it means to be a neighbor. If a P4xx has not heard from a specific neighbor P4xx in this number of milliseconds, then that neighbor is dropped from the Neighborhood Database. The P4xx will then no longer attempt to range to the deleted neighbor. This parameter is passed as a 32-bit binary number and can be set to any value between 0 and 2^{32}-1.

Range Info: Whenever the P4xx takes a range measurement it will normally send the range information to the Host. This is the normal operation when the system is operating in Ranging Mode. However, when operating in Networking Mode, it might not be necessary to report each range measurement. After all, this information is already in the Neighbor Database. The Range

Info packet also consumes communication bandwidth. This drop-down gives the user freedom to suppress or limit Range Info transmissions from the P4xx. The drop-down options are described below. Note that this setting will also affect the information posted on the Ranging Tab.

None: Range Info packets will be entirely suppressed.

Successful: Only successful PRMs (PRMs with no error messages) will be reported.

All: Successful and unsuccessful PRMs will be reported.

<u>NDB Size :</u> This drop-down allows the user to indicate how much information is to be automatically reported on the Neighbor Database page. This capability allows the user to limit the amount of information which might be sent over slow speed serial interfaces such as CAN and Serial. The choices are:

None: The P4xx will not send any information from the NDB. It will therefore be the responsibility of the Host to specifically request data to be sent. Requests are handled using the Get command on the Network Stats tab.

Full: The P4xx will send all NDB data for display by the GUI.

Small: The P4xx will send a limited set of information from the NDB for display by the GUI. The set includes: Node ID, Range, Range Velocity, Range Type, and Measurement Age.

<u>NDB Sort:</u> This drop-down allows the user to control the order in which data is reported from the Neighbor Database. The data can be sorted by Node ID, by Node ID that is the closest distance to the connected P4xx, or by age (most recent to oldest).

8.4 ALOHA Parameters

<u>Beacon Mode:</u> When this box is checked, the P4xx will act as a Beacon. A Beacon sends out an occasional message as a way of announcing its presence. This occasional message is also called a “beacon” and it contains the Node ID and a few flag bits. This message acts as a seed for the network and its purpose is to prompt other units to range to it. Beacons will not initiate range requests but will respond to them. Beacons will transmit at an interval determined by the user or, if Automatic Congestion Control is selected, then RangeNet will establish the beaconing rate. This interval is reset to zero whenever the Beacon responds to a range request. This behavior guarantees that the system will occasionally hear Beacons but also ensures that a busy network will not bear the burden of unnecessary Beacon messages.

Unlike ranging data packets, a Beacon will not generate a Data Info Packet.

This capability is useful in a number of instances. For example, given a system consisting of four P4xx nodes in which one node is a Mobile and the other three are stationary references, the three references would typically be set in Beacon-only mode. The Mobile uses received Beacon messages as a means to discover any references that might be in range. Once a Beacon is discovered it will be added to the Mobile’s Neighbor Database. The Mobile could range to all of the references but the references would never range to any node. This would allow the Mobile to calculate its own location relative to the references.

Automatic Congestion Control: This checkbox allows the user the option to engage or disengage Automatic Congestion Control (ACC).

ACC is a RangeNet algorithm operating in the P4xx which dynamically maximizes the rate at which units range to each other. If the network only has a few neighbor nodes, then ACC will set the average request rate to a high rate. If the network has many neighbors, then ACC will set the average request rate to a low rate. This rate will be further adjusted as nodes join or leave the network.

If the user disengages ACC, then the node will range at the rate defined by the Min Time Between TX and the Max Time Between TX. When ACC is on, these entries are ignored. They will be gray and the user will not be able to change the values.

For additional information see the whitepaper entitled "RangeNet/ALOHA Guide to Optimal Performance."

Min Time Between Tx (ms) and Max Time Between Tx (ms): These parameters only have meaning when Automatic Congestion Control is off. These parameters allow the user to manually define the limits of when the P4xx-based scheduler will initiate a range request. More specifically, the scheduler will initiate a request at a random time between these minimum and maximum times. The RangeNet GUI will not allow the user to enter a minimum time greater than the maximum time. When using the API directly with C, MATLAB, or some other code, the user must provide his own limit checks.

If the user sets the minimum and maximum times to be equal, then the unit will send range requests at exactly this interval.

When setting these limits, the user must be mindful to the fact that a range request takes a finite amount of time to execute. For example, if PII 7 is used, then a range request will take ~20 ms. It would therefore make no sense to set the maximum time to less than 20 ms. The user can set the minimum time less than 20 ms. If the scheduler attempts to initiate a range request before the previous one has completed, then that range request will be ignored.

The chief advantage of this arrangement is that the user can easily define a mean rate at which range requests will be issued. The mean rate is the average of the minimum and maximum. The Conversation Timing block (described below) provides useful information regarding the time required for a given message packet. This is a convenient reference when manually setting minimum and maximum transmit times.

These parameters are passed as a 16-bit binary number and can be set to any value between 0 and 2^{16}-1. The units are milliseconds.

Timing: This button (window shown in **Figure 8-4**) provides the user with statistics on the duration of a range conversation. These durations are determined by the integration rate and the amount of additional user data which is transmitted. For convenience, the RangeNet GUI will compute the times for the following eight different types of messages:

- Range Request without Data

- Range Response without Data
- Range Request with additional Data (with maximum set by ALOHA parameter)
- Range Response with additional Data (with maximum set by ALOHA parameter)
- Time required for a complete range conversation (without additional data)
- Time required for a complete range conversation (with maximum data)
- Data Packet without additional data (a null message used for announcing presence)
- Data Packet with maximum additional data

This data is recomputed each time the use clicks the Set Configuration button on the ALOHA Tab.

This information is provided as a reference. It is useful when the user is operating in ALOHA, without ACC and it is necessary to manually set Min and Max times between transmissions.

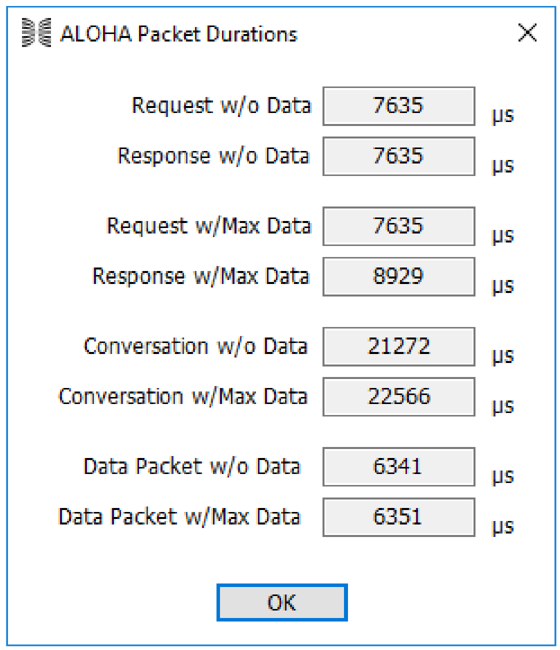

Fig. 8-4: This window provides the duration of packets sent while using the ALOHA protocol

<u>Black List:</u> This button allows the user to instruct the P4xx to exclude (i.e., not range to) a particular Node ID or set of Node IDs.

This capability is useful for those cases in which some of the units are located at a fixed and immoveable location and is most useful for ALOHA systems. (It is not particularly useful for TDMA systems because the capability is implicit in the construction of the Slot Map.)

For example, consider a system consisting of three fixed references connected together with an Ethernet backhaul to a Host computer and a single Mobile node unconnected to the Ethernet. Given that the location of the references is fixed and known, there is no reason for the references to range to each other. In this configuration, each reference could be set up such that all other reference units were excluded and the Mobile would be set up in Beacon-only mode. With this configuration, the references would range to the Mobile and would send the measured ranges to the Host such that the Host system would be able to compute the location of the Mobile.

Clicking the Black List button will display the Excluded Target IDs window shown in **Figure 8-5**.

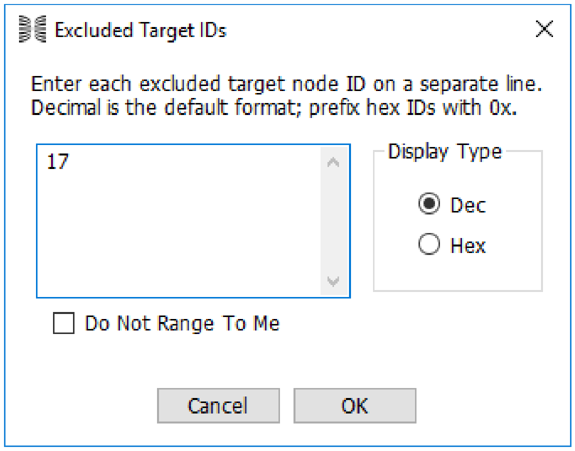

Fig. 8-5: This window provides the user with the ability to limit communications with other units. The attached P4xx will not range to any units in the exclusion list. If the "Do Not Range to Me" box is checked, then other units will not range to it.

The screen consists of the following controls and displays:

<u>Scrollable box:</u> This box displays the Node IDs of any node which the attached P4xx is to exclude from conversation. In the example shown in **Figure 8-5**, Node ID number 17 has been specifically excluded. The list currently inside the P4xx is uploaded to the RangeNet GUI when the GUI makes its initial connection to the P4xx.

The maximum number of excluded IDs is 256. The user can use the scroll bar to search the list. Node IDs can be deleted from the list, edited, and additional IDs can be added to the bottom of the list.

<u>OK:</u> Clicking this button will load the currently excluded target IDs to the connected P4xx and return the user to the Networking Tab.

<u>Cancel:</u> Clicking this button will not make any changes to the excluded target IDs and will return the user to the Networking Tab.

<u>Display Type:</u> This allows the user to view or enter Node IDs either in Decimal or Hexadecimal format.

<u>Do Not Range To Me:</u> This flag is sent with every range request and range response. If the flag is set (the box is checked), then it will prevent any recipient of the message from ever initiating a range request to the flagged node.

8.5 TDMA Slot Map

This block gives the user the ability to:

- Load and save TDMA Slot Maps from and to disk files
- View, define, and modify slot maps
- Determine the amount of time it will take the system to sequence through the entire Slot Map once

The contents of the TDMA Slot Map are uploaded from the attached P4xx immediately on connection with RangeNet GUI.

This screen has a number of data and control fields. These fields only have meaning when the unit is in Networking Mode. As a practical matter, changes to the Slot Map are best done when the unit is in Ranging Mode. It is best to ensure that all of the P4xx units in the system have the correct Slot Maps before the units are returned to Networking Mode.

Load From CSV: This command allows the user to load an existing Slot Map from disk to the RangeNet GUI. To download to the attached P4xx, the user will need to click the Set button.

Save to CSV: This command allows the user to save the current Slot Map to disk.

Duration: This field displays the amount of time which will be required for the P4xx to cycle through the entire Slot Map one time. This field is updated whenever the Set button is clicked.

Slot Map Controls: **Figure 8-6** shows the TDMA Slot Map controls. With these controls the user can navigate to any row in the Slot Map. The maximum size of the slot map is 32 entries.

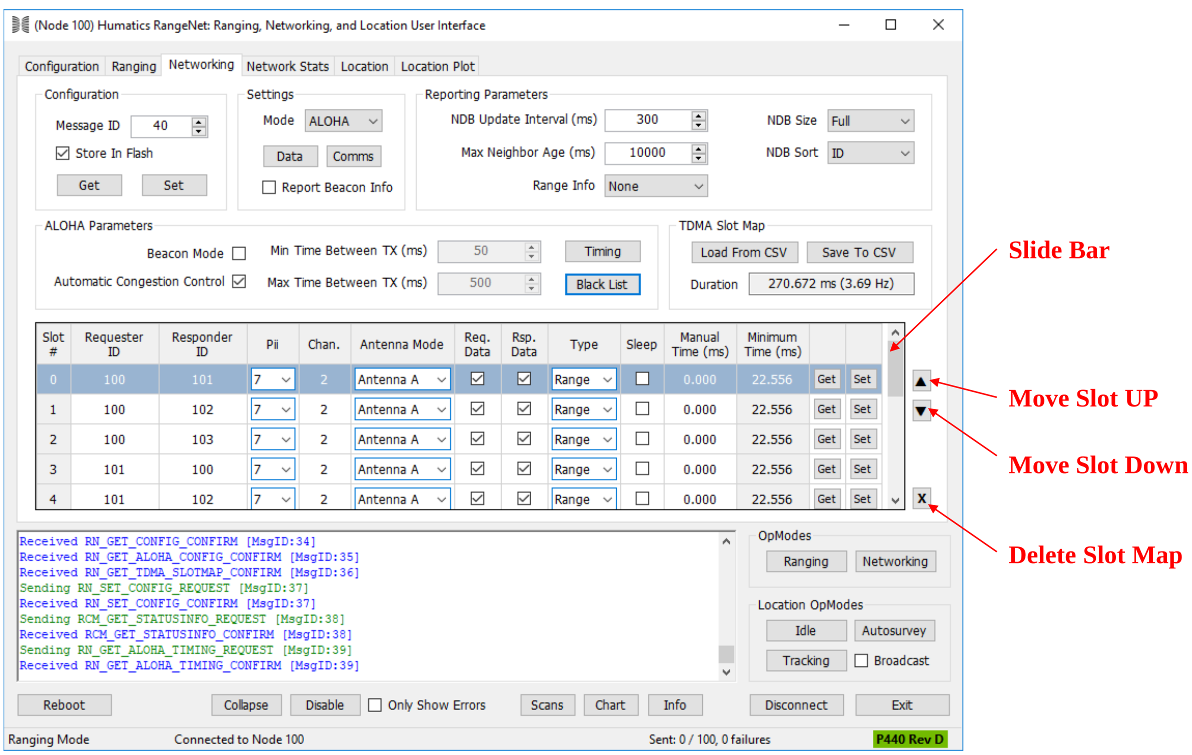

Fig. 8-6: TDMA Slot Map and controls

Each row in a Slot Map is a slot. The actual number shown is dependent on the size of your display. The user can review any slot by moving the Slide Bar or operating the Up and Down arrows. Each slot has a slot number, eleven parameter fields, and individual Set and Get buttons. Any change to an entry will light the Set button. This is a reminder that the entries have not been downloaded to the attached P4xx. The fields are described below:

Slot #: The number of each slot. The Requester in Slot 0 is the master unit and all of the other units in the system maintain synchronization with this unit. This unit is a single point of failure for the entire system, in that if this unit fails or leaves the system, then the units will lose their source of synchronization. See the *320-0313 RangeNet API Specification* for additional information on Slot Maps and synchronization. Their oscillators will then start to drift relative to one another and the system will ultimately lose synchronization and collapse. However, because the unit oscillators are very accurate and very stable, it could be many seconds, if not longer, before the network degrades. This will give the operator time to either replace the master or give the system the time to redefine a new master. The redefinition is not performed automatically. The Host computer attached to the P4xx units would need to recognize the situation and then take appropriate action. For example, all of the Host units connected to the various system P4xx units could notice that the master had failed and could then delete Slots 0-2, thereby promoting unit 101. Once again, this is only an illustration of a notional response to the loss of the master. The proper response is dependent on the end application and would, in any event, be controlled by the user's Host application.

Requester ID: The ID of the P4xx which has permission to initiate a transmission.

Responder ID: The ID of the P4xx to which a range request will be directed.

PII: The Pulse Integration Index with which the transmission will be made.

Channel: The Code Channel which will be used for the communication.

Antenna Mode: This drop-down menu allows the user to define which antennas will be used for the communication.

Requester Data: Clicking this button will allow the requesting unit to transmit the indicated maximum number of user bytes. If the button is not clicked, then the requester will not be able to send additional data.

Responder Data: Clicking this button will allow the requesting unit to respond with the indicated maximum number of user bytes. If the button is not clicked, then the requester will not be able to send additional data.

Type: This drop-down allows the user to designate this slot as either a ranging or data message. If the slot is reserved for data messages, then the data will be broadcast to all units instead of to just an individual unit. In this case, it is not necessary to identify a Responder ID in the third field.

Sleep: Setting this flag will put the attached unit in Sleep Mode "Idle" state for every slot in which the unit is not either a requester or responder.

Manual Time: The message parameters such as PII and data bytes will define the duration of a slot. This is the minimum amount of time a slot will require. However, this field allows the user to define a slot duration greater than the absolute minimum.

Minimum Time: This field indicates the amount of time the slot will require. This value is not computed by the RangeNet GUI but rather by the P4xx. Consequently, any changes made to the slot parameter that effect duration will not be reported until after the user does a Set and a Get for the Slot Map.

Get: This field allows the user to retrieve the slot information for this particular slot number from the P4xx. This differs from the Slot Map Get, which retrieves the slot information for all of the slots.

Set: This field allows the user to download the slot information for this particular slot number to the P4xx. This differs from the Slot Map Set, which downloads all of the slot information to the P4xx.

8.6 Creating a New Slot Map

To create a new slot map, first zero out the existing map by clicking the Delete Slot Map button. Next, click anywhere in the top slot. A new slot will appear populated with the system defaults. See **Figure 8-7**.

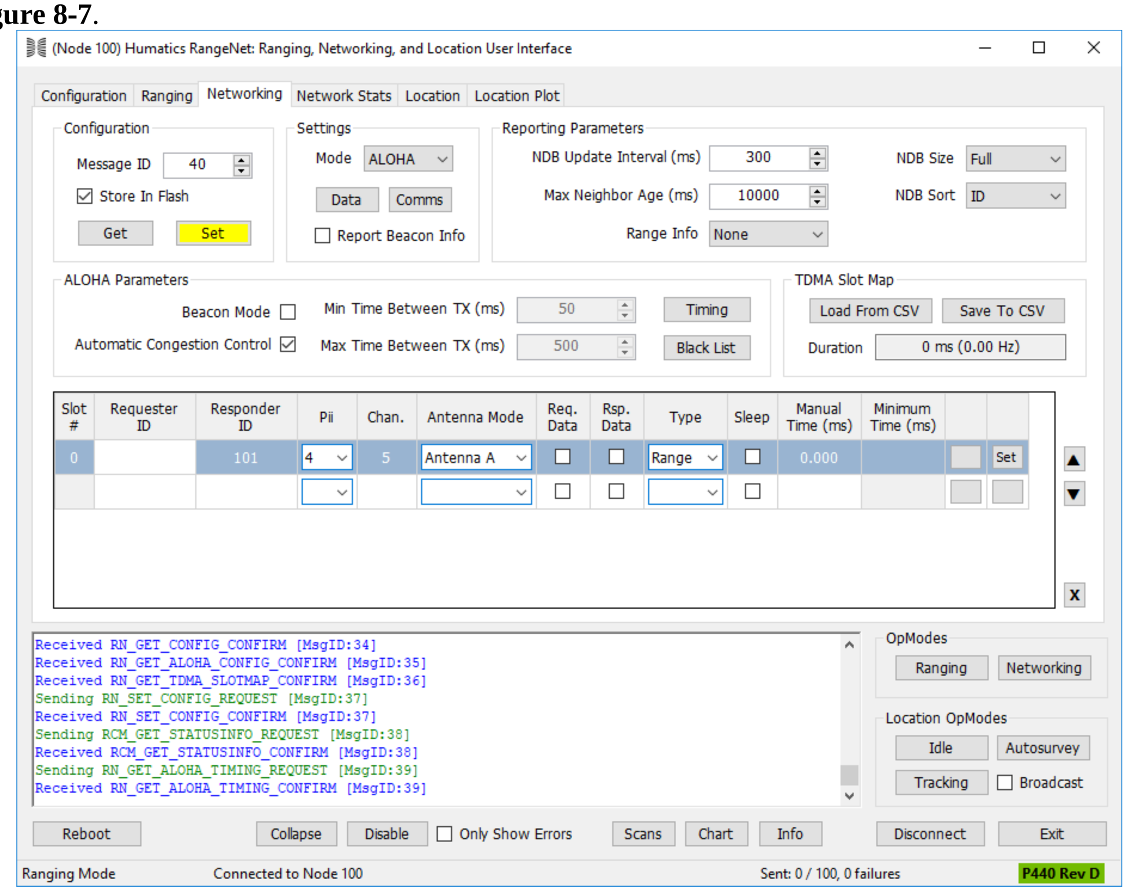

Fig. 8-7: Example default settings for a new slot

Next, fill in the desired settings and click either the Set button in the Configuration block or the Set button at the end of the line. Note that the Get button will turn green. This is an indication that the slot duration has changed. (To find out what the duration is, the user can click the Set button.) At this point the first slot is complete and ready to go. Of course, this is a trivial case in that Unit 100 will range to Unit 101 forever.

This single entry Slot Map is quite similar to doing a point-to-point range measurement in Ranging Mode. It is different in one important regard. When in Ranging Mode, the requests are driven by the Host. The RangeNet GUI will issue a request, wait for a response, and issue another request. This conversation time is an overhead which limits the ranging rate to approximately 90% of the maximum ranging rate specified in the Data Sheet. In contrast, when operating in Networking Mode, the requests are driven by the P4xx (and not the Host) so the ranges are not limited by the various request times. This yields the maximum rate possible.

To add another slot, move the cursor to the next available slot and left-click your mouse. This will add a new entry using the previous entries as the defaults. Continue the procedure as before and when you have entered all of the slots of interest, click the Set button in the Configuration block.

If you want to delete an entire slot, then left-click on the slot to be removed and then press the delete key on your keyboard.

If you want to edit only one slot, then make the changes and then either click the Set button in the Configuration block or click the Set and Get buttons at the end of the line.

Once the slot map is final, it is a good idea to save this configuration to file. This is accomplished by clicking the Save to CSV button.

9. Network Stats Tab

The Network Stats Tab (see **Figure 9-1** below) is divided into three parts: Controls, Database Information, and Statistics. The Controls section allows the user to determine such things as how much data is presented and units of measure. The Database block provides a window into the Neighbor Database maintained in the connected P4xx. It shows items such as the range between units, the signal strength of the link, status of the Beacon flag, etc. The Statistics block provides information on other parameters such as the number of members in the Neighbor Database, the number of ranges, the number of communications timeouts and failures. All of these fields will be individually discussed in this section.

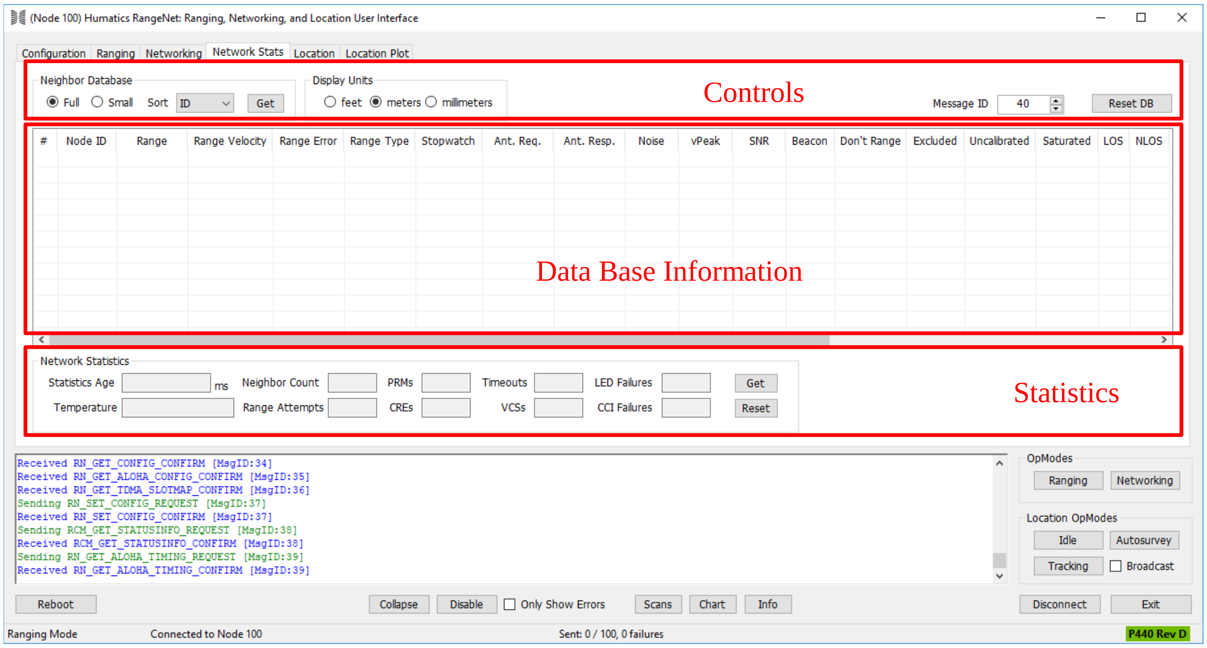

Fig. 9-1: Three key parts of the Network Stats Tab

9.1 Controls

Neighbor Database Block

If the user has selected “None” for NDB Size on the RangeNet Configuration Tab, then the attached P4xx will not send any update information unless specifically requested to do so. This block of controls gives the user the ability to upload the attached P4xx’s Neighbor Database on demand. The user can select how much data he wishes to upload by clicking either the Full or Small buttons. The order in which the NDB is displayed can be selected by choosing one of the methods from the Sort drop-down. Pressing the Get button will cause the data to be uploaded.

> Full or Small: If Full is selected, then each time the Get button is clicked the RangeNet GUI will ask for a Full update of the entire database stored in the attached P4xx. If Small is selected, then clicking the Get button will collect a reduced set of information from the attached P4xx.
>
> Sort: This drop-down controls the order in which the contents of the Neighbor Database of the attached P4xx unit will be displayed. The choices are ordered by Node ID (smallest to largest), ordered by range (nearest to farthest), and by age (most recent to oldest).
>
> Get: Clicking the Get button will cause the RangeNet GUI to ask for either a Full or Small update of the Neighbor Database stored in the attached P4xx. This is useful only if the user has set the NDB Size on the Network page to “None.” If so, then pressing the Get button is the only way to upload the Neighbor Database. If NDB Size is set to Full or Small, then the Neighbor Database will be updating automatically, and while each click of Get will produce another update of the database, it will be quickly overwritten by the next automatic collection.

Display Units: This button allows the user to change the units in which the range measurements are reported. Note that this control will set the units for all measurements regardless of what tab on which they might appear.

Message ID: This field contains the number of the next message which will be sent from the Host to the P4xx. For a detailed description of Message ID fields and a discussion of their use, see the Message ID part of **Section 5.1 - Radio Configuration Block**.

Reset DB: There are a number of statistics which are computed by the system and reported in the Neighbor Database. Examples include the parameters Success Rate and Stats Age. Clicking Reset DB will reset these parameters.

9.2 Database Information

Figure 9-2 displays the Network Stats Tab for a 4 node network consisting of nodes 100, 101, 102, and 103 in which the RangeNet GUI is connected to unit 100. Node 100 therefore has units 101, 102 and 103 as neighbors. While the database stored in the P4xx unit can easily maintain several hundred neighbors, the maximum number of entries which can be displayed is 36. The rationale behind this limitation is that one will never have more than 36 neighbors in the immediate vicinity. If there are more, then you can filter based on distance and display the closest 36 neighbors. (**Note:** RangeNet Lite is limited to 9 neighbors.)

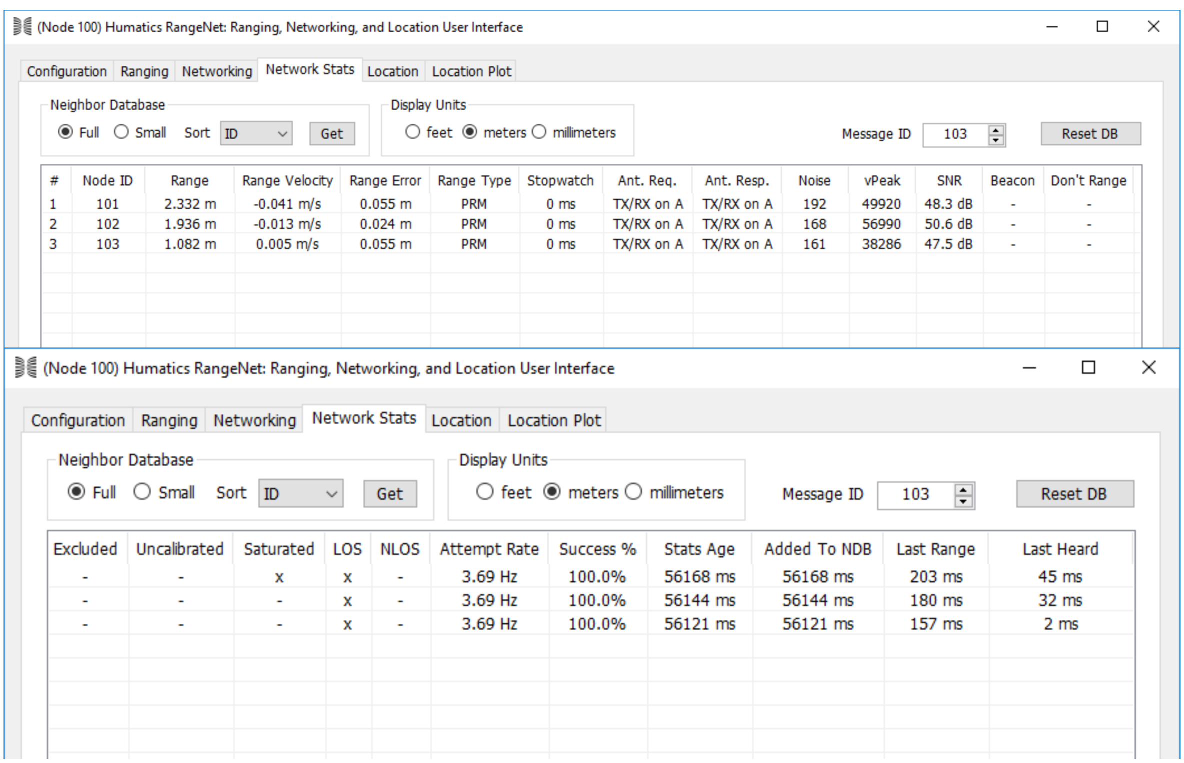

Fig 9-2: Database example of a four node system (left-most 14 parameters on top, right-most 11 parameters on the bottom)

The following are the definitions of each field:

#: The row number of the Neighbor Database.

Node ID: The Node ID of the Neighbor.

Range: Range between the connected P4xx and the Neighbor. If PRM is selected on the RangeNet Configuration page as the Range Type of choice then PRMs are reported. If FREs are selected, then FREs are reported.

Range Velocity: Rate at which the Neighbor is approaching (negative value) or retreating (positive value) from the connected P4xx. This value is updated by both CREs and PRMs.

Range Error: An estimate of the error in the range measurement. This value is updated by both CREs and PRMs.

Range Type: Indicates whether the range measurements are Precision Range Measurements (based on TW-TOF) or Filtered Range Estimates. Two types of Filtered Range Estimates are reported: FRE-PRM and FRE-CRE. The first are filtered PRMs. The second are CREs which have been calibrated and filtered based on PRMs.

Stopwatch: Measurement of the time required for a full two-way range conversation. This value should be close to that predicted by the statistics in the TDMA Slot Map or in the ALOHA Packet Durations window. However, it will be different because the measurement is performed using a timer that resolves down the nearest millisecond. As a result, it can be off by 2 ms relative to the value reported on the ALOHA Tab. A zero value indicates that the measurement was generated by a CRE.

Ant. Req: Indicates which of the Requester's two antennas was used to transmit and which was used to receive.

Ant. Resp: Indicates which of the Responder's two antennas was used to transmit and which was used to receive.

Noise: This is the scaled estimate of the noise experienced by the P4xx receiver and is identical to the value reported on the Ranging Tab. This value is updated by both CREs and PRMs.

VPeak: This is the scaled estimate of the maximum received signal in the leading edge as measured by the P4xx. It is identical to the value reported on the Ranging Tab. This value is updated by both CREs and PRMs.

SNR: This is an estimate of the Signal-to-Noise Ratio (SNR) of the received signal. It is computed using the following formula. This value is updated by both CREs and PRMs.

$$SNR = 20*\log10(Vpeak/Noise)$$

Noise, Signal/Vpeak, and SNR are discussed in greater detail in **Appendix E: Noise, Signal, and SNR**.

Beacon: An "x" indicates that the unit is a Beacon.

Don’t Range: An “x” indicates that the target node does not want to be ranged to.

Excluded: An “x” indicates that this node is specifically excluded from the Neighbor Database.

Uncalibrated: This is a Neighbor node which has been heard, but which has not yet completed a precision range conversation with the attached P4xx. Once the Neighbor node has responded to a range request, then that PRE can be used to calibrate subsequent CREs from the Neighbor node.

Saturated: Indicates that the received signal is so strong that the receiver is starting to saturate. Saturation occurs when the units are closer than approximately 15 feet (5 meters). Saturation rarely has any impact on range measurement accuracy. A node in saturation will not generate CREs. **Note:** in **Figure 9-2** all of the units are within 2 meters of each other and are not in saturation because each has been provided with a 10 dB attenuator to reduce the transmit power and therefore avoid saturation.

LOS: Indicates the ranging link is Line-of-Sight.

NLOS: Indicates that the ranging link is Non-Line-of-Sight. A Non-Line-of-Sight link will not generate CREs.

Attempt Rate: This is the rate in Hertz of the number of successful ranges over a given period of time. The user can reset the period of time by clicking the Reset Stats button.

Success %: This is the number of successful range attempts divided by the total number of attempts over a given period of time. The user can reset the period of time by clicking the Reset Stats button.

Stats Age: This is the number of milliseconds over which the previous rates were calculated. The user can reset the period of time by clicking the Reset Stats button.

Added to NDB: This is the number of milliseconds since the given node was added to the Neighbor Database.

Last Range: This is the amount of time in milliseconds which has elapsed since a successful PRM was measured to the target node.

Last Heard: This is the amount of time in milliseconds which has elapsed since the target node was last heard from either with a PRM or a CRE.

The Neighbor Database has a large number of data fields. Care was taken to arrange the order in a logical sequence. However, there will be times when the user will want to focus on just a few specific fields or perhaps view them in a different order. The user can move a column to a different place by moving the cursor over the header of the field to be moved, holding the left button down and then dragging the column to the desired location. This rearrangement is temporary. Exiting RangeNet will reset the column arrangement to the original state.

9.3 Network Statistics

Statistics Age: Amount of time in milliseconds since the Reset button was last clicked.

Temperature: Temperature of the P4xx as measured by the onboard temperature sensor in Centigrade.

Neighbor Count: Number of Neighbors in the database at the moment when the Get button was clicked.

Range Attempts: This is the number of times since the Reset button was last clicked that a precision range was attempted.

PRMs: This is the number of times since the Reset button was last clicked that a precision range was successfully completed.

CREs: This is the total number of CREs received since the Reset button was last clicked.

Timeouts: This is the number of times since the Reset button was last clicked that a precision range measurement failed to successfully complete because the measurement timed out. A large number of Timeouts suggests that one or more nodes are at maximum range.

VCSs (Virtual Carrier Sense): This is the number of times since the Reset button was last clicked that a PRM failed to successfully complete because a Virtual Carrier Sense error occurred. Failures indicate that there were communications packet collisions. A high number of VCS failures indicate that the number of nodes on the network is starting to exceed capacity. ("High" is a relative term that needs to be assessed on an application basis.)

LED (Leading Edge Detection) Failures: This is the number of times since the Reset button was last clicked that a PRM failed to successfully complete because of an LED failure. While LED will occasionally fail, an unusually high number of such failures indicate that the network is operating in a high multipath environment. ("High," in regard to the number of failures, is a relative term that needs to be assessed on an application basis.)

CCI (Co-Channel Interference) Failures: This is the number of times since the Reset button was last clicked that a PRM failed to successfully complete because of Co-Channel Interference. This interference could have been sensed either at the responder or at the requester. This conversation may produce an actual range measurement, but that measurement will flagged as unreliable and discarded. It will not count as a successful completion. A high number of CCI Failures indicates that there are other RF users in the vicinity and they are interfering with the network. These users might be other UWB devices, extremely powerful transmitters just out of band, or other users in the 3-5 GHz band.

Note: Range Attempts = PRMs + Timeouts + VCSs + LED Failures + CCI Failures

Get: Clicking this button will retrieve the statistics from the attached P4xx.

Reset: Clicking this button will reset all of the Network statistics.

10. Localization Principles

This section presents a high-level description of RangeNet's localization capability. Details on the configuration, control, and monitoring of this function are provided in **Sections 11** and **12**.

There are three general application areas for UWB ranging:

1. Measuring the separation distance between two arbitrary points
2. Measuring the separation distances between many arbitrary points
3. Measuring the location of one or more points

All three of these applications are supported by RangeNet. The controls in the Ranging Tab allow the user to range between two points. The Networking Tabs allow the user to systematically and conveniently measure the separation distances between either a fixed or an indeterminate number of P4xx units using either the TDMA or ALOHA network protocols. (Note that RangeNet is supported on all of the members of the P400 family. At present, the family consists of the P400, P410, P412 and P440 platforms).

With just the ranging or networking controls, the user can construct a system that transfers the range measurements from the P4xx units to a Host and then develop Host-based localization algorithms that convert the ranges into positions. However, doing so is an expensive and time consuming task.

To simplify matters, TDSR has added a Location layer to the RangeNet network that converts range measurements into locations. This layer operates in the P4xx units such that the units report not just ranges, but also location in the X, Y, and Z dimensions. Implementing the Localizer (or Location Engine) in the P400 has an added benefit in that it substantially off loads the computational responsibilities of the Host processor.

In addition, the Location layer takes advantage of the UWB network to transfer the location information throughout the network. Because of this the user can connect to any node and collect location information from every unit in the system.

Finally, the RangeNet GUI provides additional tools for configuring, controlling, monitoring, logging, and displaying location results.

The overall objective is to quickly enable the user to demonstrate the ability of UWB to provide location-based information for proof of concept projects. While the performance of the UWB only localization software is quite good, it can lack robustness (especially if the mobile is moving quickly). This shortcoming can be solved by integrating or fusing UWB ranging with additional sensor technologies such as IMUs, wheel odometry and GPS. Those interested in fused systems should contact TDSR directly.

The Location Engine assumes that the P4xx units are either fixed references (Anchors) or Mobiles. The total number of units in the system is limited to 60 units, but the capacity can be expanded by defining multiple systems.

The Location Tab allows the user to define the location of the Anchors and the operating characteristics of the system, and then use the RangeNet network to broadcast this information throughout the system. Given that Mobiles will know the position of the Anchors and can range to Anchors, it is possible for the Mobiles to calculate their location.

The location of the Anchors can be determined in one of two ways. First, the user can survey the location of the Anchors and enter that information into RangeNet. Second, if the user's system is limited to 3 or 4 Anchors, then RangeNet's Autosurvey capability will instruct the Anchors to determine their own locations using UWB ranging. The Autosurvey capability is convenient and useful. Of course, surveys performed using a laser survey system will provide the most accurate results.

The Location Engine is resident on each node and uses either a Kalman or a Geometric solver to calculate the node's location. Basically, the Engine uses the first several range measurements and a Nonlinear Least Squares (NLS) Geometric location solver to produce an initial location measurement. After this is complete, the Engine will either compute locations based on the Geometric solver or, at the users option, transition to the Kalman solver which uses the combination of range measurements and a motion model to compute a location. Note that the Kalman solver is good for localizing objects in motion, such as autonomous robot vehicles. The Geometric version uses a more traditional NLS solver and it is very good for locating objects that are static or move very slowly.

A Geometric solver is better at tracking stationary or slow-moving Mobiles. If a Mobile moves too quickly, then this solver will predict locations that lag in time relative to the actual location of the Mobile. Both solvers have strong points and weaknesses based on the type of motion the Mobile exhibits. Therefore, the user must pick the solver that best fits the expected motion. For example, a Kalman solver effectively incorporates a sense of motion and inertia. It estimates location based on knowledge of the previous location and the rate of change in velocity. This is excellent for measuring the motion of moving objects. However, if a Mobile stops rather suddenly, the Kalman filter will tend to predict continued motion. As a result, a suddenly stationary Mobile will appear to move past the stopping point and then retreat to the actual final location.

The Location Engine also calculates the Geometric Dilution of Precision (GDOP) for each measurement. If the GDOP calculated is too large, then this is an indication that either the geometry defined by the location of the Mobile relative to the Anchors is poor or the quality of the range measurements is very poor. In this case, the Location Engine will reinitialize.

The parameters of the filter (as well as the GDOP parameters) are user-adjustable and there are multiple safeguards to (a) maximize the probability that reliably accurate locations will be calculated and (b) reinitialize the Engine if the quality of the location calculation is suspect.

The nodes behave in the following manner:

Anchor P4xx units are fixed in location and have only two functions:

- Anchors occasionally send Beacon messages to announce their presence. This behavior acts as a seed to start communications between units in the ALOHA network.
- Anchors can, if so directed by the user, report any range or location information which it may have received from a Mobile to a Host computer.

Mobile P4xx units, as the name suggests, do not have a fixed location but rather move either continuously or intermittently. They have four functions:

- Mobiles will issue range requests to any Anchor whose Beacon message they might hear.

- During initialization, once a Mobile has ranged to a sufficient number of Beacons, it will compute its location and update that position after each subsequent successful range measurement.
- As part of each range request message a Mobile transmits, it will, if so directed by the user, also transmit their last calculated location as data.
- Mobiles can, if so directed by the user, report any range and/or location information which it may have received to a Host computer.

Location has three operational modes: Idle, Autosurvey, and Tracking. While in the Idle Mode, the X, Y, and Z locations of the Anchors and the Z location of the Mobiles can be broadcast to the other units in the network using a flooding algorithm. This algorithm has acknowledgements so it is easy to confirm that all units in the system have received the messages. Once this information has been distributed, the system will transition to Tracking Mode. In this mode, the location of Mobiles will be calculated and that information distributed through the network as configured by the user. Autosurvey is an optional mode. When engaged, Autosurvey Mode will direct the Anchors to range to each other while the Mobiles stay idle. The GUI will collect the Anchor ranges and use them to compute the Anchor locations.

If properly set up and operated in a benign environment, the system will provide location accuracy of the Mobiles on the order of a centimeter. In some cases, accuracies of 1 or 2 millimeters have been achieved. Guidance on how to achieve the best accuracy possible is provided in **Appendix G: Maximizing Location Performance**.

11. Location Tab

The commands on this tab allow the user to:

- Define which units are Anchors and which are Mobiles
- Define where the Anchors are located
- Define rates at which the units range to others
- Define what information the units will send to each other
- Define what information the units will report to the Host
- Define what actions units take when they power-up (or reboot)
- Use UWB communications to load this configuration in all units in the system
- Load/save this configuration information from/to disk
- Use UWB ranging to locate all of the Anchors in the system
- Define which localization solver to use (Kalman vs. Geometric)
- Define whether localization solutions will be 2D or 3D

These capabilities are divided into four command blocks (see **Figure 11-1**). These are summarized below and will be described in detail in subsequent subsections.

- **Location Map** commands allow the user to define unit types, ALOHA protocol settings, inter-unit communications, and Anchor locations.
- **Settings** commands allow the user to define the units' start up state and what sorts of information they report to the Host.

- **Configuration** commands allow the user to transmit the system configuration information to all units in the system.
- **Autosurvey** commands give the user the option of using UWB ranging to locate the references.

While the Location OpModes are accessible from any tab, the description of these commands will be provided in this section.

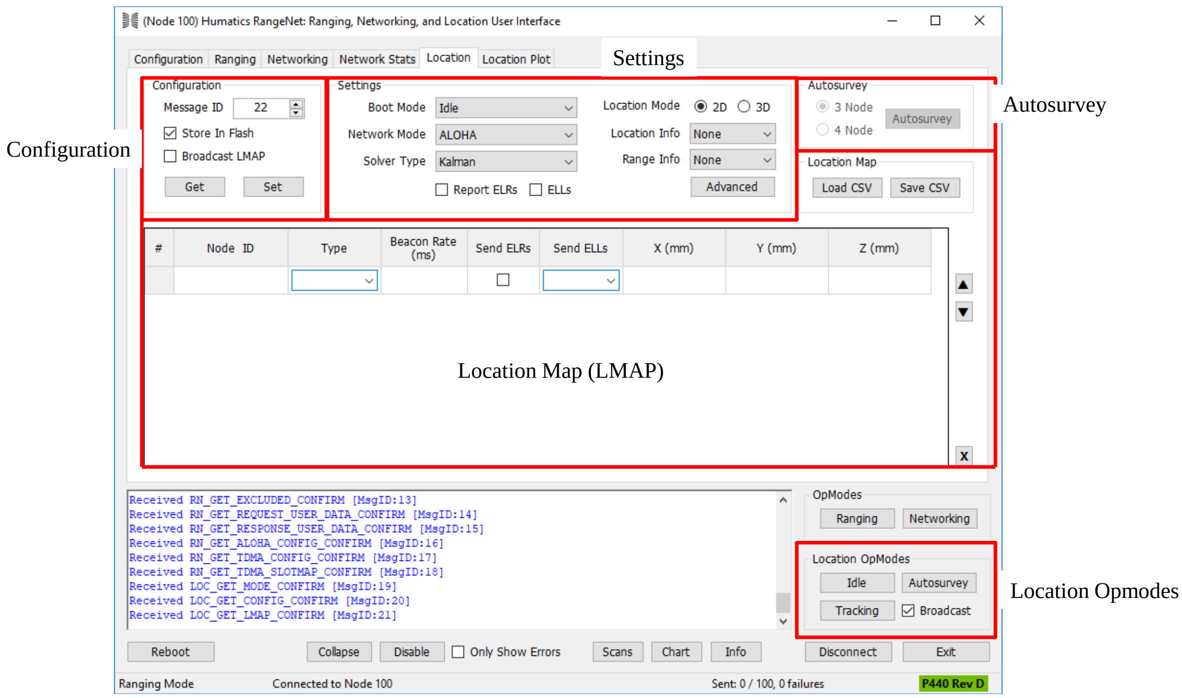

Fig. 11-1: Configuration commands by group (Location Map, Settings, Configuration, and Autosurvey) plus the Location OpMode control block

11.1 Location Map

The Location Map (LMAP) is used to define:

- How many units are in the system
- The roles of the units in the system (Mobile or Anchor)
- How the units interoperate
- Where the Anchors are physically located

In addition, the Save To CSV and Load From CVS buttons allow the user to save the current LMAP to disk or load an existing LMAP from disk. Files are stored with a .csv extension type in a user-definable directory.

The LMAP has one entry per node and the system can have up to 60 nodes.

The up and down arrows to the right of the table allow the user to adjust the order of the entries in the LMAP by moving an entry in the map up or down. Clicking the button marked with an X will reset the table. The arrows and X key can be found in the highlighted area in **Figure 11-2.** Clicking a line and then clicking the Delete key will delete only that line.

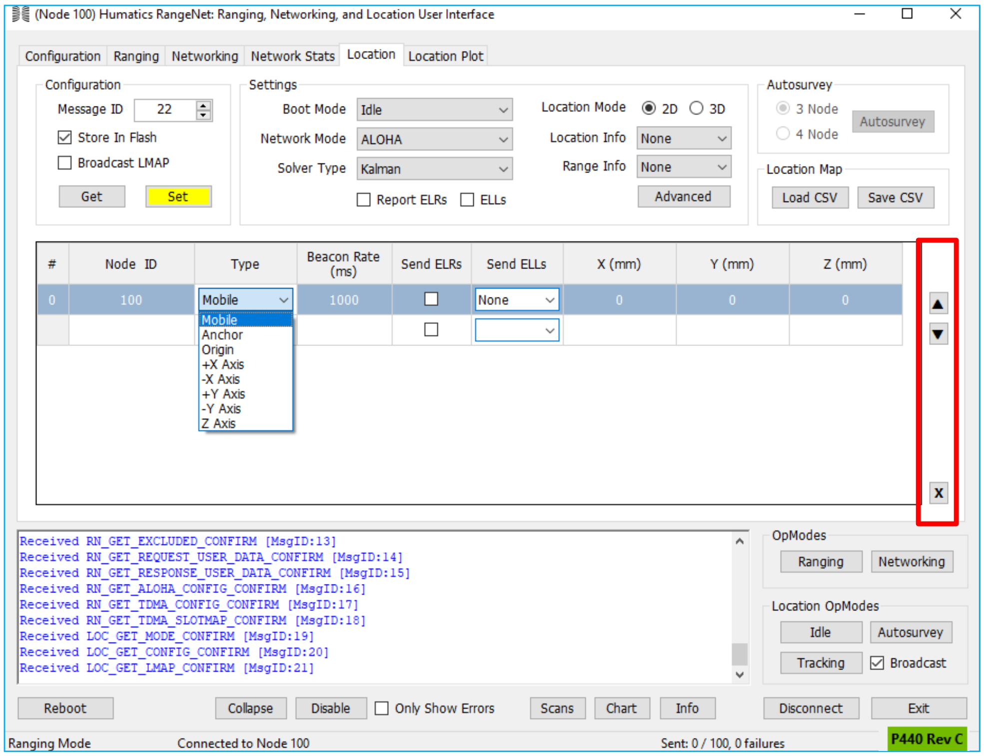

Fig. 11-2: LMAP with control buttons indicated in red and Type drop-down shown

The following is a description of each of the LMAP columns:

Node ID: To load the table, click on the first line in the table (entry or row # 0) and enter the Node ID. Subsequent lines in the LMAP are numbered sequentially.

Type: This field defines the role which the node will take. The selections are shown in the drop-down menu (see **Figure 11-2**). There are two basic choices. The unit can either be an Anchor node or a Mobile node. Any number of Anchors and Mobiles may be defined, but the total number of units in the system must not exceed 60. If the Autosurvey capability is to be used, then it is necessary to define one Origin Anchor and either a +X or – X Anchor and either a +Y or a –Y Anchor. You may optionally define a Z Anchor. The Z Anchor is used in one of the Autosurvey modes. The Origin, X, Y, and Z Anchors are used to define a Cartesian coordinate system. If you are not going to use Autosurvey and wish to enter the Anchor locations manually, then use the "Anchor" type for all Anchors.

When using Autosurvey, it is important to link the frame of reference used to display positions on the computer terminal with the frame of reference you use when looking at the physical units. Consider the example shown in **Figure 11-3**. The system consists of 4 Anchors (shown in black) and a single red dot, which represents the Mobile. The +Y and +X node subtypes are used to define the direction of the X and Y axis. The +Z point is optional and serves as a redundant Anchor for one of the Autosurvey modes. The icon of the person has been added to connect the physical reality of what one sees with the coordinate system shown on a computer screen.

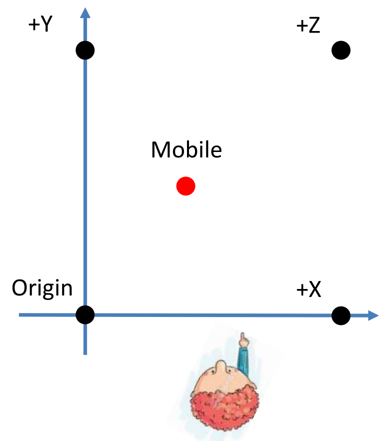

Fig. 11-3: Cartesian coordinate system with Origin, +X, +Y, and +Z Anchors defined

While this arrangement is intuitively obvious, there will be times when this frame of reference will be inconvenient or confusing to others. For example, consider the situation where you are demonstrating the system to others in a conference room and something, perhaps the position of a display screen or furniture in the room, limits where you can conveniently place your Anchors. Consider the example shown in **Figure 11-4.** In this case it is not logistically possible to install the Origin in the lower left corner. To maintain the same orientation/frame of reference, the Origin has been moved to the upper right corner and the axis Anchors now define the –X and –Y axis.

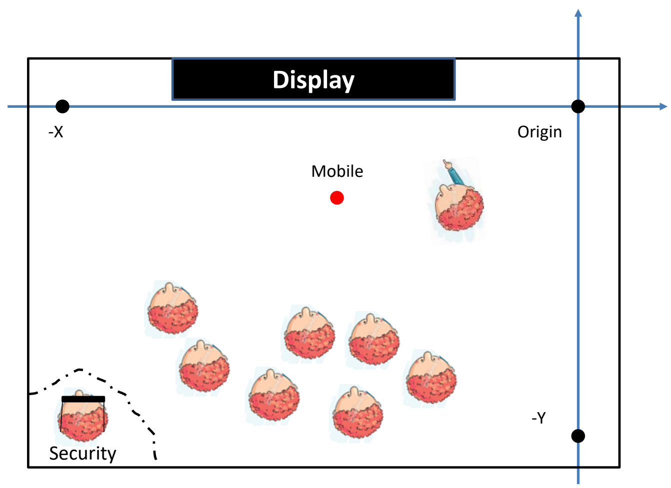

Fig. 11-4: Using –X and –Y Anchors allows flexibility in locating axis

Beacon Rate: This field is use to define the average rate at which Anchors or Mobiles communicate. Mobiles will issue range requests at random intervals with a minimum time not less than the time required to complete a range request. Anchors operate in the same manner with two exceptions. First, an Anchor will never issue a range request. Instead, it will transmit a short data packet announcing its existence. Second, every time it receives a range request, it will reset to zero the timer associated with Beacon transmission. This ensures that an Anchor will beacon frequently in an environment with few Mobiles generating infrequent range requests, and infrequently if there are many range requests occurring.

The user can also set the Beacon Rate to 0. In this case, RangeNet will use Automatic Congestion Control (ACC) to throttle the Beacon Rate. If there are a large number of units in the area, then ACC will lower the Beacon Rate. If there are few units operating, then ACC will increase the Beacon Rate. ACC is very useful for Mobiles because it ensures that they will range as fast as possible but not so fast that one Mobile's radio transmissions are able to completely block the transmissions of another Mobile. It is much less useful for Anchors, because Anchors should in all cases beacon as infrequently as possible.

Therefore, TDSR recommends setting the Anchors up at a low Beacon rate (such as 1000 ms) and then setting the Mobile Beacon rates to 0. If there is only one Mobile in the system, then the user can either set the Beacon rate to 0 so that it will run as fast as possible, or at a specific rate of the user's choice.

Send ELRs: This checkbox determines if the node will send Echo Last Ranges (ELRs) to other nodes. While this is useful for Mobiles, the field has little utility for Anchors because they never issue range requests and will therefore never Echo Last Ranges. Note that it is also possible to set the ELR flag on Configuration Tab. However, the Send ELR flag on the Location Tab is different in that it is only active when the unit is in a Location Mode. In this case, it will override any other RangeNet ELR flag setting.

Send ELLs: This drop-down menu is used to determine whether or not the unit will send Echo Last Locations (ELLs) to other nodes and if so, whether or not they will be ELLs or ELLEX. An ELL is similar to an ELR in that when a node has computed its location, it will transmit that location the next time it sends a range request. Since a range request is basically a broadcast message, this is an excellent way of transferring information through the network. An ELLEX message is an ELL which contains more information and therefore uses a bit more airtime. The *320-0313 RangeNet API Specification* has details on exactly what information is contained in these messages.

As in the case of ELRs, this capability has little utility for Anchors because they never calculate their own location. Therefore, it doesn't matter what the user enters in this field for Anchors.

X (mm), Y (mm), and Z (mm): These three fields allow the user to enter the X, Y, and Z locations of Anchor nodes and the Mobiles. If a unit is designated as an Anchor, then the user will need to enter the X, Y, and Z locations.

If Autosurvey is being used, then Autosurvey will calculate all of the X and Y locations. The only exception is the Y value for the X axis. The user needs to enter this value and will typically enter zero. Entering a non-zero value will effectively rotate the coordinate system. The user will need to manually enter the Z dimension for all units (Anchors and Mobiles) in the system.

It is much less important to define the X, Y, and Z locations of Mobiles. Entering these values for the Mobiles offers a way to set their initial location. This is, at best, a minor benefit. **Warning:** If you are operating in 3D mode, and all of the Anchors are at exactly the same Z height, then **<u>do not</u>** set the initial Z location of any of the Mobiles to be exactly equal to the Z height of the Anchors. Doing so will cause a convergence problem. This can be avoided by insuring the Z heights of the Mobiles are different from the plane of the Anchors by at least 1 mm.

All X, Y, and Z locations are measured from the phase center of the Antenna and should be entered in millimeters. The phase center of the antenna is shown below in **Figure 11-5**. If the units in the system are identical in shape and orientation then the X, Y, and Z locations can be measured from a point common to all units.

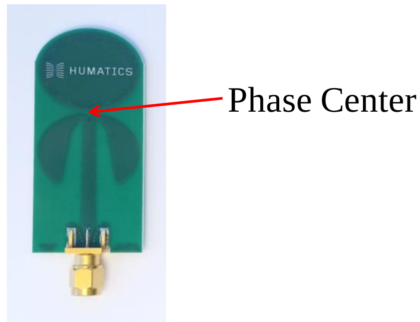

Fig. 11-5: Antenna Phase Center

An example LMAP is shown in **Figure 11-6** is one of the examples delivered with RangeNet. (All of these examples are write protected). To load this configuration, go to the Configuration Tab, click the Load From File button, browse to the directory

C:\Program Files (x86)/Humatics/RangeNet220/

And select the file

RangeNetConfig_Location_3D_Kalman_4Anchors_1Mobile.rnl

The only step needed to complete this LMAP is to enter the Z positions for the +X, +Y, and Z Anchors and any Mobiles in the system.

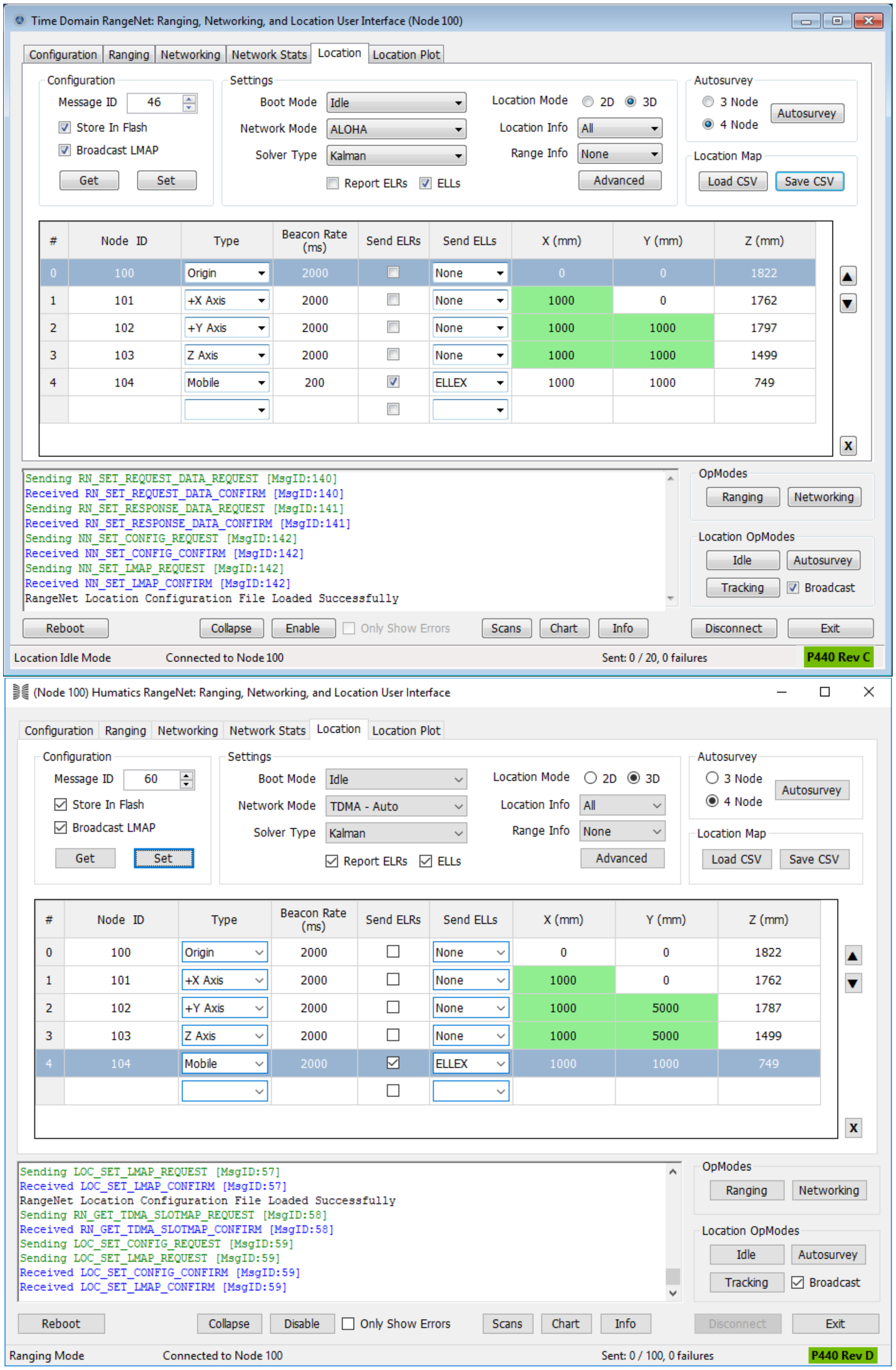

Fig. 11-6: Example completed LMAP for a 4 Anchor, 1 Mobile system

11.2 Settings

The Settings block allows the user to define:

- In what state the unit will operate when it initially boots
- Which network protocol (ALOHA or TDMA) will be used
- Which Solver will be used (Kalman or Geometric)
- What information will be reported by the units to each other and to the Host
- Whether the system will compute 2D or 3D locations
- Tuning parameters associated with operation of the Kalman Filter Localization

The following is a description of each of the fields.

Boot Mode: If a unit is in Location Mode and it is powered off, then when power is restored it will return in one of three boot states: IDLE, Autosurvey, or Tracking. The default state is IDLE. The Boot Mode specified on this display is active only when the unit is in a Location Mode. For example, if the unit is in Ranging or Networking Mode, then this setting has no effect. The modes have the following behavior:

- IDLE: This mode has the minimum activity. Anchors will beacon but Mobiles will neither initiate nor respond to range requests. Units will not send any info messages to the connected Host.
- Autosurvey: In this mode the Anchors will range to each other and send ELRs. These ranges will be reported to the Host which sent the units into Autosurvey mode. That Host will compute the locations of the Anchors until the location residual of the Anchor locations have reached a user defined threshold.
- Tracking: In this mode the Mobiles will range to Anchors, compute and report their location. Before entering this mode the user needs to ensure that the LMAP has been sent to all units. The process for distributing the LMAP is described in **Section 11.4.4**.

While there is little reason to select Autosurvey as the Boot Mode, there are advantages and disadvantages to selecting either IDLE or Tracking. IDLE is a good choice for checking out and validating system operation because if power is turned off, then the unit will go to a passive state. This is excellent for debugging systems. However, systems that are expected to operate in the Tracking state more or less continuously should probably use Tracking as the selection for Boot Mode. That way if a reboot is caused either by a power failure or a random reboot, then the unit will return to normal operation with minimal downtime. Otherwise the operator or a Host will need to order the unit to return to the Tracking state.

Network Mode: This drop-down menu determines if the localizer will operate using the ALOHA protocol or the TDMA protocol. The user has the choice of selecting either TDMA-Slot Map (in which case the P4xx will use the Slot Map defined by the user on the RangeNet Networking Tab) or TDMA-Auto (in which case the RangeNet GUI will define the Slot Map to be used by the P4xx and use the PII, antenna port, and code channel as defined on the Configuration Tab). When localizing with either TDMA-Auto or ALOHA and PII4, the system will not allow slot times of less than 9ms.

Solver Type: This drop-down menu determines whether the Kalman or Geometric solver will be used. Both solvers have advantages. If the Mobiles are moving, then the Kalman solver is the better choice. It will be better because it uses a motion model to help compute and predict the Mobile's location. The filter essentially adds a sense of inertia to the reported location. However, if the Mobile stops then this inertia will cause the reported location to overshoot the Mobile's actual location. After a few readings, the inertia will effectively dissipate and the reported location will converge to the actual location.

A Geometric solver is better for Mobiles which tend to remain stationary because it does not use a Kalman filter and therefore has no sense of inertia. However, this means that the readings will tend to be more sensitive to noise. This will cause the position of the Mobile to randomly jitter. This jitter can be minimized by applying a box car filter to the reported locations. However, if the Mobile moves, the filter will cause the reported location to lag the actual location.

Location Mode: This drop-down menu determines whether the localizer will operate as a 2D or 3D solver. A 2D system will require one fewer Anchor than a 3D system. While the elevations of the units (and in particular that of the Mobiles) can be manually entered, the implicit assumption is that the Mobiles will never change their elevation. Any changes in actual elevation will result in an error in X,Y location computation. A 3D system doesn't have this disadvantage, but it does require at least one additional Anchor.

Location Info: This drop-down menu determines whether or not the unit currently connected to the RangeNet GUI will report to the Host any Location information and if so, then whether or not the reported information will include only the successful calculations or all calculations, including unsuccessful ones. For details on the exact information reported see the *320-0313 RangeNet API Specification*, Section 5.13 LOC_LOCATION_INFO message 0x5201. See also the following **Cautionary Note**. Mobiles will normally have Location Info set to All or Successful.

Range Info: This drop-down menu determines whether or not the unit currently connected to the RangeNet GUI will report to the Host range measurement results and if so, then whether or not the reported results will include only the successful range measurements or all measurements, including unsuccessful ones. For details on the exact information reported see the *320-0313 RangeNet API Specification*, Section 3.32 RCM_FULL_RANGE_INFO message 0x0201. See also the following **Cautionary Note**.

Report ELRs: This checkbox determines whether or not the connected unit will report ELRs (Echo Last Range messages) to the Host. See the following **Cautionary Note**.

Report ELLs: This checkbox determines whether or not the connected unit will report ELLs (Echo Last Location messages) or ELLEXs (Echo Last Location EXtended messages) to the Host. See the following **Cautionary Note**.

Cautionary Note: There is a natural temptation to send all reportable data available to the Host. With that in mind, the user might Select "All" for Location and Range Info, then click both Report ELRs and Report ELLs. However, doing so will generate a great number of messages. The message traffic can be so large relative to the speed of your computer that there will be a delay in reporting messages. This delay will be most noticeable (and will increase with time) when monitoring the motion of Mobiles on the screen. In this case the motion of the Mobile may be delayed by several seconds relative to their actual motion. The problem is not with RangeNet but rather with the capacity of the Host computer to handle the flood of messages. This delay can be minimized either by getting a faster computer or by minimizing the transmission or display of information. The easiest remedies are to:

- Click the Only Show Errors button. Since most messages are successful this will reduce the display load by >90%.
- Click either the Collapse or Disable buttons. This will prevent any messages from being reported to the display.

Note that these actions will not limit the user's ability to log all of the received messages to file.

Advanced: The user can modify five tuning parameters associated with operation of the Location Engine. For most applications the user can safely use the defaults.

In fact, it is sometimes better to gain experience with operation of the system before reading this section. Adjusting the parameters in this section will help deal with some of the more subtle behaviors of the units associated with phenomenon such as operating at the edge of performance or improving the accuracy of localization in dynamic situations. The default values are shown in **Figure 11-6** and are subsequently described. (The GDOP Anchor History Depth default varies based on the number of Anchors in the system. Systems with three Anchors [2D] have a default of 8, while systems with four or more Anchors [3D] have a default of 4.)

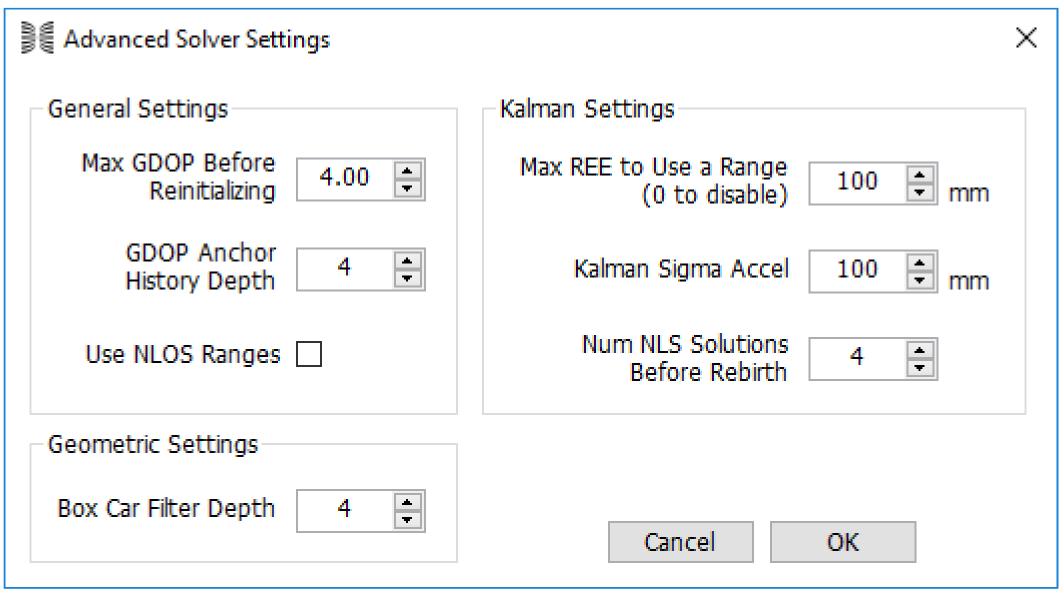

Fig. 11-6: Default advanced tuning constants for the location engine

Since Anchors never compute a location, these parameters are only relevant for Mobiles. These settings are not distributed over the air but need to be set-up on an individual basis.

There are three types of parameters: (1) general settings common to both the Kalman and Geometric solvers, (2) parameters specific to Kalman solvers, and (3) parameters specific to Geometric solvers.

General Settings:

<u>Max GDOP Before Reinitializing</u>: This user-defined threshold is used by the location engine as a safeguard against reporting an irrational value for the location. When the GDOP

(Geometric Dilution of Precision) calculated by the location engine exceeds this threshold, then the location engine will stop and reinitialize. Valid numbers are 1.00 - 40.95.

GDOP is a unit-less quality metric that measures how much the accuracy of the location measurement has been affected by the location of the Mobile relative to the Anchors. For example, if all of the Anchors are relatively close to each other and the Mobile is very distant from the Anchors, then the ranges between the Anchors and the Mobiles will all be roughly the same. As a result, any computation of location will have a great deal of error. GDOP is a measure of this degradation in performance. Values of 1 indicate no significant loss of precision while large values indicate a large loss in precision.

If the Location Engine computes an excessive GDOP it will assume that the geometry to the Anchors is unfavorable or that some of the range measurements are seriously in error. It will then terminate calculation and reinitialize. Reinitialization may solve the problem. If not, it may be necessary to move the Mobile back to a more “healthy” location. In either event, this behavior maximizes the probability that reasonable location measurements are reported, prevents units from reporting unreliable readings, and minimizes the number of unreliable location measurements generated by the system.

The default value of 4 works well in most situations. Making the number smaller will reduce the number of marginally accurate readings reported but will increase the number of times the units need to reinitialize. Increasing the threshold minimizes reinitialization time but also decreases the accuracy of reported locations.

GDOP Anchor History Depth: This parameter controls latency with which GDOP failures cause the Location Engine to reset. Generally, this parameter is set to 6 for systems which use 3 Anchors and is set to 4 for systems which use 4 or more Anchors.

The calculation of GDOP is important because excessive GDOP values are used as an indication that the location measurements are unreliable and will cause the Location Engine to restart. In order to calculate GDOP it is necessary to have successful ranges between the Mobile and at least 3 Anchors. This need is complicated by two factors. First, the range measurements are taken at slightly different times while the Mobile might be moving and second, range measurements are not always successful. For example, a range might fail because (a) there is a collision as two units try to range at the same time, (b) there might be temporary blockage, or (c) one of the range measurements might be discarded as invalid. In this case, it is necessary to use recent measurements as a substitute for missed measurements. As long as the recent measurement was “recent enough” the calculation of GDOP will probably be “good enough.” This is an important compromise to make because otherwise any lost range measurement would cause the Location Engine to reset.

In general, making the parameter too small will cause the Location Engine to be very sensitive to any failure and the Engine will restart too often. Making the parameter too large will make the localization insensitive to failures such that the Engine will take too long to notice that the location values it is producing are suspect.

The defaults provided work well with 4 Anchor systems. With three Anchor systems a default value of 6 will operate better. For systems with larger numbers of Anchors, there may be value in increasing this parameter.

Use NLOS Ranges: NLOS ranges tend to be inaccurate. This control box allows the user to decide whether to ignore range measurements which have been flagged as Non-Line-of-Sight or to allow their use in the calculation of location.

Kalman-Specific Parameters:

Max REE to Use a Range: This parameter gives the user the ability to filter ranges such that unreasonable measurements are ignored. When localizing, the Location Engine in the attached unit will ignore any range measurements which have an associated Range Error Estimate (REE) greater than the value in this field. Setting the Max REE to zero will disable the check. The user can enter any value between 1 and 65535 millimeters. The units of this field are always millimeters.

Kalman Sigma Accel: This threshold determines the degree to which the Location Engine Kalman Filter relies on its motion model compared to actual range measurements. Numbers less than 100 shift the balance to the motion model. Numbers greater than 100 shift the balance to the range measurements.

This requires a bit of explanation. The Location Engine computes position based on two sources of information: the known motion of a unit and actual range measurements. The motion model is used to predict the location of the node based on its history of motion. In other words, since a Mobile has mass, it will continue to move in a given direction such that the motion model can predict a location. This is useful because it prevents the noise inherent in range measurements from generating irrational locations. For example, one noisy range measurement could generate a location measurement that indicates an instantaneous reversal in direction of a moving Mobile. This reversal would be followed by an equally discontinuous reversal when subsequent range measurements corrected the location estimate.

This threshold offers a way of balancing how the system deals with noise. For example, if you had a very slow moving Mobile and range measurements which are taken very quickly relative to the speed of the Mobile, then you would want to shift the balance to the range measurements. If the Mobile was moving fast relative to the range measurement rate then the balance should be shifted toward the motion model. In the first case, the motion model will have difficulty predicting the motion because slight changes in direction are more likely. This difficulty will result in false predictions of location, or “noisy” location measurements.

A physical example would be motion models associated with robotic ground vehicles relative to drones. The robotic ground vehicle would tend to move in one direction, so the balance should be shifted to the motion model. Drones change direction very quickly, so the balance should be shifted to the range measurement.

While this control offers significant improvement, it isn’t a magic solution. For example, if the ground vehicle rolls to a stop, the motion model will predict continued forward progress for a short time after the vehicle has stopped. In a few moments, this error will correct and the vehicle will appear to return to its actual stopping point. The Kalman Sigma Accel threshold is significant in that it can be adjusted such that these sorts of overshoot or undershoot phenomenon can be held to acceptable limits.

Num NLS Solutions Before Rebirth: This threshold is used on startup to indicate when enough information has been taken to warrant starting or "rebirthing" the Location Engine Kalman Filter. This threshold can be set to any value between 1 and 255.

This warrants a discussion of the rebirth process. First of all, the Location Engine computes location using a Kalman Filter which relies on both range measurements and a motion model. Once a unit transitions from Idle mode to Tracking, it engages the Location Engine. However, on startup, the motion model has no history and therefore has no input to provide. Therefore, a Nonlinear Least Squares (NLS) method is used to initially calculate location. As the system collects range measurements it will compute both a location and a value for GDOP. When the localizer has measured location and has computed a GDOP value less than a threshold "y" for "x" consecutive times then it will transition from the NLS method to the Location Engine Kalman Filter. In this case "y" = the threshold "Max GDOP Before Reinitializing" and "x" is the value entered for "Num NLS Solutions Before Rebirth."

Setting this threshold to 4 is a good compromise. A value lower than this will result in a faster but less reliable initialization, resulting in more time spent in initialization. A value higher than this will result in more reliable initialization sequences that take longer to complete.

Geometric-Specific Parameters:

Box Car Filter Depth: This entry allows the user to apply a box car filter to the reported positions.

Cancel and OK buttons: Clicking Cancel will abort all changes. Clicking OK accepts all the changes you have made.

11.3 Configuration

The Configuration command block allows the user to download and upload configuration settings to the attached P4xx and broadcast the LMAP to all other P4xx units in the system.

Message ID: This field contains the number of the next message which will be sent from the Host to the P4xx. For a detailed description of Message ID fields and a discussion of their use, see the message ID field discussion in **Section 5.1 - Radio Configuration Block**.

Store In Flash: Clicking this button will cause the P400 to store the Location parameters in the P4xx's non-volatile memory. This ensures that the parameter changes will survive through the power-down of the attached P4xx.

Broadcast LMAP: Clicking this button will cause the LMAP to be broadcast to the listening area whenever the Set button is clicked. This should only be done when the system units are in IDLE Mode. While it is physically possible to broadcast the LMAP in Autosurvey or Tracking Mode, this is not a good practice because some units may not receive the updated LMAP.

Set: This button will turn yellow when any of the configuration items on this page are changed. This serves as a reminder that changes made on the Host are not downloaded to the connected unit until the Set button is clicked. If the Broadcast LMAP button is set, then the LMAP will be broadcast to all of the units in the system. A flooding algorithm is used to ensure that this broadcast reaches all units. Each unit which received the LMAP will transmit an OTA Ack (Over the Air Acknowledgement) message to confirm their receipt of the LMAP. This message can be seen both in the Action Area and (by clicking the Info button) on the Info Messages display. If the Store In Flash button is set then all of the units in the system will store the LMAP in their flash regardless of the state of their Store In Flash button. Depending on the size of the system, it may take a few seconds to receive an OTA Ack response message from each of the units in the system.

Get: Clicking this button will upload the configuration and LMAP information from the connected unit to the Host.

11.4 Autosurvey

In order for Mobiles to compute a position, they need to know the location of the Anchor units. This information must be provided by the user. There are two approaches for providing this information. Either the user can measure the Anchor locations manually or the user can let Autosurvey compute the Anchor positions. TDSR recommends that Autosurvey be used only if:

- The Anchors are in a reasonably open, clear area
- The system is small and consists of only 3 or 4 Anchors
- All of the Anchors are visible to each other

If there are dozens of Anchors spread through many rooms in a building then it is easier and more accurate to survey the locations and manually enter them into the LMAP.

The best way to explain Autosurvey is through demonstration. This section will walk the reader through the Autosurvey process and explain the various display parameters and controls.

This section will:

- Describe the prerequisites for operating Autosurvey
- Describe the various controls and displays
- Demonstrate how to operate Autosurvey and describe the results
- Demonstrate how the LMAP is distributed through the system
- Discuss next steps if Autosurvey does not complete successfully

11.4.1 Autosurvey Prerequisite Steps

To demonstrate Autosurvey, the user should setup a system of 4 Anchors and one Mobile. To achieve the maximum performance possible, please *review* **Appendix G: Maximizing Location Performance**.

To achieve a reasonable level of performance, use the following guidelines:

- Use the most open area possible, preferably outdoors or in a large lobby. Operation in a large office is possible but less than ideal.
- Operate the system such that the Anchors are visible to each other.
- When using 3 Anchors, arrange them as an equilateral triangle. When using 4, arrange them in a square.
- Place the antennas at least a foot or two away from any metallic reflectors
- Try to keep the Anchors at least 3 meters from each other. This will minimize the possibility of operating with the radios in compression. When the units are in compression, they experience a small degradation in performance. If the units are in compression, they will report that condition. At which point the user can either (a) ignore and suffer some degradation, (b) increase the separation distance, or (c) add an RF attenuator (3 - 10 db) between each P4xx and its antenna.
- Measure the height of each Anchor and Mobile relative to each other. (We typically mount the units on tripods and then measure the distance from the ground).

Next, the user must define an LMAP which uses 4 Anchors and a Mobile. In addition, the Anchors must include an Origin Anchor, a + or –X-axis Anchor, a + or –Y-axis Anchor, and a Z-axis Anchor. If this rule is not followed, then the user will not be able to access the Autosurvey capability. The only option at this point would be to manually measure the 3D location of the nodes.

Next, the user needs to ensure that all of the units are:

- Using the same Code Channel
- Using the same Pulse Integration Index (PII)
- Physically located in the desired spot
- Capable of communicating to each other
- Calibrated such that their antenna delays are correct (this is most important)
- All have a complete LMAP (all units and Z locations entered)
- The Broadcast LMAP flag must be set.
- The Report ELLs flag must be set
- The Location Info must be set to All or Successful.
- In IDLE mode

A simple & reliable shortcut: The easiest way to insure that all the units have the same settings is to load one unit as desired, then save the configuration to a disk file. This configuration can then be loaded into each of the other units in the system.

A complete and tested sample configuration has been included with the release and can be downloaded to each of your nodes. The only requirement is that your units have Node IDs numbered from 100 through 104 and that they be physically located in the order shown in **Figure 11-7.**

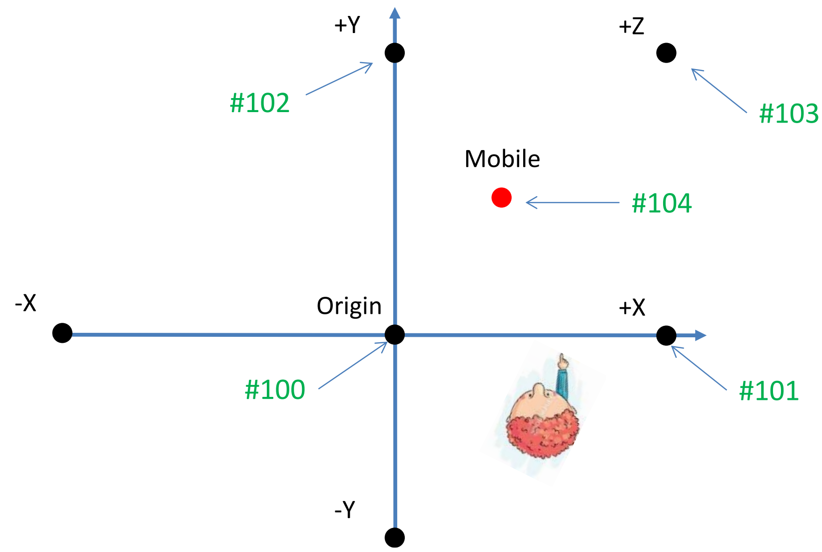

Fig. 11-7: Orientation of units necessary to use the default file

The procedure for loading is simple:

1. Click on the Configuration Tab, click Load From File, browse to the directory

   C:\Program Files (x86)/Humatics/RangeNet220/

   For the file

   RangeNetConFig_Location_3D_Kalman_4Anchors.rnl

2. Click Load.

3. Check the lower left corner mode indicator and confirm that the unit is in Location Idle Mode. If not, click the Idle button and then Set button.

4. Repeat this process for each of your five nodes.

At this point all of your nodes should be in Location IDLE Mode.

5. Measure a Z value for all of the nodes and enter the values into the LMAP table of the node to which you are currently connected. Z is measured in integer millimeters, Entering a non-integer value will set the value to 0. Ideally, the Z should be measured from the antenna phase center to the ground. However, since the Z is a relative measure, it doesn't matter where on the unit you measure Z as long as you measure it from the same point on all units. Note that the important parameter is the difference in height between the Anchors and the Mobile(s). Typically it is easier to set the height of the nodes relative to the ground by using a tape measure, laser range finder, or other measuring device. But you can set any of the node's height to 0 and enter the difference in height of the other nodes for their respective height. If you are operating in 3D mode, then do NOT set all of the Z values to exactly the same value. Doing so will confuse the initialization part of the localizer. Even a 1 mm difference is sufficient to avoid the confusion.

This completes set-up.

> **A word about accuracy:** If the antenna delays are optimally calibrated, then the accuracy of the Autosurvey will be excellent. If the antenna delays have not been calibrated or the antennas are separated from their respective P4xx by coaxial cables and/or attenuators, then Autosurvey will still operate and Mobiles will still localize, but the accuracy of the locations computed will be compromised. For example, Anchors arranged in a perfect square may, after Autosurvey is completed, appear squashed or distorted. Similarly, laser measurement of the Z location is ideal, but estimating heights will still work, if not as well.
>
> Even an uncalibrated system will provide results that look reasonable. All of the node positions will appear reasonable, there will be some amount of jitter to the reported locations but it will be modest and if the Mobile moves it will do so in a reasonable manner. This could lead you to conclude that the accuracy of the system is on the order of a few centimeters.
>
> The inaccuracies of the system will not become apparent until the position of the nodes is compared with truth data. At that point you will realize that while the standard deviations of the reported positions were small, the bias errors are driving the localization accuracy. Calibrating out the bias errors and more exactly determining the location of the anchors will greatly improve the results.
>
> If the antenna delays are optimally calibrated and the location of the Anchors is known exactly, then the accuracy of the Autosurvey will be excellent.
>
> It should be noted that all P440s are factory-calibrated such that their bias is less than one or two centimeters. This calibration is done with the standard Broadspec antenna and a single 90-degree SMA right angle connector. (P400s, P410s, and P412s have not been calibrated to this degree.)

Once the system is set up, the user should connect to one of the nodes (it doesn't matter whether it is a Mobile or an Anchor, but typically it is more convenient to connect to an Anchor) and build an LMAP which contains an Origin Anchor, either a +X-axis or a –X-axis Anchor, either a +Y-axis or a –Y-axis Anchor, and (optionally) a Z-axis Anchor. When entering LMAP Anchor information, remember that setting Z to 0 is valid only if all of the units are at the same height.

If the user properly enters this information, then either the 3 Node button or the 4 Node button will engage. This indicates that the user has entered enough Anchors to run Autosurvey. (**Note:** If 4 nodes are indicated, the user then has the option to downgrade to 3 nodes by clicking the 3 Node button.) For more information on building an LMAP, see **Section 11.1 – Location Map**.

11.4.2 Description of Autosurvey Displays and Controls

Clicking on the Autosurvey button will bring up the window shown in **Figure 11-8.**

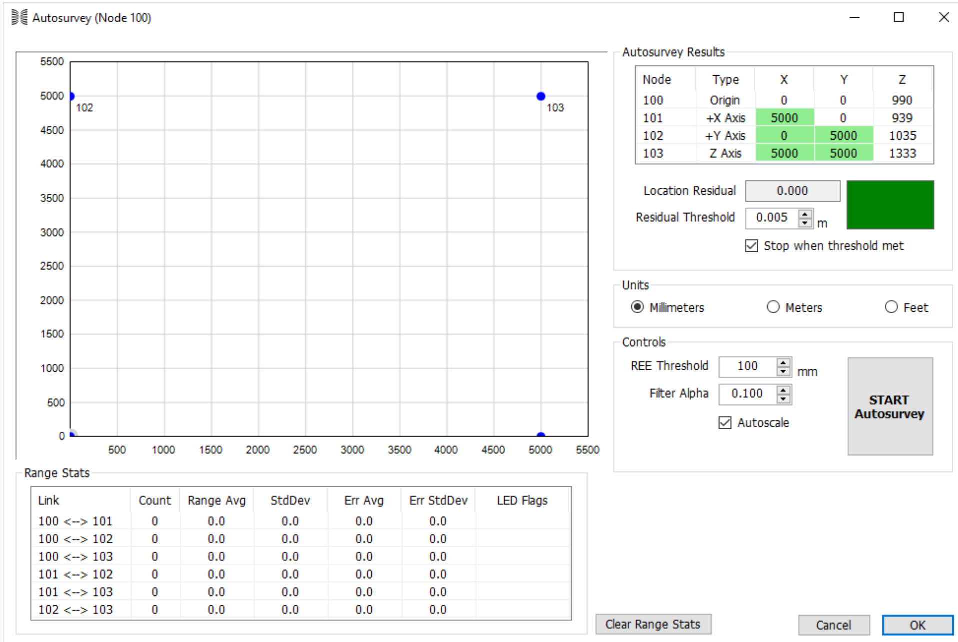

Fig. 11-8: Initial Autosurvey screen

This display has the following sections:

Cartesian Coordinate Map: This map shows the initial position of the anchors. Choice of units is defined in the Units control block.

Autosurvey Results Block: This block has several displays and controls:

Anchor Table: This displays the Anchor nodes by node number and type and the initial X, Y, and Z locations. The values with the green background are the values that will be computed by Autosurvey.

Residual Threshold: This threshold allows the user to define the required Anchor location accuracy. Computation of Anchor position is an iterative process. The Anchors will range to each other and report these ranges to the Host, which will then calculate the instantaneous (larger grey dot) and the average (smaller blue dot) location of each Anchor in the system. As the location values are updated and averaged, the difference associated with those location measurements will tend to converge to a low number. The process will continue until all the Anchors in the system have a Location Residual which is less than the user-defined Residual Threshold. The residual is expressed in meters.

Location Residual: This reports the current residual.

Stop when threshold met: Checking this box will instruct the Autosurvey function to range until the threshold has been achieved. Not clicking this button will cause the Autosurvey process to continue until the user clicks the Stop Autosurvey button.

Status Box: The color of this box indicates the state of the Autosurvey process. It will initially be green but will turn red after the Start Autosurvey button is clicked. It will remain red until the Location Residual is less than or equal to the Residual Threshold.

Units Block:

This set of buttons controls the units (millimeters, meters, feet) in which the Cartesian coordinate system is displayed.

Controls Block:

REE Threshold: REE (Range Error Estimate or Precision Range Error Estimate) is computed for all range measurements. If the REE exceeds the REE Threshold, then the range reading will be ignored by the Autosurvey process.

Filter Alpha: The location measurement shown is the weighted average of all of the computed locations since the Autosurvey button was pressed or the Clear Range Stats button was clicked. New location measurements are averaged with a weight factor determined by the Filter Alpha parameter. The default Filter Alpha setting of 0.100 means that the most recent value will be weighted at 10% of the current average.

Autoscale: Checking this box will cause the Cartesian display to autoscale any time Autosurvey updates the display. An unchecked box allows the user to adjust the scale using the left and right mouse buttons.

Start Autosurvey: Clicking this button will initiate the Autosurvey process and rename the button to Stop Autosurvey. The process will continue until either Location Residual falls below the Residual Threshold or the user terminates the process by clicking the Stop Autosurvey button.

Range Stats Block:

This block provides statistics on the individual Anchor-to-Anchor range measurements. The most useful statistic is the StdDev (standard deviation). A link with a high standard deviation may increase the amount of time required for Autosurvey to complete. Odd statistics may provide insight into odd Autosurvey behavior.

Miscellaneous Control Buttons:

Clear Range Stats: This button allows the user to reset the range statistics effectively restarting Autosurvey.

Cancel: Exits the Autosurvey display without updating the LMAP.

OK: Updates the LMAP with the latest result and exits the Autosurvey display.

11.4.3 Demonstrating Autosurvey

Once the steps in 11.4.1 have been completed, the user should click the Start Autosurvey button. Once clicked, you will observe that:

- The green entries in the Autosurvey Results table update in real time.
- The location of the references will be displayed each time their location is reported. The most recently calculated location is shown as a gray dot, while the blue dot indicates the average location calculated by Autosurvey.

- The range statistics update when a new Anchor-to-Anchor range measurement is reported.
- The green square next to the Location Residual will be red for as long as the Location Residual is greater than the Threshold. When it is less or equal to the threshold, it will turn green and stop the Autosurvey process.

In an ideal situation the Autosurvey process will complete within 1-10 seconds. An example is shown in **Figure 11-9**.

Note that the Autosurvey Results now show meaningful values for the X and Y locations and the Cartesian plot on the display should compare reasonably with the positions of the physical Anchors. Be careful when judging “reasonably” because your eyes can be fooled if you reference your Cartesian coordinates to something visible like walls and not the frame of reference defined by your Anchors. By definition, in Autosurvey the Origin is at (0,0) and X is at (x,0). As a result the Origin’s blue and gray dots will be at the same location. The unit at +Y is in the general direction of +Y axis. Do not expect the +Y-axis node to have an X value = 0. This will only happen if you were miraculously lucky enough to have placed the unit exactly at a right angle to the Origin and X-axis nodes.

Once this step is complete the user should click the OK button to return to the Location Tab.

Fig. 11-9: Successful Autosurvey completion

11.4.4 Distributing LMAP through the system

Once the LMAP has been completed with the X, Y and Z locations of the Anchors (whether by manual entry or by Autosurvey), the next step is to distribute that information to all of the units in the system.

If the Anchors have been physically mounted in their final positions, this would also be a good time to save the LMAP to file by clicking the Save To CSV button, or the entire configuration by visiting the Configuration Tab and clicking Save to File. This will allow the user to add new Mobiles to the system without requiring another survey effort.

To distribute the LMAP to the other units in the system, ensure that the Configuration checkboxes Store In Flash and Broadcast LMAP are selected and then click the Set button. A flooding algorithm will then broadcast this map to all of the units in the system. Successful distribution of the LMAP can be observed either by looking at the message stream in the Info Message display or in the Action Area. See **Figure 11-10** for examples.

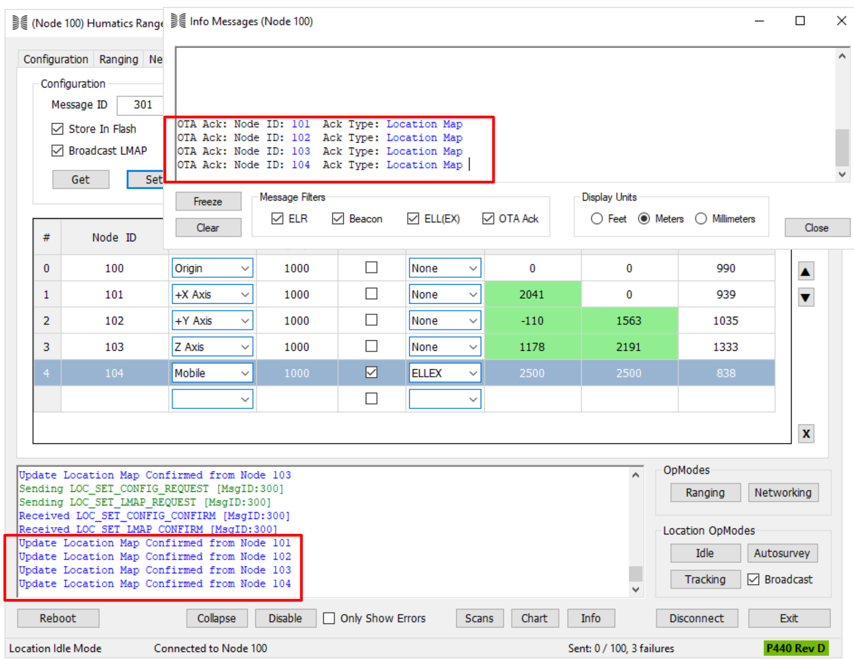

Fig. 11-10: Messages confirming successful distribution of the LMAP

When changing from state to state it is useful to observe the OTA Ack messages. Each state change should be accompanied by an acknowledgement from each unit in the system. A missing response indicates that one unit has either stopped working or hasn't been properly configured.

11.4.5 Actions to take if Autosurvey fails to complete

Autosurvey can fail to complete for several reasons:

- The units may not be properly configured.
- The Z-axis might not be properly entered in the LMAP.
- The initial positions of the Anchors may be too far off of the truth. As a general rule, don't set the X and Y of the Anchors to 0 and ensure that the initial conditions have the correct signs.

- The antenna offset might not be correctly set.
- The units may be too close to each other such that they are in compression. To avoid compression, maintain at least 3 meters Anchor-to-Anchor separation. If you need to routinely operate at shorter distances then insert an attenuator between the P4xx and its antenna.
- The geometry of the Anchors might be poor. For a 3 Anchor system, the best geometry will be an equilateral triangle with the best performance achieved when the Mobile is in the exact middle of the triangle. For a 4 Anchor system, the best geometry will be achieved with the units arranged in a square and the best performance will be achieved when the Mobile is in the middle of the square. Having said that, the user should expect very good performance outside the square or triangle until the Mobile-to-Anchor separation distance is about 10x the average separation distance of the Anchors.
- The antennas may be mounted too close to a metallic reflector.
- There may be intermittent blockages between units. (A person walking between Anchors during Autosurvey can cause issues.)
- The Residual Threshold maybe set to a value that is too low. The default of 0.01 m works well but increasing it to 0.3 m (or higher) will normally allow Autosurvey to complete.

11.5 Location OpMode Controls

The three mode buttons Idle, Autosurvey, and Tracking are used to put the connected unit in the desired location mode. If the Broadcast box is checked, then clicking any of the three mode buttons to be broadcast to all of the units in the system and they will be put in this mode as well. If the box is not set, then the change will affect only the connected unit. Clicking the mode buttons will not only cause a change in state but it will also turn the Configuration Set button yellow. Clicking the Set button will guarantee that the opmode state clicked will persist on reboot or when power to the unit is turned on.

A short description of the three modes is provided below.

- <u>Idle Mode:</u> This mode has the minimum activity. Anchors will beacon but Mobiles will neither initiate nor respond to range requests. Units will not initiate and send any info messages to the connected Host.
- <u>Autosurvey:</u> Clicking this button will force units into the Autosurvey mode. However, the preferred mechanism for entering Autosurvey mode is through the control at the top of the display. That entry point is preferred because checks are included to insure that the system is ready to enter Autosurvey. Clicking the Location OpMode Autosurvey button should never be needed. Sometimes units will fail to transition to the desired mode. When this happens the user can force compliance by clicking the appropriate OpMode button.
- <u>Tracking:</u> In this mode the Mobiles will range to Anchors, then compute and report their location. Before entering this mode, the user needs to ensure that the LMAP has been sent to all units. The process for distributing the LMAP is described in **Section 11.4.4**.

12. Location Plot Tab

The Location Plot Tab shown in **Figure 12-1** has three sub-tabs: Display, Info, and Misc. The RangeNet GUI will display the sub-tab last used in the previous session. These sub-tabs will be described in the following sections.

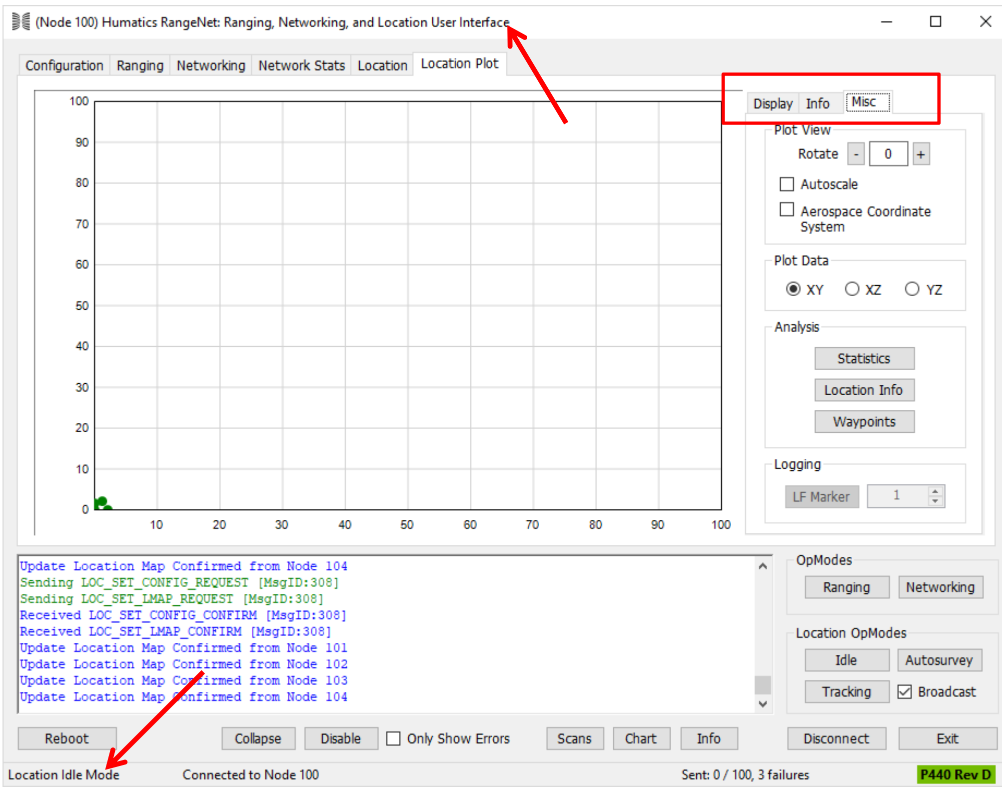

Fig. 12-1: Messages confirming successful distribution of the LMAP

You will notice that RangeNet is connected to unit 100 (an Anchor node) and the system is currently in the Idle Mode. This is the state the unit is in at the conclusion of the Autosurvey demonstration described in **Section 11.4.3**. If the system is still in that state, then the system can be transitioned to Tracking (if the Broadcast box is checked) by clicking the Tracking button. Doing so provides a very visual means of demonstrating the function and operation of the Display, Info and Misc buttons.

12.1 Basic Location Plot Controls

Once the system enters the Tracking mode, the Action Area will be flooded with messages and the Cartesian coordinate system may or may not be useful depending on the scales which were selected.

Removing the Action Area: If the messages are a distraction, then close the Action Area by clicking the Collapse button. Subsequently clicking the button (now renamed Expand) will return the Action Area to it normal state.

Changing the scaling manually: Double-clicking the left button on your mouse will automatically scale the display, at which point the display shown in **Figure 12-2** will appear. Holding the left button down and moving the mouse will move the origin to any point on the screen. Holding the right button down and moving the mouse will change the scale.

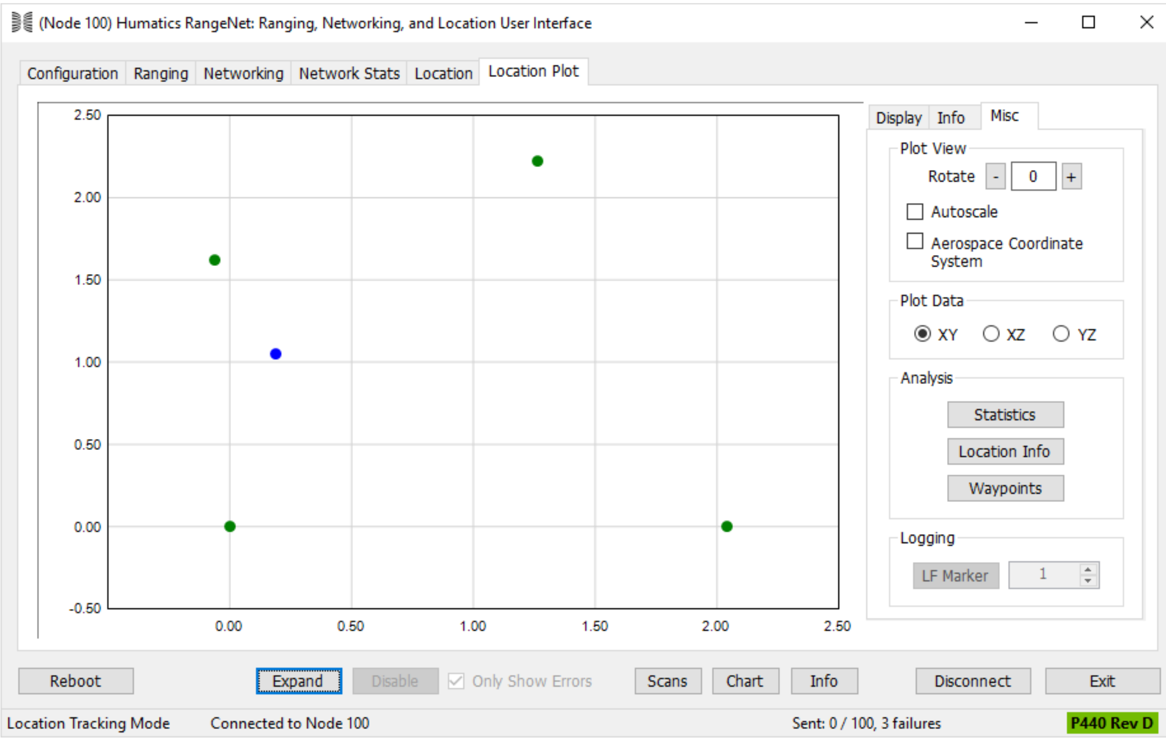

Fig. 12-2: Autoscaled display of the Location Plot with the Action Area collapsed

12.2 Display Sub-Tab

The Display sub-tab allows the user to customize how the tracking information is displayed. The following is a description of each of the controls in the three areas. An example display with all options set is shown in **Figure 12-3.**

Anchors Area:

Show checkbox: provides the option to show the location of each Anchor.

Shape drop-down: provides the option to display the Anchor location as either a circle or a square.

IDs checkbox: provides the option to display the Anchor Node ID.

Size drop-down: provides the option to display the Anchor location icon in different sizes.

Colored square: provides the option to change the color of the Anchor location icon.

Mobiles Area:

Show checkbox: provides the option to show the location of each Mobile.
Shape drop-down: provides the option to display the Mobile location as either a circle or a square.

IDs checkbox: provides the option to display the Mobile Node ID.

Size drop-down: provides the option to display the Mobile location icon in different sizes

Colored square: provides the option to change the color of the Mobile location icon.

Trails checkbox and entry: provides the option to display the "n" reported Mobile locations, where "n" is entered in the box to the right of the Trails checkbox. The maximum number of N is 65k. However, when using trails be advised that the Host computer will re-compute the location of all points each time new information arrives. This is a substantial processing load and at some point will slow the Host computer and thereby introduce significant latency. Values of n on the order of a few hundred are easily handled by Hosts with modest processors.

Colored square: provides the option to change the color of the trail.

Error Ellipse checkbox: provides the option to display the error ellipse computed for that location measurement. The ellipse is computed in the standard fashion using the Variance and Covariance information produced by the Location calculation. Normally, the ellipse is very small relative to scales of interest. To make the ellipse more readily visible, it has been increased in size using a scaling factor of six.

Colored square: provides the option to change the color of the error ellipse.

Ranges checkbox: provides the option of displaying ranges from Mobiles to Anchors. (This is only useful if the Location Tab options Report Ranges and/or Report ELRs have been set.)

Ranges drop-down: provides the option of specifying whether displayed ranges are from all of the Mobiles or a specific one.

Colored square: provides the option to change the color of the error ellipse.

Waypoints Area:

The user has the ability to define Waypoints in the system. Waypoints are fixed reference points at known locations that are not associated with either an Anchor or a Mobile. These will appear on the Cartesian graph at the position defined by the user. For example, a waypoint is shown in **Figure 12-3** at location (1.5, 1.0). They are normally used for testing and validating location performance. Waypoints are defined and discussed in **Section 12.4 – Misc Sub-Tab**.

Show checkbox: provides the option to show the location of each Waypoint.

Shape drop-down: provides the option to display the Waypoint location as either a circle or a square.

IDs checkbox: provides the option to display the Waypoint ID.

Size drop-down: provides the option to display the Waypoint location icon in different sizes

Colored square: provides the option to change the color of the Waypoint location icon.

Restore Defaults: Clicking this button will restore the default display settings.

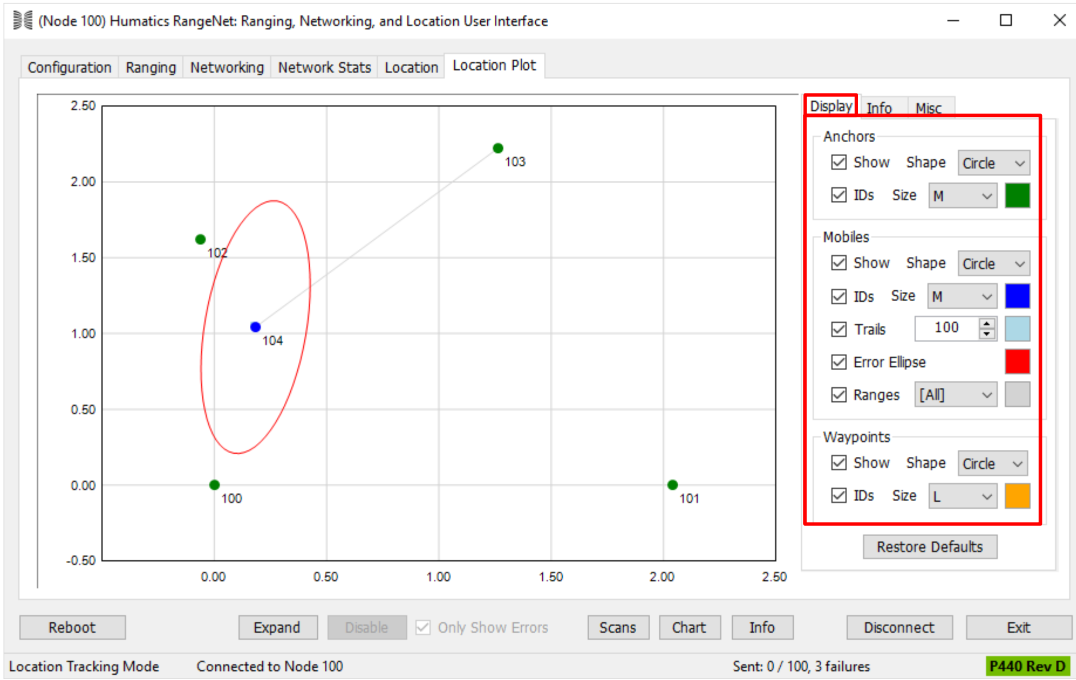

Fig. 12-3: Example of the Display sub-tab with all options checked

12.3 Info Sub-Tab

The Info sub-tab displays location statistics associated with a location measurement. Statistics include the X, Y, and Z location, Variance, and Covariance, as well as the Location Engine State (Initializing, Nonlinear Least Squares, Kalman), the number of Anchors used to compute the location measurement, and a computation of GDOP (Geometric Dilution of Precision, see Wikipedia for a discussion). An example display is shown in **Figure 12-4**.

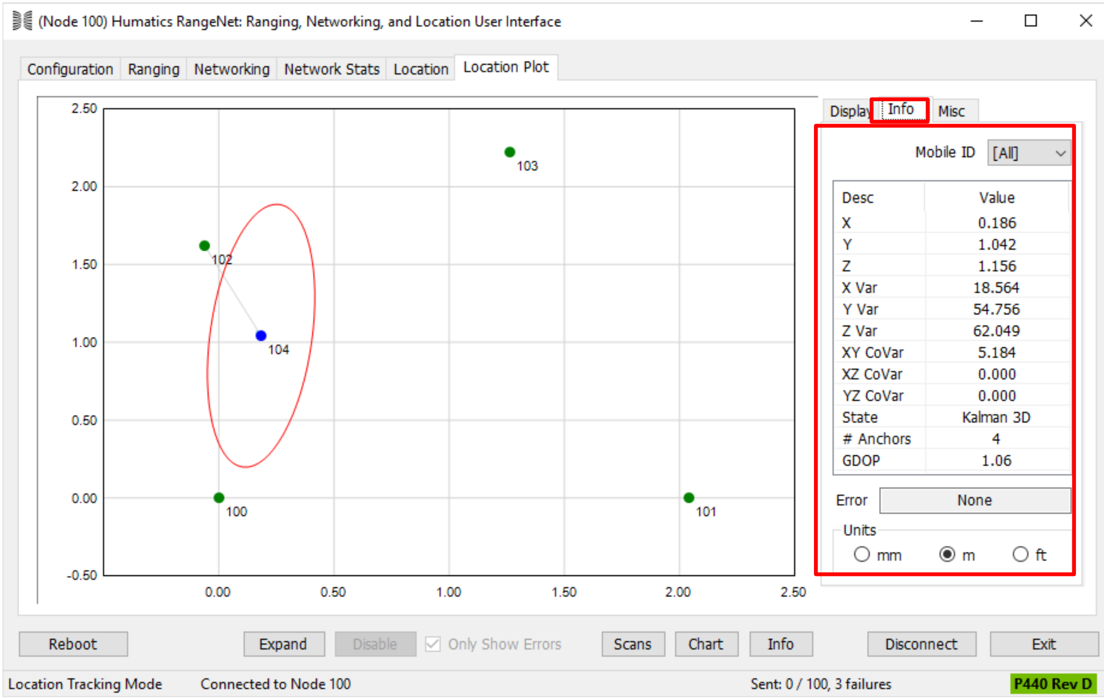

Fig. 12-4: Messages confirming successful distribution of the LMAP

12.4 Misc Sub-Tab

The Misc sub-tab (see **Figure 12-5**) has three blocks of commands: Plot View, Analysis, and Logging. They are described in the following subsections.

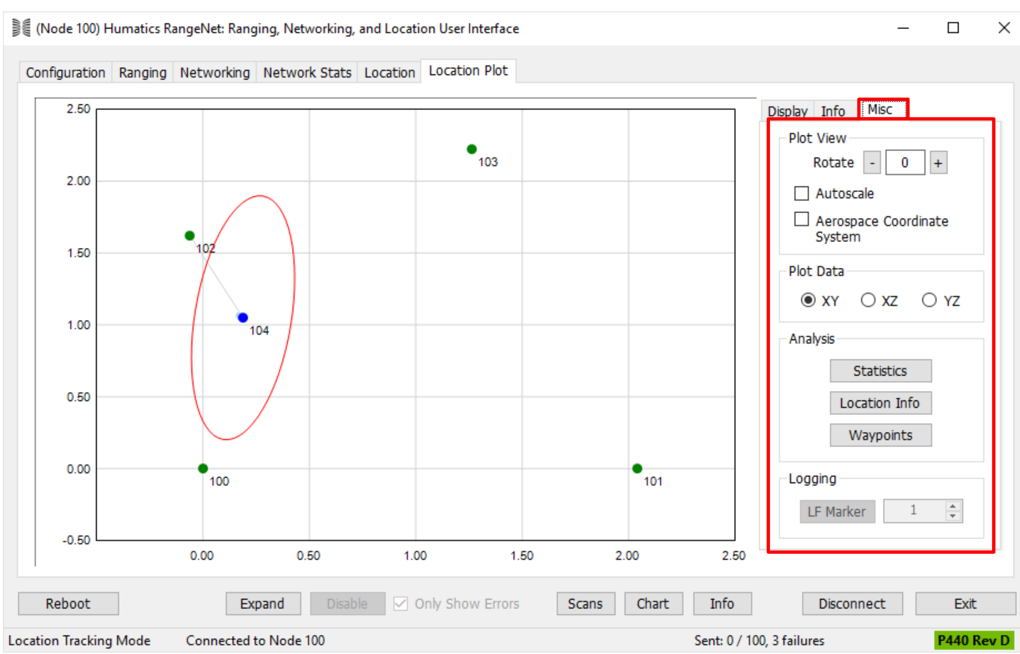

Fig. 12-5: Example of the Misc Sub-Tab on the Location Plot Tab

12.4.1 Plot View Block

Rotate fields: These fields allow the user to rotate the Cartesian plot in 90 degree steps, either clockwise or counterclockwise.

Autoscale box: checking this box will cause the Cartesian plot to autoscale whenever receiving information.

Aerospace Coordinate System box: The default RangeNet coordinate system is the Cartesian system. The default can be changed to support the Aerospace system by clicking this box. The difference between the two is illustrated in **Figure 12-6**. Basically, the Cartesian system shows +Z pointing up whereas the Aerospace system shows +Z pointing down.

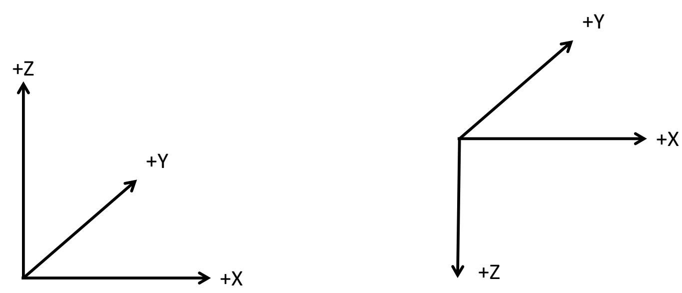

Fig. 12-6: Cartesian system (L) and Aerospace system (R)

12.4.2 Plot Data

The default display shows the data in the X and Y plane. The Z plane is not shown. This control block allows the user to change the display such that it plots data in either the XY, the XZ, or YZ planes.

12.4.3 Analysis Block

The Analysis blocks displays statistics and controls associated with the display of Location Info, Range Info, and Waypoints.

12.4.3.1 Statistics

An example is shown in **Figure 12-7**. Clicking the Statistics button opens the Location Stats display window. This window will remain open and the user will be able to open other windows in RangeNet as well as minimize or maximize the Location Stats display. The window will close either when the Close button is clicked or when the window’s red X button is clicked.

Location Info: This consists of the Location Info block of controls (Mobile ID and Stats Count) above a table containing various location statistics either reported by the node or computed by the RangeNet GUI. The location statistics in the table are computed based on the Mobile ID the user selects.

***Mobile ID*:** This drop-down allows the user to select the Mobile ID for which the information is to be displayed.

***Stats Count*:** This field displays the number of range readings which have been received by the RangeNet GUI. The count will stop when the Stats Count equals the Boxcar Depth.

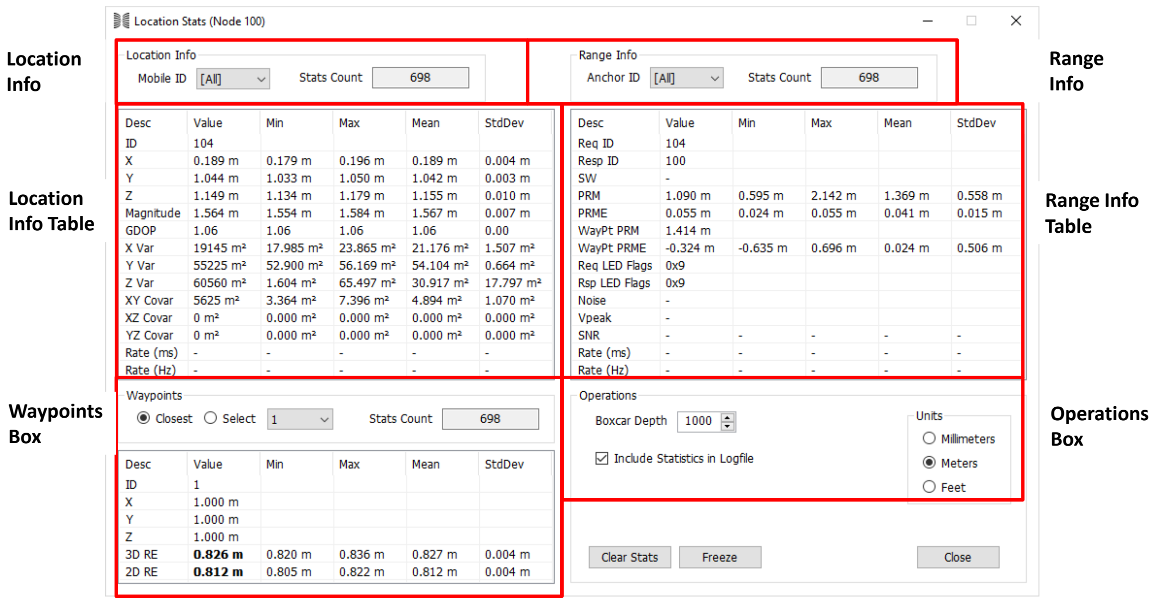

Fig. 12-7: Example of the Location Stats display

Location Info Table: The column headings are generally self-explanatory; however a few comments on the Min, Max, Mean, and StdDev definitions are required. These statistics are computed on the last "n" readings which the RangeNet GUI has received. "N" is defined by the Boxcar Depth field in the Operations block. Note that these statistics are computed based on the Mobile ID selected by the user. The user may select "All" from the drop-down in which case the utility of the statistics will change and may not be useful. For example, the average X location of all Anchors and Mobiles has little meaning.

The rows are also self-explanatory. The location information is provided as (X,Y, Z), (X Variance, Y Variance, Z Variance), (XY Covariance, XZ Covariance, and YZ Covariance) and a measure of GDOP is also provided.

Magnitude is the square root of the sum of the squares of the X, Y, and Z values. The standard deviation of this set of values would be a measurement of the precision of the range measurements.

The rate at which location measurements are being received are displayed in both milliseconds and hertz. The rate information has no meaning when the Mobile ID is set to All.

Range Info: This consists of the Range Info block of controls (Anchor ID and Stats Count) above a table containing various range statistics either reported by the node or computed by the RangeNet GUI. The range statistics in the table are computed based on the ranges measured from the Mobile ID the user selected in the Location Info block and the Anchor ID in the Range Info block.

Anchor ID: This drop-down allows the user to select the Anchor to which the range measurements are being made.

Stats Count: This field displays the number of range readings which have been received by the RangeNet GUI. The count will stop when the Stats Count equals the Boxcar Depth.

Range Info Table: The column headings in the table are generally self-explanatory; however a few comments are required.

The Min, Max, Mean, and Stdev statistics are computed on the last “n” readings which the RangeNet GUI has received. “N” is defined by the Boxcar Depth field in the Operations block. Note that these statistics are computed based on the Mobile ID and Anchor ID selected by the user. The user may select “All” from the drop-down in which case the utility of the statistics will change and may not be useful. For example, the average SNR between Mobiles and Anchors has little meaning.

The parameters shown on the rows are all defined in the Ranging Tab (see **Section 6**).

SW is the time it takes to complete one range measurement.

The measurement rate is provided both as a period (milliseconds) and in Hertz.

The user should keep in mind that the information shown in the Range Info Table is plotted based on Range Info or ELR messages received by the Host. Whether or not these messages are reported by the connected node is controlled by the user through checkboxes on the Location Tab. In other words, you should not expect to see information in the Range Info Table if you have asked that no range info messages be sent.

Also, some of the statistics shown are only provided through the Range Info message and NOT through ELRs. Anchors only receive ELRs. Therefore, if you are connected to an Anchor some of the Range Info Table information may not be displayed simply because it is not available at the Anchor. If the missing information is important, then you should connect to the Mobile which is generating the range requests.

Waypoints: This area consists of the Waypoints control block and a table containing the location of the selected Waypoint and the distance between the Waypoint and the Mobile selected in the Mobile ID. The user can determine whether the statistics are computed from the Mobile and either the closest Waypoint or a particular Waypoint. Stats Count displays the number of range readings which have been received by the RangeNet GUI.

Distance in this case is the length of the vector that connects the waypoint with the mean of the measurement point. This is the bias. In an ideal situation this value would be zero. Bias is computed two ways. For those interested in just 2D measurement, 2D RE is the preferred bias measure. For those interested in 3D measurement, 3D RE is the proper bias value.

Operations Block:

Boxcar Depth: This drop-down allows the user to specify the number of readings which will be used to form a running average of the various statistics.

Include Statistics in Logfile: If the user is logging Host-P4xx messages to disk then the statistics shown on the display will be logged to disk if this checkbox is checked.

Clear Stats: This button allows the user to reset all of the statistics

Freeze: This button allows the user to prevent the tables from updating. Once clicked, it will become an Unfreeze button allowing the user to resume updates to the table.

Units: These buttons allows the user to define the units of measure (millimeters, meters, or feet).

Close: This button allows the user to close this window.

12.4.3.2 Location Info

Clicking this button will open a window which displays location information for the selected Mobile ID in a font large enough to be seen from a considerable distance. An example is shown in **Figure 12-8**. Once clicked, this window will remain open until it is specifically closed, thus allowing the user to monitor or control other windows at the same time. The window can be closed either by clicking the Close button at the bottom of the display or the red X in the upper right corner. All of the fields shown are described **Section 12.4.3.1 - Statistics**.
There are a few differences:

- Double-clicking the displayed measurements will change the units of measure
- The user can change the Mobile ID from this window
- Stage (State) field: Indicate which state (Initializations, Nonlinear Least Squares, or Kalman) the location engine is in.
- Error: Errors generated by the localization process will be reported here.

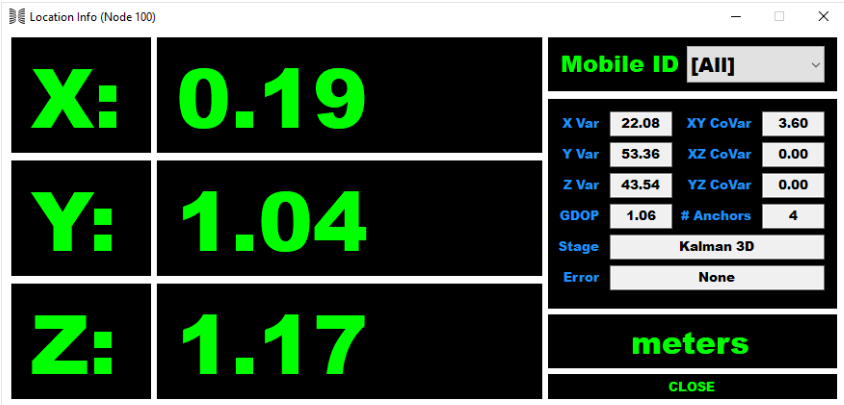

Fig. 12-8: Example Location Info display

12.4.3.3 Waypoints Manager

This button opens the Waypoint Manager window, which allows the user to add or delete Waypoints from the system. A Waypoint is a virtual location which the user can add to the location map. Once a Waypoint is added to the system, the RangeNet GUI will compute the distance from a user-selectable Mobile to any given Waypoint. An example is shown in **Figure 12-9**.

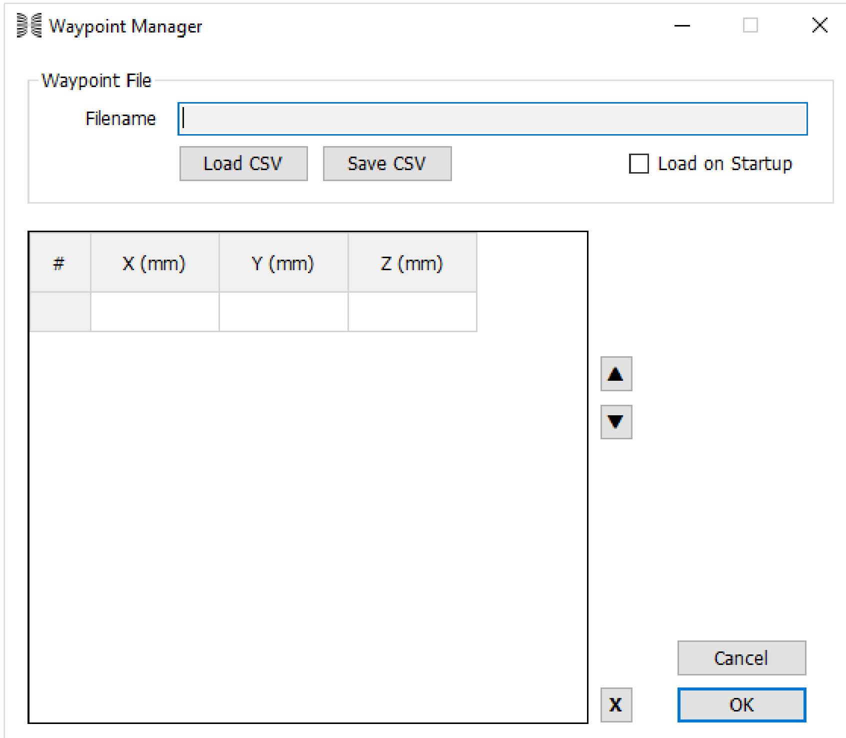

Fig. 12-9: Example of the Waypoint Manager window

The instructions are very similar to the ones for working with the TDMA Slot Map.

- The "x" button deletes all of the entries in the Waypoint table.
- To add a Waypoint, simply move the cursor to the next available entry and then load in the X, Y, and Z locations.
- To maneuver up and down in the table, use the up and down arrows.
- The maximum number of entries in the table is 255.
- The user can load an existing table from file or save a Waypoint table to file.
- Clicking Load on setup will cause the Waypoint table to be loaded into the RangeNet GUI whenever the user first opens the RangeNet GUI.
- Pressing Cancel will cancel the change and close the window.
- Pressing OK completes the entry and closes the window.

12.4.4 Logging Block

This command gives the user the opportunity to add a marker to the logfile. Each time the user clicks the LF Marker button, an entry will be added to the logfile. The entry will have three fields. The first field is the computer time, the second is the name "LogfileMarker," and the third will be the number in the box located to the right of the LF Marker button. The user can set this value as needed and it will automatically increment each time the LF Marker button is clicked. This is a handy way of noting an interesting location in a logfile that may be dozens of megabytes in length.

Appendix A: Connecting with Ethernet

In order to successfully connect a Host computer to a P4xx it is necessary to (a) determine if the P4xx is configured for DHCP or static IP addresses, and if so, what that address is, and (b) confirm that the Host computer is properly set up to handle this interface.

Determining P4xx configuration: The P440s are delivered either as (1) Development Kits and Labs or (2) as individual modules. In the first case, the units will be configured with a static IP of 192.168.1.xxx where the value for “xxx” can be found on a label printed on the Ethernet connector. See **Figure A-1** below.

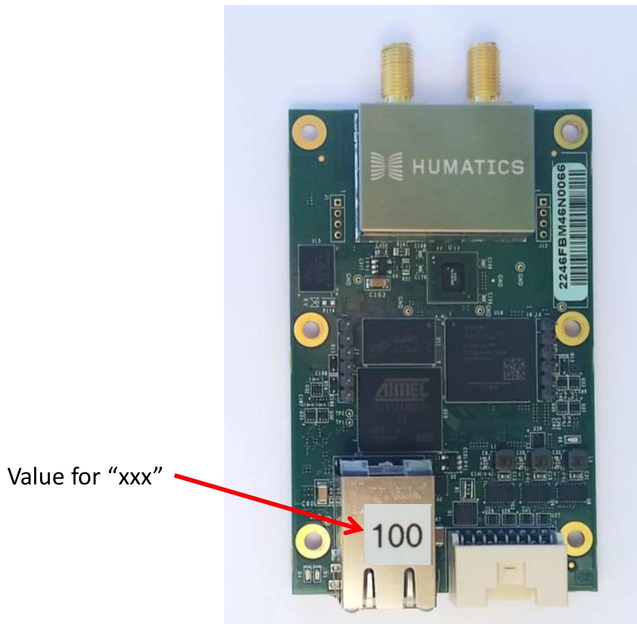

Fig. A-1: Last 3 digits of IP address of a Kit or Lab P440 can be found on the Ethernet connector

In the second case, the P440 is currently being delivered with a fixed IP address of 192.168.1.100. In the future, this will change as it is TDSR’s intention to deliver all standalone units with DHCP (Dynamic Host Configuration Protocol).

If you are unsure how your P440 is set-up, or you wish to change how the Ethernet is configured, then the easiest approach is to connect using USB (or Serial) and then either identify or change the set-up using RangeNet. See **Section 5.5 - IP Configuration Block** of this manual for details.

Setting up the Host computer with Static IP addresses: If the P4xx is using Static IP addresses then you need to configure your Host computer with the proper Subnet Mask. In principle, this is very easy, but Microsoft changes the location of this control each time they release a new version of the Windows operating system.

1. Click **Open Network and Sharing Center** and then click **Change Adapter Settings**.

2. Right-click **Local Area Connection** and then click **Properties** from the drop-down menu. The window shown in **Figure A-2** will appear.

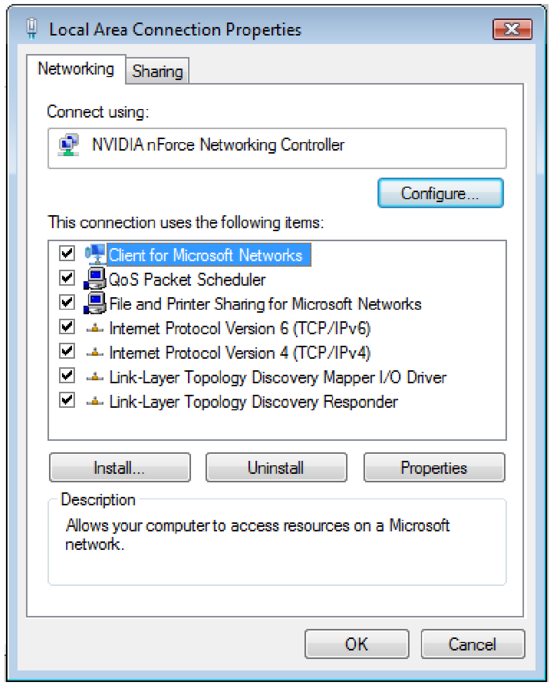

Fig. A-2: Reaching the Local Area Connection Properties screen

3. In the box labeled "This connection uses the following items," click on the words **Internet Protocol Version 4 (TCP/IPv4)**, and then click **Properties**.

4. When the **Internet Protocol (TCP/IPv4) Properties** dialog box appears (see **Figure A-3**), enter the IP address and Subnet mask as shown in **Figure A-3**.

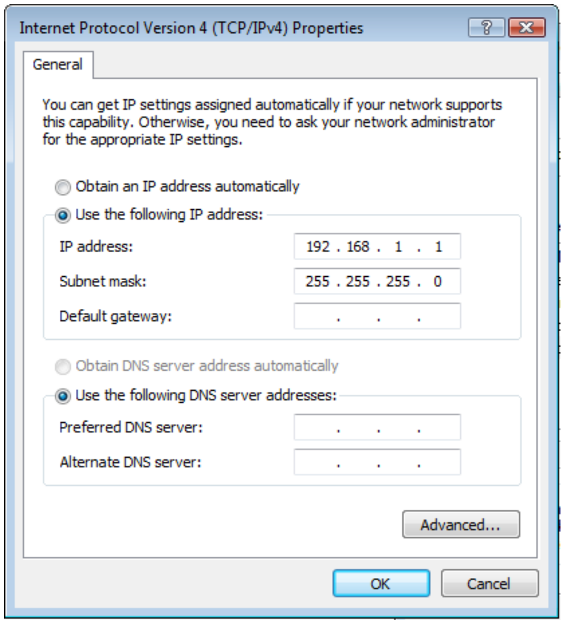

Fig. A-3: Set Host IP address and subnet mask as shown

5. Click **OK**.

Once this is complete, you should be able to connect to the P440 either directly with an Ethernet cable or through an Ethernet hub.

Setting up the Host Computer for DHCP: Setting up a Host computer to support DHCP is an arcane and involved process. If you understand what a DHCP server is then you probably already know how to set up the Host. If you are not an IT professional, then you need to consult with your IT manager.

Appendix B: Issues with USB & Microsoft Windows

MicroUSB connectors and cables are designed for long life and a great many insertions. However, it is possible that over time (and after a great many insertions) the USB connectors can lose their integrity and become intermittent. The USB power connector at the P4xx appears to be vulnerable to this issue. One normally notices a bad cable when the connector connections look correct, but the power is not on. If wiggling the cable fixes the problem, then it is probably time to find a new cable.

Microsoft Windows doesn't handle USB interfaces particularly robustly. The allocation of COM port assignments is not predictable (at least not by mere mortals) and is not robust. It can be particularly frustrating if the user is attempting to monitor a network of several P4xx which are all connected to multiple USB ports on a single PC. In such a configuration, the PC will intermittently and randomly disconnect individual P4xx units from the PC. Reconnecting the P4xx to the PC may require rebooting of the P4xx or even the Host PC. This problem can be usually be addressed by connecting the units under test to a USB hub and then connecting the hub to the PC. But this doesn't always work. It may work fine for many hours but fail if allowed to run overnight.

This is just an example of a Windows/USB issue. There are likely other such traps.

Note that this issue has not been seen on Host machines that operate under Linux.

While USB is convenient and easy to use it is not robust. For this reason, TDSR strongly recommends that you switch to Ethernet as soon as possible.

Appendix C: Calibrating Ranging Bias

Overview

The bias error on a P440 using the standard connector and antenna is minimal (<3cm) and very stable, so there is no need to periodically re-calibrate the units. While this is adequate for most applications, it is occasionally insufficient. For example, some applications require the most precise bias measurements possible. In other cases, the user may have changed the bias by using different antennas, different connectors, or with additional cabling between the antenna and the antenna port. In any event, it is sometimes necessary to recalibrate the unit.

Link vs. Unit Calibration

The following calibration procedure will allow the user to easily recalibrate the bias. However, the recalibration procedure described will calibrate a given link and not a specific unit. By that we mean that all adjustments to bias will be divided evenly between the two units in the link without regard to cabling differences between the two units. For example if you have a link between two units where one uses a standard antenna and other has a 3 meter cable between the antenna and RF port, then this procedure will split the bias between BOTH radios and assume that half the cable is on one unit and half on the other. This procedure works very well for individual link in which only two units are involved, but is not suitable for operation in a network where one unit may need to range to multiple units. Calibration of individual units (rather than pairs of units) requires a different procedure. While TDSR has not yet implemented an automatic means of performing such calibrations we have published a procedure which describes how to manually calibrate individual radios. This is described in document *320-0327 Distributed Calibration of TDSR UWB Ranging Radios.*

The Calibrate button (see **Figure 5-1**) on the RangeNet Configuration Tab provides a simple method of determining antenna (measurement bias) delay due to the antenna and cables/connectors arrangement for either antenna.

Primary Purpose of Calibration

The primary purpose of calibration is to allow a user to deal with operation with non-standard antennas or cables. Any changes to the connection to the RF ports will change the calibration. A longer cable, different SMA connections, or different antennas will all change the effective path length relative to the standard configuration. This change in path length will add an offset or bias to the range measurements. For example, adding an SMA connector or RF attenuation might lengthen the path by a few centimeters, while adding a 2 meter cable will add a few meters of bias. This bias error is referred to as “antenna delay.”

Calibrating a Link

To determine antenna delay for a particular link, set up a pair of P4xx units with identical configurations. Connect one P4xx to the RangeNet GUI and set the second P4xx at least 5 meters way. This spacing will ensure that the neither unit is in RF saturation and that they have an unobstructed line-of-sight path to each other.

Click the **Calibrate** button on the Configuration Tab, then enter the Node ID of the responder P4xx. Enter a number of ranges to average (100 is typically a good value). See **Figure C-1**.

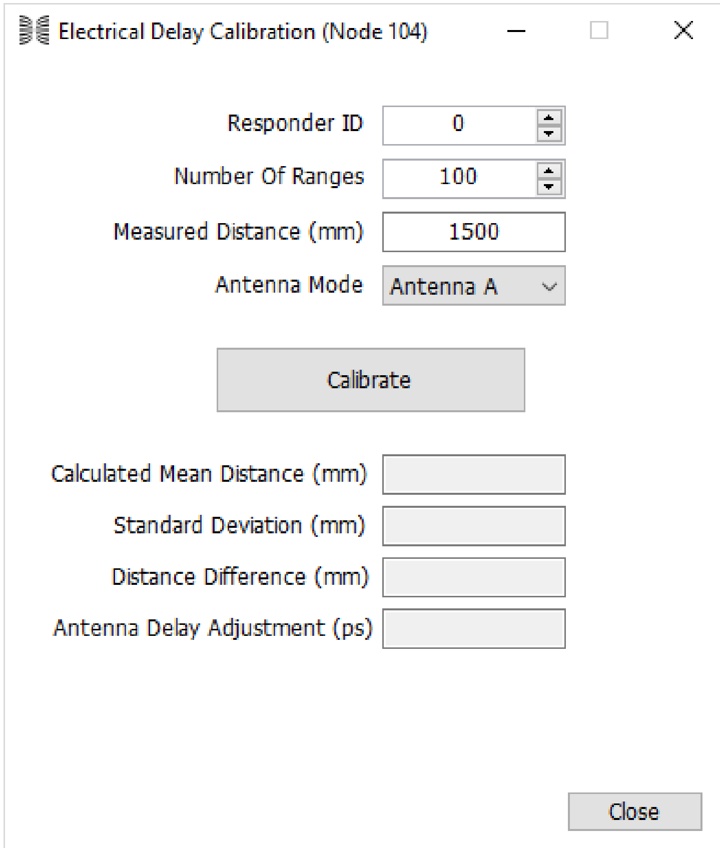

Fig. C-1: Example of Electrical Delay Calibration window

Measure the exact distance between the phase centers of the two antennas (see **Figure C-2**) and then enter that value into the field Measured Distance (mm). Remember to enter it in millimeters.

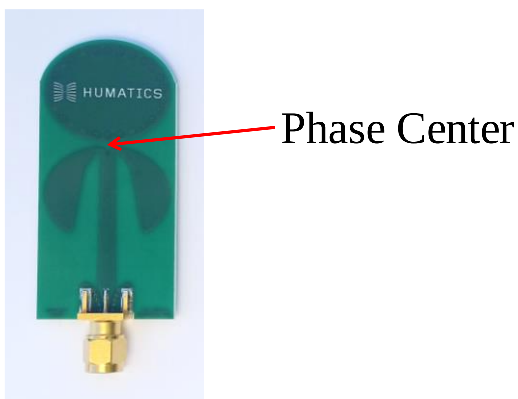

Fig. C-2: Phase center of a TDSR Broadspec antenna

Click the **Calibrate** button. RangeNet will automatically and repeatedly measure distance for the specified number of iterations and produce several statistics from the data. During this time, do not move or walk between the devices. When finished, the required antenna delay bias, in picoseconds, will appear at the bottom of the tab. Click the **Write to Flash** button to save the value in the P4xx's non-volatile memory.

After successful antenna delay calibration, the constant range bias will be quite small (less than a couple of centimeters). To confirm the calibration was successful, you may leave the P4xx units in place and select **Calibrate** again. The Distance Difference and Antenna Delay Adjustment should be calculated very close to zero.

Secondary Purpose of Calibration

A secondary goal might be to calibrate the units such that they provide the most accurate reading possible. This would typically be done if one were trying to achieve accuracies of a few millimeters or operate the radios at very close range.

If this is the goal, then one needs to take into consideration the phenomenon of signal compression. The ranging measurement algorithm assumes that the radio link is being operated in its linear range. If the radios are too close to each other, then the receiver will be overwhelmed by the strength of the transmitted signal. It will then compress or saturate. While the radio will still operate, the accuracy of readings taken in compression will be compromised. In compression, the bias of the range readings will change and will become slightly non- linear. These errors total only a few centimeters and generally are of no consequence to most applications.

Things to avoid

- Do not calibrate a unit while in Networking mode.
- Since precision is normally important, calibrate the units in an RF-quiet area. In other words, do not calibrate in the immediate vicinity of an active UWB system. Either shut down the network or perform the calibration in a different area of the building, preferably an area with a few walls or 10 meters between the link under calibration and active UWB transmitters. If this isn't possible, then the system will still calibrate but the standard deviation will be a bit higher.

Appendix D: RangeNet Logfile Format

The RangeNet logfile contains a running account of all interactions between the RangeNet GUI (Host application) and the connected P4xx. This includes all messages produced when operating in the Ranging, Networking, and Location modes. **Figure D-1** is an example of part of one such logfile.

Before the FIRST instance of each message type, a header description is provided (illustrated in **red** below). The initial timestamp (always the first parameter in each data line) is a floating point time value, in seconds, provided by the Host PC.

All other parameters are generated and received from the local P4xx. The specifics of the parameters are described in either the *320-0313 RangeNet API Specification*.

```
Timestamp, Config, PulseIntegrationIndex, AntennaMode, AntennaToggleFlag, CodeChannel, AntennaDelayA,
AntennaDelayB, ScanInfo, DisableCRERanges, TransmitGain
1338055415.281, Config, 7, 0, False, 1, 0, 0, 1, False, 0
Timestamp, RcmSendRangeRequest, MessageId, ResponderId, AntennaMode, DataSize, Data
1338055424.047, RcmSendRangeRequest, 14621, 102, 0, 0,
Timestamp, RcmSendRangeConfirm, MessageId, Status
1338055424.141, RcmSendRangeConfirm, 14621, 0
Timestamp, RcmScanInfo, MessageId, SourceId, AntennaId, LEDFlags, ChannelRiseTime, Vpeak, Timestamp,
LeadingEdgeOffset, LockspotOffset, NumScanSamples, ScanData
1338055424.156, RcmScanInfo, 14621, 102, 0, 0, 1, 42824, 144123, 176, 193, 350, -42, -8, -115, -101, -65, -75,
-26, -108, 126, -3, 50, 23, 65, -32, 5, 65, 12, 2, -14, -37, -125, -61, -43, 3, 53, 6, 67, 75, 38, 65, -27, 96, 3, 42, 22,
59, 18, 43, 9, -10, -5, -24, 54, 116, 59, 36, 51, 73, 68, 7, -49, 90, -51, 26, 73, 0, 48, 21, 38, 128, -40, 86, -78, -31,
1, -68, -26, -41, -18, 11, -31, 15, -36, -47, -28, 93, -54, 63, -3, -66, 21, 44, 92, 32, 14, -39, -74, 82, -21, 128, -5,
-31, -176, 55, -49, 50, 72, -81, -26, 80, -3, 10, -22, 30, 58, 160, 94, 34, -85, -46, 56, 50, -34, -53, -96, 48, 58, 95,
33, -2, -9, 75, 38, -18, 89, 9, 61, 12, 46, 96, 119, 21, -62, 10, -13, 20, -4, -14, -79, 43, 108, 161, 134, -3, 51, 27,
-65, 102, 71, -49, 112, 12, 52, -26, -69, -33, 64, 53, -111, 55, -3, -30, 1, 28, -33, 106, 106, -268, -108, -71, 6, -89,
24, -99, 66, 6, -30, -82, 45, 314, -300, -1078, 1910, 2013, -4799, -3865, 10308, 3935, -16290, -2579, 20683, 524,
-21412, -1214, 19254, 5346, -15182, -8904, 12314, 10191, -7710, -12354, 4190, 11202, 17, -8762, -3595, 7093,
7463, -4982, -9908, 2639, 9805, -1543, -8106, 2350, 5786, -1374, -4395, 1365, 4229, -696, -4888, 352, 6103,
252, -5784, -1076, 4300, 166, -1617, 1457, -818, -2920, 2272, 3647, -2421, -3387, 2425, 2619, -1664, -2508,
1490, 3187, -1872, -4128, 3289, 4684, -3227, -5267, 2637, 5433, -1262, -5407, -611, 5662, 1357, -5862, 150,
4314, -1751, -2739, 3630, 857, -4900, 928, 5572, -996, -5797, 981, 6236, -517, -6300, 235, 5755, -1452, -5192,
1647, 4903, -2228, -4458, 2324, 4834, -1794, -5562, 791, 6306, 1025, -6152, -2753, 4955, 3110, -2853, -3151,
451, 2086, 1017, -1371, -1279, 503, 100, -148, 1238, 94, -2603, -101, 2907, -124, -2741, -32, 2390, 460, -1895,
-1281, 1688, 3192, -1591, -4632, 691, 5152, 420, -4504, -1123, 3305, 2382, -1993, -3041, 1175, 3488, -1393,
-3599, 1370, 3864, -684, -3870, -273, 3905, 1527, -3260, -1575, 2428, 1775, -1198, -1489, 695, 1503, -261,
-1548, 215, 1757
Timestamp, RcmRangeInfo, MessageId, ResponderId, RangeStatus, ReqAntennaMode, RespAntennaMode,
StopwatchTime, PrecisionRangeMm, CoarseRangeMm, FilteredRangeMm, PrecisionRangeErrEstMm,
CoarseRangeErrEstMm, FilteredRangeErrEstMm, FilteredRangeVelocityMmPerSec,
FilteredRangeVelocityMmPerSecErrEst, RangeMeasurementType, ReqLEDFlags, RespLEDFlags,
ChannelRiseTime, Vpeak, CoarseTOFInBins, Timestamp
1338055424.172, RcmRangeInfo, 14621, 102, 0, 0, 0, 20, 3763, 3763, 3763, 55, 55, 3, -1, 322, PCF, 8, 8, 1,
42824, 14254, 144123
```

Fig. D-1: Example RangeNet logfile format

Appendix E: Noise, Signal, and SNR

The SNR reported by the RangeNet GUI is based on an estimate of the signal and noise made by the P4xx and reported through the API. SNR is 20*Log10(Vpeak/Noise) where Vpeak is a measure of the largest signal near the leading edge of the scan and noise is an estimate of the noise prior to the leading edge. Note that the Noise and Vpeak values reported by the P4xx are scaled. These numbers are scaled identically. To get the unscaled values, multiply the value returned by the Scan Info message and multiply by (2^pii)/256. While both of these estimates are close, neither estimate is exact. Consequently the measure of SNR is close, but not exact.

First, SNR is actually computed from the scan measured during waveform generation after the receiver has acquired lock. Given that, SNR is not the SNR the radio sees when it acquires, but rather the SNR it sees during the waveform scan. However, these SNRs are believed to be close to each other.

Noise and Signal are also imperfect estimates in the following senses. For example, the “proper” way of calculating noise might be based on computing the standard deviation of the N readings which occur prior to the leading edge. For processor computation reasons a much simpler estimation process was used. This noise estimate has proven to be adequate and we believe it is within 1-2 dB of being accurate. In addition, Vpeak is the magnitude of the absolute value of the largest lobe. However, if the radio is not locked on the largest lobe then the receiver will be experiencing a smaller magnitude signal. In those cases, the SNR reported can be a few dB higher than the SNR which the receiver is actually experiencing.

As a practical matter this SNR estimation process has proved to be a useful and repeatable (if slightly inaccurate) tool for describing radio performance. Users wishing more exact estimates of SNR can log scan waveforms and develop custom algorithms that yield more accurate results.

There is one additional complication to consider. The 170330 release (RangeNet 2.1) enables P440s (but not earlier platforms) to use an FFT during the process of converting a waveform scan into a range reading. The FFT improves the SNR of the reading by 6 or more dB and thereby improves the accuracy of the range measurement while also decreasing the probability that the range reading reported is an outlier.

The FFT only affects the waveform scan and range measurement process but does not benefit the acquisition process at all. In particular, the FFT improves the SNR primarily by reducing the system noise.

However, SNR is also used as a metric of link performance. More specifically, many users rely on SNR as a means to judge how far the system will operate. Therefore, using SNR based on the FFT will add confusion to anyone or any process that uses SNR to judge link performance.

This confusion has been eliminated through a mathematical compromise. If the FFT is used then:

- The waveform scans reported by the system are shown using the FFT.
- The noise value reported through the API is reported with an adjustment that effectively returns the noise value to the value prior to the FFT. While this adjustment is not perfect, testing has shown that the adjustment is accurate to less than 1dB.

Appendix F: CRE Demonstration Exercise

This appendix describes how the operation of CREs can be demonstrated.

Consider a system of 3 radios numbered 100, 101, and 102. Let us assume that unit 100 ranges to 101 and that 101 ranges to 100. In each of these cases, the requester will send a request packet to the other radio and the responder will echo back a response packet. While this is occurring, unit 102 will receive all 4 packets. The signal strength of each of these packets will be measured by 102. If unit 102 has previously ranged to either unit 100 or 101, then those PRMs will be used to calibrate the signal strength of each of the received packets. This calibrated signal strength will be reported as a CRE.

To demonstrate this, perform the following steps:

1. Set up a system of 3 nodes (numbered 100, 101, and 102) with each connected to the Host computer via RangeNet and confirm that each unit can range to the other successfully.

2. Set them up such that they are not in compression and that they are in clear line-of-sight environments. Units in compression or not in line-of-sight will NOT generate CREs. This can be accomplished either by setting them up with about 5 meters separation between each unit or by adding 10-20 dB of attenuation between the antennas and SMA connectors. When you range you can confirm that the units are not in compression or in non-line-of-sight conditions by monitoring the Leading Edge Detection Flags on the Ranging Tab. Values other than 0x8 indicate an issue that will prevent CREs from being generated.

3. Ensure that the following settings are properly set:

    a. Confirm that each unit's CRE Ranges box (located on the Configuration Tab) is checked.
    b. Confirm that each unit's Range Type (located on the Ranging Tab) is set to FREs.
    c. Confirm that the units are separated by not more than 100 meters.

    If these setting are not properly set, then CREs will NOT be produced.

4. Set up all three units such that they will send only 1 range request each time the Send button is clicked. At this point you should have 3 copies of RangeNet running simultaneously such that you can monitor and control the Ranging tab of each unit.

5. Observe the Statistics block on unit 102 while you send a range request from unit 100 to 101. You will notice that each time you issue a range request, unit 102 will update the statistics indicating that it received a packet. If you look closely you may observe that it actually receives and displays information first from the 100 requester packet and a fraction of a second later from the 101. This demonstrates that the 102 is receiving packets. However, because 102 has not yet measured the range to either 100 or 101 it is unable to calibrate the received signal strength and generate a range measurement.

6. Repeat this process a few times and notice that the CRE measurement reported at 102 is stable and reliable. Note that the accuracy is also reasonably good. It might not be as good as a PRM but it will be adequate for may applications.

7. Range from Unit 102 to 101. This will generate a reference measurement.

8. Range from Unit 100 to 101. The response packet sent from 101 to 100 will be received at 102 (as well as at 101). Since 102 has successfully ranged to 101 a calibration reference value exists and the P4xx is able to generate a CRE. This measurement is reported on the Ranging tab. See **Figure F-1** for an example. Note that the CRE value is reported in Blue.

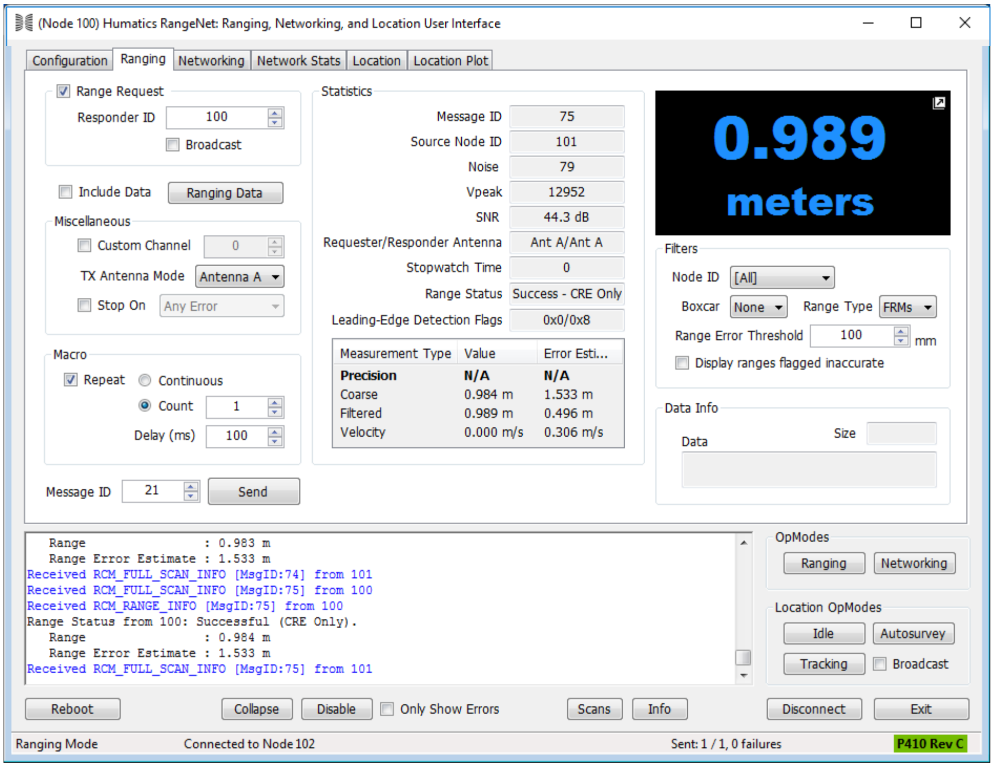

Fig. F-1: Example received CRE

9. Next range from 102 to 100. This will capture a calibration range measurement for any packet received from 100. Repeat for 100 to 102 and 101 to 102.

10. If you now range from 100 to 101 you will:

    a. Generate a PRM from 100 to 101.
    b. A CRE from 101 measured at 100
    c. A CRE from 100 measured at 102
    d. A CRE from 101 measured at 102.

    If you have several units operating in the area and they have all previously ranged to each other, then a few PRMs will generate a huge number of CREs. Using this approach you can flood the system with range measurements and thereby increase the system ranging capacity.

Appendix G: Maximizing Location Performance

Location performance is a function of many factors including range measurement accuracy, range measurement bias errors, Anchor placement, geometry, update rate, and other physical phenomenon. These and other factors will be discussed in this section. It is also true that performance is a function of the end application requirements. What is considered acceptable performance in one situation might not pass in another application. Therefore, this discussion will focus on the physical and operational factors to be considered (however minor) and let the user consider these effects in the context of the target application.

The following topics will be discussed:

- Definition of Performance Metrics
- Range Error Sources
    - Repeatability and Accuracy
    - Bad measurements
    - Compression
- Placement Issues
    - Partial blockages
    - Antenna placement
    - Anchor and Mobile locations
- GDOP Errors
- Survey Error
- Latency Error
- Acceleration Error

In addition, general guidelines for setting up of Anchors and Mobiles can be found in **Section 11.4.1 - Autosurvey Prerequisite Steps**.

G.1 Definition of Performance Metrics

The definition of performance metrics is sometimes a function of the industry with which the user is most familiar. So, it is worth a moment or two to discuss the various terms used to define performance like precision, repeatability, bias, offset, zero and accuracy.

Precision is a measure of how much a measurement will vary from one reading to the next assuming that no other changes occur. Repeatability takes into consideration how changes, like hysteresis, might affect the readings. Since there are no measurable hysteresis-like effects with UWB transmissions, precision has the same meaning as repeatability. Both are measured in 1 standard deviation. TDSR has standardized on the term repeatability.

Bias, offset, zero and accuracy all relate to the difference between the reported measure and truth when the repeatability is perfectly 0. Of these several terms, TDSR has standardized on the term accuracy.

The following graphic illustrates how repeatability and accuracy are defined. **Figure G-1** shows the results of three hunters at target practice.

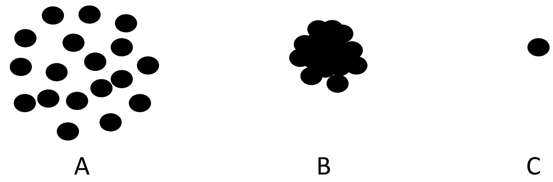

Fig. G-1: Example of Repeatability (Precision)

In this example, each hunter fired 18 times and Hunter C was clearly the best shot. All of his shots were in the same place. One could confirm this mathematically by measuring the standard deviation of the distance of each bullet hole to the mean hole position. If the standard deviation or repeatability determines the winner, then in this case the winner would be Hunter C.

But repeatability is not the only metric. One must also consider the repeatability of the shot pattern relative to the actual target. The shot pattern and target size (shown in blue) is shown in **Figure G-2.**

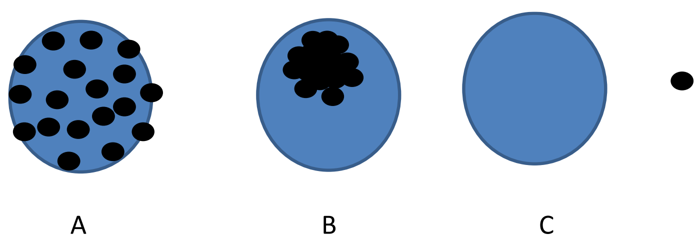

Fig. G-2: Accuracy (bias, zero, or offset) is the difference between the mean of the shot pattern and the actual true location.

In this case Hunter C has a problem with accuracy. If this accuracy error could be calibrated out, then he would be the best shot. In this case the result is likely a draw between Hunters A and B. Hunter A is almost perfectly accurate, but has high standard deviation (low repeatability) while Hunter B has better repeatability but a non-trivial accuracy.

These definitions are worth remembering both when evaluating data sheet specifications, range measurement accuracy and location measurement accuracy.

G.2 Range Error Sources

G.2.1 Range Measurement Repeatability and Accuracy

Range measurement accuracy is a function of both repeatability and accuracy. The repeatability (precision) of the P400 series of units is largely determined by the quality of the algorithm which measures the first arriving energy. The most recent releases of that algorithm are substantially better than earlier versions and as a result demonstrate better performance. While the P400 specification sheets normally show repeatability of about 20 mm, future releases will likely hold the precision errors to less than 5 mm on a consistent basis.

The accuracy (bias) error of a P400 is fixed and can be calibrated out. The lower limit of what is achievable through calibration is set by the repeatability of readings that are taken. In other words, if the repeatability is 5 mm then the best accuracy (bias) error one can hope for is 5/2 mm.

There is an exception to this rule. To the degree that the probability distribution of the range measurements is Gaussian, it is possible to use averaging to reduce the standard deviation (repeatability). Given that fact and assuming a very good calibration method, then it should be possible for the overall accuracy to be limited by the repeatability.

Since repeatability is a function of the software release (and not the native hardware), all members of the P400 family have approximately the same repeatability. The accuracy (bias) does not vary greatly across a given radio type, but there is some variation from type to type. Furthermore, the P440s have been factory calibrated such that they will typically have bias errors less than 2 cm. (Note that this will be the case if you are using the unit with a standard Broadspec antenna and right angle SMA connector.) Older types will have significantly more variation.

For procedures on how to remove the bias, see **Appendix C: Calibrating Ranging Bias**.

G.2.2 Bad Range Measurements

The key to good range measurements is a robust Leading Edge Detection (LED) algorithm. However, no algorithm is perfect and one can expect that the unit will occasionally report grossly inaccurate range readings. While this happens infrequently, most location measurement applications generate so many readings that anomalous range readings are inevitable. To guard against this, TDSR produces range quality flags and, on the basis of the shape of the received waveform, provides an estimate of the error in the readings. Range readings that have warning flags set or have very large estimates of error should be ignored. While this helps, it does not completely solve the problem and the user must be aware that odd readings can sometimes slip through.

G.2.3 Compression

If the radios are placed too close to each other, then transmissions from one unit will tend to overdrive the receiver of the other unit. This is called compression and when this occurs it will change the bias of the range measurement by a few centimeters. The user can expect units to be in compression at separation distances of less than 3-5 meters. The shorter the separation distance, the greater the effect will be. Fortunately this effect is of little importance in most applications because the Anchors are normally placed at some elevation and all units are well separated. The main exception to this rule is the case where the user is testing or demonstrating operation of the system in a small room. In this case compression will result in inaccurate computation of locations.

When operating a system, the user should monitor the quality flags. In particular, one of these flag bits will warn that the unit is in compression.

While compression is a relatively infrequent occurrence, it is sufficiently common that future releases of software will include a compensation mechanism that minimizes this problem.

G.3 Placement Issues

G.3.1 Partial Blockages

The very best ranging performance occurs in clear line-of-sight situations, where the only path between the transmitter and the receiver is the direct path. Sometimes the direct path is blocked by a stationary or moving object. For example, a person could walk between the two units such that the direct path is blocked. In this case, the transmission will probably diffract around the person and yield a perfectly reasonable range measurement. However, because the energy diffracted around the person, the range reported will be slightly longer than the direct path and therefore introduce an error.

Similarly, the path could be entirely blocked by a partially RF transparent wall. If so, then the path length will be a function of how fast the RF energy moved through the wall and how it may have changed the shape of the waveform. Any delays in time or changes in shape will affect the range measurements.

Sometimes the direct path is completely blocked and yet the signal will find a way to bounce through the environment and reach the receiver. In this case the range reported will match the length of the path travelled and not the direct path.

G.3.2 Antenna Placement

Antennas should be mounted at least 30-50 cm from any sizable reflector of RF energy. If the antenna is placed closer than this, then the antenna will receive the sum of the direct path energy plus any energy which bounces off of the reflector. If that reflected energy arrives out of phase with the direct path, there will be cancellation. If there is sufficient cancellation, then the accuracy of the range measurements will suffer. While antenna placement is generally not a concern, it is critical if the user is trying to localize to less than a few centimeters.

G.3.3 Anchor and Mobile Placement

When placing Anchors and operating Mobiles, it is not a good practice to operate the Mobile on the same plane as the Anchors. For example, if the biases are such that all range readings are a bit short, then it will not be possible to calculate a location from the measured ranges. The system will work best when the angle between two Anchors and a Mobile is approximately 90 degrees. See **Figure G-3** for an illustration. While 90 degrees is ideal, anything more than about 30 degrees will give good results.

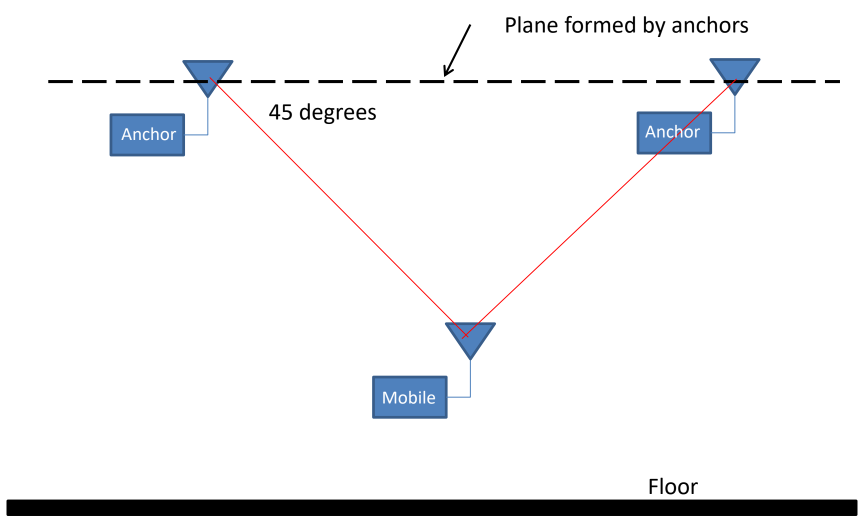

Fig. G-3: Anchors and Mobiles should not be on the same plane

It is also a bad practice to place the Anchors in a straight line or closer to each other than to the Mobiles. For example, the ideal 3 Anchor configuration is an equilateral triangle and the ideal 4 Anchor configuration is a square. Ideal location performance will be achieved in the geometric center of the triangle or square. While those are the ideal locations, performance anywhere inside the box will be very good. Performance outside the box will slowly degrade until at some point it becomes unacceptable. An explanation of why this is the case is provided in the following section.

G.4 GDOP Errors

While GDOP (Geometric Dilution of Precision) isn't actually a range measurement error source, this phenomenon is often the most significant component to error in localization systems which otherwise have good line-of-sight coverage and good geometry. GDOP amplifies the range error when forming a 2D or 3D solution. GDOP is best (a value of 1.0) when the Mobile is in an ideal central location in the middle of the Anchors. At this location the localization error is identical to the ranging error (TotalError = RangeError*GDOP). Anywhere else GDOP will grow, reflecting a growth in error in the cross-axis (the perpendicular to the line connecting the Mobile and the centroid of the Anchors).

For example consider the system of Anchors (blue) and Mobiles (Red) shown in **Figure G-4**. Hopefully, it is intuitively clear that any range errors experienced by Mobile B will tend to magnify errors in the computation of location. This effect is minimized in the case of Mobile A because it is in the middle of the Anchors.

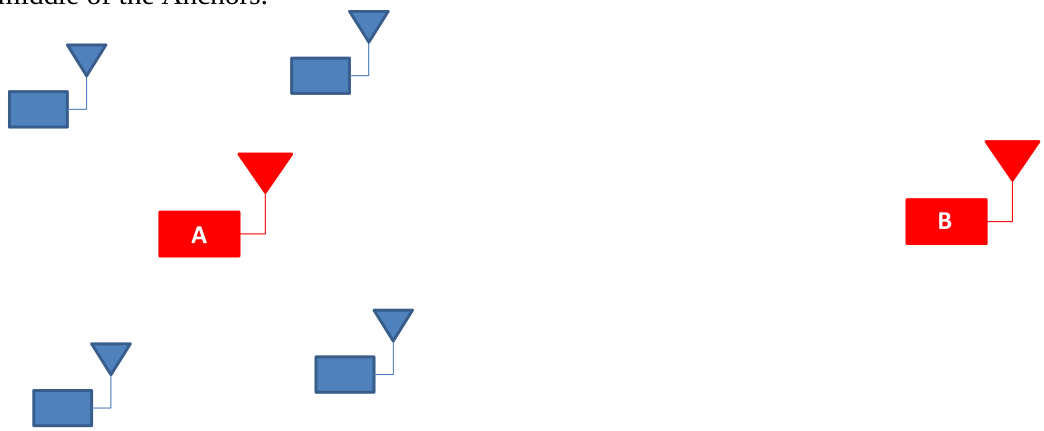

Fig. G-4: Given the same ranging accuracy performance, Mobile A will be able to compute its location with more accuracy than Mobile B.

A GDOP estimate is reported by the RangeNet Location Engine and used by the Engine to determine whether or not the computed location value is valid. If it isn't valid, then the Engine will reset.

G.5 Survey Errors

The Location Engine combines distance measurements to Anchors at "known locations" to compute location of a Mobile. If there is an error in these "known locations" then this error will be propagated to the location solution. It will appear as an instantaneous range bias error in the direction of the Anchor. For example, if the polygon described by the Anchors is artificially small, then a centralized Mobile will jump away from each Anchor with each range update, just as if each range measurement had a small positive bias. In addition, for 2D systems, the Mobile height is an assumed (measured) constant. Since the Mobile "snaps to" this assumed height, any error in the prerequisite height assumption will manifest as a horizontal error in the xy plane.

G.6 Latency Errors

The Location Engine computes a new location with each new range measurement. If the Mobile is moving faster than the system update rate can support then the Mobile solution will appear "behind" its true location.

G.7 Acceleration Errors

This error is similar to latency errors described previously. The Kalman solver in the Location Engine blends each range measurement in a filter. This filter averages ranges together and assumes a constant velocity. When acceleration occurs, the filter requires an extended number of measurements to recompute its velocity (speed and direction). Acceleration can take the form of speeding up, stopping, or changing course left or right. A quick reversal of forward motion is an easy way to induce the most acceleration on the Mobile and cause the most error in the form of "overshoot". This is a common phenomenon in all localization systems. A user-configurable parameter called "KalmanSigmaAccel" (KSA) has been provided which can be adjusted based on the user's assumption of how fast the Mobile will accelerate. Mobiles with lots of inertia (vehicles) typically have a low KSA factor, and Mobiles with very little inertia (hand held) will need a higher KSA factor. By default, this factor has been set to a value in between.

Slowly approaching a Waypoint before stopping will reduce this effect.

Also, this explains why accelerometers are an ideal fusion sensor for UWB localization. Fusing accelerometers with UWB ranging effectively corrects the underlying constant velocity assumption. A tag with accelerometer fusion would be more accurate in the face of accelerations, or allow for slower ranging rate. Slower ranging rate allows more Mobiles to share the same number of Anchors thereby increasing capacity. However, the velocity assumption helps when the Mobile is moving but adds error when it's static. In any event, even an inexpensive MEMS accelerometer, fused in the Kalman solution, would reduce the velocity estimation error caused by noisy ranges and improve accuracy during precision static conditions as well.