AN1364: Using the Wi-SUN Network Performance Measurement Application

The Wi-SUN Network Performance Measurement Application provides a simple tool for testing Silicon Labs Wi-SUN FAN (Wireless Smart Ubiquitous Network, Field Area Network) stack performance. Using the IPv6 ping capability, the application can trigger round-trip latency tests within a Wi-SUN mesh network. It provides information about the packet error rate, Routing Protocol for Low-Power and Lossy Networks (RPL) routing metrics, average ping latencies with different neighbors, and more. To do so, the application exposes two interfaces: a Command Line Interface (CLI) and the WSTK mainboard LCD screen.

The Wi-SUN FAN stack is supported on the EFR32FG12 and EFR32MG12 devices. The radio boards used have to support one of the sub-GHz bands.

**KEY POINTS**
- Presents the Wi-SUN Network Measurement application capabilities.
- Introduces the LCD screen interface.
- Introduces the CLI interface.
- Provides guidelines to improve the ping latency in a Wi-SUN network.
1 Introduction

Silicon Labs recommends that you review QSG181: Silicon Labs Wi-SUN SDK QuickStart Guide to familiarize yourself with the Silicon Labs Wi-SUN stack and Simplicity Studio 5 before reading this document.

The following features are provided as part of the Wi-SUN Network Performance Measurement application:

- Transmits pings and receives pong replies.
- Computes ping latencies.
- Configures the number of pings to be sent during a test.
- Configures the ping payload size.
- Configures the devices to target with the ping packets.
- Provides the minimum, maximum, and average ping latencies on a given test.
- Provides the ping error rate, the MAC-level packet error rate, and RPL metrics.
- Enables access to the previous features through an LCD screen or a CLI. In addition to these features the Wi-SUN Network Performance Measurement application behaves like a standard Wi-SUN router once connected to a Wi-SUN network. During the connection steps, it automatically selects a suitable parent to connect to the network. When connected, it can be selected by another Wi-SUN device to be its parent.

The Wi-SUN Network Performance Measurement application requires you to have at least two WSTK mainboards and two preferably from the following list of matching radio boards:

- brd4163a
- brd4164a
- brd4170a
- brd4172a
- brd4173a
- brd4253a
- brd4254a
2 Theory of Operation

This chapter discusses the operation of the Wi-SUN Network Performance Measurement application independently from the interface. You can execute these either through the CLI or the LCD screen interface. Specific interface information is shared in the following sections.

For the first step you need to create a Wi-SUN network using one of these solutions:

- The Wi-SUN SoC Border Router demo available in the Gecko SDK through Simplicity Studio 5 (for more information, see QSG181: Silicon Labs Wi-SUN SDK QuickStart Guide).
- The Wi-SUN Linux Border Router solution (for more information, see AN1332: Silicon Labs Wi-SUN Network Setup and Configuration).

Follow the steps to get your border router up and running and move to the next chapter.

2.1 Flash the Application

In the Simplicity Studio 5 Launcher perspective, select the EFR32 evaluation kit you want to use to run the Wi-SUN Network Performance Measurement application. In the EXAMPLE PROJECTS & DEMOS panel, find the Wi-SUN - SoC Network Measurement project and click CREATE to add it to your workspace.

Finally, build the wisun_network_measurement project and flash it on the selected EFR32. Refer to QSG181: Silicon Labs Wi-SUN SDK QuickStart Guide for the detailed steps.

2.2 Connect to a Wi-SUN Network

By default, the Wi-SUN Network Performance Measurement application tries to connect to the Wi-SUN Network. If a network with this name and a matching Wi-SUN PHY configuration is available nearby, the Performance Measurement node connects to it using the best parent node available (selected by the RPL routing protocol).

There are two solutions to change the default network name:

- Using Simplicity Studio 5 prior to building the project: open the wisun_network_measurement.slcp file and go to the SOFTWARE COMPONENTS panel. After you select the Wi-SUN/Application/Setting component, you can configure the default connection settings. Under Wi-SUN network configuration, modify the Network Name parameter to match the name of your Wi-SUN network.
- Use the CLI available in the application. (For more information, see chapter 4 Command Line Interface.)

Each EFR32 radio board reference number defaults to a specific Wi-SUN PHY configuration matching its radio capabilities. To change the Wi-SUN PHY used by the project, refer to chapter 4 of UG495: Silicon Labs Wi-SUN Developer’s Guide.

2.3 Start a Ping Test

You can trigger a ping test using either interface of the Wi-SUN Network Performance Measurement application (LCD screen or CLI). The test consists of emitting ping packets on the Wi-SUN network to an IPv6 target (other Wi-SUN nodes or external IPv6 devices). This device replies with pong packets for each ping received. When the pong is received by the Performance Measurement node, the Wi-SUN Network Performance Measurement application computes a round-trip latency on the communication link. During the test, the Wi-SUN Network Performance Measurement application monitors several metrics to provide insights into the Wi-SUN stack behavior.

2.4 Retrieve Test Results

After a ping test has ended, test results are available. They sum up the following information:

- Ping packet loss percentage
- Minimum ping latency in milliseconds
- Maximum ping latency in milliseconds
- Average ping latency in milliseconds

In addition to the ping test results, the Wi-SUN Network Performance Measurement application also monitors metrics associated with the Wi-SUN stack.
2.5 Wi-SUN Metrics

To provide a better understanding on the Wi-SUN stack behavior the stack maintains internal statistics. Once it has, the Wi-SUN Network Performance Measurement application monitors several metrics during the tests:

- Lifetime
- MAC transmission count
- MAC transmission failed
- RPL rank
- Expected Transmission Count (ETX)
- Received Signal Level OUT (RSL out)
- Received Signal Level IN (RSL in)

The metrics are maintained for each neighbor devices in the routed network (that is, the parent and all of the children in the RPL mesh tree). Each metric is described in the following sections.

2.5.1 Lifetime

The lifetime is a counter maintained with each neighbor to evaluate the state of the connection with this device. After each successful unicast communication with the neighbor, the counter is reset to 2200 seconds. When no unicast communication is exchanged with the neighbor, the counter is decreased each second.

2.5.2 MAC Transmission Count

The MAC transmission count (or MAC TX count) represents the number of packets transmitted over the air. A single ping attempt can result in several MAC-level transmission if the first attempts have not been successful. The number also considers packets not related to the ping test itself. Packets routed by the device to its parent and network maintenance related communications also increase this number.

2.5.3 MAC Transmission Failed

The MAC transmit failed (or MAC TX failed) represents the number of unsuccessful transmission attempts. In the Wi-SUN FAN specification, the peer must acknowledge every unicast packet. If a packet is not acknowledged within a given timeout, the transmission is considered failed. The packet is retransmitted by the Wi-SUN stack MAC layer until it reaches the maximum number of transmission attempts.

2.5.4 RPL Rank

The RPL rank represents the rank or hop distance from the tree root (that is, the Wi-SUN border router). For more information, see section 3.5 of RFC 6550.

2.5.5 Expected Transmission Count

The Expected Transmission Count (ETX) is an Exponentially Weighted Moving Average (EWMA) of the number of expected packet transmissions required for error-free reception at destination. The ETX is calculated as (frame transmission attempts)/(received frame acknowledgements) *128 with a maximum value of 1024, where 0 received frame acknowledgments sets ETX to the maximum value. This metric is maintained as part of the RPL protocol (RFC 6550) and participates in the best parent selection.

2.5.6 Received Signal Level OUT

The Received Signal Level out (RSL out) is an EWMA of the received signal level for the node-to-neighbor direction. The RSL is calculated as the received signal level relative to standard thermal noise (290°K) at 1 Hz bandwidth or -174 dBm. This provides a range of -174 (0) to +80 (254) dBm.
2.5.7 Received Signal Level IN

The Received Signal Level in (RSL in) is an EWMA of the received signal level for the neighbor-to-node direction. The RSL is calculated as the received signal level relative to standard thermal noise (290°K) at 1 Hz bandwidth or -174 dBm. This provides a range of -174 (0) to +80 (254) dBm. The RSL in value is communicated through an information element in the Wi-SUN packet exchanges between the device and its neighbor.

2.6 Test Configuration

The Wi-SUN Network Performance Measurement application provides several settings to configure the ping test. The capabilities vary depending on the interface used but some of the configurations are shared:

- **Packet count**: Defines the number of ping packets sent per target during the tests (default value 10). If the test targets the border router and the parent, 10 ping attempts would be sent to the border router followed by 10 attempts targeting the parent.

- **Packet length**: Defines the payload size of the ping packet sent to the targets (default value 40). The size corresponds to the ICMPv6 payload including type field (1 byte), code (1 byte), checksum (2 bytes), identifier (2 bytes), sequence number (2 bytes), and finally data field (dependent on the packet length configuration).

- **Target devices**: Defines which Wi-SUN devices are targeted by the ping test. There are three options:
  - Every known device, that is, the border router, the parent, and the device children
  - The border router
  - The parent

**Note**: If the device running the Wi-SUN Network Performance Measurement application is connected directly to the border router, the parent device and the border router are equivalent.
3 LCD Screen Interface

The first interface that can be used to interact with the Wi-SUN Network Performance Measurement application is the mainboard LCD screen and two push buttons. They provide an easy-to-use interface to configure/start ping tests and consult the test results. The LCD interface can leverage most of the application features with few limitations related to the limited interface it offers (for example, it is not possible to input an IPv6 address to start a test with a "unknown" device).

**Note:** When using the LCD screen interface, keep track of the actions associated with each push button because they can change depending on the context.

3.1 Connection Screen

The Wi-SUN Network Performance Measurement application starts with a connection attempt to the Wi-SUN network configured in the project. The network name is displayed in the upper part of the screen. The connection steps are shown in the lower section (Wi-SUN connection steps 1 to 5 on the LCD screen).

![Figure 3.1. Connection Screen](image)

When the node is successfully connected to the Wi-SUN network, the Wi-SUN Network Performance Measurement application switches the screen to display the main menu.

**Note:** If the Wi-SUN Network Performance Measurement application is stuck in the connection step 1 **Select PAN**, verify the configuration used matches the border router configuration (network name and Wi-SUN PHY used).

3.2 Main Menu

The Network Measurement main menu provides access to the Wi-SUN Network Performance Measurement application main features. Scroll down through the options using push button 1 (**PB1**). Select a sub-menu using **PB0**.
3.3 Node Info Screen

The Node Info screen displays information related to the Wi-SUN device and its configuration (network name, Wi-SUN PHY configuration, TX power, IPV6 addresses, and so on). You can scroll through the information available using PB0.

3.4 Start Test Option

If you select Start Test on the main menu, the Wi-SUN Network Performance Measurement application starts a ping test with the settings previously configured with the other menus. A progress bar indicates the number of ping packets sent over the packet count configured for the test. The test is replicated for each configured target device (border router, parent, and children).
You can stop the test for a given target at any time by pressing PB1. When the tests are completed, pressing PB0 opens the test results display.

3.5 Test Results Display

You can access the Test Results display either after a test or from the main menu. The results are split for each available target. When you select a target, you access its test results, including the ping packet loss and associated percentage, the minimum/maximum/average ping latency, the test settings, and the associated RPL metrics.

3.6 Neighbors Info Screen

The Neighbors Info screen provides access to metrics individualized per neighbor device. This includes the mandatory parent in the Wi-SUN network but also all the potential children using the device to communicate with the rest of the network. The information includes the device IPv6 address and numerous RPL-related metrics.
3.7 Settings Menu

The Settings menu enables you to configure the ping test settings like packet count, packet length, and target devices. In each sub-menu, the currently configured value is displayed in the upper black box. You can select a new value using the two push buttons.

In the following figure, the application packet count is currently configured to 10 packets.

![Figure 3.5. Packet Count Configuration Menu](image)
4 Command Line Interface

The CLI provides an alternative interface to the LCD screen with additional features and test scripting. In addition to exposing a broader API, the CLI enables you to:

- Configure the network name, network size, and TX output power.
- Control the connection state.
- Connect or disconnect the Wi-SUN node.
- Input IPv6 addresses to perform ping tests with devices other than the border router, parent, and children.

The Wi-SUN Network Performance Measurement application leverages the common Wi-SUN application CLI for standard Wi-SUN actions. It adds a specific "measure" command that is able to start ping tests equivalent to the one triggered from the LCD screen interface. You can access the complete list of commands by executing `wisun help` at the command prompt which produces the following result.

```
> wisun help
connect                       Connect to a Wi-SUN network
disconnect                    Disconnect from the Wi-SUN network
set                           Set a variable
[*] empty | help | [string] Key [string] Value
get                           Get a variable
[*] empty | help | [string] Key
save                          Save variables to non-volatile storage
reset                         Reset variables to default settings
measure                       Measure a remote host or quick measurement
    [string] Remote address or 'all' or 'parent' or 'br'
    [uint16] Count of measurement packets
    [uint16] Measurement packet length
ping                          Ping a remote host
    [string] Remote address
```

The Wi-SUN Network Performance Measurement application also maintains settings that you can access by executing `wisun get wisun`. This returns all the settings available in the Wi-SUN CLI component. You can check whether a setting is only readable by executing `wisun get wisun help` or if it can be modified by executing `wisun set wisun` as shown in the following examples.

```
> wisun get wisun help
[rw] wisun.network_name
[rw] wisun.network_size
[rw] wisun.tx_power
[ro] wisun.regulatory_domain
[ro] wisun.operating_class
[ro] wisun.operating_mode
[ro] wisun.connection_state
[ro] wisun.ip_address_global
[ro] wisun.ip_address_link_local
[ro] wisun.ip_address_border_router
```

Similarly, the writable settings are listed when you execute `wisun set wisun help`.

```
> wisun set wisun help
[rw] wisun.network_name
[rw] wisun.network_size
[rw] wisun.tx_power
```

The CLI interface provides a more advanced interface with additional configurations that you can leverage to automate performance testing.
5 Ping Latency Improvement

Using the Wi-SUN Network Performance Measurement application in its default configuration (Lowest speed Wi-SUN PHY, Network size set to small, and default broadcast dwell interval), the ping latency performance is not optimal. This chapter describes ways to optimize the solution ping latency and explains some of the trade-offs associated with the modifications.

5.1 AN1330 Application Note

AN1330: Silicon Labs Wi-SUN Mesh Network Performance reports the ping latency internal tests performed by Silicon Labs in real-world deployments. The tests focus on characterizing the expected Wi-SUN stack latency in point-to-point communications but also in round trip messages travelling over several hops. The tests are performed with the Wi-SUN stack default (non-optimized) configuration using the 50 Kbps North America Wi-SUN PHY. The results provide a good reference point to compare your own test results. Keep in mind that using a different region PHY impacts the results in the following figure.

![Neighbor Ping Latency Histogram](image)

Figure 5.1. Neighbor Ping Latency Histogram

5.2 Wi-SUN PHY Impact

The first critical configuration impacting the ping latency is the Wi-SUN PHY which is used by every device in a Wi-SUN network. A point-to-point ping is composed of four messages over the air. A ping with a payload of 512 bytes triggers 1332 bytes exchanged on the air. It represents approximately 30 milliseconds spent sending messages on the radio medium (see the following figure).
Figure 5.2 512-byte Ping Diagram

The Wi-SUN PHY also impacts the transmissions triggered to manage the Wi-SUN network. Both the speed and number of channels available in the PHY factor into the penalty that is applied to a ping latency sent close to a network management event. The two main time-consuming network management mechanisms are the PAN advertisement and PAN configuration events. For example, a PAN advertisement sent using the 50 kbps North America PHY using 128 channels holds the radio for approximately two seconds (about 15 milliseconds spent on each channel). The PAN advertisement and configuration events explain the periodical delays that can be noticed during a long ping test. Using a Wi-SUN PHY with a higher modulation speed and fewer channels highly reduces the impact of those network management events on the ping latency (for example, 300 kbps North America PHY with 41 channels). The drawback or trade-offs are the effective distance for a good communication between nodes in the network is reduced. Finally, you need to consider how changing the network size setting can affect the network management event intervals (see 5.3 Network Configuration and Size Setting).

In addition to the PHY speed itself, the frequency hopping mechanism and the associated channel switches can delay transmissions of packets to prevent sending a message on a channel change. The default unicast dwell interval is 255 milliseconds.

5.3 Network Configuration and Size Setting

The network configuration plays an integral role in the way packets flow through the Wi-SUN network. These network configurations impact the ping latency:

- The border router broadcast interval defines at which interval a broadcast dwell interval happens. By default, the border router broadcast interval is set to 1 seconds and 20 milliseconds. You can modify it on the border router side. The configuration of the border router broadcast interval propagates throughout the Wi-SUN network and every device part of the network uses the same interval. If an application focuses on unicast messages, Silicon Labs recommends that you increase the border route broadcast interval.
- The broadcast dwell interval defines the time of a broadcast frequency hopping slot (by default, 255 milliseconds equal to the unicast default dwell interval). The longer the broadcast dwell interval, the less time remains for unicast communications. Silicon Labs recommends that you reduce the broadcast dwell interval for a unicast-focused application. You change this configuration on the border router side.
- The network size setting dictates the intervals between network management events among other things. To optimize the ping latency, Silicon Labs recommends that you use the large or medium configuration depending on your network deployment size to increase the network management exchanges interval. Be aware of the potential trade-off with the network connection speed and network configuration update speed.

Considering all the options available for a Wi-SUN solution developer, you can greatly improve the ping latency from the initial results retrieved from the default solution configuration. Keep in mind that every setting change is a trade-off with another Wi-SUN network performance component.
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