Application Note

TI Wi-SUN® Network Performance

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ABSTRACT

This application note presents the results of the TI Wi-SUN® network performance study covering multiple network and stack configurations. This document provides a high-level overview of the Wi-SUN Field Area Network (FAN) stack, in addition to the testing methodology and results. The results are to provide a general guideline on design practices with different network configurations and expected performance in the field.

For more information on APIs and implementation details, refer to the TI Wi-SUN Stack User's Guide and the SIMPLELINK-LOWPOWER-SDK product page.

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Trademarks

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1 Acronyms

Table 1-1. Acronym List

Acronym	Definition
LNT	Large Network Test
Wi-SUN FAN	Wireless Smart Utility Network Field Area Network
IDE	Integrated Development Environment
SDK	Software Development Kit
RTOS	Real Time Operating System
UDP	User Datagram Protocol
RFC	Request for Comments
IOT	Internet of Things
IETF	Internet Engineering Task Force
FAN	Field Area Network
CCS	Code Composer Studio
RN	Router Node
BR	Border Router
PAN	Personal Area Network
GTK	Group Transient Key
PHY	Physical Layer of the OSI model
EAPOL	Extensible Authentication Protocol over LAN
IPv6	Internet Protocol Version 6
IPv4	Internet Protocol Version 4
WAN	Wide Area Network
DLMS/COSEM	Device Language Message Specification and Companion Specification for Energy Metering
CSMA/CA	Carrier-sense Multiple Access with Collision Avoidance

2 Introduction

Wi-SUN is a wireless communication standard aiming to enable large-scale IOT networks in a mesh structure with a network which typically consists of line powered routers and gateways. The Wi-SUN® Alliance has more than 300 members from 46 countries, with 100M+ devices deployed world-wide. The Wi-SUN FAN v1.0 design is based on the open0source IETF RFC components integrated on top of the Wi-SUN compliant TI 15.4 Stack frequency hopping scheme. A network interface model is provided based on an open-source SPINEL interface. Customers typically develop applications on top of IPv6 using UDP as the transport layer. The Wi-SUN FAN Stack adapts the 6LoWPAN, RPL, IPv6, ICMPv6 and UDP layers from open source components. The Wi-SUN FAN v1.0 design is optimized for a small memory footprint to fit embedded devices. Integration and testing of the software stack are done in tagged, certified releases. Texas Instruments has certified multiple FAN profiles with Wi-SUN Alliance to be used on CC13x2x and CC13x4x10 devices. Not every device supports all of the FAN profiles due to constraints of the internal memory. Table 2-1 gives an overview of the supported software and devices at the time of release of this document.

Table 2-1. TI Wi-SUN Support

Component	Version
TI WiSUN FAN	1.0
Distribution	Included in SDK8.30 for CC13x2 and CC13x4 devices as library code
IDE support	Code Composer Studio™ (CCSTUDIO)
Compiler support	TI Clang 2.1 LTS
RTOS support	TI-RTOS, Free RTOS
Supported devices	Border router: CC1312R7, CC1352P7, CC1314R10, CC1354R10, CC1354P10 Router nodes: CC1312R, CC1312PSIP, CC1352R, CC1352P, CC1312R7, CC1352P7 CC1314R10, CC1354R10, CC1354P10

The goal of this application note is to describe the mesh network performance, join speed, and reliability by using CC1312R1, CC1312R7, CC1352R1, CC1354P10-1 to test the performance.

3 Network Configuration

This section describes the different network profiles in a TI Wi-SUN FAN network. Like most wireless networks, Wi-SUN network also has control traffic (routing packets, neighbor discovery, link maintenance, and so forth), which helps form the network, determine routes for data packets and handle broken links. An increased control traffic implies that different protocol layers can have shorter timeouts, leading to a more responsive network. However, the protocol overhead from such control traffic also takes up air time, limiting the maximum available network capacity for application data traffic.

The TI Wi-SUN FAN solution defines three profiles which determine the amount of network control packet overhead. Each profile has a recommended configuration, which can be changed to accommodate for any additional requirements. The profiles are available as a quick selection using SysConfig. Table 3-1 gives a short overview of the difference between each network profile.

Table 3-1. LNT Network Configuration Options

Network Profile	Configuration Brief
Maximize responsiveness	Increased network control packet traffic owing to shorter protocol timeouts.
Balanced mode	Balances network overhead and application traffic compared to other two profiles.
Maximize scalability	Aims to minimize network control traffic per node to provide more overall network capacity at expense of decreased responsiveness per device.

SysConfig can be used to select the desired network profile based on Table 3-1. The change field for each profile can be found under the advanced settings tab, shown in Figure 3-1.

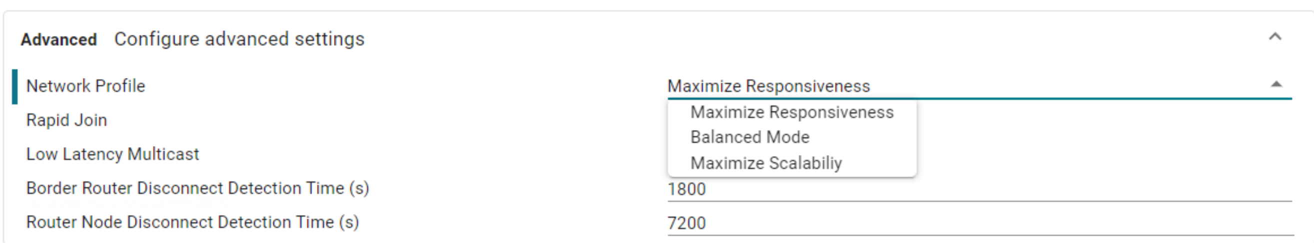


Figure 3-1. SysConfig Network Configuration Setup Menu

4 Wi-SUN FAN and Joining Process

This section of the application note briefly explains the Wi-SUN FAN, by giving an example of a network connection and the process a router node must go through to join the network.

4.1 Wi-SUN FAN

An example of a field area network on a larger scale is shown Figure 4-1. Such a network is used in equipment that requires large scale communication. An example are street lights inside of a city or sensors communicating in a factory.

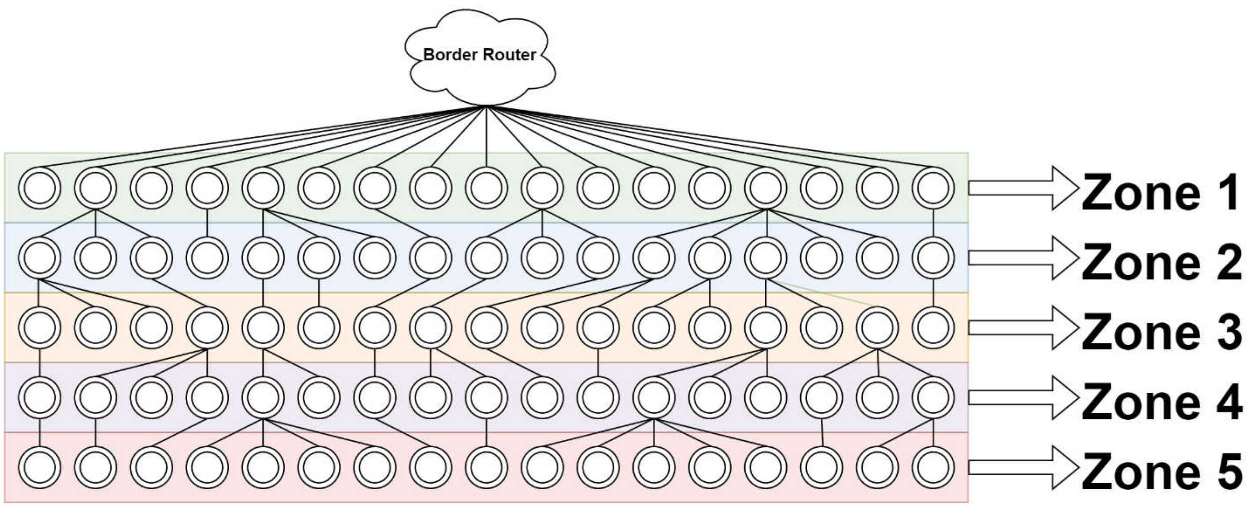


Figure 4-1. Example of a FAN

A FAN is made up of many smaller size personal area networks (PAN). Figure 4-1 shows an example of one PAN distribution with a border router (BR) as the head device for WAN connectivity and many router nodes (RN) as end devices. The BR keeps track of the addresses of all the router nodes within the network and manages routing to them. Each RN provides upward and downward packet forwarding inside the PAN and can be used to add new devices to the network by sharing security and address protocols to a new device. For additional information on the Wi-SUN FAN, refer to TI Wi-SUN FAN.

4.2 Joining Process

Router nodes are able to join the network by sending the PAN advertisement solicit in the area, which allows them to get an image of the networks around. The router node selects the network to join using the PAN ID of the network, which starts the authentication process through the EAPOL layer. Once authenticated, a security exchange is performed, which results in the router node receiving GTKs. Further PAN configuration is done securely, using the GTKs to decrypt incoming configuration messages. With the PAN configuration completed, the router node exchanges routing information with the network. If this is done successfully, then the joining device becomes an operational router node in the network. The joining router node can add new router nodes to the network. Figure 4-2 shows the steps in the process. Each state is explained in more detail in the TI Wi-SUN Stack User's Guide.

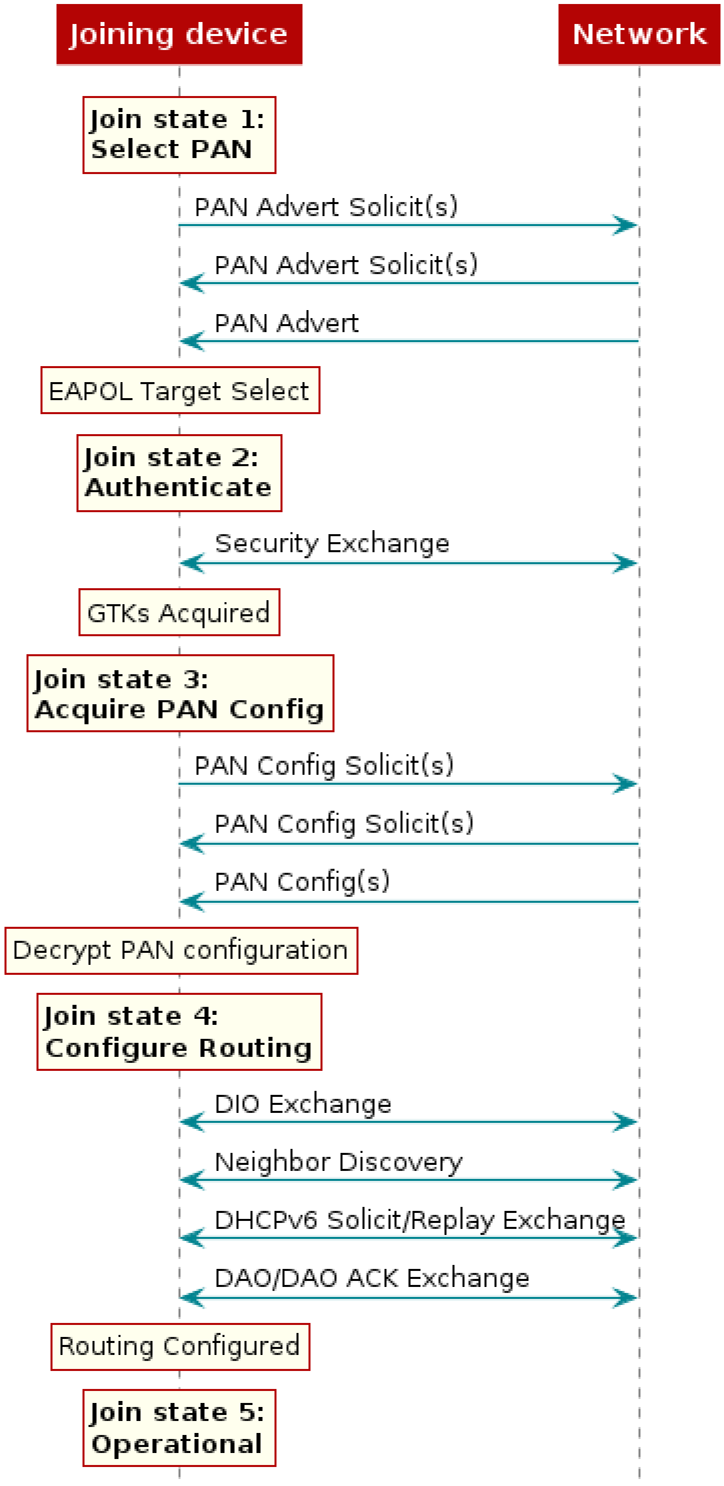


Figure 4-2. Router Node Join Process

5 Test Results

The tests shown in this chapter have been carried out using the SDK version shown in Table 2-1. The board configuration for the measurements can be seen in Figure 5-1.

Figure 5-1. LNT Board Setup

5.1 Join Time - Maximize Responsiveness, Balanced Mode, Maximize Scalability

Join time is the time required for all router nodes to join a new network. The test is carried out using the setup shown in Figure 5-2 for each network configuration. Figure 5-3 plots the number of nodes joined in the network versus the time required to do so.

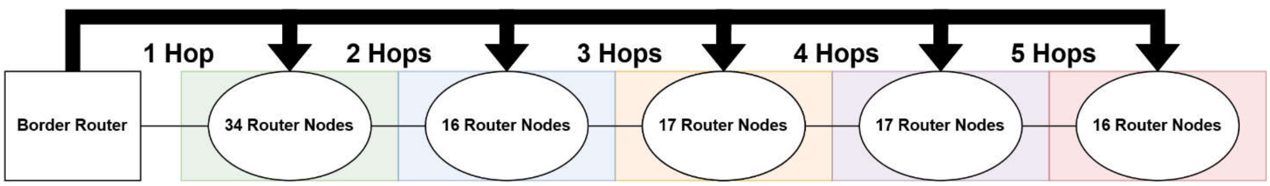


Figure 5-2. Large Network Test Setup

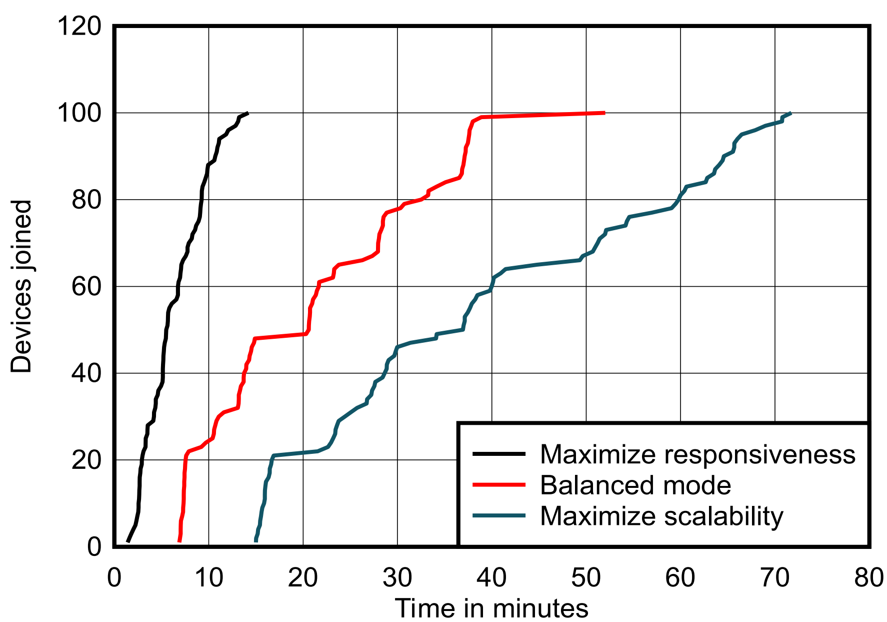


Figure 5-3. Wi-SUN® Join Time for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations (50kbps PHY)

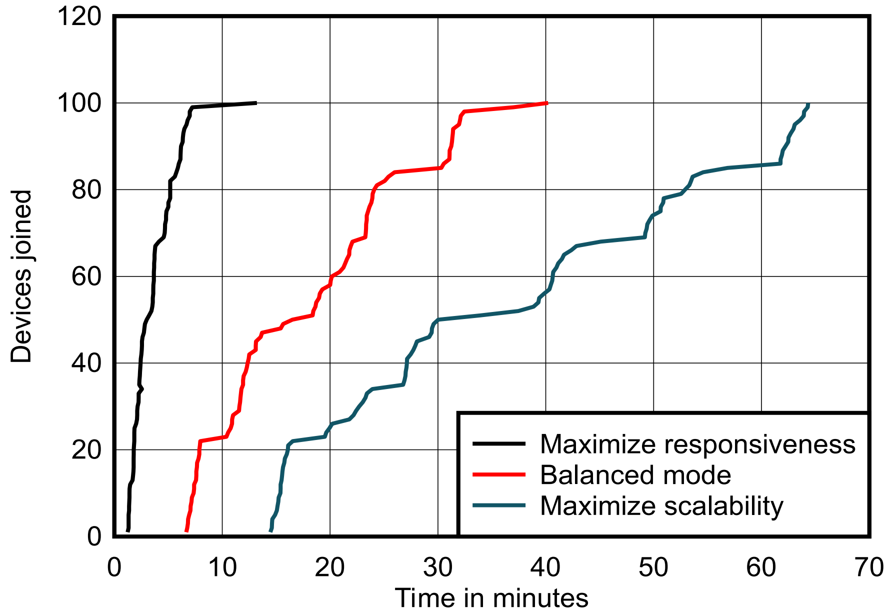


Figure 5-4. Wi-SUN® Join Time for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations (300kbps PHY)

The maximize responsiveness network configuration connects the fastest, which is the expected result based on the definition for each of the configurations in Section 3.

While 300kbps has a lower join time due to higher data rate, this does not provide a significant or proportional reduction. This is expected as the determining factor for the join time are the protocol timer configurations at different layers of the protocol stack.

5.2 Rejoin Time - One Router Node

During operation, disconnect a router node from the network. One router node rejoin time measures the time required for the router node to reconnect back to the PAN. The measurement is done by disconnecting a device in a fully joined network (see Figure 5-5) and is carried over in each network configuration (maximize responsiveness, balanced mode, maximize scalability).

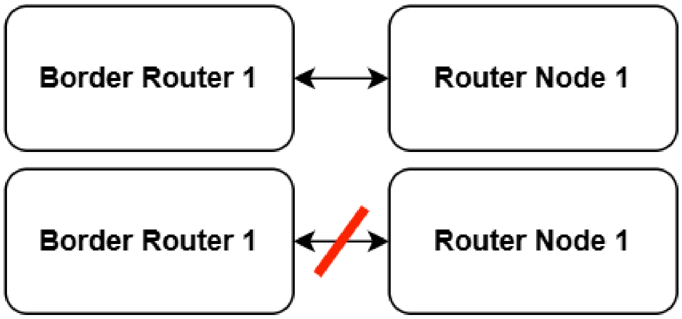


Figure 5-5. One Router Node Rejoin Time Test Diagram

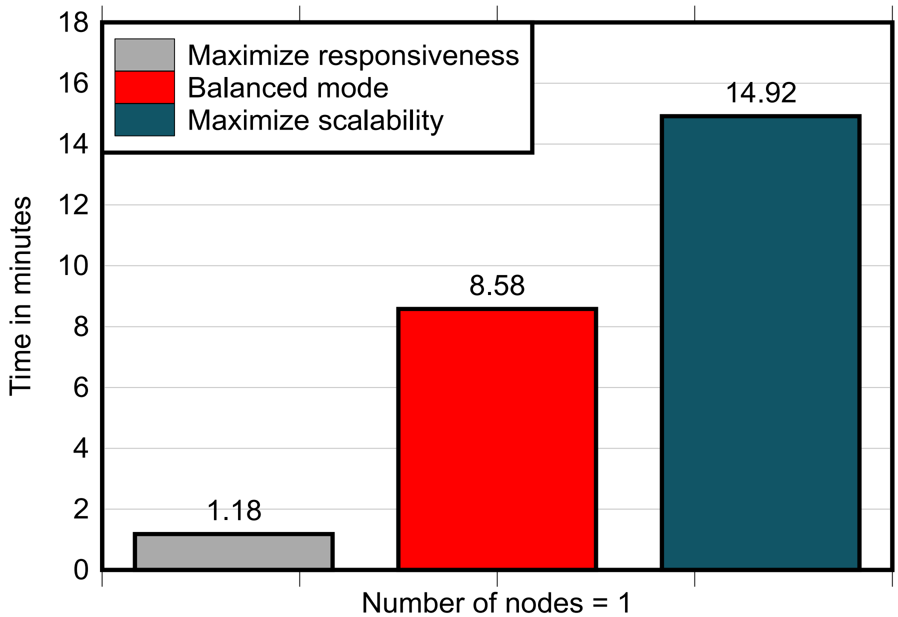


Figure 5-6. One Router Node Rejoin Time for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations

Similar to the join time results, the maximize responsiveness network rejoins the fastest due to the increased number of messages exchanged between the RNs and the BR over a period of time.

5.3 Rejoin Time - Full Network

Similar to the 1RN Rejoin time, the full network rejoin time measures the time for every router node to reconnect back to the border router device. This test is used to simulate a full power down scenario in the field, allowing estimation of the performance in an area where there is an elevated risk of the router nodes losing power. The full network rejoin test uses the same topology as the initial join time tests to avoid any possible changes due to a different network topology. Figure 5-7 shows a diagram of the full network rejoin test. All router nodes are reset and the time to rejoin the network is measured.

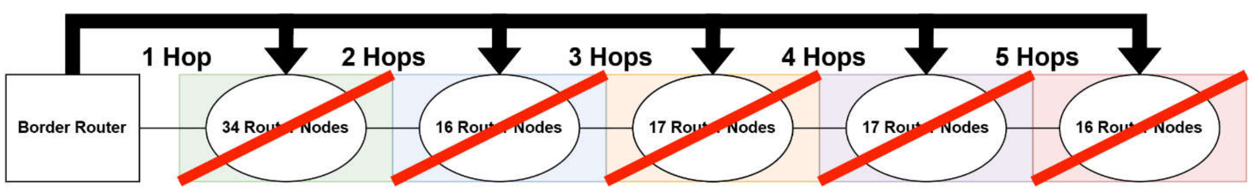


Figure 5-7. Full Network Rejoin Time Test Setup

Figure 5-8 and Figure 5-9 show the rejoin time results using the setup above. The test is run using both a 50kbps and a 300kbps PHY.

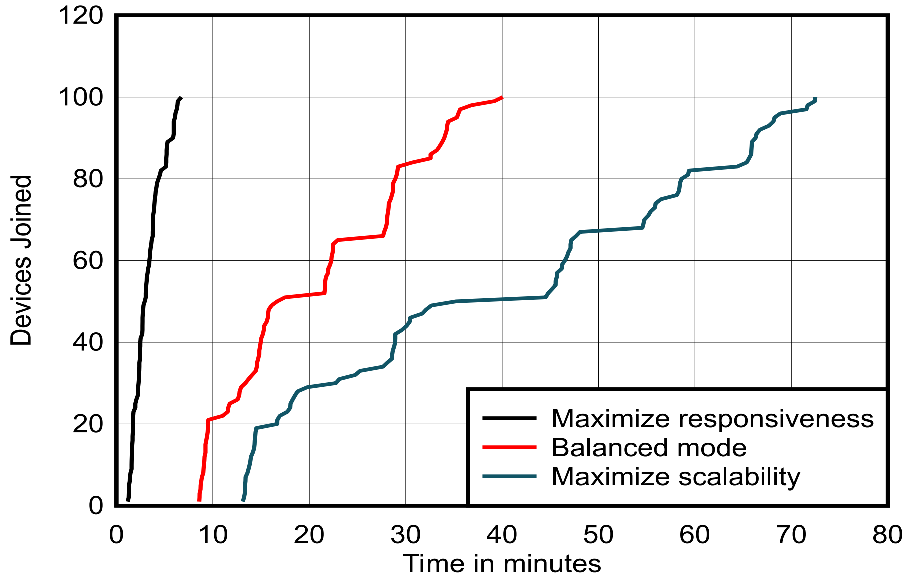


Figure 5-8. Full Network Rejoin Time for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations (50kbps PHY)

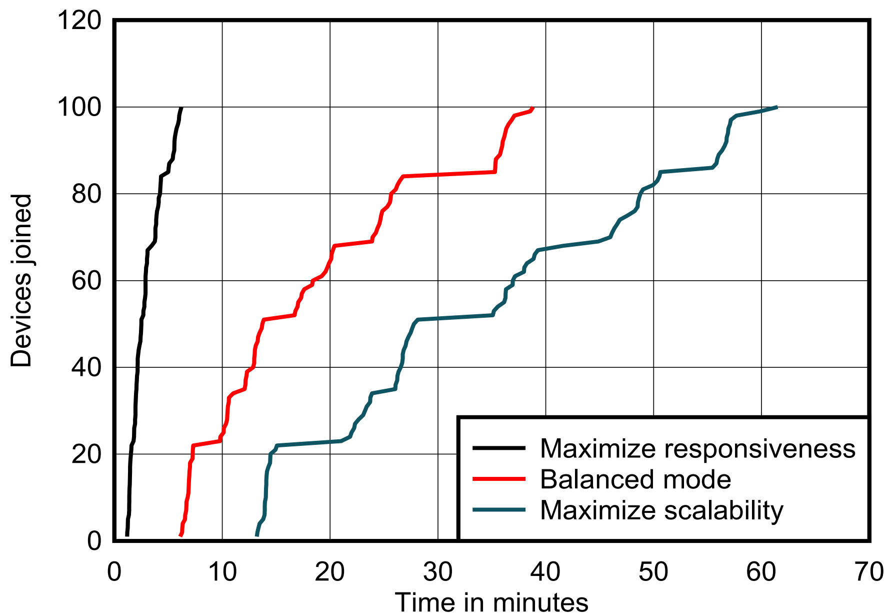


Figure 5-9. Full Network Rejoin Time for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations (300kbps PHY)

Since the router nodes have already been configured during the initial join, the router nodes can retain the configuration and GTKs which makes the rejoin time faster than the initial join time. For *maximize responsiveness* and *balanced mode* configurations, the PHY does not make a big difference as the determining factor is still the protocol timers. However, at *maximize scalability*, since the protocol overhead is low, the protocol timers are no longer the only determining factor and increased data rate provides a noticeable improvement in rejoin time.

5.4 Throughput - Maximize Responsiveness, Balanced Mode, Maximize Scalability

The throughput test is performed using unicast iPerf. Figure 5-11 shows the throughput of different PHYs, using the *maximize responsiveness* network configuration. The test is carried out by sending 1200-byte payload packets for 60 seconds between one router node, connected to a border router, as shown in Figure 5-12.

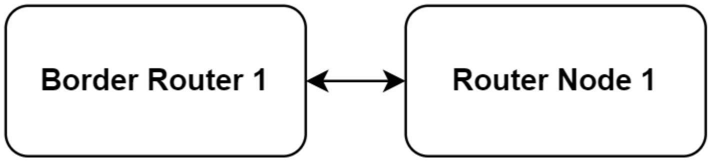


Figure 5-10. One Router Node Throughput Test Diagram

The results for each different PHY in the one router node throughput test can be seen in Figure 5-11.

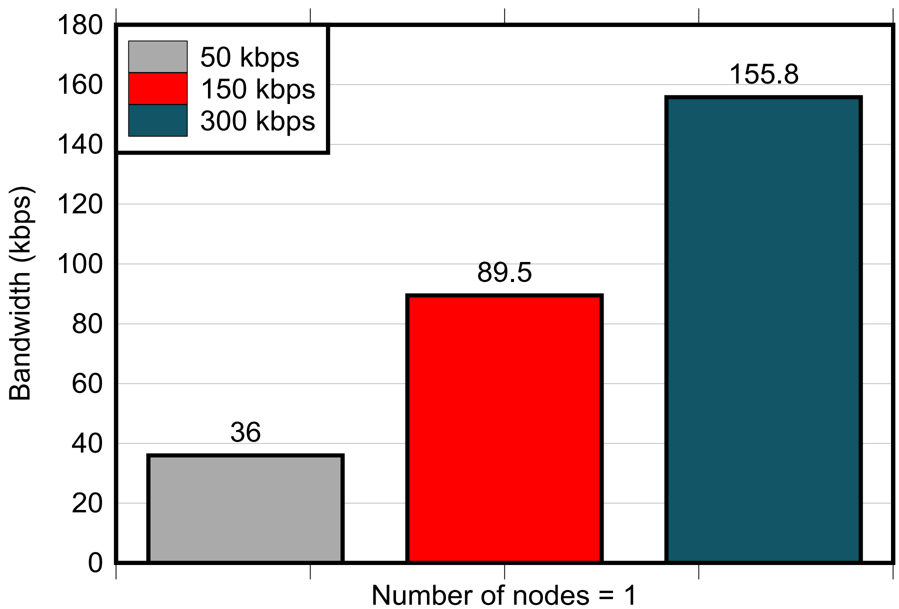
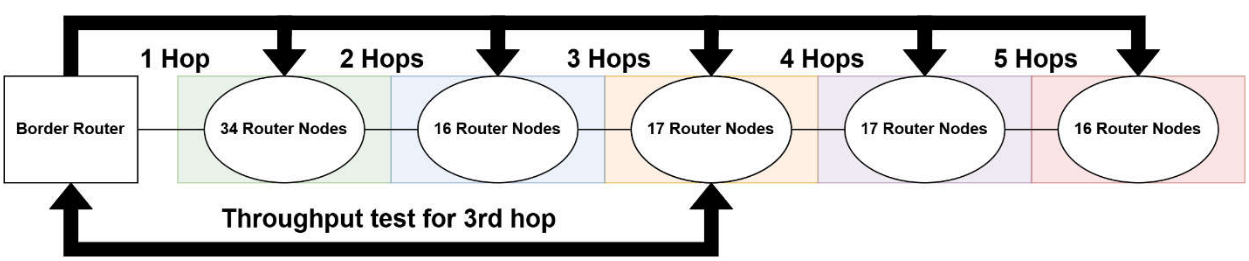


Figure 5-11. One Router Node Throughput Test for 50kbps, 150kbps, 300kbps PHY

Figure 5-11 shows the measured results showing increased throughput for higher data rates as expected. The throughput test is also repeated with large network configuration using the same configuration as the join tests for a given data rate to study impact of throughput for one pair of devices from number of hops and other neighboring devices and is shown in Figure 5-12.



A. The test for the nodes at the 3rd hop is shown as an arrow below the diagram.

Figure 5-12. LNT Throughput Test Configuration

After a full join of the network shown above, the throughput on each hop is tested by selecting three different router nodes from this hop and sending 1200-byte payload packets for 60 seconds between the border router and each node. This increases the maximum throughput until the packet error rate is greater than 2%. The test is repeated for every hop (1-5) and network configuration (maximize responsiveness, balanced mode, maximize scalability). The results are outlined in Figure 5-13.

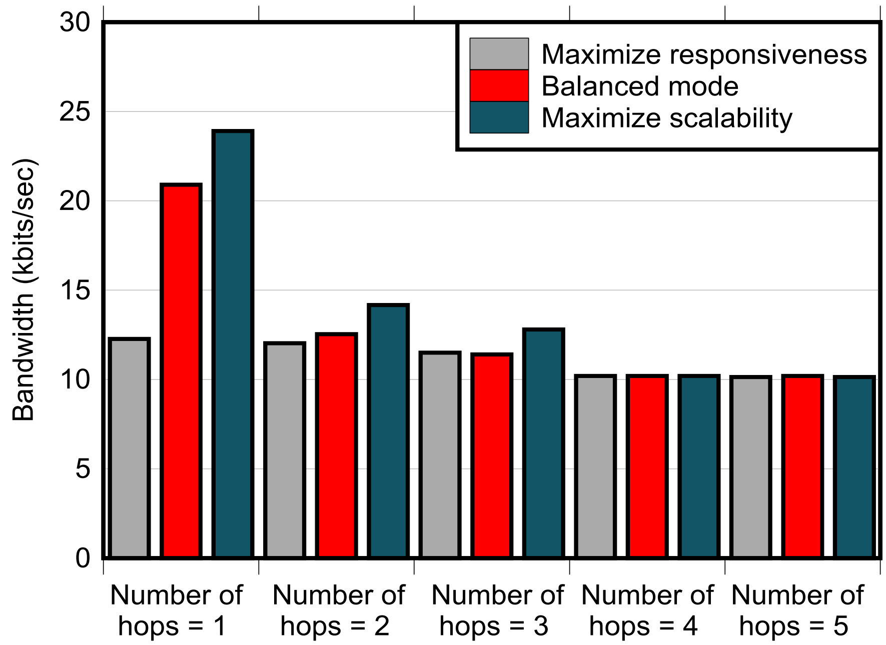


Figure 5-13. LNT Throughput Test for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configuration (50kbps PHY)

The throughput test is performed using unicast iPerf-based traffic, which injects back-to-back UDP packets into the network. In the default TI Wi-SUN configuration, broadcast dwell time and broadcast interval are set to 250ms and 1s, respectively, implying that only 75% of airtime is available for unicast traffic. Considering the 50kbps data rate, this implies a maximum possible network capacity for unicast traffic as 37.5kbps.

For the *maximize scalability* configuration, which has the least control overhead and leaves most of the available bandwidth to *data throughput*, the result throughput is approximately 24kbps. This is 65% of network capacity, as expected for a CSMA based network.

For the *maximize responsiveness* configuration, a data throughput of approximately 12kbps (approximately 33% of available capability) implies that the remaining 32% , which were available in the *maximize scalability* configuration, is taken over by additional network control traffic.

As the number of hops increases, spatial diversity helps increase maximum parallel transmissions compared to total number of hops needed to cross for a given packet.

The frequency hopping scheme in the Wi-SUN stack utilizes the network spectrum in a multihop scenario. Theoretically, if everything else is good and the throughput of a one hop network is *X*, then the throughput of a 2 hop network is ½X (only 1 parallel transmission to cross 2 hops). The throughput of a 3 hop network is also ½X (can be either 1 or 2 parallel link transmissions to cross 3 hops). Similarly, the throughput for 4 hop network and 5 hop network is also ½X.

In the *maximize scalability* configuration, where most of the network capacity is used for application throughput, this pattern is more apparent. For the *maximize responsiveness* and *balanced mode* configurations, the application throughput does not show significant proportional loss for higher hops since the protocol overhead from all nodes in network dominates the overall traffic which scales with additional hops. Throughput tests with other data rates are expected to show similar trends depending on available network capacity.

5.5 BR Detection of RN Disconnection

During the mesh network operation, some router nodes can be disconnected due to power loss, poor signal, or other environmental factors. To understand the time required for the border router to detect this disconnection, Figure 5-14 outlines a test scenario with two router nodes connected to border router 1.

During the test, router node 2 is disconnected. The time for the border router 1 to detect this change is recorded.

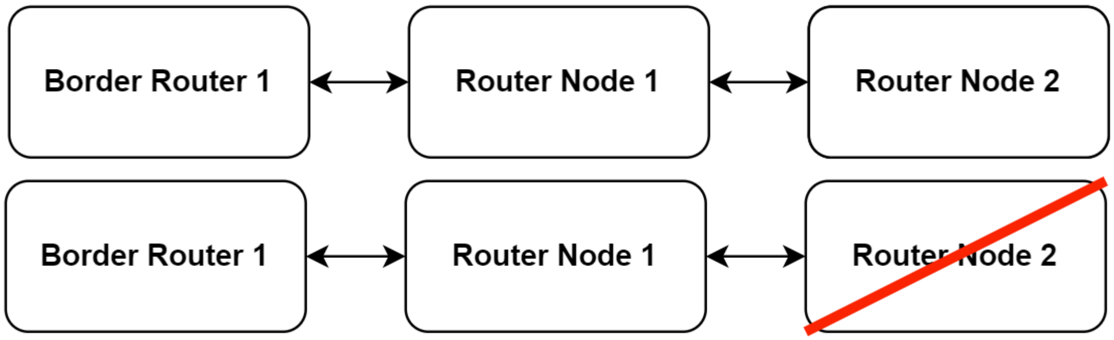


Figure 5-14. BR Detection of RN Disconnection Example Diagram

When using different network configurations, change the BR and RN disconnect detection time by SysConfig as shown in Figure 5-15.

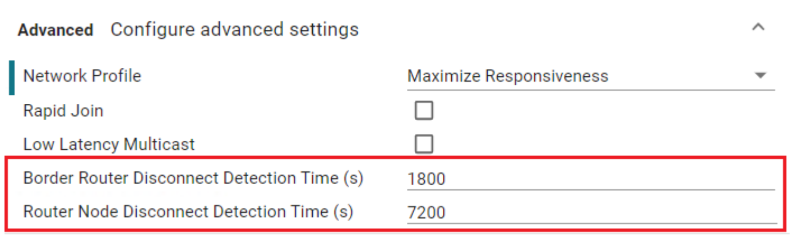


Figure 5-15. Maximize Responsiveness BR and RN Disconnect Detection Time Setting

The default values for each configuration are shown in Table 5-1. These values are chosen to have less impact on the network, but a more responsive detection can be accomplished by either chosing an aggressive route refresh strategy or by other application methods.

Table 5-1. Network Configuration Default Settings For BR and RN Disconnect Detection Time

Network Configuration	Default Router Node Disconnect Detection Time (in Minutes)	Default Border Router Disconnect Detection Time (in Minutes)
Maximize scalability	480	90
Balanced mode	240	60
Maximize responsiveness	120	30

Table 4 outlines the time required for border router 1 to detect the disconnection of router node 2.

Table 5-2. BR Detection of RN Disconnection Times for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations

Network Configuration	Time to Detect Disconnection (in minutes)
Maximize scalability	478
Balanced mode	238
Maximize responsiveness	119

The measured times match the default detection times set in SysConfig for each network profile considering protocol timers and measurement accuracies.

5.6 RN Detection of BR Disconnection

This scenario, similar to the one above, outlines the time required for the router node to detect a disconnection on the border router side and attempt to connect to a different border router with the same network name. Figure 5-16 shows two nodes connected to Border Router 1.

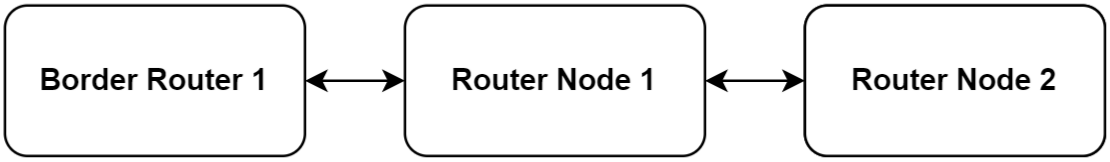


Figure 5-16. RN Detection of BR Disconnection Example: Initial Setup

During the test, Border Router 1 is disconnected. Border Router 2, with the same network name, is turned on. The test measures the time for Router Node 1 to detect this change and adapt accordingly. The process is shown in Figure 5-17.

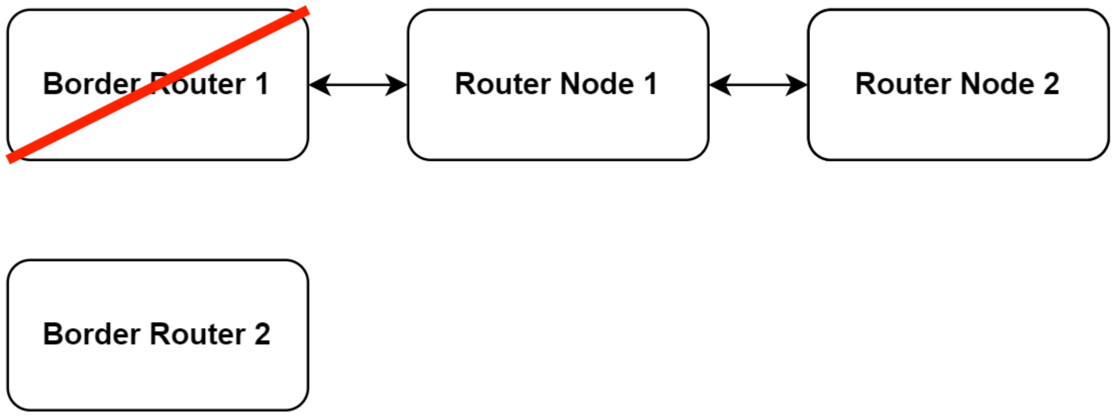


Figure 5-17. RN Detection of BR Disconnection Example: Disconnect BR1 and Connect BR2

Using the same default times for disconnection as shown in Table 3, the time for RN detection of BR disconnection is shown in Table 5-3.

Table 5-3. RN Detection Of BR Disconnection Times for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations

Network Configuration	Time to Detect Disconnection (in Minutes)
Maximize scalability	89
Balanced mode	58
Maximize responsiveness	26

Similar to the BR detection of RN disconnection, the RN detection of BR disconnection matches with the default values set in SysConfig.

6 Latency

Figure 6-1 gives an overview of the average one router node ping latency with error bars, denoting the maximum and minimum latency values recorded during the test. The setup for this test has the BR sending 3600 packets to the RN with a size of 64 bytes; the time for each packet is recorded and the average is plotted.

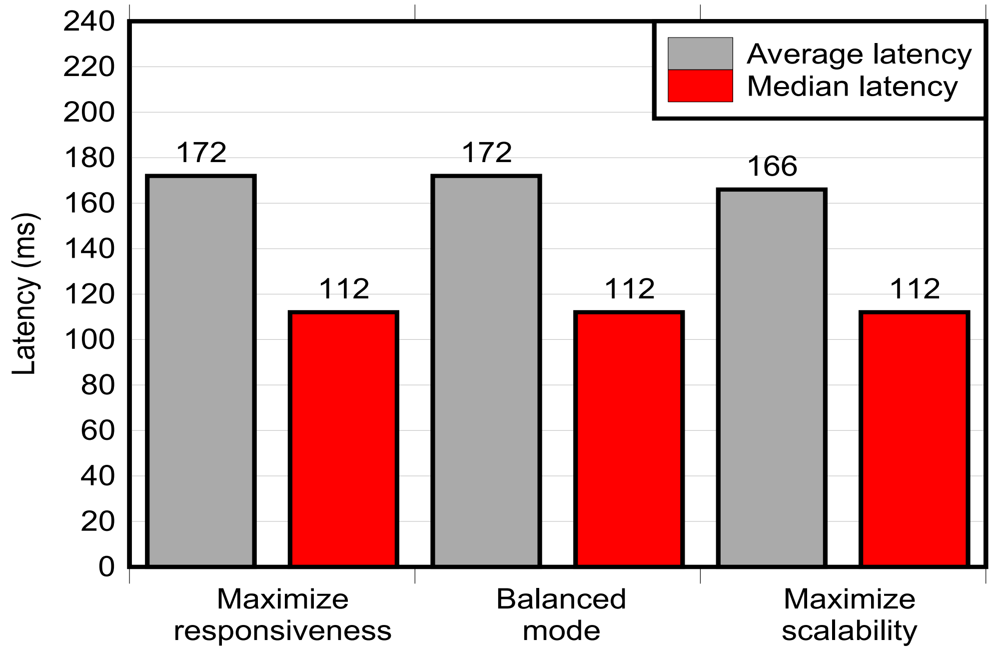


Figure 6-1. One Router Node Ping Latency (in Milliseconds) for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations

The test results show that the change in network configuration does not affect the one node latency by a high margin. The histograms for the latency tests of each network configuration can be found in Section 8.

Figure 6-2 shows the change in latency, measured in milliseconds, in a *maximize responsiveness* network configuration using different PHYs.

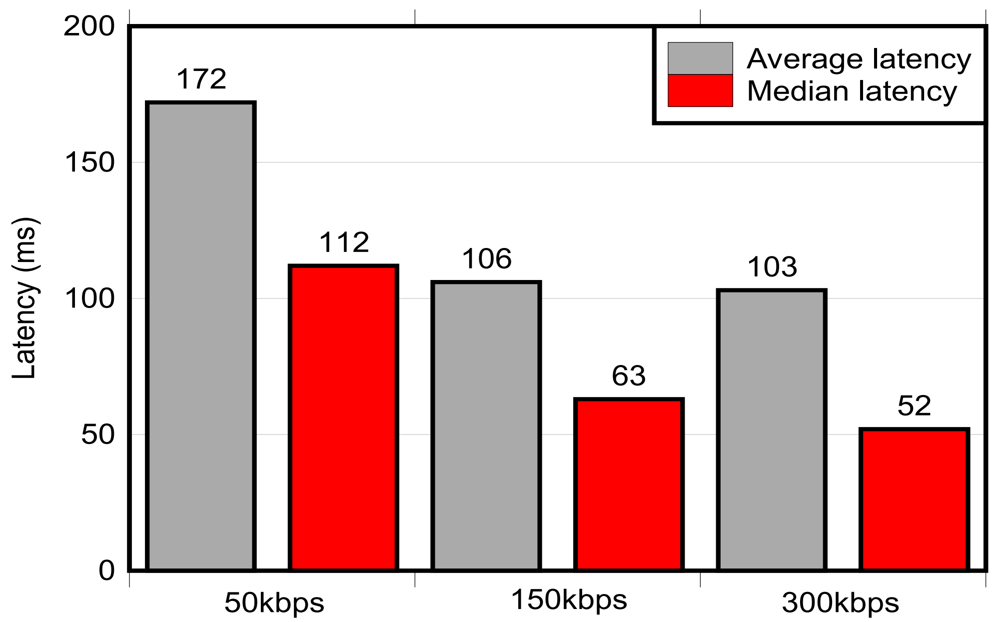


Figure 6-2. One Router Node Ping Latency (in Milliseconds) for Different PHY Configurations Using The Maximize Responsiveness Network Configuration

Note

Increasing the PHY data rate results in a decrease in latency.

Figure 6-3 shows the change in ping time, measured in milliseconds, as the number of intermediate hops is increased by connecting more router nodes.

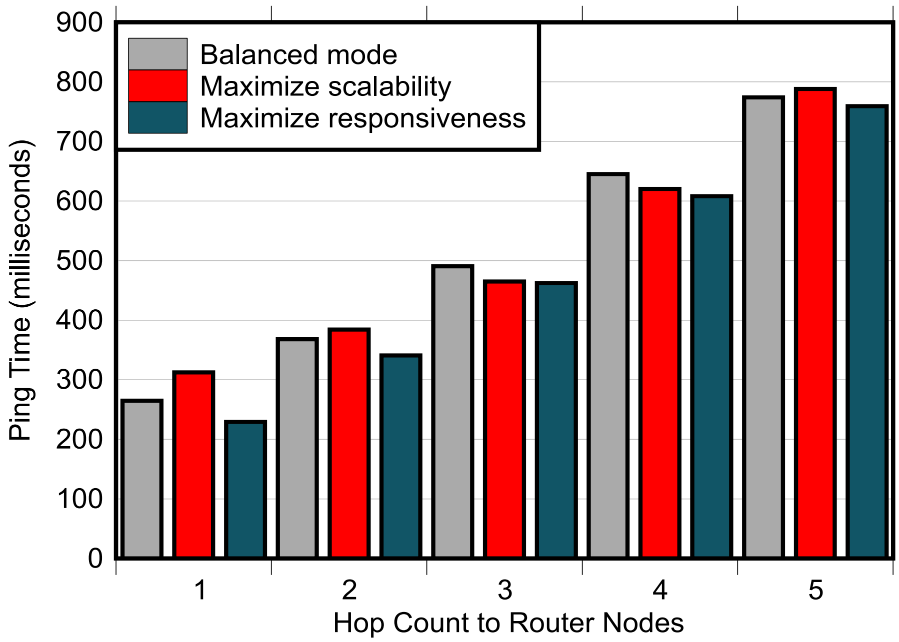


Figure 6-3. Unicast Ping Test (in Milliseconds) for Maximize Responsiveness, Balanced Mode, Maximize Scalability Network Configurations

A given ping packet is delayed by one of the intermediate hops when the hops have to send another control packet to forward this data packet. While the probability of this increases with higher control overhead, this is still expected to happen only for a small portion of the network. This is corroborated by the results seen in Figure 6-3.

7 Preferred Parent and Disconnected Parent

7.1 Preferred Parent

The preferred parent test case shows the required time for a router node to switch to a different parent router node to improve connection. In this example, an unconstrained 3-hop network is presented with a new router node, and the time for switchover is measured. The connection is shown in Figure 7-1.

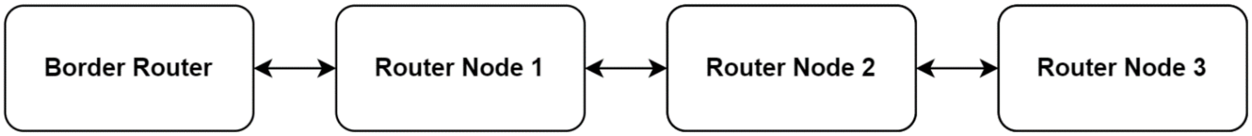


Figure 7-1. Preferred Parent Example: Initial Setup

Router Node 4 is introduced into the network, allowing adjacent router nodes to use as an alternative route to the border router (see Figure 7-2).

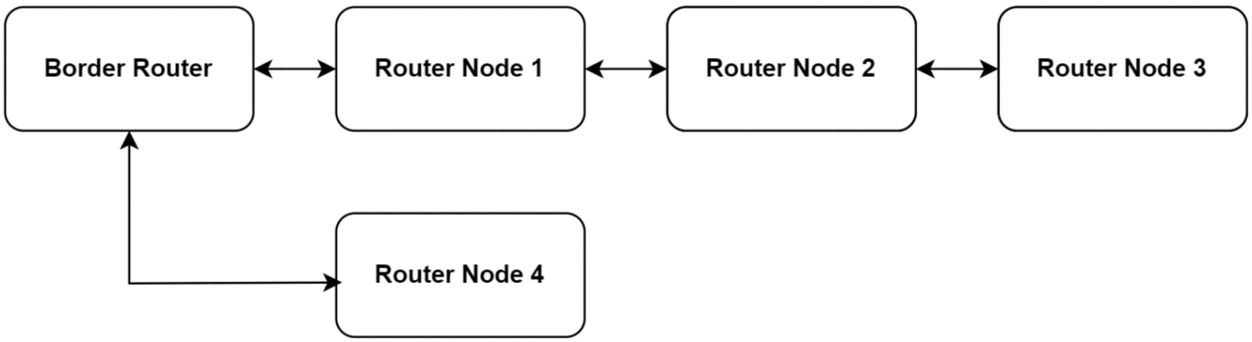


Figure 7-2. Preferred Parent Example: Connect RN4

Figure 7-3 shows Router Node 3 switching connections from Router Node 2 to Router Node 4, decreasing the number of hops required to communicate with the BR.

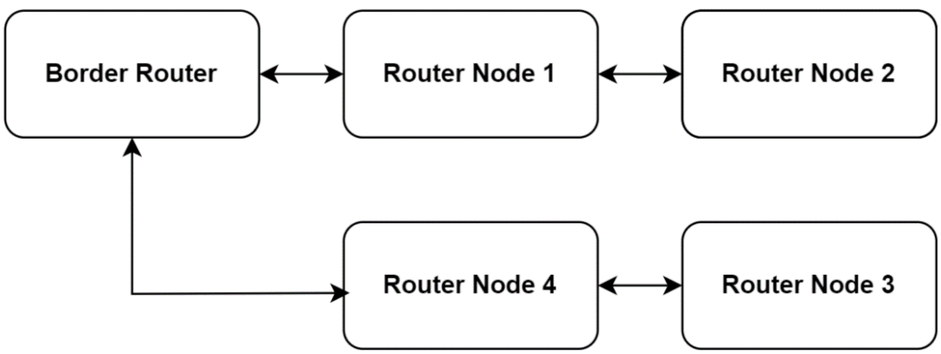


Figure 7-3. Preferred Parent Example: Observe Rerouting of RN3

7.2 Disconnected Parent

The same configuration, as shown in Section 7.1, can be used to give an overview of the disconnected parent case (see Figure 7-4).

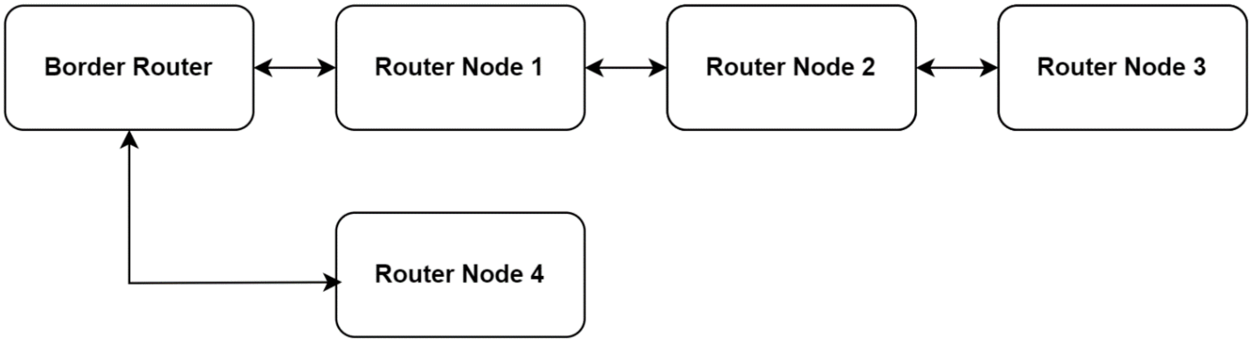


Figure 7-4. Disconnected Parent Example: Initial Setup

In this scenario, Router Node 1 is disconnected, severing communication between the Border Router and Router Nodes 2 and 3, as shown in Figure 7-5.

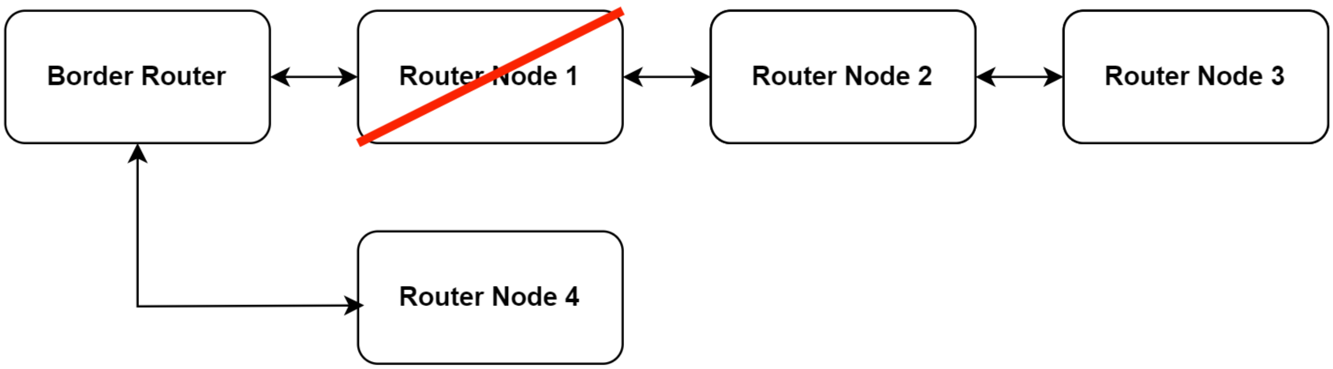


Figure 7-5. Disconnected Parent Example: Disconnect RN1

When the disconnection of the parent router node is detected by Router Node 2, Router Node 2 tries to connect to the closest available alternative (see Figure 7-6). This is Router Node 4 in this scenario

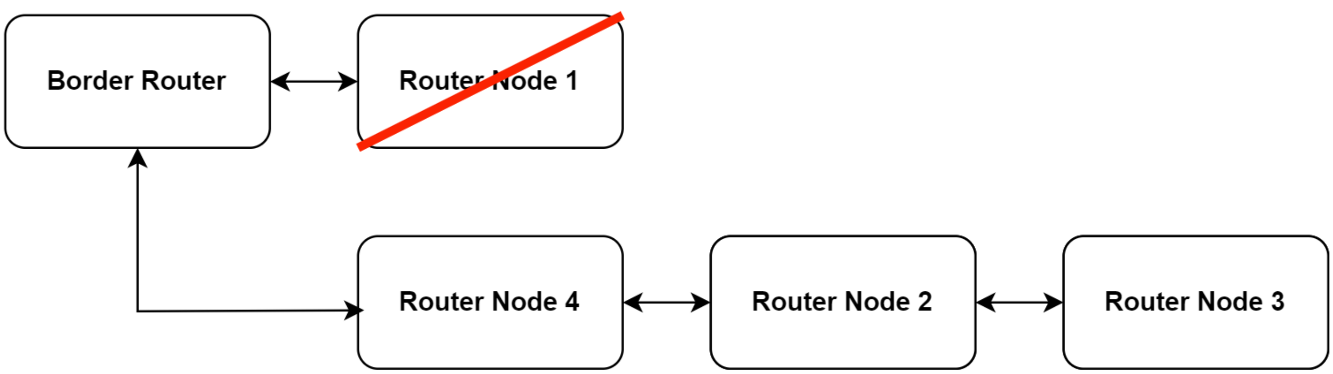


Figure 7-6. Disconnected Parent Example: Observe Rerouting across RN4

7.3 Test Results for Preferred Parent and Disconnected Parent

Table 7-1 shows the recorded times for preferred parent and ran over five separate tests, where the RN had to change the preferred parent. The average time is shown in the last row of Table 7-1.

Table 7-1. Preferred Parent Measurement Results for Maximize Responsiveness Network Configuration (50kbps PHY)

Test #	Time (sec)
1	46
2	36
3	41
4	66
5	51
Average	48

During the preferred parent test, the router nodes usually undergo reconfiguration in less than one minute.

Similar to the preferred parent tests, Table 7-2 shows the recorded times for the five separate disconnected parent tests, where the RN had to change the parent due to a disconnection of a previous RN in the chain. The average time is shown in the last row of Table 7-2.

Table 7-2. Disconnected Parent Measurement Results for Maximize Responsiveness Network Configuration (50kbps PHY)

Run #	Time (sec)
1	73
2	156
3	110
4	141
5	108
Average	117

The disconnected parent example shows that the router nodes generally take less than 2 minutes to notice a broken link to the BR and reconfigure themselves accordingly. Note, however, that the border router disconnection time is 30 seconds, bringing the disconnected parent detection time down to 87s.

8 Additional Information

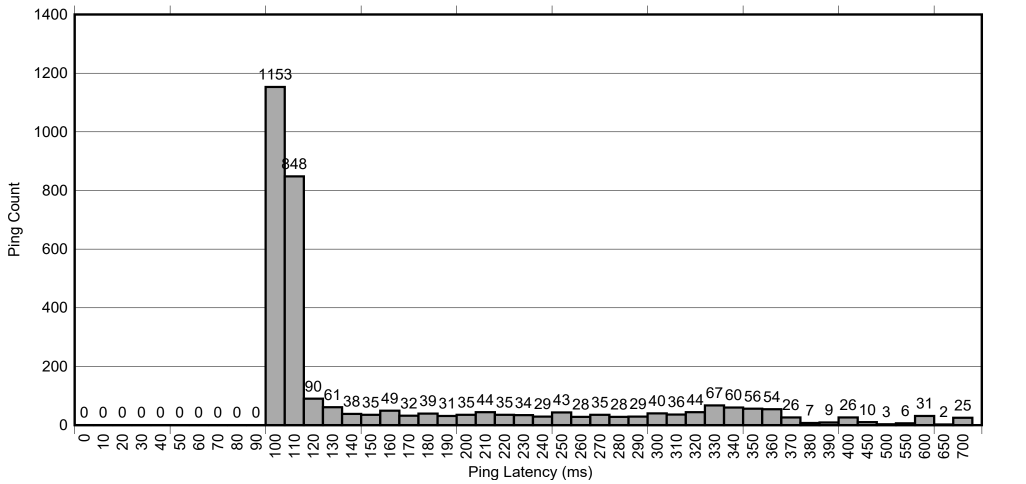


Figure 8-1. Ping Latency Histogram (1 Router Node, 50kbps) for Maximize Responsiveness Network Configuration

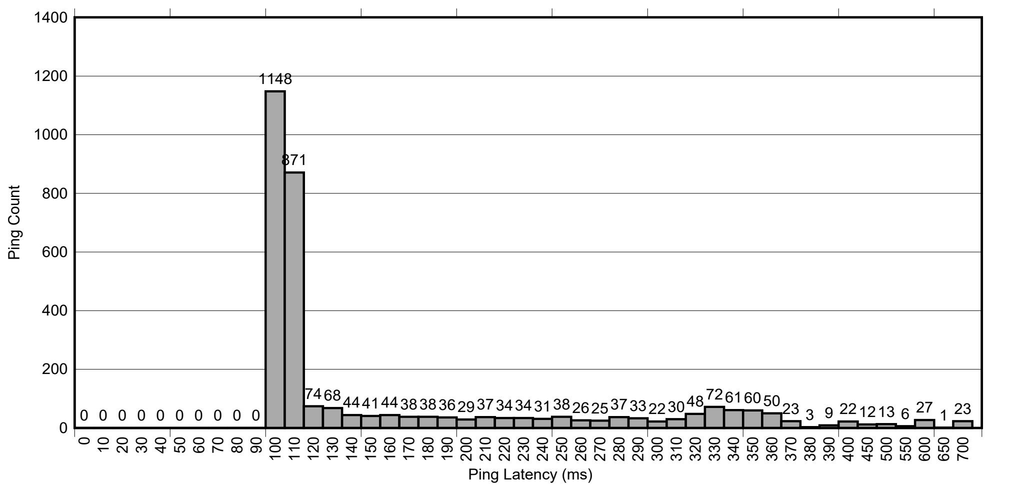


Figure 8-2. Ping Latency Histogram (1 Router Node, 50kbps) for Balanced Mode Network Configuration

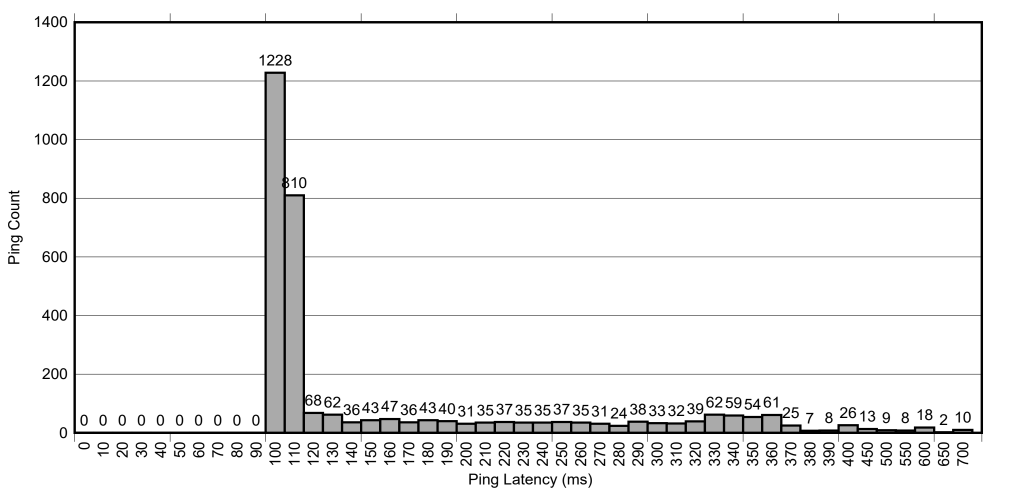


Figure 8-3. Ping Latency Histogram (1 Router Node, 50kbps) for Maximize Scalability Network Configuration

9 Summary

The TI Wi-SUN FAN design provides expected network performance for a given network configuration profile and topology. The TI Wi-SUN FAN offers three different network profiles to configure the network control packet overhead to varying levels for a given network size.

The network profile is determined by the network administrator based on the required network size and application traffic profile.

- *Network size*: for large networks (for example, 1000+), a *maximize responsiveness* configuration is not possible as the control protocol overhead required is higher than the available network capacity.
- *Application traffic profile:* if the typical data traffic profile is expected to be only one pair of nodes communicating at a given time in a request or response type transaction, then the overhead from such a data traffic needs to be less than the available data overhead for any configuration. In this case, only network size needs to be considered and TI recommends to pick the most aggressive profile possible to get a more responsive network. This is also corroborated by the latency test results in Latency, which was not affected by network configuration. However, if the application traffic requires every node to transmit and receive large chunks of data in parallel that can take up significant data capacity, then a less aggressive network profile is recommended.

For a typical e-metering application based on DLMS or COSEM, where the traffic pattern is most expected to be based on a central client reading for each server a time, the most aggressive profile possible for a network size is recommended. While actual network overhead depends on node placement and topology, which can affect the network profile determination, the following recommendations are for a typical network of given sizes.

Network Profile	Network Size Recommendation
Maximize responsiveness	< 300
Balanced mode	300 - 500
Maximize scalability	> 500

10 References

- Texas Instruments, TI Wi-SUN® FAN Stack - Software Overview, product overview
- Texas Instruments, TI Wi-SUN Stack User´s Guide
- Texas Instruments, SIMPLELINK-LOWPOWER-SDK product page
- iPerf, The ultimate speed test tool for TCP, UDP and SCTP

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