Product Overview

TI Wi-SUN® FAN Stack - Software Overview

ABSTRACT

The TI Wi-SUN® software overview describes the overall Wi-SUN® FAN software content and supporting ecosystem from Texas Instruments based on the TI Wi-SUN® FAN 1.0 implementation. The document provides a high level overview of the features and capabilities of the Wi-SUN® FAN software without specific details. For further information on APIs and implementation details, see the Wi-SUN® Developers Guide and the SIMPLELINK-LOWPOWER-F2-SDK.

Table of Contents

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1 Acronyms

This product overview uses the following acronyms:

- BR - border router
- CA- certificate authority
- CLI - command-line interface
- CoAP - constrained application protocol
- FAN - field area network
- GTK - group transient key
- IETF - internet engineering task force
- IPv6 - internet protocol version 6

- NWP - network processor
- OAD - over-the-air download
- PKI - public key infrastructure
- PMK - pairwise master key
- PTK - pairwise transient key
- RFC - request for comments
- RN - router node (also mentioned as embedded router)
- RTOS - real time operating system
- UDP - user datagram protocol

2 Overview

Wi-SUN® is a standards-based mesh network with frequency hopping. The Wi-SUN® Alliance (wi-sun.org) has more than 300 members from 46 countries, with 100M+ devices deployed world-wide. Wi-SUN® supports IPv6 protocol suite and standards based multilayer security. The standard supports multiple data rates and frequency bands to meet different regulatory requirements world-wide. Applications include smart grid and smart city applications, with certified products enabling multi-vendor interoperability.

TI's Wi-SUN® FAN v1.0.0 design is based on the open source IETF RFC components integrated on top of the Wi-SUN® compliant TI 15.4 Stack. A Network Interface Model is provided based on an open-source SPINEL interface. Customers typically develop their application on top of IPv6 using UDP as the transport layer.

TI's Wi-SUN® FAN v1.0.0 design is optimized for a small memory footprint to fit embedded devices, in addition to optimizations for low-power operation. Integration and testing of the software stack is done in tagged, certified releases.

Table 1. Software Overview

Component	Version
TI Wi-SUN® release	v1.0.0
Distribution	Included in SDK7.10 for CC13x2 and CC13x4 devices as library code
IDE support	CCS v 12.5 for Microsoft® Windows® 10, Linux®, and macOS®
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
Recommended development kits	Border router: Personal Computer (PC) host + CC1352P7 LaunchPad™ Development Kit or CC1354P10 LaunchPad™ Router nodes: CC1352P LaunchPad™ or CC1354P10 LaunchPad™

TI has certified multiple FAN profiles with the Wi-SUN® Alliance to be used on CC13x2x as well as CC13x4x10 devices. Not every devices support all of the FAN profiles due to constraints of the internal memory of the device. Table 2 lists the Wi-SUN® FAN profiles with the corresponding certificate and the certificate for the PHYs that can be used with the respective device.

Table 2. Wi-SUN® Certifications for FAN Profiles and PHYs

Wi-SUN® Certificate	FAN profile	Corresponding PHYs
WSA0272	FAN profile (router) for CC13x2R or CC13x2P	WSA0260 WSA0262 (800MHz)
WSA0273	FAN profile (router) for CC13x2R7 or CC13x2P7	WSA0261 WSA0263 (800MHz)
WSA0278	FAN profile (border router) for CC13x2R7 or CC13x2P7	WSA0261 WSA0263 (800MHz)
WSA0313	FAN profile (router) for CC13x4R10 or CC13x4P10	WSA0311 WSA0312

Table 2. Wi-SUN® Certifications for FAN Profiles and PHYs (continued)

Wi-SUN® Certificate	FAN profile	Corresponding PHYs
WSA0314	FAN profile (border router) for CC13x4R10 or CC13x4P10	WSA0311 WSA0312

3 Reference Examples

The SimpleLink™ SDK incorporates a number of examples for the different roles in a Wi-SUN® FAN. Not every role and example is available for every device. This is due to the memory requirements of some roles. Lower memory devices are therefore not be able to be used as a border router role. A list of examples with the corresponding capable devices is listed in Table 3 and Table 4.

Table 3. Code Examples Included in the SDK

Application	Usage
Python interface module for NWP	Reference code to control a NWP from a Linux or Microsoft® Windows® 10 PC. Public on TI GitHub
Border router in NWP configuration	Border router controlled over UART with TI-defined API (based on SPINEL interface layer).
Router in NWP configuration	Router node controlled over UART with TI defined API (based on SPINEL interface layer).
Embedded router example	Single chip router example with embedded CoAP server
Embedded router with off-chip OAD capability	Single chip router example with embedded CoAP server and off-chip over-the-air-download capability (for CC13x2x7 devices)
Embedded router with on-chip OAD capability	Single chip router example with embedded CoAP server and on-chip over-the-air-download capability (for CC13x4x10 devices)

Table 4. Available Memory With Reference Examples Running on Select TI Devices

Code Example and Wireless MCU	SDK Example Designation	Available FLASH	Available RAM	Comments
NWP border router on CC1312R7 or CC1352P7	ns_br	309kB (44%)	21kB (15%)	The user is not expected to add code to the NWP image. Only board-level configuration is done by user.
NWP border router on CC1314R10 or CC1354R10	ns_br	633kB (61%)	134kB (52%)	
NWP router on CC1312R or CC1352P	ns_node	15kB[(1)] (5%)	14kB[(1)] (19%)	
Embedded router on CC1312R7 or CC1352P7 (CoAP based)	ns_coap_node	380kB (54%)	88kB (61%)	—
Embedded router on CC1314R10 or CC1354R10 (CoAP based)	ns_coap_node	704kB (32%)	201kB (77%)	—
OAD off-chip on CC1312R7 or CC1352P7 (CoAP based)	ns_coap_oad_offchip	380kB (54%)	88kB (61%)	—
OAD on-chip on CC1314R10 or CC1354R10 (CoAP based)	ns_coap_oad_onchip	364kB (34%)	201kB (77%)	352kB flash memory reserved for OAD image

(1) Expected available FLASH and RAM in future release

The memory footprint is based on using the TIRTOS7 and TICLANG compiler. It is possible that the footprint varies when using FreeRTOS or another compiler.

4 RF Protocols – Wi-SUN® PHYs

Wi-SUN® supports a number of frequencies and data rates to enable world-wide coverage and address different application needs. Major frequency bands used are 902 to 928 MHz for North America, 863 to 876 MHz for Europe and 920 to 928 MHz for Japan. Further details and information about frequency plan and channels is available to Wi-SUN® alliance members.

Table 5. Wi-SUN® PHYs and TI Support Overview

Symbol Rate (ksymbol/s)	Modulation Index	Wi-SUN® Mode	Frequency Bands	Regulatory Compliance Targets
50	0.5	#1a	EU	EN300 220
	1.0	#1b	NA, BZ, JP	FCC 15.247
100	0.5	#2a	EU	EN300 220 FCC 15.247
	1.0	#2b	NA, BZ, JP	ARIB STD-108
150	0.5	#3	EU, NA, BZ, JP	FCC 15.247 ARIB STD-T108
200	0.5	#4a	NA, BZ	FCC15.247
	1.0	#4b	JP	ARIB STD-T108
300	0.5	#5	NA, BZ, JP	FCC15.247 ARIB STD-T108

5 Software Block Diagram

Table 6. Overview of Software Layers and TI Implementation

Layer	Wi-SUN® FAN	TI Router and Border Router
NWP	Not Defined	Based on open source SPINEL interface.
Security	EAP-TLS, 802.11i, 802.1X	Based on open source components.
Transport Layer	UDP	
Network Layer	IPv6	
	ICMPv6	
	RPL	
	6LoWPAN	
Data Link Layer	Frequency hopping MAC	Based on TI 15.4 Stack.
PHY Layer	IEEE 802.15.4g	Based on TI 15.4 Stack.

The Wi-SUN® FAN protocol is defined up to the Transport Layer and the TI stack supports UDP as the transport layer.

6 Network Topology and Features

TI's Wi-SUN® FAN v1.0.0 flow supports the following device types and designs:

- Border router
  - Based on TI CC13x2x7 series (704KB) and CC13x4x10 series (1MB) memory devices in Network Processor (NWP) mode requiring a Host Processor for providing backhaul connectivity
  - Supports UART communication through a TI defined NWP interface (based on SPINEL interface layer)
- Router device in NWP mode
  - Supported in both TI CC13x2xx series (352 KB), CC13x2x7 series (704 KB) and CC13x4x10 series (1MB) devices
  - Supports UART communication through a TI defined NWP interface (based on SPINEL interface layer)
- Embedded Router
  - Based on TI CC13x2x7 series (704KB) and CC13x4x10 series (1MB) memory devices
  - Provides an example implementation based on CoAP Application
  - Over-the-Air Download (OAD) functionality with off-chip memory for CC13x2x7 series (704KB) and on-chip memory for CC13x4x10 series (1MB)

A network can consist of a variety of the aforementioned devices and roles in a Wi-SUN® FAN. One possible network architecture that displays all of the roles is visualized in Figure 1.

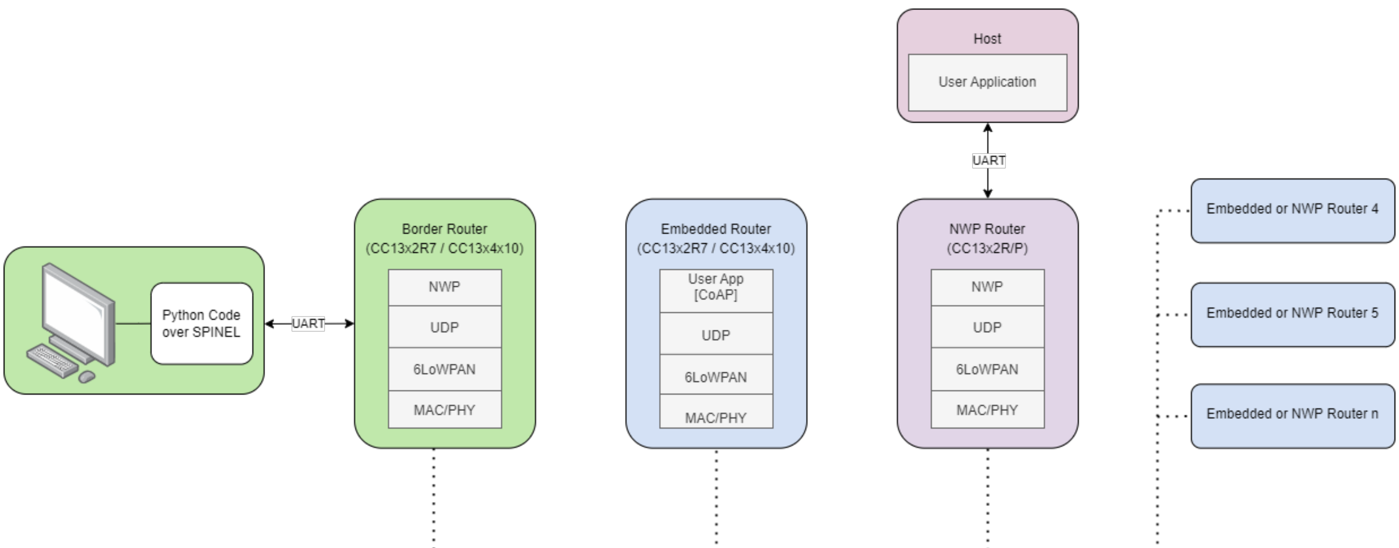

Figure 1. Available Network Architectures With Border Router and Routers Using NWP Implementation and Embedded Routers

The network associated with a border router is called a PAN. Multiple PANs can be connected through a WAN Backhaul to extend the network coverage. This backhaul is not part of the Wi-SUN® FAN specification.

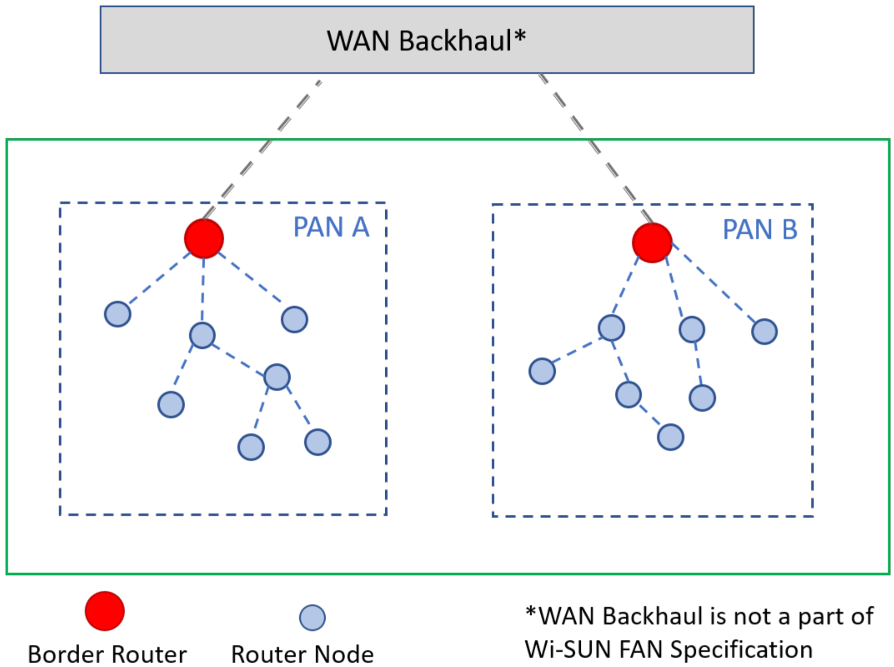

Figure 2. Wi-SUN® Network Topology Consisting of Two PANs

7 Security

TI's Wi-SUN® FAN v1.0.0 solution supports best-in-class network security based on the IEEE 802.1x specification:

Table 7. Security Enablers in TI Wi-SUN® FAN v1.0.0

Category	Security Enabler
Wi-SUN® FAN v1.0.0 security specification	IEEE 802.11i key WAN Management
	IEEE 802.1x for authentication and encryption
	AES-128 encryption
	ECC based key exchange and signature verification
	True random number generation for security protocols
	IEEE802.1AR defined X.509 certificates

Figure 3 summarizes key aspect of the key exchange mechanism:

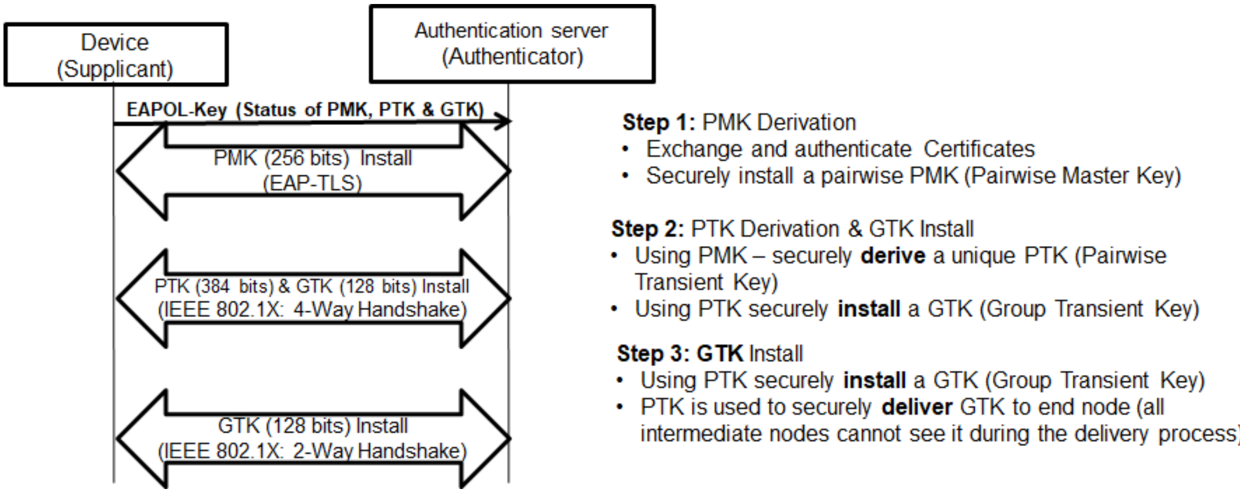

Figure 3. Security Key Exchange Mechanism in Wi-SUN®

7.1 Certificate Management

TI recommends obtaining a unique certificate for each device. Customers can either use their own PKI infrastructure or work with Global Sign (a Wi-SUN® Alliance Partner - wi-sun.org/cyber-security-certificates).

7.2 Key Exchange Process

The following list is an overview of the security key exchange process:

- A unique Pairwise Master Key (PMK) and Pairwise Transient Key (PTK) is established between Device and Border Router
- A PTK is used to securely install a GTK (Group Transient Key) to individual devices
- A GTK is used by devices to encrypt MAC payload packets using AES-128 CCM* as defined in IEEE 802.15.4
- Network management defines the lifetime for different keys and performs key management
- Lifetime of PMK, PTK , and GTK are typically in descending order (default value: 4, 2 and 1 month respectively)

This stack release supports default certificates (compiled into code for field trials).

8 Performance and Test Data

For this revision, a test with a 100-node mesh network and a 5-hop network topology was carried out. The border router *pings* each device periodically one by one. The ping packet size is 50 bytes; ping interval is 5 seconds with a ping response timeout of 30 s. The test is run for 24 hours.

Table 8. 100-Node Mesh Network Test Data

Test Parameter	Result
End-to-end delay	Hop 1: 373 ms Hop 2: 471 ms Hop 3: 574 ms Hop 4: 760 ms Hop 5: 899 ms Overall average: 583 ms
Average packet error rate (PER)	0.001%
Average network join delay	48.3 minutes

Looking at the average join delay, the designer must consider that this is tested with a 100-node network with the 5-hop architecture as shown in Figure 4. Every hop incorporates a different number of router nodes. Table 9 lists a differentiation of join delay per hop. The average join delay per hop is defined by the average time it takes from powering up the devices until 100% of the nodes in one hop have joined the network.

An out-of-the-box network with 2-3 nodes joins in 3 to 5 minutes after powering up. The exact join time is dependent on multiple timing factors and the desired data rate. Configure these settings in SysConfig.

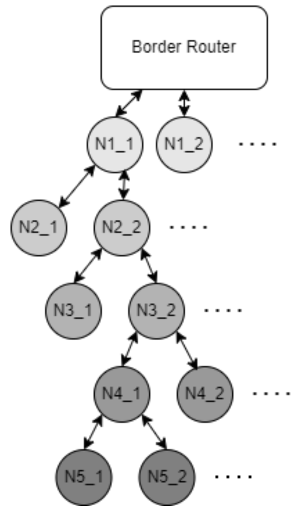

Figure 4. Network Topology for the 100-Node Mesh Network Test

Table 9. 100-Node Mesh Network: Join Delay per Hop

Hop	Number of Routers per Hop	Average Join Delay (Minutes)
Hop 1	32	37.3
Hop 2	16	27.2
Hop 3	12	58.8
Hop 4	20	60.5
Hop 5	16	68

Table 10. TI Wi-SUN® FAN 1.0 Performance Data

Performance Data	Result
Maximum network hops	Wi-SUN® FAN 1.0 standard supports up to 24 hops
Maximum network size	Network size is limited by border router's RAM, in addition to application use-case details. TI recommends using up to approximately 100 nodes per border router for devices with 144KB RAM. Multiple border routers can be used to scale the network. TI devices with larger memory can support larger networks.
PHY certification results	Wi-SUN® FAN 1.0 PHY for: • US and BZ regions • EU1, EU2, IN, and SG regions
FAN certification results	Wi-SUN® FAN 1.0 certified router stack

The OAD tests were conducted with an image size of 352256 Bytes using different block sizes. The results vary depending on the number of hops that the data has to travel to the destination. OAD was tested for a maximum hop count of 2. Consider these values to be taken in a mostly noise-free environment. Heavy traffic leads to repeating packets, which increases the total download duration.

Table 11. Wi-SUN® OAD Performance

Number of Hops	Block Size (B)	Download Duration (Minutes)
1	128	8:30
1	512	3:31
1	1024	3:01
2	128	15:56
2	1024	4:34

9 Out-of-box Experience

This stack release is intended for initial development of a Wi-SUN® network. This release provides the following out-of-box experience:

- Setup a border router by using PCs communicating with a NWP border router over a CC1352x7 or CC1354x10 series device (a reference implementation is provided)
- Compile router notes (even in a NWP model) as a self contained solution that can join a network when powered on and respond to an IPv6 ping
- Perform field testing by pinging individual devices without building a customer application
- Build customer applications on a separate host and communicate with a router over a NWP interface using UART
- Host a simple CoAP server over a router device through an embedded router node example based on CC13x2x7 and CC13x4x10 series devices
- Reference Python scripts that provide examples for interacting with out-of-box CoAP server resources
- Develop single-chip custom applications over Wi-SUN® stack using the embedded router node example as reference

Start by going to the CC1352P7 Product Folder.

10 Training

As part of the SimpleLink™ Academy TI provides training material for the Wi-SUN® FAN implementation including hands-on examples using the CC13x2R7 and CC13x4R10 LaunchPads. The examples are split into three parts:

1. Fundamentals to Wi-SUN® FAN: This training guides the user on how to create a simple Wi-SUN® FAN using one border router connected to a host PC running PySpinel CLI to control the network. Basic serial commands to start the network and ping connected nodes are explained.
2. Over-the-Air Download: This training explains the concept of OAD using Wi-SUN®, the memory layout necessary for saving multiple images and how to setup the OAD environment and perform the download.
3. CoAP Messaging: This training is intended to introduce fully embedded router nodes to transmit CoAP messages between the BR and RN. Examples are given for confirmable and non-confirmable CoAP messages. An example for an EV charger application sending status information to the BR is given.

Find these trainings through the links above or on dev.ti.com.

11 Tools

11.1 Code Composer Studio™ IDE

Latest release per October 2023 is v12.5.0. Link to Code Composer Studio™: www.ti.com/tool/CCSTUDIO.

11.2 SysConfig

The SysConfig Utility is a software tool which provides a Graphical User Interface for configuring pins, peripherals, radios, subsystems, and other components for TI devices. Results output as C header and code files that can be imported into software development kits (SDKs) or used to configure custom software.

11.3 Packet Sniffer

Latest release per October 2023 is v2.18.1. Link to Packet Sniffer: www.ti.com/tool/PACKET-SNIFFER.

- Wi-SUN® PHY modes supported: #1a, #1b, #2a, #2b, #3, #4a, and #4b
- Packet sniffer is single channel only, but multiple boards can be used to sniff multiple channels

11.4 TI Wi-SUN® FAN Spinel

The TI Wi-SUN® FAN Spinel CLI exposes the configuration and management APIs running on a TI Wi-SUN® FAN Network Processor (NWP) via a command line interface. This tool is primarily suitable for manual experimentation with controlling TI Wi-SUN® FAN NWP instances and is not meant for expanding into production grade driver software for TI Wi-SUN® FAN NWP devices. A detailed guide on how to use the TI Wi-SUN® FAN NWP Interface can be found here: NWP Interface Guide.

This tool is helpful for the following purposes:

1. As a path for automated testing and performing field trials with TI Wi-SUN® FAN NWP running on TI SimpleLink™ devices.
2. As a simple debugging tool for NWP builds of TI Wi-SUN® FAN stack.

Public on TI GitHub

11.5 TI wfantund – User-Space Network Interface Driver

The wfantund provides a native IPv6 network interface to a connected TI Wi-SUN® FAN border router that is operating in NWP mode. The repository (public on TI GitHub) provides software to run on a Linux host with a Wi-SUN® FAN NWP connected over UART. wfantund also offers the possibility to visualize the network topology graphically with the use of a webapp as shown in Figure 5. This webapp is also part of the wfantund GitHub repository.

Reference cross compilation support is provided for the TI AM64x platform as well as the BeaglePlay board.

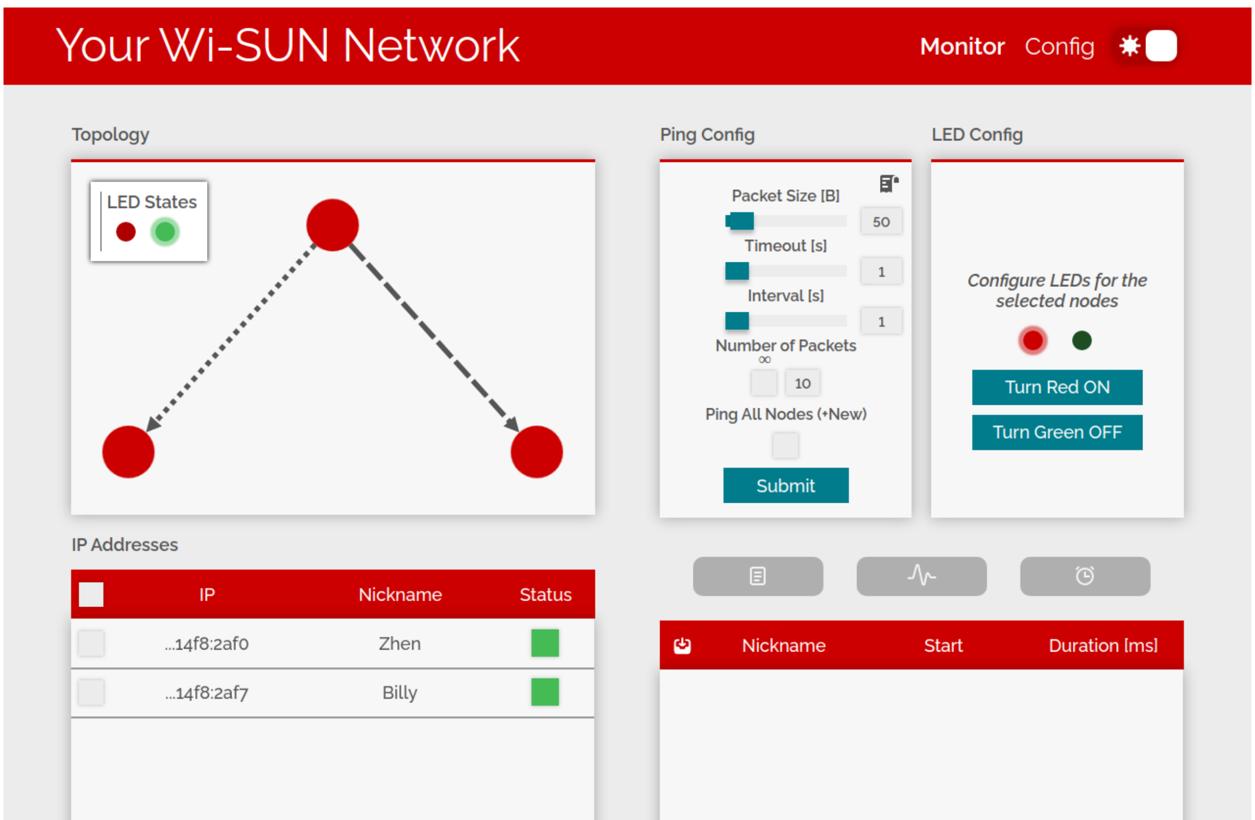

Figure 5. FAN Visualization in wfantund Webapp

12 Known Limitations

This version is tested with a 100-node network.

13 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (July 2021) to Revision A (November 2023) **Page**

- Added terms to the *Acronyms* section....................1
- Updated the *Overview* section....................2
- Updated contents in *Reference Examples* 3
- Updated Table 5 4
- Added text to Section 5 4
- Updated Section 6 5
- Updated Section 8 7
- Added the *Training* section....................9
- Updated *Code Composer Studio* 9
- Updated the *Packet Sniffer* section....................9
- Added *TI wfantund – User-Space Network Interface Driver* 10
- Updated *Known Limitations*....................10