



IEEE Standard Test Procedures for IEEE Std 1901.1™ for Medium Frequency (less than 15 MHz) Power Line Communications for Smart Grid Applications

IEEE Communications Society

Developed by the
Power Line Communication Standards Committee

IEEE Std 1901.1.1™-2020

STANDARDS

IEEE Standard Test Procedures for IEEE Std 1901.1™ for Medium Frequency (less than 15 MHz) Power Line Communications for Smart Grid Applications

Developed by the
Power Line Communication Standards Committee
of the
IEEE Communications Society

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IEEE SA Standards Board

Abstract: The interoperability and compliance testing for IEEE 1901.1 products built, in which physical (PHY) and media access control (MAC) layers of the medium frequency band (less than 12 MHz) broadband power line communication technology for smart grid applications (SGPLC) based on orthogonal frequency division multiplexing (OFDM), is specified in this standard. The corresponding PLC application scenarios and test environment are introduced, and the PHY/MAC test cases and test scenarios are provided. The procedures for compliance, interoperability, and certification of IEEE Std 1901.1™ are specified in this standard.

Keywords: BPL, broadband power line, IEEE 1901.1™, IEEE 1901.1.1™, PLC, power line communication, smart grid, test standard, interoperability and compliance testing, certification

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Introduction

This introduction is not part of IEEE Std 1901.1.1-2020, IEEE Standard Procedures for IEEE 1901.1™ for Medium Frequency (less than 15 MHz) Power Line Communications for Smart Grid Applications.

Test procedures for compliance and interoperability testing of devices implementing IEEE Std 1901.1™, “Standard for Medium Frequency (less than 15 MHz) Power Line Communications for Smart Grid Applications” are specified in this standard.¹ Application scenarios and use cases for IEEE Std 1901.1-based implementations and associated channel models and performance expectations are also described. A collection of examples of real-life implementations allowing enhancement of test procedures with the input from the field are provided.

¹ Information on references can be found in Clause 2.

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1. Overview

1.1 Scope

This standard specifies test procedures for compliance and interoperability testing of devices implementing IEEE Std 1901.1™, “Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications.”² This standard also describes application scenarios and use cases for IEEE 1901.1 based implementations and associated channel models and performance expectations. This standard provides a collection of examples of real life implementations allowing enhancement of test procedures with the input from the field.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1901.1™-2018, IEEE Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications.^{3,4}

² Information on references can be found in Clause 2.

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⁴ IEEE publications are available from the Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁵

amplitude map: A table of amplitude scaling values assigned to each carrier.

association: A service used to create subordinate relationships among members on a communication network.

bandwidth coordination: A process in which the central coordinators (CCOs) perform negotiation on bandwidth when multiple networks coexist.

beacon: A management packet that is sent by the central coordinators (CCOs), proxy coordinator (PCO), or station (STA). The Beacon carries information about network management and maintenance, and is used for a specified purpose. Beacons sent by the CCO, PCO, and STA are called central, proxy, and discovery Beacons, respectively.

beacon period: The interval at which the central coordinators (CCOs) sends a central Beacon based on the network scale.

broadband carrier communication network: The broadband carrier communication network supports the transmission of digital data over electrical power lines.

direct route: Routes of one hop.

heartbeat detection: A process in which a station periodically sends heartbeat packets and other stations and the central coordinator determines whether the station is online or offline based on the sent heartbeat packets.

host: Computing system with integrated IEEE 1901.1 communications module.

indirect route: Routes of more than one hop.

multi-network coordination: The process in which the central coordinators (CCOs) on different networks perform negotiation to help ensure that the networks can mutually coexist.

network identifier: A Network Identifier (NID) uniquely identifies a broadband carrier communication network.

protocol data unit: Protocol data units are exchanged between two entities.

test case: A collection of related test steps that confirm a specific functional test objective.

test step: A specific operation within a test case.

whitelist: A list of MAC address of stations (STAs) allowed to connect to the communication network.

⁵*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

3.2 Acronyms and abbreviations

AMI	advanced metering infrastructure
BPC	beacon period count
CCO	central coordinator
CIFS	contention inter frame space
CRC	cyclic redundancy check
DT	delimiter type
DUT	device under test
DCU	data concentration unit
MPDU	MAC protocol data unit
MSDU	MAC service data unit
NID	network identifier
NTB	network time base
ODTEI	original destination terminal equipment identifier
OSTEI	original source terminal equipment identifier
PCO	proxy coordinator
PHY	physical layer
PLC	power line communication
SACK	selective acknowledgment
SOF	start of frame
STA	station
TDMA	time division multiple access
TEI	terminal equipment identifier
TMI	tone map index

4. General description

IEEE Std 1901.1 specifies Physical (PHY) and Media Access Control (MAC) layers of the medium frequency band (less than 12 MHz) power line communication technology for smart grid applications (SGPLC) based on Orthogonal Frequency Division Multiplexing (OFDM). Interoperability and

Compliance testing are key tools for the development of an ecosystem of interoperable products. This contribution describes an approach to interoperability and compliance testing of devices implementing IEEE 1901.1.

In Clause 5, application scenarios of IEEE 1901.1 are introduced, which includes typical use case and typical data flow and bandwidth requirements for the PLC network.

In Clause 5 the test structure and test modes are illustrated, including a general diagram of the IEEE 1901.1 testbed.

A total of 26 test cases are included in this document, and are divided into three parts (Clause 6, Clause 7, and Clause 8):

- The physical layer test: Includes seven test cases regarding the physical layer features of the tested PLC device, e.g., receiver's sensitivity and communication rate.
- The MAC layer test: Nine test cases are listed in this part regarding the MAC layer features, including Beacon mechanism, timeslot management, channel access, SOF packet processing, selective ACK and retransmission, unicast/broadcast processing, multi-network coexistence, network establishment, and network maintenance.
- Interoperability test: Ten test cases are included, namely the device interoperations with the golden node in the star, line, and tree topologies.

Annex A gives more information about the power line channel including the multipath model and noise models.

5. Application scenarios

5.1 General

Increasing urban population and limited resources present more and more challenges to city operations around the world. Making cities more intelligent, secure, and environmentally friendly is closely associated with the efficient and refined management for municipal public domains in each city. Monitoring and controlling of all urban infrastructures help ensure efficient and refined city management.

PLC-IoT uses low-voltage power line as the communication media. Multiple CCOs can be deployed on a power grid so that gateways of different systems establish independent PLC communication networks. PLC-IoT allows STAs to switch to the repeater mode, and adjusts the network topology based on power line environment changes. With dynamic network optimization, PLC-IoT allows electrical devices to adapt to complex power grid environments.

PLC can be used to monitor and control onsite devices of many subsystems in smart city. For example, electrical meter data collection, city street lamp control, and control of charging poles of electric vehicles are typical and common application scenarios of PLC. The application scenarios of PLC-IoT include, and are not restricted to, the examples in Clause 5.

5.2 Application Scenario 1: AMI

Electrical meter communication in advanced metering infrastructure (AMI) scenarios is typical application of PLC, which is mainly considered by IEEE Std 1901.1™. The AMI solution is an end-to-end solution for reading and control of electrical meters, covering accounting and power grid analysis, onsite device data

backhaul, and onsite meter communication and data collection of electric power companies. In the AMI solution, PLC-IoT is used for communication between onsite electrical meters and DCUs. DCUs use PLC-IoT to collect metering data of electrical meters or deliver switch-on and switch-off instructions to electrical meters. After a DCU completes electrical meter data collection, the DCU backhauls data to the HES through 3G, LTE, Ethernet, and optical fibers. Then, the HES delivers the data to each application system that is closely associated with the operation of electric power companies for accounting, power-supply analysis, and line loss calculation. Each application system of electric power companies requires real-time, accurate, and comprehensive data of electrical meters, so the communication reliability of PLC-IoT and communication bandwidth are the prerequisites for analyzing applications.

5.2.1 Typical use case of AMI

In typical AMI networking for electrical meters, each transformer connects to one or more DCUs, and the DCUs connect to all electrical meters mounted to the transformer through PLC. A DCU often connects to hundreds of electrical meters, or even more than 1000 electrical meters in specific scenarios. Star Topology is commonly used in urban areas where population density is large, while tree topology is deployed in the rural areas. Tree topology is realized by using the Proxy Coordinator (PCO), which means some PLC devices are able to act both as STAs and Proxy. Figure 1 gives a typical architecture of a use case with Star Topology.

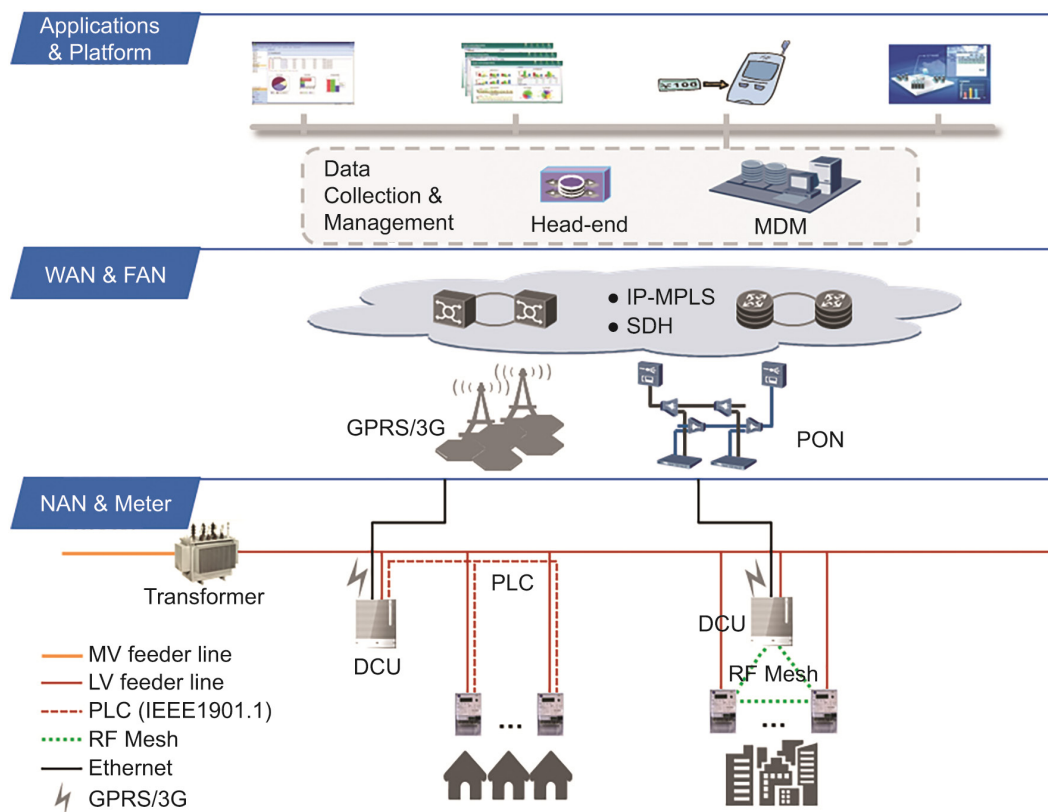


Figure 1—Example of typical AMI networking for electrical meters

5.2.2 Typical data flows and bandwidth requirements for the PLC network

In AMI scenarios, there is a large amount of data from electrical meters. A transformer often connects to hundreds or even more than 1000 electrical meters. Each electrical meter generates several pieces of daily

and monthly frozen data. The frozen data that is generated by 15 min, 5 min, or even 1 min is used to generate data curves. In addition to periodic frozen data, events and alarms from electrical meters, remote recharging instructions and power supply control instructions from electric power companies are generated at any time.

Through PLC-IoT, each CCO can connect to more than 1000 electrical meters, and each transformer at the low voltage side can allow multiple CCOs to communicate on a power line. PLC-IoT supports self-networking and repeater capabilities. With automatic optimization through multi-level and automatic proxy, the electrical meters that are installed in households with complicated power lines can communicate with CCOs at any time. This helps to ensure the integrity of metering data.

5.3 Application Scenario 2: Single network

The street lighting solution deploys a street lamp controller in each street lighting region. The street lamp controller obtains control instructions from the control system of a data center through WAN communication technologies, or delivers predefined control policies such as the switch-on and switch-off time, environment, and grouping. The street lamp controller configured with predefined control policies can control street lamps as long as the PLC-IoT between the street lamp controller and street lamps works properly, even if the communication on the WAN is not smooth temporarily. The PLC-IoT improves normal running of public lighting utilities; in this case, the reliability of PLC-IoT is one of the key elements of the street lighting solution.

5.3.1 Typical use case of street lighting

In street lighting scenarios, PLC is used for communication between street lamps and street lamp controllers. Each street lamp has a built-in PLC chip, and each street lamp line has a street lamp controller deployed. The street lamp controller can control switch-on, switch-off, and brightness of street lamps through the PLC network, and can collect power consumption data from street lamps to determine whether the street lamps work properly. Tree topology is used to cover long distance data transmissions. In street lighting scenarios, the number of street lamps on a power supply line is small. The length of a power line is long because streets are contiguous. Therefore, multiple levels of repeaters may be deployed on the PLC network. However, the number of street lamps connected to each level of repeaters is not large.

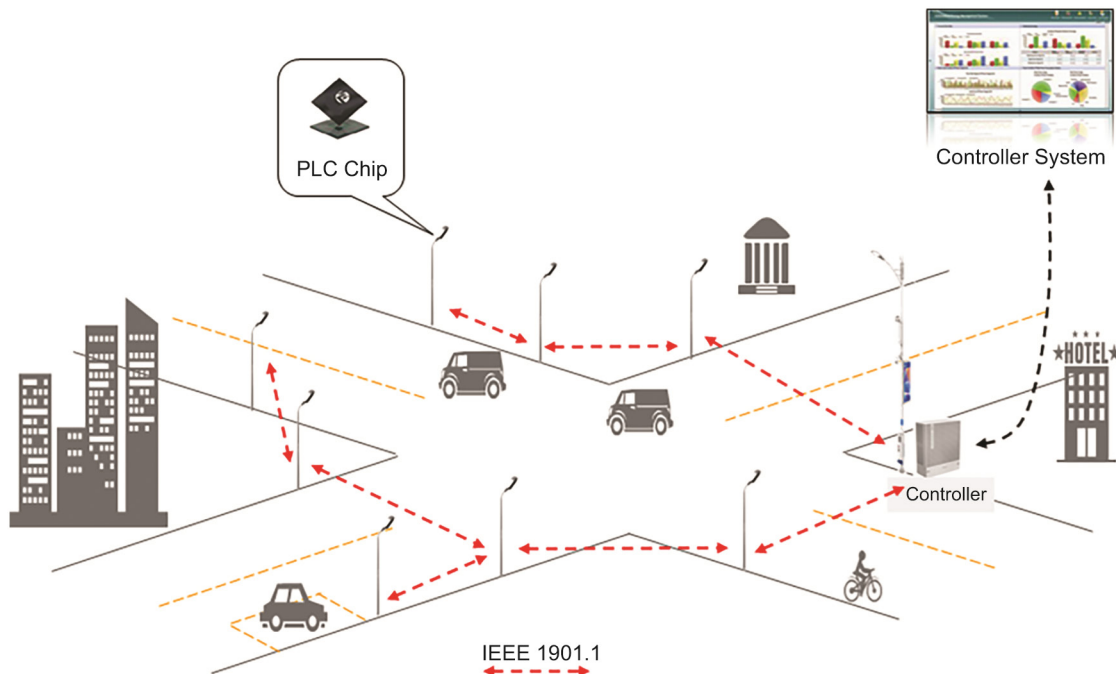


Figure 2—Example of PLC network in street lighting scenarios

5.3.2 Typical data flows and bandwidth requirements for the PLC network

In street lighting scenarios, the amount of data is not large. The data mainly includes small-sized street lamp control packets and status collection packets. The street lamp controller delivers control instructions such as switch-on, switch-off, and brightness adjustment, collects the working status of street lamps such as the working current and power consumption, and sends the information to the street lamp control system. The street lamp control system determines whether street lamps work properly and whether street lamps need to be repaired or replaced based on information analysis.

5.4 Application Scenario 3: Electric vehicle charging

The emergence of electric vehicles brings a main issue, namely the EV charging infrastructure, to which a solution will be needed in the coming future. Each electric vehicle supply equipment (EVSE) will require communications to the Grid for metering, user interface, purchasing transactions, vehicle verification, and system maintenance/management. PLC-IoT is a good candidate for the EV charging scenario, and provides a reliable last mile communication for the services described in application scenarios.

5.4.1 Typical use case of electric vehicle charging

In the EV charging scenario, each charging pole in a parking lot has a PLC chip installed to communicate with the communication controller. Through the communication controller, the control system of charging poles can obtain the charging status of each charging pole and perform charging and accounting based on the charging status, information about charging vehicles, and charging amount. Only reliable PLC-IoT can synchronize the charging status and charging information of charging poles to the control system to help ensure the operation of charging poles. Star Topology is used in the sub-network in an EV charging station where communications are realized by PLC-IoT between the charging poles and the communication controller.

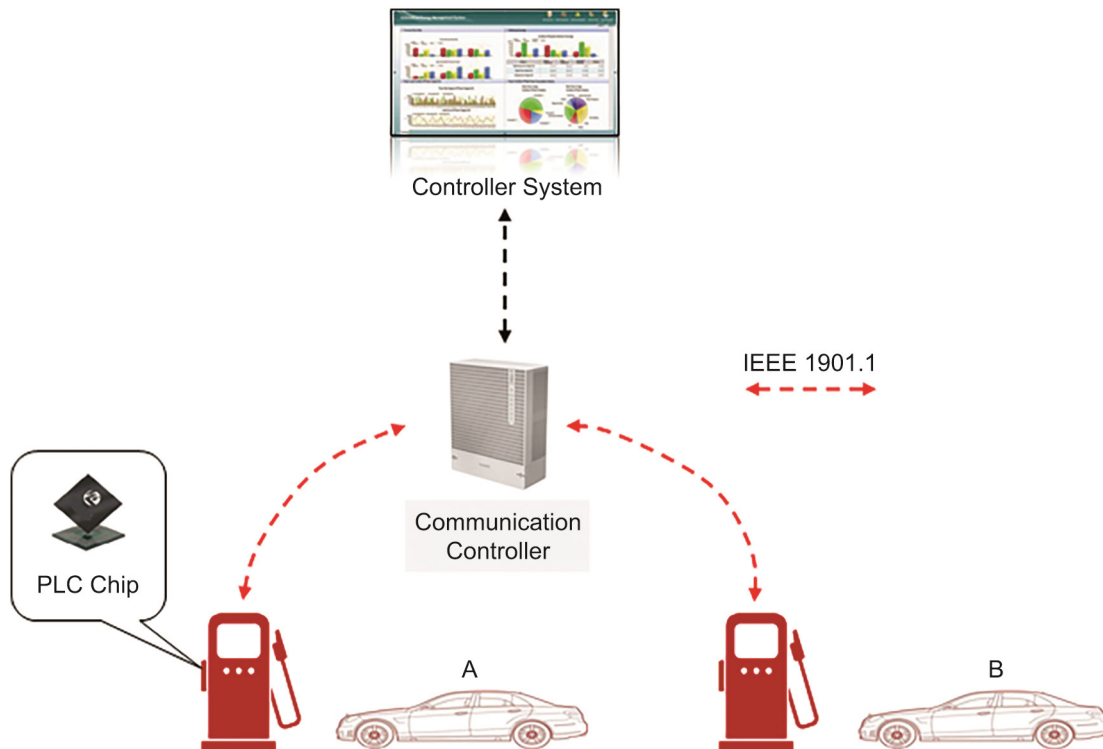


Figure 3—Example of PLC network in electric vehicle charging scenarios

5.4.2 Typical data flows and bandwidth requirements for the PLC network

In the EV charging scenarios, there is not much communication data. The data mainly includes the working status of charging poles and some control instructions. The control system delivers control instructions to charging poles through the communication controller. Vehicles start or stop charging at any time, so charging poles report charging information to the control system through the communication controller at any time, for example, charging pole status, charging current, and charging amount.

5.5 Application Scenario 4: Smart city

Smart city is the use of information and communication technologies to analyze and integrate the key information of a city, so as to include people's livelihood, environmental protection, public safety, urban services, as well as industrial and commercial activities. The essence of smart city is to achieve intelligent urban management and operation. Wireless communication technologies might be the main force in this scenario, but there are some cases that undermine the advantages of wireless technologies, e.g., due to physical barriers, communication distance inside buildings or underground is limited when using wireless technologies. Inside buildings, PLC can be used to reinforce management by collecting statistics on building energy consumption so as to reduce energy consumption fee. With the existing power line infrastructure, PLC-IoT is a good support for the smart city scenario that helps to build fully covered IoT networks in a city.

5.5.1 Typical data flows and bandwidth requirements for the PLC network

In the smart city scenario, the main requirement is the use of IP data packets for communication, and this enables the uniqueness of each device regardless of its communication medium. One device may be able to

receive an IP data packet from PLC and then send it to another device through wireless links, and vice versa. A large amount of data flow on PLC links including both monitoring data and control commands.

6. Test environment

6.1 General

In this standard, all test cases are listed that identifies the interoperability and conformance tests with pass/fail conditions.

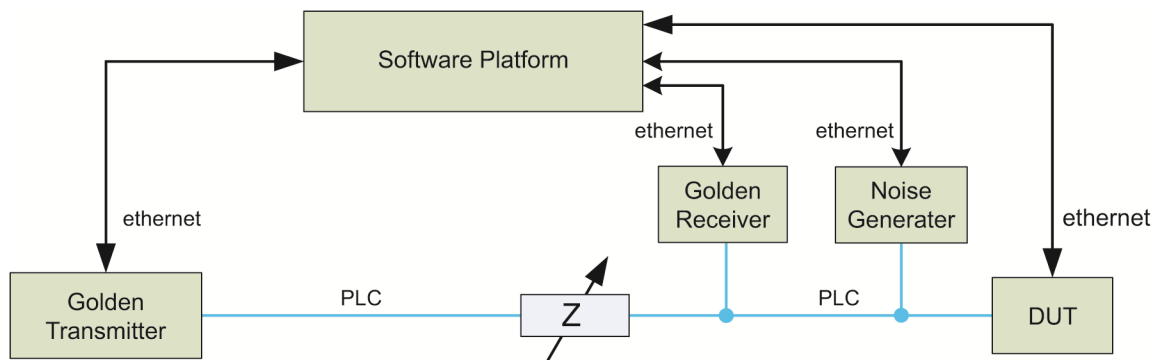


Figure 4—Overview of IEEE Std 1901.1 testbed

6.2 The test structure

The golden node is the device that is verified to work and perform in conformance with the standard.

The golden transmitter will send protocol frame on the PLC according to IEEE 1901.1 controlled by the software platform.

The golden receiver will capture all the 1901.1 data on the PLC, and report it to the software platform.

The device under test (DUT) will react in accordance with the protocol defined in IEEE Std 1901.1 and it will send the IEEE 1901.1 compliant data on the PLC.

The software platform will decide whether the reaction of the DUT is in compliance with IEEE Std 1901.1.

The noise generator will generate white noise, impulse noise, and noise collected from the field.

The band of the attenuator is from 1dB to 120 dB, step 1 dB.

For the physical layer test, the DUT does not need to join the network. But the physical layer test needs a special set of test commands. For example, after receiving Command 1, the DUT may report the data it received to the software platform through the Ethernet or serial port.

For the datalink layer, the DUT and the transmitter need to join the network. When the DUT is STA, the transmitter works as the CCO. And when the DUT is CCO, the transmitter works as the STA.

6.3 The test modes

In IEEE Std 1901.1, the “MSDU type” field is included in the MAC header of MSDU, and the value ‘50’ corresponds to the testing frame. In the testing procedure, the testing frame should be used.

To test expediently, the test commands should be added to make the DUT enter the test mode or perform corresponding configuration operations on the DUT. For STA and CCO, these commands are received from the carrier channel. The DUT needs to support physical layer transparent transmission mode, physical layer return transmission mode, MAC layer transparent transmission mode, frequency band switching operation, and ToneMask configuration operation. After the DUT is reset, the DUT should switch back to normal working mode. The definitions are outlined in Table 1:

Table 1—Format of test command

Field	Octet number	Bit number	Field size (bits)
Test protocol ID	0	0–5	6
Packet length	1	6–7	6
Test mode		0–3	
Reserved	2	4–7	4
Test mode duration (Unit: Minute)		0–3	4
	3	4–7	12
		0–7	

The test protocol ID is to be used when the protocol improves. The current test protocol in this document uses value ‘0’ for testing.

The “packet length” field is used to indicate the packet length of the test command. The value in this field corresponds to the number of bytes of the length.

The “test mode” field specifies a certain mode during the test. Currently seven test modes are specified with the definition as follows:

- a) Test mode value 1: Represents the forwarding of application layer packets to the application layer serial channel test mode. After forwarding the first frame, the test mode is exited. The mode duration/configuration value is filled with 0.
- b) Test mode value 2: On behalf of forwarding the application layer to the carrier channel test mode, exit the test mode after forwarding the first frame, and fill in the mode duration/configuration value; test mode is currently not used).
- c) Test mode value 3: Enter the physical layer transparent transmission test mode, transparently transmit the received FC+PB to the serial port channel, and leave the test mode to “test mode duration” and exit. Fill in the specific test mode duration (Unit: Minute).
- d) Test mode value 4: Enter the physical layer return test mode, automatically reply to the received FC+PB to the carrier channel, and exit the test mode until the “test mode duration.” Fill in the specific test mode duration (Unit: Minute).
- e) Test mode value 5: Enter the MAC layer transparent transmission test mode, transparently transmit the MSDU of the received packet to the serial channel, and exit the test mode until the “test mode duration.” Fill in the specific test mode duration (Unit: Minute).
- f) Test mode value 6: Perform band switching operation, the mode duration/configuration value is filled in the value corresponding to the target frequency band to be switched, where the value 0 indicates the communication band 0, i.e., 1.953~11.96 MHz, value 1 indicates communication band 1, i.e., 2.441~5.615 MHz.

- g) Test mode value 7: Perform the ToneMask configuration operation. The mode duration/configuration value fills in the value corresponding to the target ToneMask to be configured. The value 0 indicates the ToneMask configuration corresponding to the frequency band 0: [zeros (1,80), 1 0 0 1 1 0 1 0 0 1 1 1 0 0 0 1 0 0 1 1 1 1 zeros (1, 30), ones (1, 359), zeros (1, 21)], a value of 1 indicates the ToneMask configuration corresponding to Band 1: [zeros (1100), 1 0 1 1 1 1 1 1 1 0 1 0 0 1 1 1 0 1 1 1 1 ones (1109), zeros (1, 512–231)].
- h) Other nonzero value reservations, subsequent expansion according to requirements.

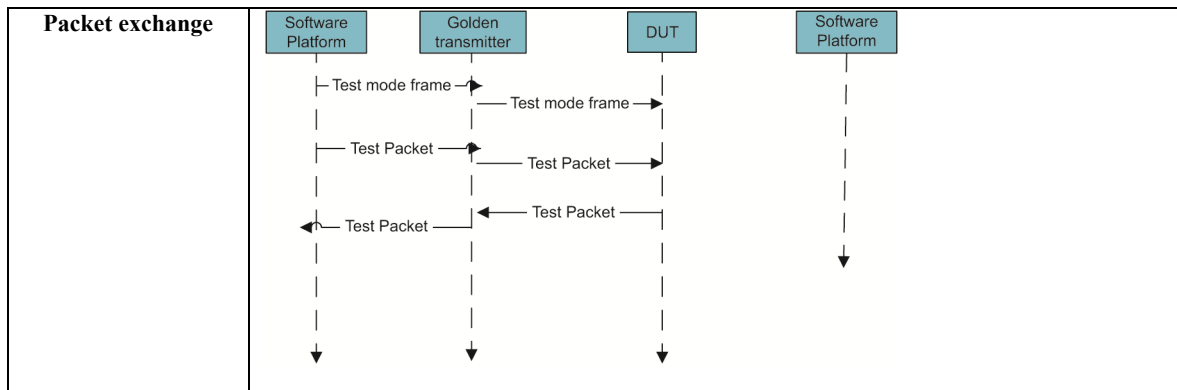
7. The physical layer test cases

7.1 General

The physical layer test uses the test environment and test bed as described in Clause 6. The PHY test cases are illustrated in 7.2 through 7.8.

7.2 Test Case 1: Working frequency band and power spectral density test

Test objective	To verify that the signal sent by the DUT meets the requirements or not
Test equipment	CCO, STA, golden transmitter, test software
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Add 20 dB attenuator is connected between the golden transmitter and the DUT. 3) Through the software platform, send the channel switch command to the tested device, make the device enters to channel 0, and then send the command to DUT, make the DUT change to return mode. 4) Set the spectrum analyzer parameters, Set the spectrum to channel power test mode, set the center frequency to 7 MHz, SPAN to 12 MHz, the integration bandwidth to 9MHz, the reference level to 10dBm, the power compensation to the actual line loss value (device to be tested to the spectrum analyzer), RBW is 10 kHz The VBW is 100 kHz, the Trace mode is MAX HOLD, and the detection mode selects rms mean detection. 5) Sent test packets to the golden transmitter. The golden transmitter sends a test packet to the DUT according to the set TMI mode. After receiving the packet, the DUT returns the data through the power line, and the spectrum analyzer captures the signal sent by the DUT. 6) Set the standard device to send test packets 100 times. 7) Obtain all points of the spectrum, Horizontal ordinate (Hz), Ordinate (dBm) value, In-band PSD value. 8) From the data read in the previous step, the rising edge of the spectrum and the inflection point of the falling edge are calculated as the working frequency band. 9) Reset the spectrum analyzer parameters, set the spectrum to channel power test mode, set the center frequency to 0.9 MHz, SPAN to 2 MHz, the integration bandwidth to 1.3MHz, the reference level to 10dBm, and the power compensation to the actual line loss value (DUT) To the spectrum analyzer, the RBW is 10 kHz, the VBW is 100 kHz, the Trace mode is MAX HOLD, and the detection mode selects rms mean detection. (Outside band: 0.25 MHz–1.55 MHz). 10) The software platform sends the test packet to the golden transmitter. The golden transmitter sends a test packet to the DUT based on TMI mode. After receiving the packet, the DUT returns the data through the power line, and the spectrum analyzer captures the signal sent by the test device. 11) Set the standard device to send test packets 100 times. 12) The software platform obtains the out-of-band PSD value from the spectrum analyzer and records it as PSD1. 13) Reset the spectrum analyzer parameters, set the spectrum to channel power test mode, set the center frequency to 31 MHz, SPAN to 40 MHz, the integration bandwidth to 37 MHz, the reference level to 10dBm, and the power compensation to the actual line loss value (device to spectrum to be tested) Instrument), RBW is 100 kHz, VBW is 1 MHz, Trace mode is MAX HOLD, and detection mode selects rms mean detection. (outside band: 12.5 MHz–49.5 MHz). 14) The software platform sends the test packet to the golden transmitter. The golden transmitter sends a test packet to the DUT based on TMI mode. After receiving the packet, the DUT returns the data through the power line, and the spectrum analyzer captures the signal sent by the test device. 15) The software platform sets the standard device to send test packets 100 times. 16) The software platform obtains the out-of-band PSD value from the spectrum analyzer and records it as PSD2. 17) The software calculates PSD1 and PSD2, the larger value is the out-of-band PSD.
Check item	1) Check the operating frequency band of the signal sent by the DUT. 2) Check that the in-band transmit power of the signal sent by the DUT is < 45 dBm/Hz. 3) Check that the out-of-band transmit power of the signal sent by the DUT is < 75 dB/mHz.
Network topology	N/A



7.3 Test Case 2: Anti-white noise performance test

Test objective	To verify that the DUT meets the white noise reception performance under the TIM set of anti-white noise performance test.
Testing device	1 pcs DUT
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the test platform, verify that the noise is turned off. Use the clock inside the golden transmitter. Set the default attenuation value of the programmable attenuator to 20db. 3) Based on the software platform, send 20 test command frames (TMI = 4) in band 0 and band 1, and set the target working band of the DUT. 4) Based on the software platform, send 20 test command frames (TMI = 4) to let the DUT enter the transparent transmission mode. 5) The software platform sets the signal generator, output Gaussian white noise, the bandwidth of the noise is 25MHz and the power is -30dBm. 6) Continuously transmitting 5 Beacon frames for clock synchronization of the DUT, and the Beacon interval is 1 s (DUT(CCO/STA) receives the Beacon only for clock synchronization, and does not backhaul); 7) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (100 frames per interval) The packet sends 5 Beacon frames); 8) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 9) After receiving the content of the FC+PB packet, the software platform compares the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT considers that the packet is transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication will remain unchanged. 10) Statistical success rate, if the successful rate is less than 90%, the test ends. If the successful rate is greater than 90%, increase the programmable attenuator value (step 10db, if the limit value is less than 10db, step 1db, the performance test case attenuation step control is the same, no longer repeat), repeat step 6 through step 10 until the successful rate is just less than 90%, ending the current test. Record the attenuation value of this TMI mode. 11) Continue to select the next TMI mode, repeat step 6 through step 10 (when switching from band 0 test to band 1 test, you need to reset the frequency band of DUT, golden transmitter, carrier sense unit).
Check item	Check that each TMI has a decay rate of less than 90% success rate under the DUT TMI mode set.
Network topology	N/A
Packet exchange	

7.4 Test Case 3: Anti-frequency offset performance test

Test objective	To verify that the DUT meets the requirements for frequency offset performance under the TIM set against frequency offset performance test.
Test equipment	1 pcs DUT
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the platform environment, verify that the noise is turned off. Use the clock source that comes with the golden transmitter to set the default attenuation value of the programmable attenuator to 20db. 3) The software platform sends 20 test command frames (TMI = 4) in frequency band 0 and frequency band 1, and sets the target working frequency band of the DUT. 4) The software platform sends 20 test command frames (TMI = 4) to put the DUT into transparent transmission mode. 5) Setting software platform, set transparent forwarding device frequency offset to 0ppm at 25MHz. 6) The software platform continuously sends 5 Beacon frames for clock synchronization of the DUT. The Beacon interval is 1s (the DUT (CCO/STA) receives the Beacon only for clock synchronization and does not transmit transparently). 7) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (100 frames per interval) The packet sends 5 Beacon frames). 8) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 9) After receiving the content of the FC+PB packet, the software platform compares with the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT is considered to be transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication is unchanged. 10) Statistical success rate, if the success rate is less than 90%, the test is finished. If the success rate is greater than 90%, increase the frequency of the transparent forwarding device (step 10ppm, if the limit value is less than 10ppm, step 1ppm, The same below, no more repeat), and then repeat step 6 through step 9 until the success rate is just less than 90%, the current test is finished, and the frequency offset value is recorded as the forward anti-frequency offset of the DUT. 11) The software platform sets the transparent forwarding device to a frequency offset of 0ppm at 25MHz, resets the device, and starts testing the negative anti-frequency offset value. 12) The software platform continuously transmits 5 central Beacon frames (Beacon frame interval 1s). 13) The software platform sends a test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (5 Beacon frames are sent for every 100 frames). 14) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 15) After receiving the content of the FC+PB packet, the software platform compares the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT considers that the DUT is transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication is unchanged. 16) Statistical success rate, if the success rate is less than 90%, the test ends. If the success rate is greater than 90%, reduce the frequency offset of the transparent forwarding device, and then repeat step 12 through step15 until the success rate is just less than 90%. Current test, recording the frequency offset value as the negative anti-frequency offset value of the DUT.
Check item	Check the forward bias frequency offset and negative offset frequency offset of the DUT
Network topology	N/A
Packet exchange	

7.5 Test Case 4: Anti-attenuation performance test

Test objective	To verify that the DUT meets the attenuation performance under the TIM set of anti-attenuation performance
Testing equipment	1 pcs DUT
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the platform environment to verify that the noise is turned off. Use the clock source that comes with the golden transmitter to set the default attenuation value of the programmable attenuator to 20db. 3) The software platform sends 20 test command frames (TMI = 4) in frequency band 0 and frequency band 1, respectively, and sets the target working frequency band of the DUT. 4) The software platform sends 20 test command frames (TMI = 4) to put the DUT into transparent transmission mode. 5) The software platform continuously sends 5 Beacon frames for clock synchronization of the DUT. The Beacon interval is 1 s (the DUT (CCO/STA) receives the Beacon only for clock synchronization and does not transmit back). 6) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (100 frames per interval) The packet sends 5 Beacon frames). 7) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 8) After receiving the content of the FC+PB packet, the software platform compares the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT considers that the DUT is transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication will remain unchanged. 9) Statistical success rate, if the success rate is less than 90%, the test ends. If the success rate is greater than 90%, increase the programmed attenuator value and repeat step 5 through step 9 until the success rate is just less than 90%, ending the current test. Record the attenuation value of this TMI mode. 10) Continue to select the next TMI mode, repeat step 6 through step 9 (when switching from the band 0 test to the band 1 test, DUT, transparent access unit, carrier sense unit frequency band needs to be reset).
Check item	Check that each TMI has a decay rate of less than 90% at the success rate of the DUT TMI mode set.
Network topology	N/A
Packet exchange	

7.6 Test Case 5: Anti-narrowband noise performance test

Test objective	To verify that the DUT meets the requirements for narrowband performance under the TIM set for anti-narrowband noise performance test.
Testing equipment	1 pcs DUT
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the platform environment, verify that the noise is turned off. Use the clock source that comes with the golden transmitter to set the default attenuation value of the programmable attenuator to 20 db. 3) The software platform sends 20 test command frames (TMI = 4) in frequency band 0 and frequency band 1, respectively, and sets the target working frequency band of the DUT. 4) The software platform sends 20 test command frames (TMI = 4) to put the DUT into transparent transmission mode. 5) The software platform setting signal generators: Band 1: (1MHz, -20 dBm), (3MHz, -30 dBm), (6MHz, -30dBm); Band 0: (1MHz, -20dBm), (8MHz, -30dBm), (15MHz, -20dBm) narrow-band interference, the following steps are tested; 6) The software platform continuously sends 5 Beacon frames for clock synchronization of the DUT. The Beacon interval is 1 s (the DUT (CCO/STA) receives the Beacon only for clock synchronization and does not transmit back). 7) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (100 frames per interval) The packet sends 5 Beacon frames). 8) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 9) After receiving the content of the FC+PB packet, the software platform compares with the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT is considered to be transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication will remain unchanged. 10) Statistical success rate, if the success rate is less than 90%, the test ends. If the success rate is greater than 90%, increase the programmable attenuator value and repeat step 6 through step 9 until the success rate is just less than 90%. End the current test. Record the attenuation value of this TMI mode. 11) Continue to select the next TMI mode, repeat step 6 through step 10 (when switching from Band 0 test to Band 1 test, you need to reset the frequency band of DUT, transparent access unit, carrier sense unit).
Check item	Check that each TMI has a decay rate of less than 90% success rate under the DUT TMI mode set
Network topology	N/A
Packet exchange	

7.7 Test Case 6: Anti-pulse noise performance test

Test objective	To verify that the DUT's anti-pulse performance meets the requirements under the TIM set of anti-pulse noise performance test.
Testing equipment	1 pcs DUT
Testing procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the platform environment to verify that the noise is turned off. Use the golden transmitter to bring its own clock source. Set the default attenuation value of the programmable attenuator to 20 db. 3) The software platform sends 20 test command frames (TMI = 4) in frequency band 0 and frequency band 1, respectively, and sets the target working frequency band of the DUT. 4) The software platform sends 20 test command frames (TMI = 4) to put the DUT into transparent transmission mode. 5) The software platform sets the signal generator to output a pulse signal with a pulse frequency of 100 kHz, a pulse width of 1 us, and an amplitude of $V_{pp} = 4\text{ V}$. 6) The software platform continuously sends 5 Beacon frames for clock synchronization of the DUT. The Beacon interval is 1 s (the DUT (CCO/STA) receives the Beacon only for clock synchronization and does not transmit transparently). 7) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 500 times (100 frames per interval) The packet sends 5 Beacon frames); 8) The transparent forwarding device forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT reports the received packet data (FC16 B + payload PB block data) through the serial port. 9) After receiving the content of the FC+PB packet, the software platform compares with the content saved before the transmission. If the content of the FC+PB is the same as the content sent, the DUT is considered to be transparently transmitted. If the data before and after the packet is inconsistent, the number of successful communication will remain unchanged. 10) Statistical success rate, if the success rate is less than 90%, the test ends. If the success rate is greater than 90%, increase the programmable attenuator value and repeat step 6 through step 9 until the success rate is just less than 90%. End the current test, record the attenuation value of this TMI mode. 11) Continue to select the next TMI mode, repeat step 6 through step 10 (when switching from Band 0 test to Band 1 test, you need to reset the frequency band of DUT, transparent access unit, carrier sense unit).
Check item	Check that each TMI has a decay rate of less than 90% success rate under the DUT TMI mode set.
Network topology	N/A
Packet exchange	

7.8 Test Case 7: Communication rate performance test

Test objective	To verify the application layer packet communication rate of the DUT under the communication rate performance test TMI set
Testing equipment	1 pcs DUT
Test procedure	1) Connect the device. Power on and initialize the DUT. 2) Initialize the platform environment to verify that the noise is turned off. Use the golden transmitter to bring its own clock source. Set the default attenuation value of the programmable attenuator to 20db. 3) The software platform sends 20 test command frames (TMI = 4) in frequency band 0 and frequency band 1, respectively, and sets the target working frequency band of the DUT. 4) The software platform sends 20 test command frames (TMI = 4) to let the DUT enter the transparent transmission mode. 5) The software platform continuously sends 5 Beacon frames for clock synchronization of the DUT. The Beacon interval is 1 s (the DUT (CCO/STA) receives the Beacon only for clock synchronization and does not transmit back). 6) The software platform selects the test packet in the TMI mode set, sends the test packet to the golden transmitter, and saves the FC+PB content of the packet (the ACK only retains the FC), and the number of transmissions is 1000 times (100 frames per interval) The packet sends 5 Beacon frames). 7) The golden transmitter forward the test packet sent by the software platform to the PLC. After receiving the packet, the DUT returns the data to the entire content of the FC+PB through the power line. 8) The carrier sense unit reports the FC+PB content sent by the transparent access unit of the software platform and the FC+PB content returned by the DUT, and the corresponding NTB value. 9) After receiving the content of the FC+PB packet, the software platform compares with the content saved before the transmission. If the FC+PB content is received twice, the two NTBs are reported according to the carrier sensing unit. Value, calculate the interval of the return frame. The frame interval calculation method is: the difference between two NTBs (unit us) + the agreed application layer processing delay (100us)—the frame length, the frame interval needs to be greater than or equal to 400us. Discarding and application layer packet communication rate [application layer packet communication rate calculation method is: maximum application layer packet size that can be carried by physical block / (two NTB difference (unit us) + agreed application) layer processing delay (100us)]. 10) The software platform averages the communication rate value, which is the application layer packet communication rate of the DUT in this TMI mode.
Check item	Check the application layer packet communication rate of the DUT in the corresponding TMI mode set
Network topology	N/A
Packet exchange	<pre> sequenceDiagram participant SP as Software platform participant GT as Golden transmitter participant DUT as DUT SP->>GT: Test mode frame GT->>DUT: Test mode frame SP->>GT: Test packet GT->>DUT: Test packet DUT->>GT: Test packet GT->>SP: Test packet </pre>

8. The datalink layer test cases

8.1 Overview

The software platform controls the golden transmitter to simulate the CCO or STA to send protocol frame on the PLC.

The DUT will react as the protocol and it will send IEEE 1901.1 data on the PLC.

The golden receiver will capture all the IEEE 1901.1 data on the PLC, and report it to the software platform.

The software platform will decide whether the reaction of the DUT is compliance with IEEE Std 1901.1.

An example of text structure for datalink layer test is shown in Figure 5.

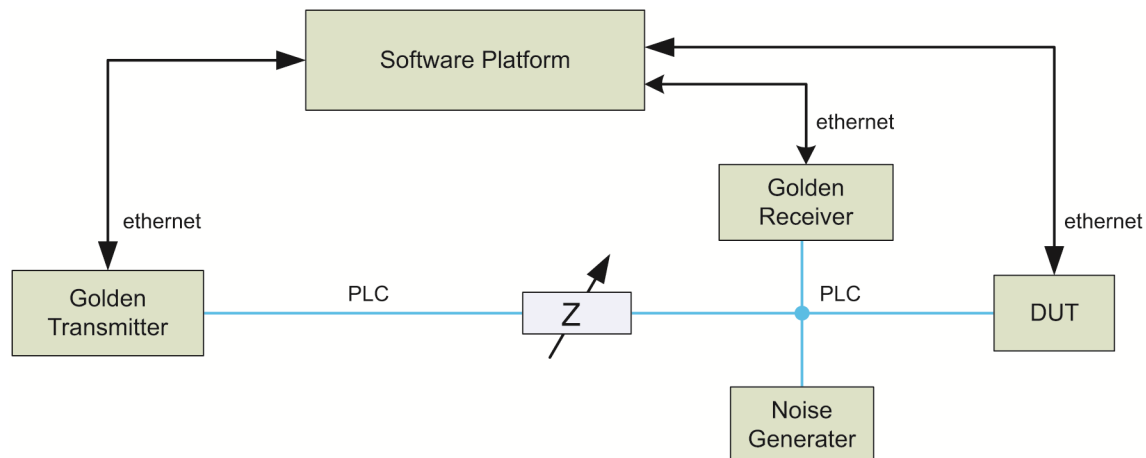
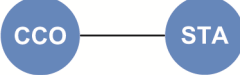
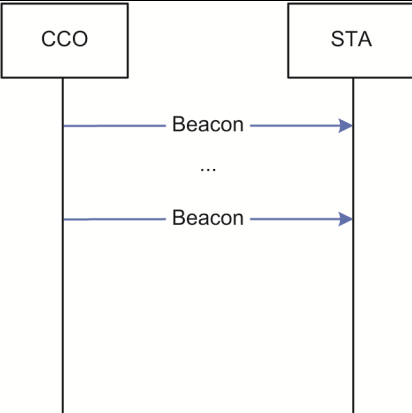


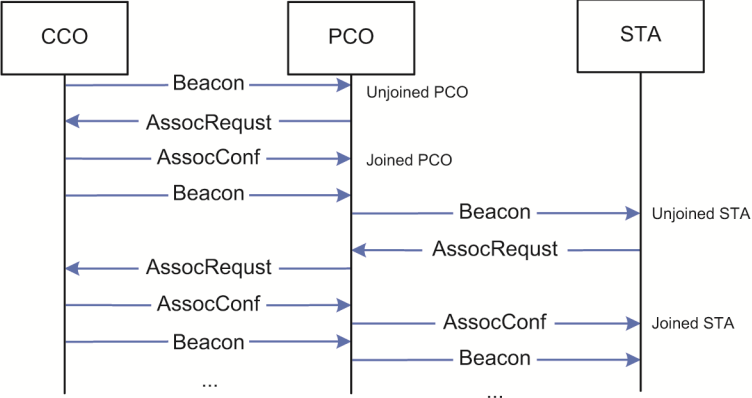
Figure 5—Example of test structure for datalink layer test

8.2 Beacon mechanism at the data link layer

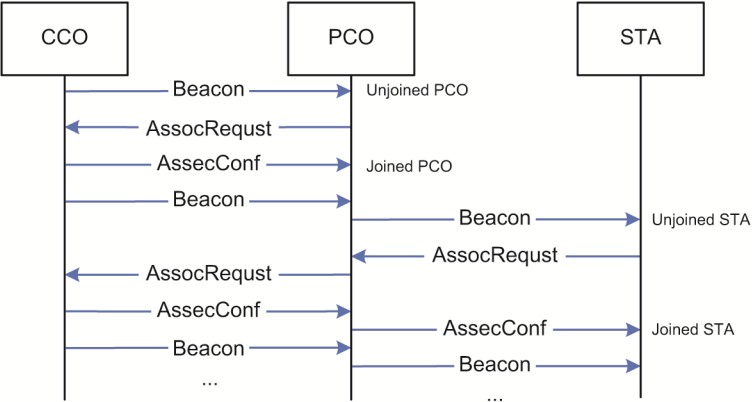
8.2.1 Testing that the CCO can periodically send central Beacon frames

Test objective	To test that the CCO can periodically send correct central Beacon frames on A, B, and C phase lines.
Test procedure	1) Power on and initialize the CCO. 2) Start a 120-s timer. 3) The golden receiver monitors PLC channels and reports received data to the software platform. 4) The software platform checks whether fields in the central Beacon frames sent by the CCO are valid. If yes, check whether they are sent within the specified central Beacon timeslot. 5) Monitor frame sending in 10 Beacon periods to check whether the CCO successfully sends central Beacon frames on A, B, and C phase lines in each Beacon period.
Check item	1) Check whether the CCO successfully sends central Beacon frames on A, B, and C phase lines in each Beacon period. 2) Check whether the sending interval between two adjacent phase lines in each Beacon period is the same as the timeslot stipulated in the central Beacon. 3) Check whether the sending interval between two adjacent Beacon frames is the same as the Beacon period. 4) Check whether the value of the Beacon period count (BPC) field is incremented by 1 for each central Beacon period. 5) Check the length and value validity of fields defined in the Beacon frame. — Check whether the Delimiter Type field has 3 bits and its value is 0 (Beacon frame). — Check whether the Source Terminal Equipment Identifier (STEI) field has 12 bits and its value is 1 (CCO's TEI is 1). — Check whether the Beacon type (BT) field has 3 bits and its value is 2 (central Beacon). — Check whether the NetworkForm field has 2 bits and its value is 0 (Networking is not complete). — Check whether the StartAssociate field has 1 bit and its value is 1 (STAs are allowed to initiate association requests.). — Check whether the UseBeacon field has 1 bit and its value is 1 (STAs are allowed to use Beacon to evaluate the quality of channel). — Check whether the CCO MAC field has 48 bits and the MAC address is the same as CCO's MAC address.
Network topology	 The DUT is the CCO.
Packet exchange	 <pre> sequenceDiagram participant CCO participant STA Note over CCO: Beacon CCO->>STA: Beacon Note over CCO: ... CCO->>STA: Beacon </pre>

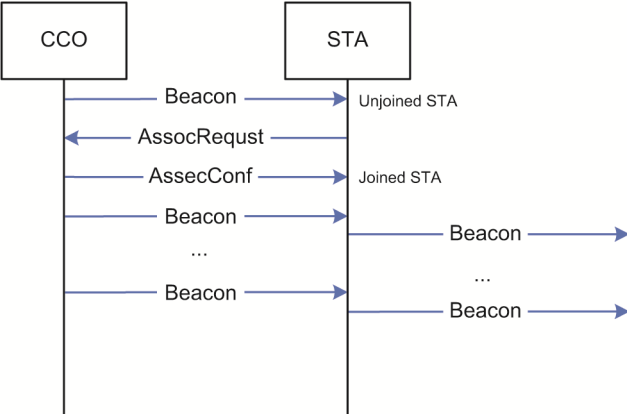
8.2.2 Testing that MMeAssocReq packet processing by the CCO when a proxy is deployed

Test objective	To test that the CCO can correctly process MMeAssocReq packets from a STA forwarded by the PCO.
Test procedure	1) Power on and initialize the CCO and PCO. 2) Start a 120-s timer. 3) The golden receiver monitors PLC channels and reports received data to the software platform. 4) The software platform simulates the PCO to forward MMeAssocReq packets from the STA to the CCO and waits for MMeAssocCnf packets from the CCO. 5) Check whether fields in the MMeAssocCnf packets received by the software platform from the CCO are correct.
Check item	1) Check whether the CCO can correctly parse MMeAssocReq packets sent by each STA and send correct MMeAssocCnf packets to the STA. 2) Check the length and value validity of fields defined in the Beacon frame. — Check whether the Delimiter Type field has 3 bits and its value is 1 (SOF frame). — Check whether the STEI field has 12 bits and its value is 1 (CCO's TEI is 1). — Check whether the Destination Terminal Equipment Identifier (DTEI) has 12 bits and its value is 2 (PCO's TEI is 2).
Network topology	 The DUT is the CCO.
Packet exchange	

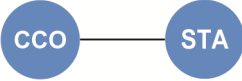
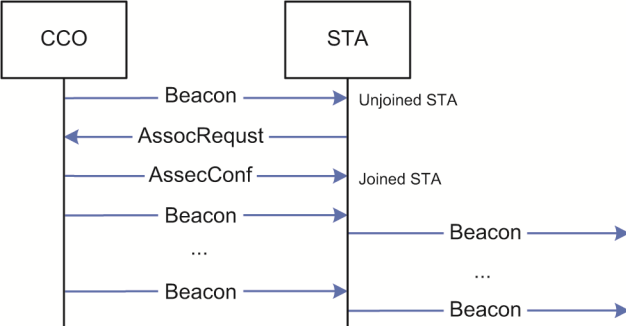
8.2.3 Testing that the PCO can send Proxy Beacon frames on a multi-level STA network

Test objective	To test that the STA (functioning as the PCO on a multi-level PLC network) can send discovery Beacon and Proxy Beacon frames.
Test procedure	1) Power on and initialize the PCO. 2) Start a 120-s timer. 3) The golden receiver monitors PLC channels and reports received data to the software platform. 4) Check whether the software platform can receive valid discovery Beacon and Proxy Beacon frames the PCO.
Check item	1) Check whether the Level-1 STA (functioning as the PCO) can successfully send valid Proxy Beacon and discovery Beacon frames. 2) Check the length and value validity of fields defined in the Beacon frame. — Check whether the Delimiter Type field has 3 bits and its value is 0 (Beacon frame). — Check whether the source terminal equipment identifier (STEI) field has 12 bits and its value is 2 (PCO's TEI is 2). — Check whether the Beacon type (BT) field has 3 bits and its value is 0 or 1(0 stands for Discovery Beacon, 1 stands for Proxy Beacon). — Check whether the PROXY TEI field has 12 bits and its value is 1(PCO's proxy is CCO). — Check whether the Send Beacon STA MAC field has 48 bits and its value is the PCO's MAC address. — Check whether the ROLE field has 4 bits and its value is 2(PCO). — Check whether the LEVEL field has 4 bits and its value is 1(level 1).
Network topology	 The DUT is the PCO.
Packet exchange	

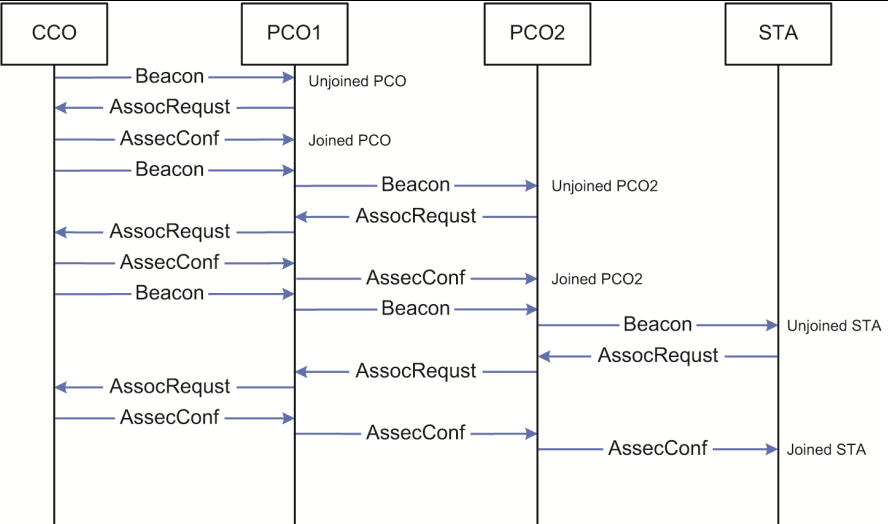
8.2.4 Testing that the STA can periodically send valid Discovery Beacon frames after receiving Central Beacon frames

Test objective	To test that the STA can periodically send valid discovery Beacon frames.
Test procedure	1) Power on and initialize the STA. 2) Start a 120-s timer. 3) Check whether the software platform can receive discovery Beacon frames from the tested STA through the golden receiver and check whether fields in discovery Beacon frames are valid.
Check item	1) Check whether the sending interval between two adjacent Beacon frames is larger than 170 s. 2) Check whether the value of the Beacon Period Count (BPC) field is incremented by 1 for each discovery Beacon period. 3) Check the length and value validity of fields defined in the Beacon frame. — Check whether the Delimiter Type field has 3 bits and its value is 0 (Beacon frame). — Check whether the Source Terminal Equipment Identifier (STEI) field has 12 bits and its value is 2 (STA's TEI is 2). — Check whether the Beacon type (BT) field has 3 bits and its value is 0 (0 stands for Discovery Beacon). — Check whether the PROXY TEI field has 12 bits and its value is 1 (STA's proxy is CCO). — Check whether the Send Beacon STA MAC field has 48 bits and its value is the STA's MAC address. — Check whether the ROLE field has 4 bits and its value is 1 (STA). — Check whether the LEVEL field has 4 bits and its value is 1 (level 1).
Network topology	 The DUT is the STA.
Packet exchange	 <pre> sequenceDiagram participant CCO participant STA CCO->>STA: Beacon STA->>CCO: AssocRequest CCO->>STA: AssecConf CCO->>STA: Beacon STA->>R: Beacon CCO->>STA: ... STA->>R: Beacon </pre>

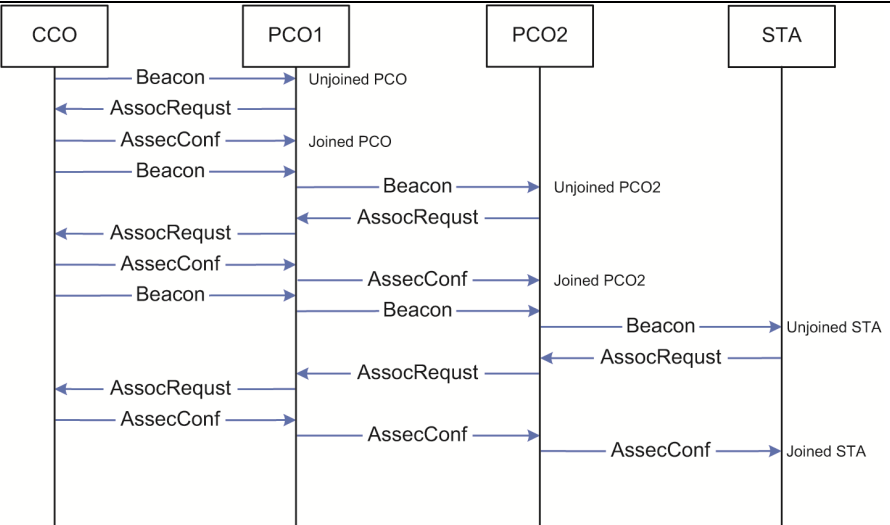
8.2.5 Testing that MMeAssocReq packet processing by the CCO

Test objective	To test that the CCO can receive and correctly process MMeAssocReq packets from the STA.
Test procedure	1) Power on and initialize the CCO. 2) Start a 60-s timer. 3) Check whether the software platform can receive Beacon frames sent by the CCO through the golden receiver. 4) Check whether the CCO can reply MMeAssocCnf packets for MMeAssocReq packets sent by the software platform.
Check item	1) The CCO can successfully parse MMeAssocReq packets and reply MMeAssocCnf packets. 2) All the fields in MMeAssocCnf packets sent by the CCO are valid.
Network topology	 The DUT is the CCO.
Packet exchange	 <pre> sequenceDiagram participant CCO participant STA Note over STA: Unjoined STA CCO->>STA: Beacon STA->>CCO: AssocRequest Note over STA: Joined STA CCO->>STA: AssecConf CCO->>STA: Beacon STA->>CCO: Beacon </pre>

8.2.6 Testing that the CCO can send MMeAssocCnf packets on a multi-level STA network

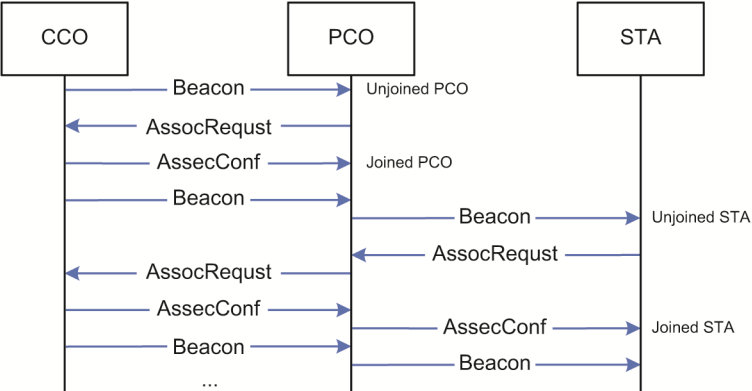
Test objective	To test that the CCO can send MMeAssocCnf packets on a multi-level PLC network.
Test procedure	1) Power on and initialize the CCO. 2) Start a 300-s timer. 3) The software platform simulates the non-connected PCO1 to send MMeAssocReq packets after receiving Central Beacon frames from the CCO. The tested CCO receives MMeAssocReq packets from PCO1 and sends MMeAssocCnf packets to it. PCO1 connects to the network successfully. 4) The connected PCO1 sends discovery Beacon frames after receiving central Beacon frames (discovery Beacon timeslots planned) from the CCO. The non-connected PCO2 sends MMeAssocReq packets after receiving discovery Beacon frames. The connected PCO1 forward the MMeAssocReq packets to the CCO. Check whether the CCO can process the MMeAssocReq packets forwarded by the connected PCO1. 5) The tested CCO replies with MMeAssocCnf packets. The connected PCO1 forward the MMeAssocCnf packets. Check whether the software platform receives MMeAssocCnf packets sent by the CCO. 6) Connected PCO1 and PCO2 send Proxy Beacon frames after receiving central Beacon frames (Proxy Beacon timeslots planned) from the CCO. Check whether the non-connected STA sends MMeAssocReq packets after receiving Proxy Beacons frames. Connected PCO1 and PCO2 forward MMeAssocReq packets to the CCO, and wait for MMeAssocCnf packets from the CCO. 7) After the software platform receives MMeAssocCnf packets from the CCO, check whether the packets are valid.
Check item	Check whether the CCO can receive MMeAssocReq packets sent by the STA and send correct MMeAssocCnf packets to the STA.
Network topology	 The DUT is the CCO.
Packet exchange	

8.2.7 Testing that PCO sends Proxy Beacon frames after receiving Proxy Beacon frames

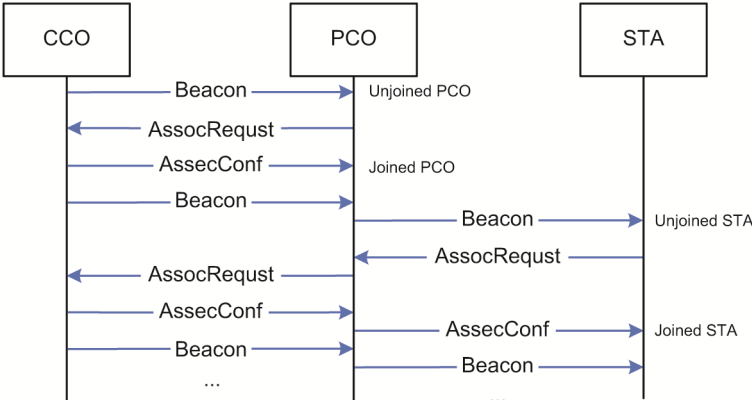
Test objective	To test that PCO2 can generate and send Proxy Beacon frames after receiving Proxy Beacon frames.
Test procedure	1) Power on and initialize PCO2. 2) The software platform simulates the CCO, PCO1, and STA to establish a PLC network with the tested PCO2. 3) Start a 120-s timer. 4) The software platform sends Proxy Beacon frames to the tested PCO2. Check whether PCO2 can generate and send correct Proxy Beacon frames.
Check item	1) Check whether the Proxy Beacon frames generated by PCO2 are valid. 2) Check whether the value of the Beacon Period Count (BPC) field is incremented by 1 for each Proxy Beacon period. 3) Check the length and value validity of fields defined in the Beacon frame. — Check whether the Delimiter Type field has 3 bits and its value is 0 (Beacon frame). — Check whether the Source Terminal Equipment Identifier (STEI) field has 12 bits and its value is 3 (PCO's TEI is 3). — Check whether the Beacon type (BT) field has 3 bits and its value is 1(1 stands for Proxy Beacon). — Check whether the PROXY TEI field has 12 bits and its value is 1(PCO's proxy is CCO). — Check whether the Send Beacon STA MAC field has 48 bits and its value is the PCO2's MAC address. — Check whether the ROLE field has 4 bits and its value is 2(PCO). — Check whether the LEVEL field has 4 bits and its value is 2(level 2).
Network topology	 The DUT is PCO2.
Packet exchange	

8.3 Timeslot management at the data link layer

8.3.1 Testing that the CCO can plan timeslots for network-wide STAs and send frames in the specified timeslots

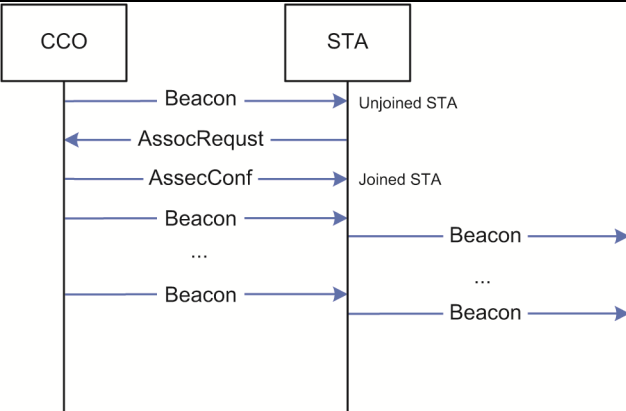
Test objective	To test that the CCO can plan timeslots for network-wide STAs based on the network topology and send frames in the specified timeslots.
Test procedure	1) Power on and initialize the CCO. 2) Start a 120-s timer. 3) After the software platform receives central Beacon frames from the tested CCO through the golden receiver, check whether the frames are sent within the specified timeslot. Simulate the PCO to send MMeAssocReq packets. 4) The software platform monitors whether it receives MMeAssocCnf packets from the tested CCO within the specified CSMA timeslot. 5) After the software platform receives central Beacon frames from the tested CCO, check whether the CCO has planned Discovery Beacon timeslots for the connected PCO. 6) The software platform simulates the connected PCO to forward MMeAssocReq packets from a non-connected STA through the golden transmitter within the CSMA timeslot planned by the CCO. 7) The software platform monitors whether it receives MMeAssocCnf packets from the tested CCO within the specified CSMA timeslot. 8) After the software platform receives central Beacon frames from the tested CCO, check whether the CCO has planned discovery Beacon timeslots for the newly connected STA and whether the CCO has planned Proxy Beacon timeslots for the simulated PCO.
Check item	1) Check whether the CCO sends central Beacon frames within the central Beacon timeslot stipulated in the central Beacon. 2) Check whether the CCO sends MMeAssocCnf packets within the CSMA timeslot stipulated in the central Beacon. 3) Check whether the CCO sends MMeAssocCnf packets to the STA connected to it through the PCO within the CSMA timeslot stipulated in the central Beacon. 4) Check whether the CCO allocates timeslots to the PCO and STA in the central Beacon.
Network topology	 The DUT is the CCO.
Packet exchange	

8.3.2 Testing that the STA and PCO send frames within the specified timeslot

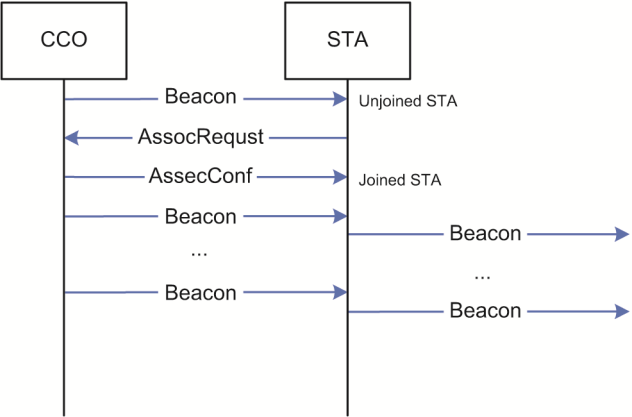
Test objective	To test that the STA and PCO can send frames within the timeslot stipulated in the Central Beacon.
Test procedure	1) Power on and initialize the STA and PCO. 2) Start a 120-s timer. 3) The software platform stimulates the CCO to send Central Beacon frames to the tested PCO through the golden transmitter. Check whether the CCO receives MMeAssocReq packets from the tested PCO within the specified CSMA timeslot. 4) The software platform sends in the MMeAssocCnf packets to the tested PCO within the specified CSMA timeslot through the golden transmitter. 5) The software platform stimulates the CCO to send Central Beacon frames to the tested PCO through the golden transmitter and plan the Discovery Beacon timeslot for the connected PCO. Check whether it receives Discovery Beacon frames from the tested PCO within the specified Discovery Beacon timeslot. 6) After receiving Discovery Beacon frames, the software platform stimulates a non-connected STA to send MMeAssocReq packets to the tested STA within the CSMA timeslot through the golden transmitter. 7) The software platform monitors whether it receives MMeAssocReq packets from the tested PCO within the specified CSMA timeslot. 8) After receiving MMeAssocReq packets, the software platform simulates the CCO to send MMeAssocCnf packets within the CSMA timeslot through the golden transmitter. 9) The software platform monitors whether it receives MMeAssocCnf packets from the tested PCO within the specified CSMA timeslot. 10) The software platform stimulates the CCO to send Central Beacon frames through the golden transmitter and plan Proxy Beacon timeslots for the PCO. At the same time, a 10-s timer is started. Check whether it receives Proxy Beacon frames from the tested PCO within the specified Proxy Beacon timeslot.
Check item	1) Check whether the PCO sends MMeAssocReq packets within the CSMA timeslot stipulated in the Central Beacon. 2) Check whether the PCO sends Discovery Beacon frames within the Discovery Beacon timeslot stipulated in the Central Beacon. 3) Check whether the PCO forward MMeAssocReq packets from the non-collected STA within the timeslot stipulated in the Central Beacon. 4) Check whether the STA forward MMeAssocCnf packets from the CCO within the timeslot stipulated in the Central Beacon. 5) Check whether the PCO sends Proxy Beacon frames within the Proxy Beacon timeslot stipulated in the Central Beacon.
Network topology	 The DUTs are the PCO and STA.
Packet exchange	

8.4 Channel access at the data link layer

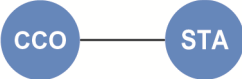
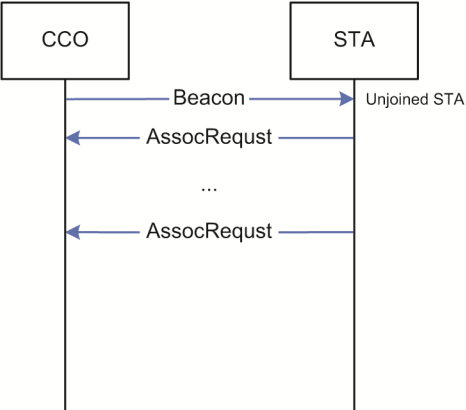
8.4.1 Testing that the STA sends frames within the CSMA timeslot

Test objective	To test that the STA sends SOF frames within the CSMA timeslot stipulated in the Central Beacon.
Test procedure	1) Power on and initialize the STA. 2) Start a 120-s timer. 3) The software platform simulates the CCO to periodically send Central Beacon frames to the tested STA through the golden transmitter and wait for MMeAssocReq packets from the STA. 4) After receiving MMeAssocReq packets from the STA, the software platform checks whether the timestamp in received packets is within the CSMA timeslot stipulated in the Central Beacon.
Check item	Check whether the STA sends SOF frames within the CSMA timeslot stipulated in the Central Beacon.
Network topology	 The DUT is the STA.
Packet exchange	

8.4.2 Testing that the CCO sends frames within the CSMA timeslot

Test objective	To test that the CCO sends SOF frames within the CSMA timeslot stipulated in the Central Beacon.
Test procedure	1) Power on and initialize the CCO. 2) Start a 120-s timer. 3) After receiving Central Beacon frames from the tested CCO through the golden receiver, the software platform stimulates a non-connected STA to send MMeAssocReq packets to the tested CCO and connect to the network successfully. 4) The software platform checks whether the timestamp in received MMeAssocReq packets is within the specified timeslot stipulated in the Central Beacon.
Check item	Check whether the CCO sends SOF frames within the CSMA timeslot stipulated in the Central Beacon.
Network topology	 The DUT is the CCO.
Packet exchange	

8.4.3 Conflict backoff test of the STA

Test objective	To test that the back off interval of conflict frames of the STA is compliant with the standards.
Test procedure	1) Power on and initialize the STA. 2) Start a 30-s timer. 3) The software platform simulates the CCO to periodically send Central Beacon frames to the tested STA and wait for MMeAssocReq packets from the STA. 4) If the software platform receives a MMeAssocReq packet from the STA but does not reply an SACK packet, packet loss occurs due to a conflict. 5) The software platform receives multiple retransmitted MMeAssocReq packets, compares these packets, and checks whether the frame interval is compliant with the standards.
Check item	The network time base (NTB) difference in the frame interval of multiple SOF frames reported by the golden receiver is larger than 400 us.
Network topology	 The DUT is the STA.
Packet exchange	 <pre> sequenceDiagram participant CCO participant STA CCO->>STA: Beacon STA->>CCO: AssocRequest Note right of STA: Unjoined STA CCO->>STA: ... STA->>CCO: AssocRequest </pre>