TECHNICAL REPORT

TR-208

Performance Test Plan For In-premises Powerline Communication Systems

Issue: 1
Issue Date: August 2015

Notice

Issue History

Issue Number	Approval Date	Publication Date	Issue Editor	Changes
1	24 August 2015	11 September 2015	Marcos Martínez, Marvell Semiconductors	Original

Comments or questions about this Broadband Forum Technical Report should be directed to help@broadband-forum.org.

Editor	Marcos Martínez	Marvell Semiconductors	marcosm@marvell.com
Metallic Transmission WG Chair	Les Brown	Huawei	lesbrown@sympatico.ca
Vice Chair	Lincoln Lavoie	IOL-UNH	lylavoie@iol.unh.edu
Vice Chair	Massimo Sorbara	Ikanos	msorbara@ikanos.com

Table of Contents

List of Figures

List of Tables

Executive Summary

Broadband powerline communication systems (PLC) are a key element of home networking since they provide a fast, flexible and reliable communication link between the different devices present in the home.

One of the main particularities of the usage of PLC systems is the difficulty to test them since, because of the specificities of the powerline medium in terms of noises, coupling methods and variety of topologies, it has been traditionally difficult to reproduce tests results and thus to compare different implementation performances. This disparity makes the task of comparing the performance of different implementations difficult for operators.

In order to address this challenge, this document is aimed to provide industry, operators, and test labs with a well defined test bed and an established set of tests that enable a performance comparison between PLC products and technologies that can be independently verified.

1 Purpose and Scope

1.1 Purpose

This document is aimed to provide industry, operators, and test labs with a well defined test bed and an established set of tests that enable a performance comparison between powerline products and technologies that can be independently verified.

Testing of wireline home-network transceivers from different vendors or technologies should be possible in a repeatable and reproducible fashion.

1.2 Scope

This document initially focuses on powerline communications (PLC) home network performance testing. Other mediums are for further study.

This document specifically focuses on performance testing. For this, this document provides a real world evaluation method that enables independent (or Operator) test lab evaluation of different products and technologies.

The main categories of tests included in this document are:

- **Throughput performances**: Testing the performance of SISO and MIMO systems under different conditions of noise and attenuation of the line.
- **Neighboring networks**: Testing of the behavior of the powerline system in presence of a neighboring network of the same technology under different attenuation conditions
- **PSD measurements**: Measurement of transmit PSD in-band and out of band for the system under test.
- **Noise immunity**: Testing the behavior of the system under different noise conditions.
- **Topology**: Testing the ability of the system to handle the topology of the network and its evolution over time.
- **Traffic**: Testing the capacity of the system to handle different traffic types and maintaining the QoS of that traffic.
- **Security**: Testing the capacity of the system to provide at least minimal security features.
- **QoS**: Quality of service performance tests
- **Multinode performance**: Testing the capacity of the system to operate in a network with multiple active nodes.

Finally, an annex is provided in a separate excel sheet with a template of a test report that will facilitate comparison of the results obtained between different products and technologies.

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [2].

SHALL	This word, or the term “REQUIRED”, means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term “RECOMMENDED”, means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term “OPTIONAL”, means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.
A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document	Title	Source	Year
RFC2544	*Benchmarking Methodology for Network Interconnect Devices*	IETF	1999
RFC 2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997

RFC2474	*Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers*	IETF	1998

2.3 Definitions

The following terminology is used throughout this Technical Report.

Pairing	Pairing two devices refers to the process that results in both devices interchanging the encryption keys in order to establish secure communications in a network
PLC Node	Any network device that contains a powerline transceiver capable of operating over premises power-line wiring (either making use of two conductors (SISO) or three conductors (MIMO)).

2.4 Abbreviations

This Technical Report uses the following abbreviations:

AC	Alternating Current
AWGN	Additive white Gaussian noise
BW	Bandwidth
DSCP	Differentiated Services Code Point
DUT	Device Under Test
EMI	Electromagnetic interference
HF	High-Frequency
IEC	International Electrotechnical Comission
L	Live
MIMO	Multiple Inputs; Multiple Outputs
N	Neutral
OFDM	Orthogonal Frequency Division Multiplexing
PE	Protective Earth
PLC	Powerline Communications
PLR	Packet Loss Rate
PSD	Power Spectral Density
PVC	Polyvinyl chloride
RFI	Radio Frequency interference
SISO	Single Input; Single Output

VAC	Volts Alternating Current
XPUT	Throughput

3 Technical Report Impact

3.1 Energy Efficiency

TR-208 has no impact on energy efficiency.

3.2 IPv6

TR-208 has no impact on IPv6.

3.3 Security

TR-208 has no impact on security.

3.4 Privacy

Any issues regarding privacy are not affected by TR-208.

4 Throughput at different layers

Table 4.1: Throughput Definitions

Throughput Type	Definition
PHY layer throughput	Bits transmitted over the physical medium over a given period. This throughput is usually provided by the DUT. It can be instantaneous (instantaneous PHY layer throughput) or estimated (average PHY layer throughput), when the DUT takes into account the estimated resources that are allocated to the transmitter.
Ethernet PHY Throughput	Bits transmitted over the Ethernet connector of the DUT over a given period. This metric is usually provided by an external entity (traffic analyzer) and does not take into account the Ethernet overhead (headers, signalling, etc…).
Application Throughput	Bits transmitted by a given application over the communication system under study over a given time. This metric is usually provided by an external entity (program running on a computer) and does not take into account the application layer overhead (headers, signalling, etc…)

Whenever one of the above throughput definitions is qualified with the word "normalized" we will refer to the throughput normalized over a 1 MHz bandwidth using the formula:

$$XPUT_{NORM} = \frac{XPUT}{BW}$$

Where,

- $XPUT_{NORM}$= Throughput (in Mbits/s per MHz) under a normalized bandwidth of 1 MHz
- XPUT = Throughput in Mbits/s
- BW = Bandwidth in MHz allowed to be used by the system (starting at 2 MHz and ending at the frequency corresponding to the maximum sub-carrier allowed to be used by the system)

5 Test Environment

Testing of PLC devices should be possible using a methodology that is standardized and findings reproducible.
Testing shall be held in a shielded environment where RFI and EMI ingress is negligible across the full 1 MHz to 100 MHz frequency range.

5.1 PLC Test Configuration

Section 9 of this document provides the different setups that have to be used during the test process.

5.2 Requirements of the Test Configuration

Cable simulation, traffic configurations, attenuators, loads, noise disturbers, mains, and test environment are clearly defined and should be adhered to. Any deviation from the program shall be noted in any published test report.

6 DUT Requirements

6.1 DUT requirements

When possible, commercially available systems shall be used for testing.

6.2 Frequency Bands

High-Frequency (HF) PLC modems generally work in two frequency ranges. Only OFDM-based PLC is considered in this evaluation document. Some HF OFDM PLC modems used a frequency range of 2 to 30 MHz, while other PLC modems use a frequency range from 2 up to 100 MHz. The following table shows the types of HF PLC considered here. Both single input, single output (SISO) and multiple input, multiple output (MIMO) modes are covered here.

Table 6.1: PLC Types by Frequency Range

PLC technology bandwidth	Short name	Start Frequency	End Frequency
25 MHz	PLC-1A	2	25
30 MHz	PLC-1B	2	30
50 MHz	PLC-2	2	50
67 MHz	PLC-3	2	67
80 MHz	PLC-4	2	80
86 MHz	PLC-5	2	86
100 MHz	PLC-6	2	100

Note – Previous table is based on currently available products based on different PLC technologies. This list may be updated in the future as needed.

6.3 Notching

6.3.1 Notches specifications over power lines

For the tests to be of “real world” validity, the international ham notches should be enabled in the devices under test (DUTs). If these notches are not enabled, it shall be reported clearly in any published test results.

6.3.1.1 International amateur radio bands

Table 6.2: International amateur radio bands in the frequency range 0-100 MHz

Band start (kHz)	Band stop (kHz)
1 800	2 000
3 500	4 000
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700
50 000	54 000

6.3.1.2 Additional radio frequency bands

Additional (optional) radio frequency bands where PSD reduction may be required by national regulations:

Table 6.3: International broadcast bands

Band start (kHz)	Band stop (kHz)
2 300	2 498
3 200	3 400
3 900	4 000
4 750	5 060
5 900	6 200
7 200	7 450
9 400	9 900
11 600	12 100

13 570	13 870
15 100	15 800
17 480	17 900
18 900	19 020
21 450	21 850
25 670	26 100

Table 6.4: Aeronautical mobile bands

Band start (kHz)	Band stop (kHz)
2 850	3 150
3 400	3 500
3 800	3 950
4 650	4 850
5 450	5 730
6 525	6 765
8 815	9 040
10 005	10 100
11 175	11 400
13 200	13 360
15 010	15 100
17 900	18 030
21 924	22 000
23 200	23 350

Table 6.5: Radio astronomy bands

Band start (kHz)	Band stop (kHz)
13 360	13 410
25 550	25 670

In case these additional (optional) notches are applied to the DUT, it shall be clearly indicated in the test report.

6.4 Mains

The mains in different countries vary from 100 to 240 Volts AC at 50 or 60 Hz, one or three phase. For the repeatability and reproducibility of test results as of phase and timing of the noises and loads it is mandatory that the power source in different test labs is constant and stable and conformant. This is defined for repeatability of test results.

Two voltage/frequency pairs are considered for this test plan 110 VAC - 60 Hz and 220 VAC – 50 Hz.

7 Equipment for Testing

7.1 Equipment specifications

The test tools shall meet the requirements specified in the following clauses. Any variation from these requirements shall be noted in any published test report.
The frequency bands used for testing PLC modems shall be from 2 MHz to 100 MHz (See Table 6-1), therefore all test equipment must be capable of covering this frequency range.

7.1.1 Attenuators, Filters, Adapters

Characteristic impedance (Z_0) of 50 Ohms will be assumed for all the attenuators, coaxial cables, splitters and power combiners mentioned in this document.

7.1.1.1 Variable attenuator

An attenuator is a passive device that is used to reduce the power of the signal received at its input. Within the scope of this document, the value of the power reduction (attenuation) is usually required to be programmable (Variable Attenuator).

Variable Attenuators used in the different setups shall:

- Cover attenuation values from 8 to 100 dB in 1 dB steps
- Frequency response shall be uniform (flat) ± 1.0 dB from 1 MHz to 100 MHz

7.1.1.2 Splitter

Within the scope of this document, a splitter is a 3dB power combiner/divider: a passive device that connects three segments of a coaxial medium combining/dividing the power of the signals that pass through this device.

7.1.1.3 Filters

Within the scope of this document, a filter is a passive device that is used to remove all unwanted frequency components (at least those that could affect the PLC frequency bands) from/to the AC supply. Usually, the filter provides a plug towards the main AC supply and a socket to provide "clean" AC supply to the powerline test setup (at least in the PLC frequency bands).

7.1.1.4 PLC to coax

Within the scope of this document, a PLC to coax adapter is a device that connects the electrical medium (powerline) to a coaxial medium. Usually, a PLC to coax adapter also provides filtered AC supply.

7.1.1.5 Universal PLC splitter

The Universal PLC splitter is an equipment that allows to transfer the powerline signal (either SISO or MIMO) that is being sent over a powerline cable into the three different coaxial conductors (corresponding to L, N and PE).

The following schematic shows an example of how such a device may be implemented:

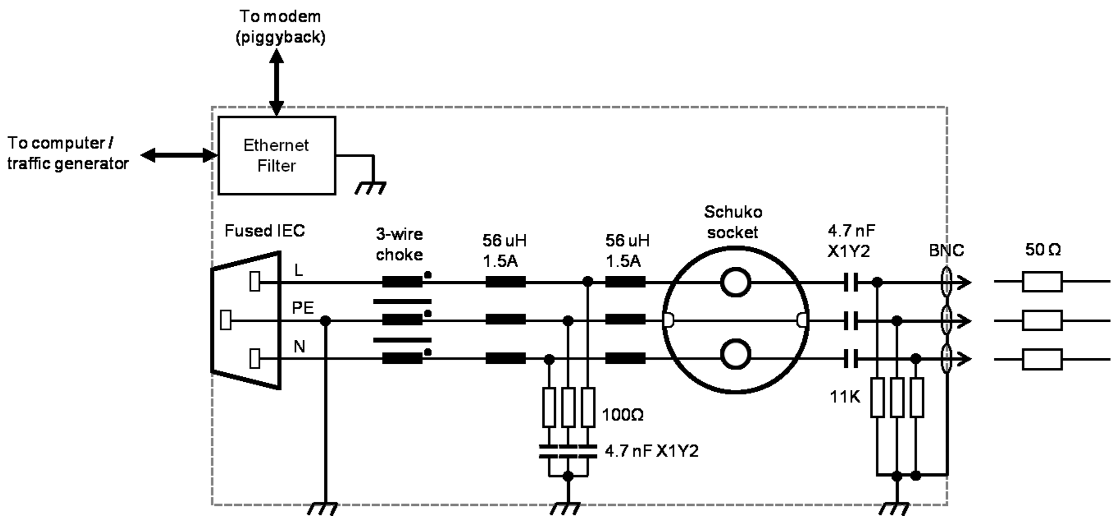

Figure 7-1: Universal PLC splitter schematic

Before using the Universal PLC splitter in any of the setups described in this document, the equipment needs to be calibrated.

7.1.1.6 Power Combiner

Within the scope of this document, a power combiner is a device that allows combining a generated noise signal and the normal signal on a coaxial line.
An example diagram of a power combiner made with three splitters in shown in Figure 7-2.
The power combiner offers three ports. Two of them (e.g. A and B) are connected to the line while the third port (C) shall be connected to the noise source.
There is always an attenuation of 6 dBs between each of the ports that shall be taken into account in the test setups when using the power combiner.

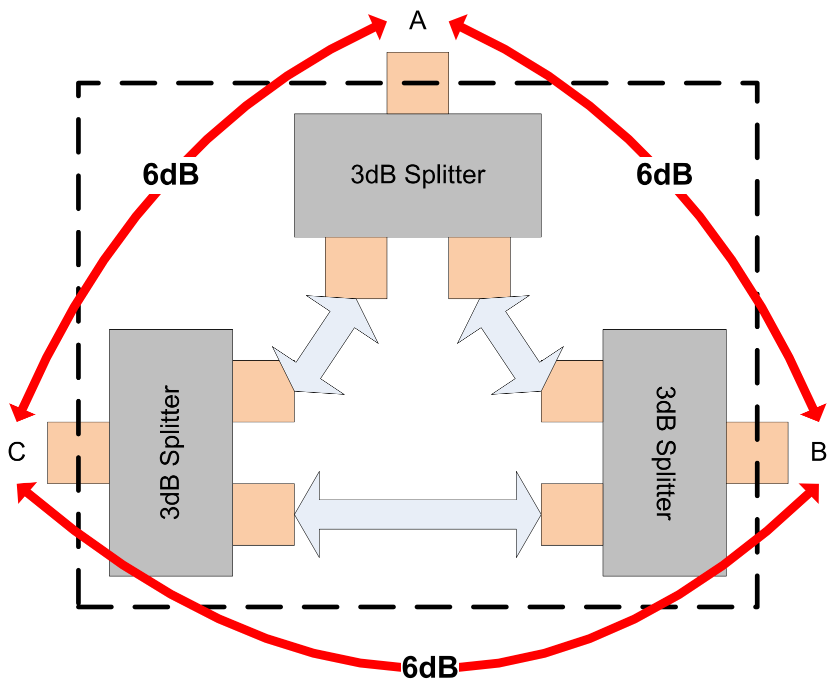

Figure 7-2: Power Combiner diagram

7.1.2 Cable Type Definition

A study of the electrical wire types used in different countries shows a large variation of possible wire types that differ in insulation, wire section and copper. The electrical characteristics of a cable that are important for high speed digital transmission are typically the attenuation of the cable, the impedance variation and the delay. The attenuation of a cable is mainly defined by the diameter of the copper conductor. However, given distances of only tens of meters or tens of feet, the wire diameter is not critical for testing PLC devices in an in-home environment.
The impedance of IEC 3-wire electricity cables tends to be around 75 Ohm.
Given the fact that attenuation based on cable diameter is not the crucial factor, and that the impedance of common IEC electrical cable is around 75 Ohm, 1.5 mm^2 PVC cable with an impedance of 75 Ohm is the cable model used for the tests.

7.1.3 Noise emulator

The following diagram shows a typical noise emulator.

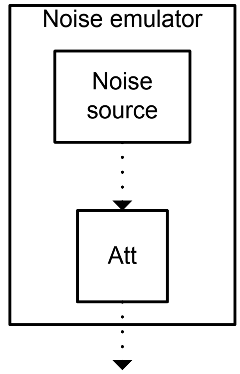

Figure 7-3: Noise emulator

The noise emulator shall be able to emulate the following types of noises:

Table 7.1: Noise Types

Noise	Noise Name	Description	Characteristics/Comments
N1	AWGN	AWGN	See clause 7.2.4.1
N2	Narrowband	Ingress noise with FM modulation	See clause 7.2.4.2
N3	Non Cyclo-stationary	Impulsive bursty noise	See clause 7.2.4.3
N4	Cyclo-stationary	Synchronous bursty noise	See clause 7.2.4.4

All the noise signal amplitudes (“Amplitude”) described in the following clauses take into account the 6dB losses introduced by the power combiners required for the noise injection. Z_0 = 50 Ohms considered for the signal generators.
Note - Use of loads and noises representing devices such as light bulbs, mobile chargers, dimmers, drills and appliances are for further study

7.2.4.1 Noise 1 (N1): AWGN

The Additive white Gaussian noise has the following characteristics:

- Noise source: Signal generator
- Amplitude: -100 dBm/Hz

The noise shall be applied from 2 MHz to 100 MHz.

7.2.4.2 Noise 2 (N2): Narrowband noise

The Narrowband noise has the following characteristics:

- Noise source: Signal generator
- Sine signal
- Central frequency: 20 MHz
- Amplitude: 0.5 Vpp
- FM modulation with BW of 100 kHz

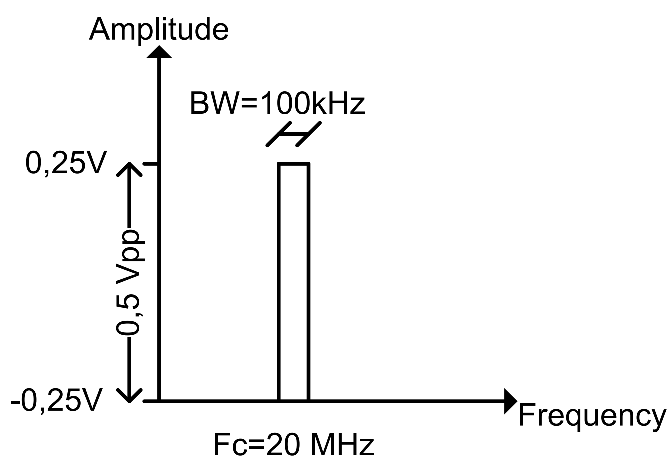

Figure 7-4: N2 noise

7.2.4.3 Noise 3 (N3): Non cyclostationary noise

The Non-cyclostationary noise has the following characteristics:

- Noise source: Signal generator
- Ramp signal
- Frequency: 100 kHz
- Amplitude: 0.5 Vpp
- Duration of the burst: 10 cycles
- Period of the burst: 3 ms

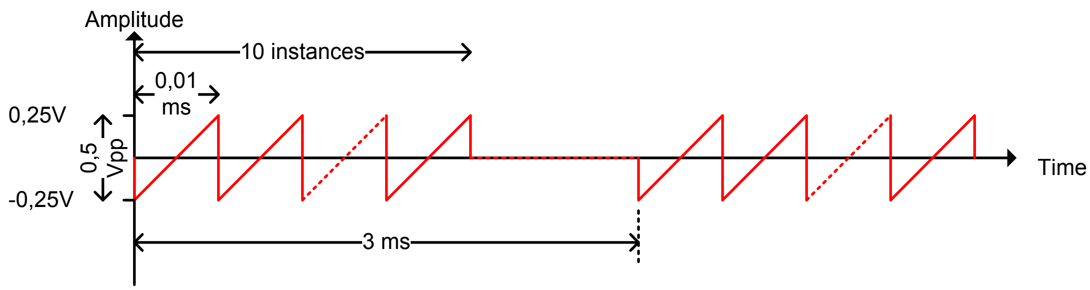

Figure 7-5: N3 noise

7.2.4.4 Noise 4 (N4): Cyclostationary noise

The Cyclostationary noise has the following characteristics:

- Noise source: Signal generator
- Ramp signal
- Frequency: 100 kHz
- Amplitude: 0.5 Vpp
- Duration of the burst: 10 cycles
- Period of the burst: 1/2 AC cycle

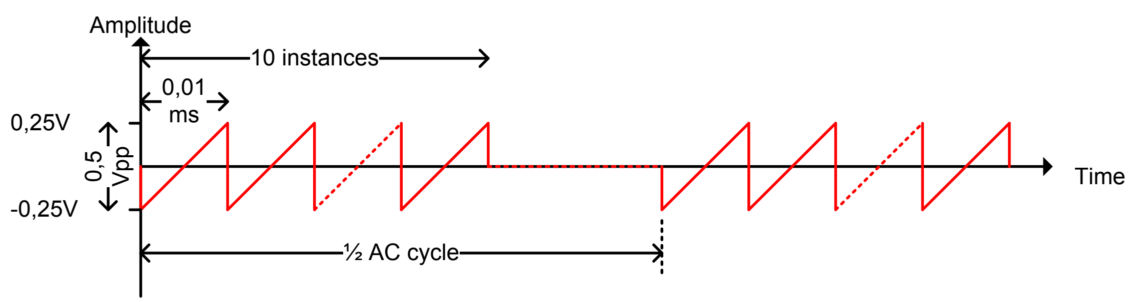

Figure 7-6: N4 noise

7.1.4 Spectrum analyzer

The spectrum analyzer to be used during PSD measurements shall be configured as follows:

Table 7.2: Spectrum analyzer configuration for f ≤ 30MHz

Parameter	Value	Unit
Start frequency	1	MHz
Stop frequency	30	MHz
Resolution Bandwidth (RBW) (Note 1)	9	kHz
Video bandwidth (VBW)	100	kHz
RF attenuation (analyzer dependent)	40	dB
Type of detector	rms	-
Sweep time	5	S

Note 1: According to CISPR 16-1, the bandwidth of the resolution filter is specified at -6 dB for EMI measurements. Not all spectrum analyzers have this feature

Table 7.3: Spectrum analyzer configuration for f > 30MHz

Parameter	Value	Unit
Start frequency	30	MHz
Stop frequency	100	MHz
Resolution Bandwidth (RBW) (Note 1)	120	kHz
Video bandwidth (VBW)	1	MHz
RF attenuation (analyzer dependent)	40	dB
Type of detector	rms	-
Sweep time	5	S

Note 1: According to CISPR 16-1, the bandwidth of the resolution filter is specified at -6 dB for EMI measurements. Not all spectrum analyzers have this feature

8 Test list

The tests included in this program are summarized in the following table. The table provides specific test information with the section where the text is described.

Table 8.1: List of Tests by type

Category	Family	Test ID	Test Descriptor	Section	Setup (SISO)	Setup (MIMO)
Throughput Performance	Rate vs Attenuation	S1	UDP point to point throughput	10.1.1.1	S-S1	S-M1
		S2	TCP point to point throughput	10.1.1.2	S-S1	S-M1
		S3	UDP point to point throughput under noise	10.1.1.3	S-S2	S-M2
		S4	TCP point to point throughput under noise	10.1.1.4	S-S2	S-M2
	Bidirectional traffic	S5	UDP bidirectional no noise	10.1.2.1	S-S1	S-M1
		S6	TCP bidirectional no noise	10.1.2.2	S-S1	S-M1
		S7	Variable UDP traffic	10.1.2.3	S-S1	S-M1
		S8	Variable TCP traffic	10.1.2.4	S-S1	S-M1
Neighboring Networks	Rate in NN conditions	N1	UDP, 2 networks	10.2.1.1	S-NN1	S-NN3
		N2	TCP, 2 networks	10.2.1.2	S-NN1	S-NN3
		N3	UDP, 3 networks	10.2.1.3	S-NN2	S-NN4
		N4	TCP, 3 networks	10.2.1.4	S-NN2	S-NN4
	Admission in NN conditions	N5	Joining a new node to an already established network	10.2.2.1	S-NN1	S-NN2
PSDMeasure ments	Validation of PSD	PS1	PSD measurement 100 KHz-200 MHz	10.3.1.1	S-PSD1	S-PSD1
	Notches	PS2	Notch validation	10.3.2.1	S-PSD1	S-PSD1
Noise immunity	Noise immunity	NI1	Noise immunity and performance	10.4.1.1	S-S2	S-M2
		NI2	On/Off Impulsive noise immunity and performance	10.4.1.2	S-S2	S-M2
Topology	Network setup	T1	Network setup	10.5.1.1	S-S1	S-M1
		T2	Joining a new node to an already established network	10.5.1.2	S-S4	S-M4
	Relay	T3	Single node relay	10.5.3	FFS	FFS
		T4	Multi-node Relay	10.5.4	FFS	FFS
Traffic	Latency	TS1	Round-trip latency	10.6.1.1	S-S1	S-M1
	Bursts	TS2	Ability to deal with bursty traffic	10.6.2.1	S-S1	S-M1
	Flow maintenance	TS3	Flow maintenance	10.6.3.1	S-S1	S-M1
	Throughput	TS4	Maximum throughput with no frame loss for	10.6.4.1	S-S1	S-M1

Category	Family	Test ID	Test Descriptor	Section	Setup (SISO)	Setup (MIMO)
			Unidirectional Traffic			
		TS5	Maximum throughput with no frame loss for Bidirectional Traffic	10.6.4.2	S-S1	S-M1
Security	Access Control	SEC1	Access Control	10.7.1.1	S-S4	S-M4
	Encryption	SEC2	P2P Encryption	10.7.2.1	S-S1	S-M4
		SEC3	P2P Encryption in a multinode network	10.7.2.2	S-S4	S-M4
QoS	QoS	QOS1	QoS	10.8.1	S-S1	S-M1
Multinode Performance	Multinode Performance	MN1	Multinode, UDP	10.9.1.1	S-MN1	S-MN2
		MN2	Multinode, TCP	10.9.1.2	S-MN1	S-MN2

9 Test Setups

The requirements are to establish a series of tests that provide a near real world test set up while at the same time stressing the technologies to ensure their limitations are understood and that they are able to be compared on a "like for like" basis regarding test set up and parameters

9.1 Test Lab Set Ups

The lab shall set up according to the figures shown in the following sections.
Note that in the following set-ups, there may be a management connection to the DUT. These are excluded from the diagrams for clarity.

Table 9.1: List of setups

Setup	Clause
S-S1	9.1.1
S-S2	9.1.2
S-S4	9.1.3
S-M1	9.1.4
S-M2	9.1.5
S-M4	9.1.6
S-NN1	9.1.7
S-NN2	9.1.8
S-NN3	9.1.9
S-NN4	9.1.10
S-MN1	9.1.11
S-MN2	9.1.12
Relay setup	9.1.13
S-PSD1	9.1.14

9.1.1 Setup S-S1

The following shall be the test bed set up for the tests in which no noise is injected.

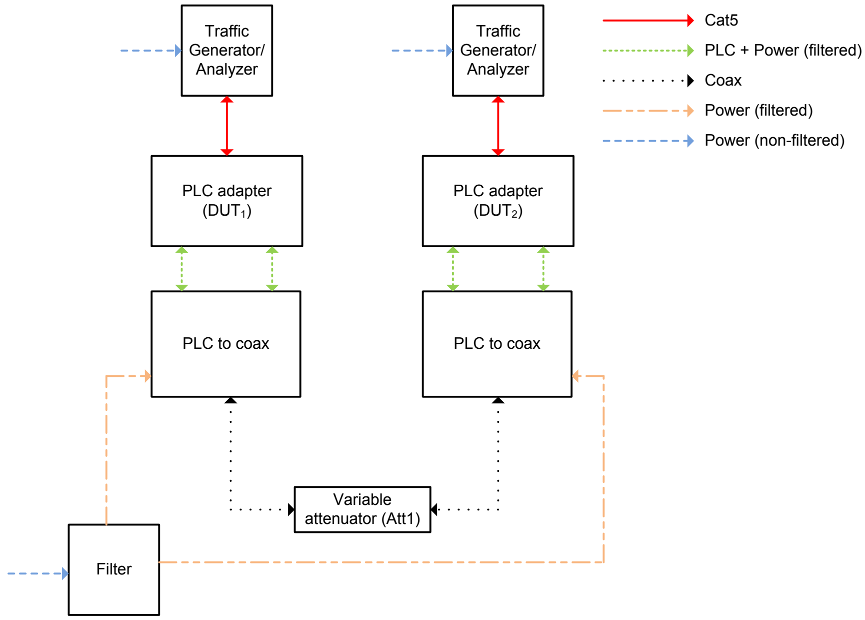

Figure 9-1: Setup S-S1

9.1.2 Setup S-S2

The following shall be the test bed set up for the tests in which noise will be injected.

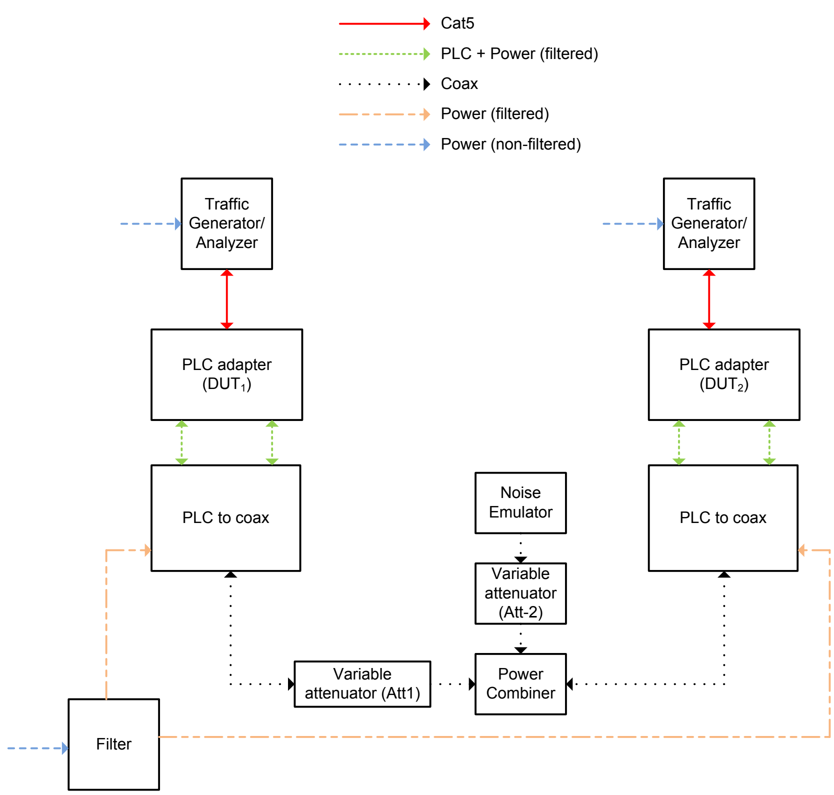

Figure 9-2: Setup S-S2

Note: In the above diagram, attenuators Att-1, Att-2 and power combiner may be included in the noise emulator.

9.1.3 Setup S-S4

The following shall be the test bed set up for the tests needing three nodes.

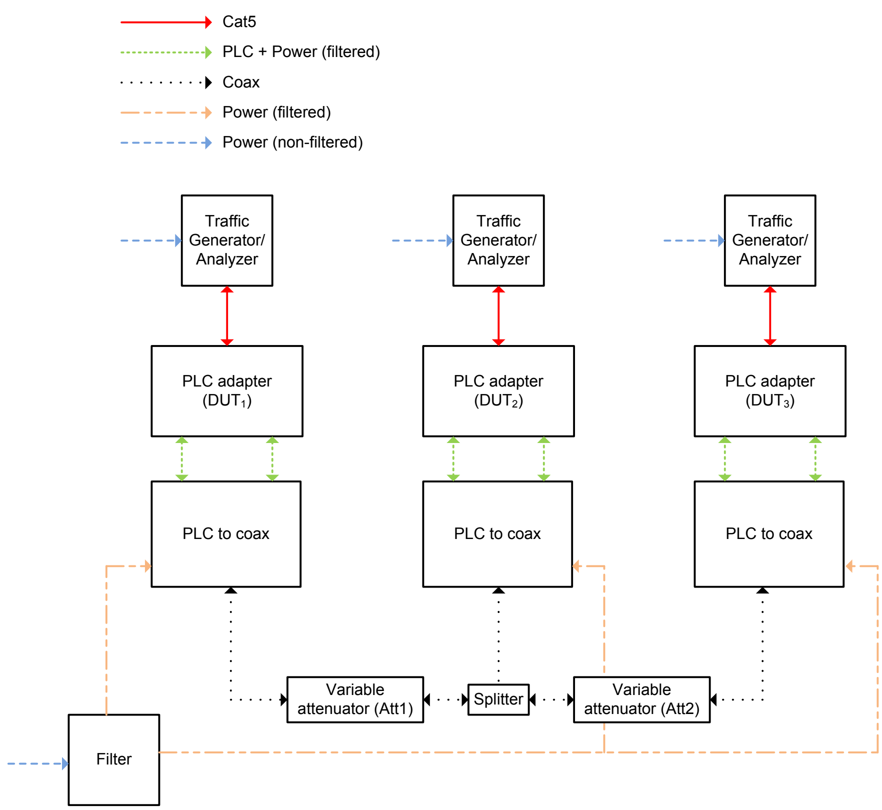

Figure 9-3: Setup S-S4

9.1.4 Setup S-M1

The following shall be the test bed set up for the tests in which no noise is injected.

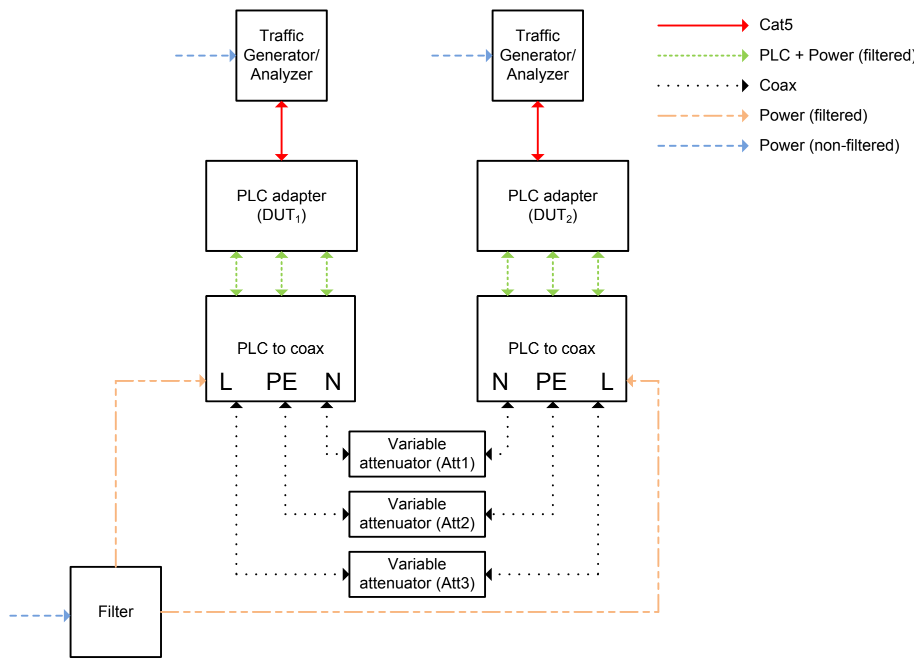

Figure 9-4: Setup S-M1

9.1.5 Setup S-M2

The following shall be the test bed set up for the tests in which noise will be injected.

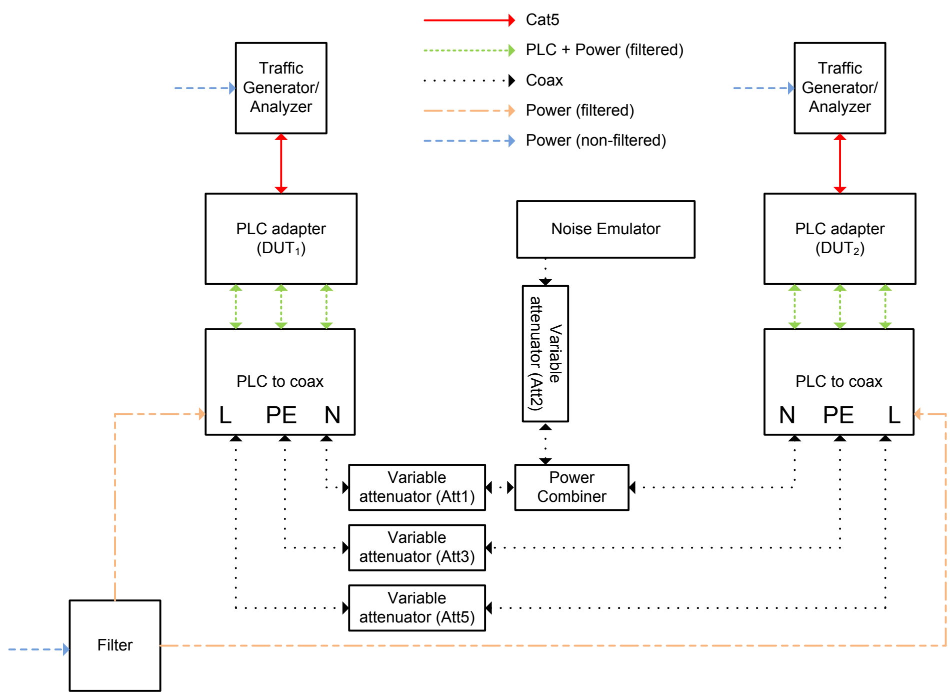

Figure 9-5: Setup S-M2

Note: In the above diagram, attenuators Att-1, Att-2, Att-3 and Att-5 and power combiner may be included in the noise emulator.

9.1.6 Setup S-M4

The following shall be the test bed set up for the tests with three nodes in which no noise is injected.

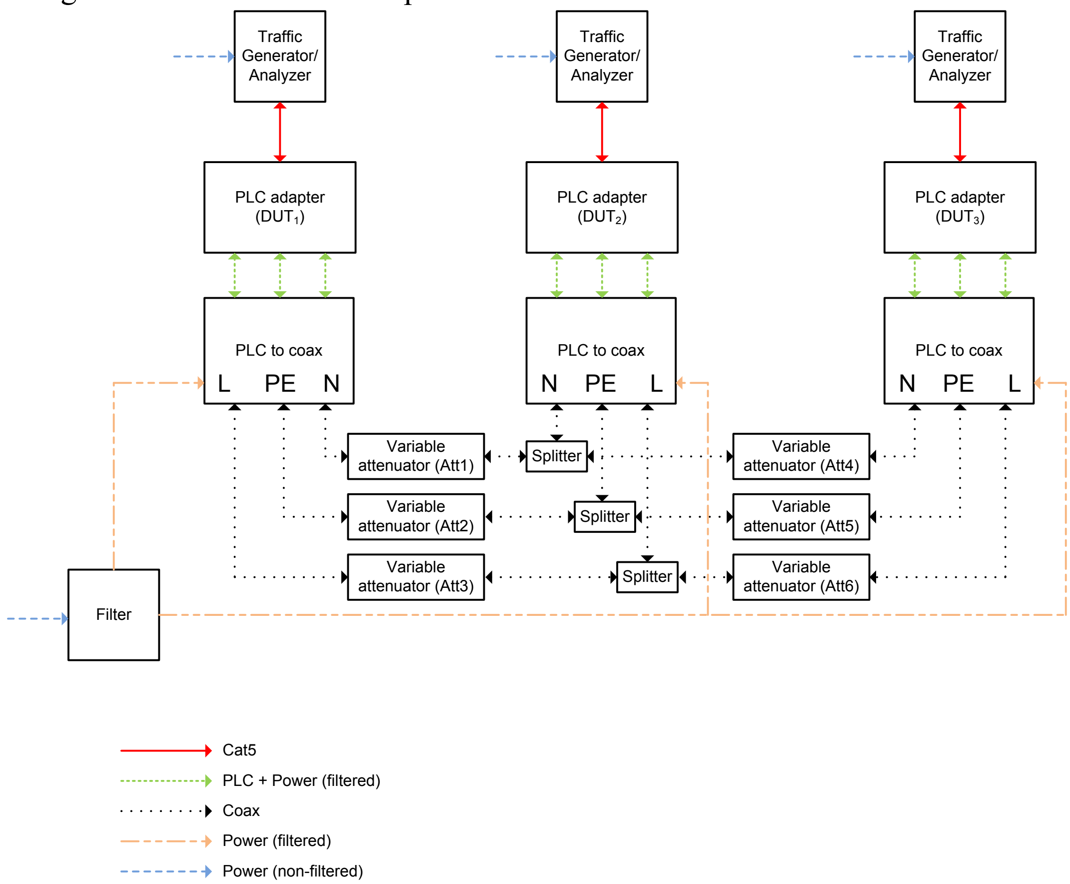

Figure 9-6: Setup S-M4

9.1.7 Setup S-NN1

This setup is used to show the performance of two neighbouring networks of the same technology (SISO case).

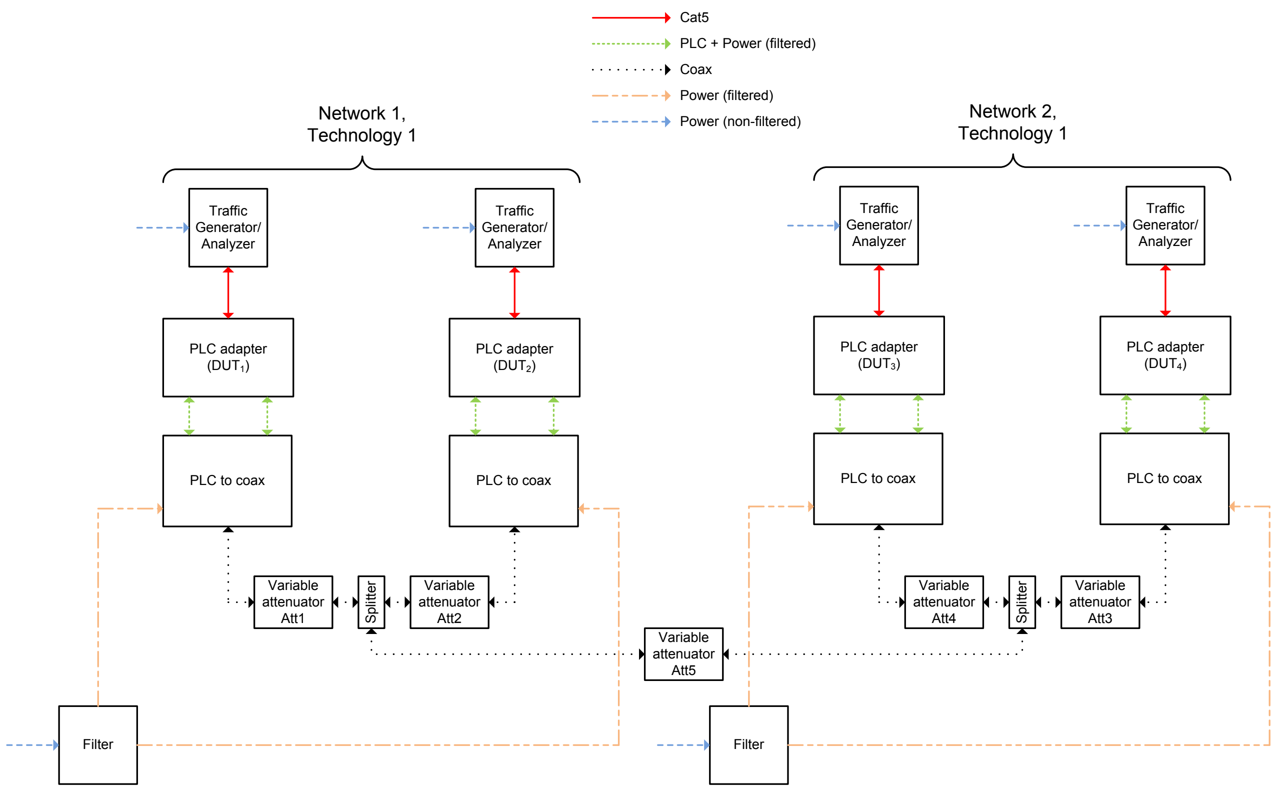

Figure 9-7: Setup S-NN1

9.1.8 Setup S-NN2

This setup is used to show the performance of three neighbouring networks of the same technology (SISO case).

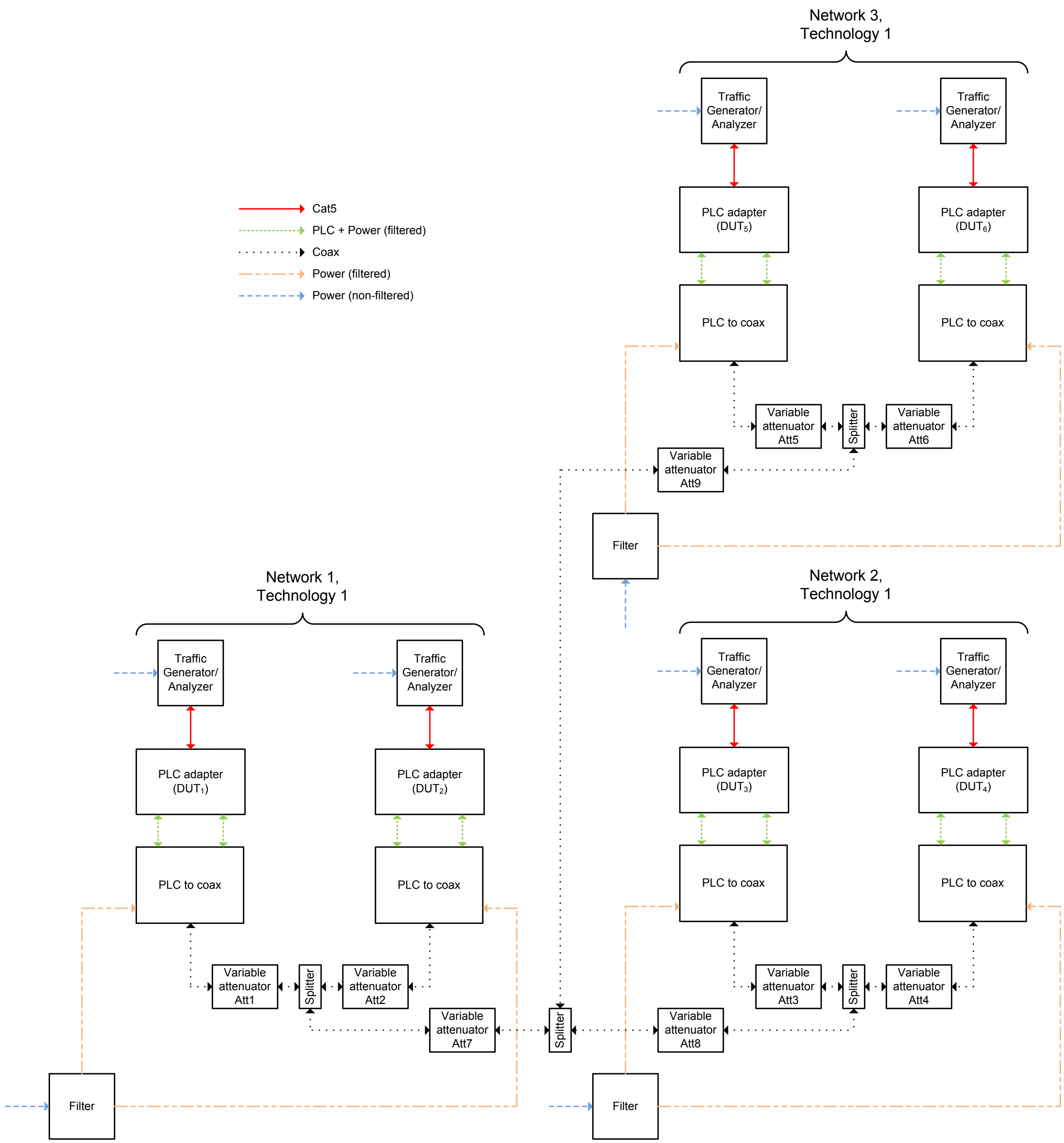

Figure 9-8: Setup S-NN2

9.1.9 Setup S-NN3

This setup is used to show the performance of three neighbouring networks of the same technology (MIMO case).

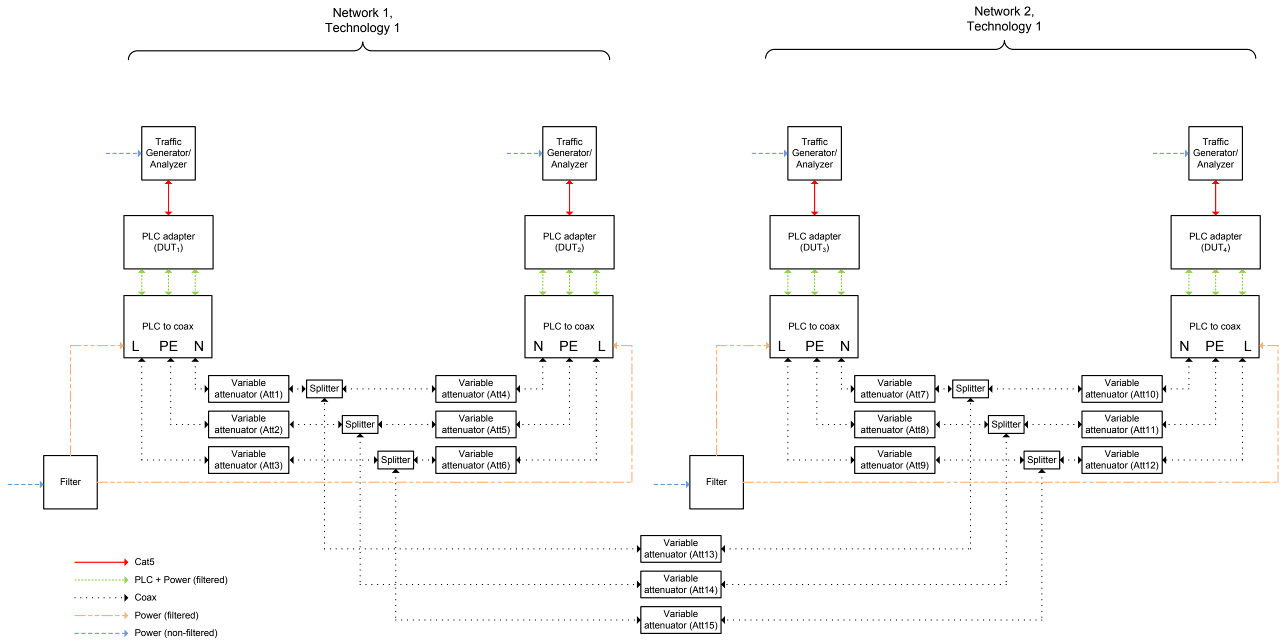

Figure 9-9: Setup S-NN3

9.1.10 Setup S-NN4

This setup is used to show the performance of three neighbouring networks of the same technology (MIMO case).

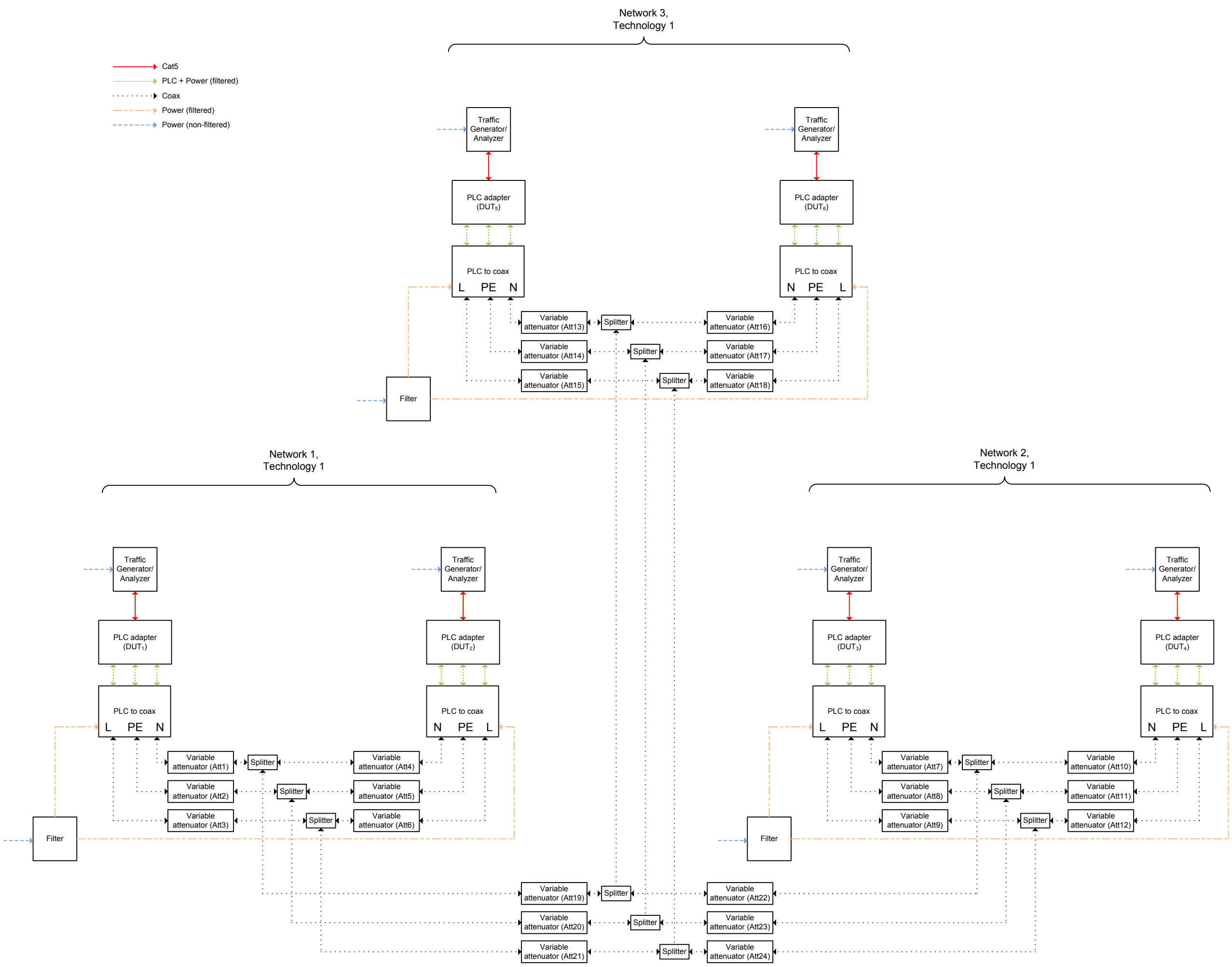

Figure 9-10: Setup S-NN4

9.1.11 Setup S-MN1

The following shall be the test bed set up for the tests with two nodes in which no noise is injected with a fixed attenuation between nodes (MIMO case).

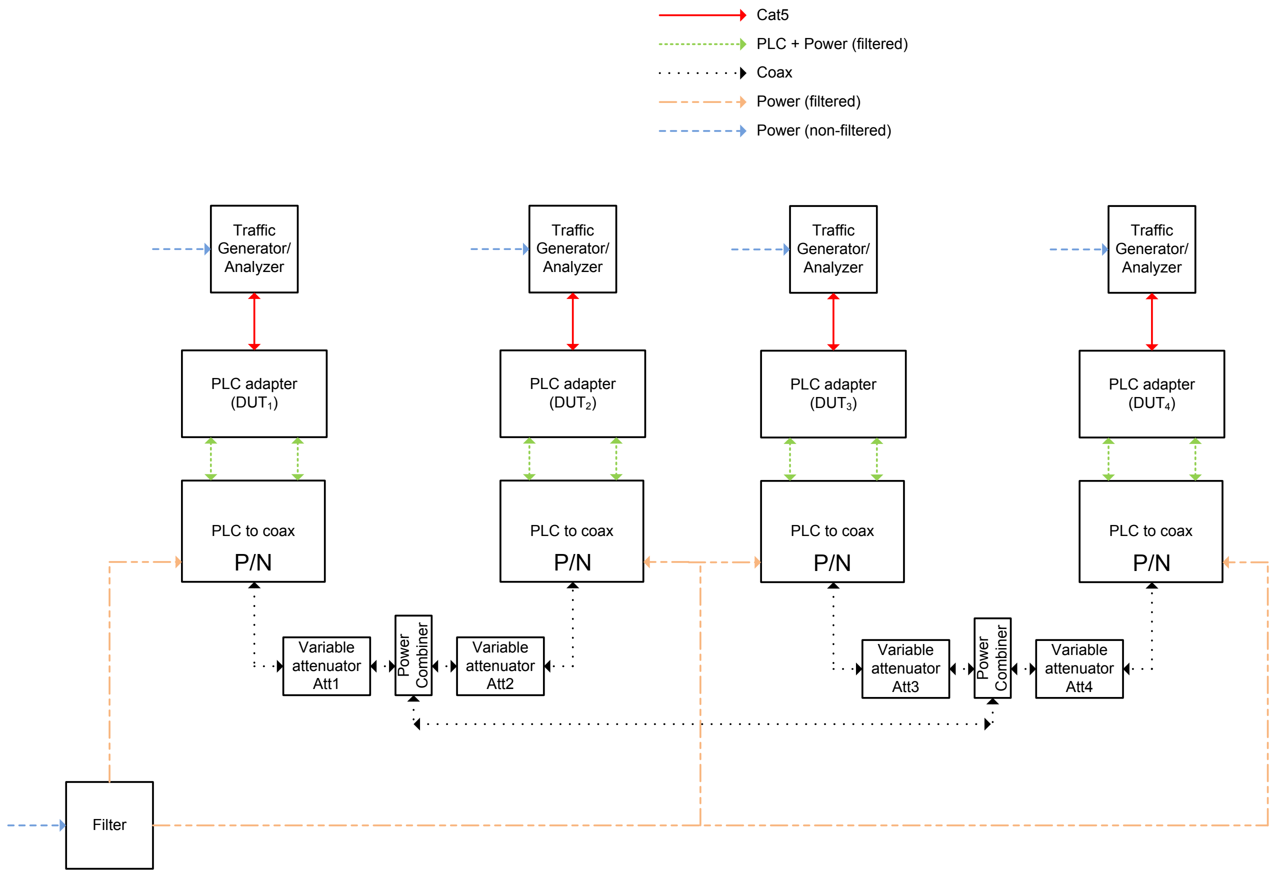

Figure 9-11: Setup S-MN1

9.1.12 Setup S-MN2

The following shall be the test bed set up for the tests with three nodes in which no noise is injected with a fixed attenuation between nodes (MIMO case).

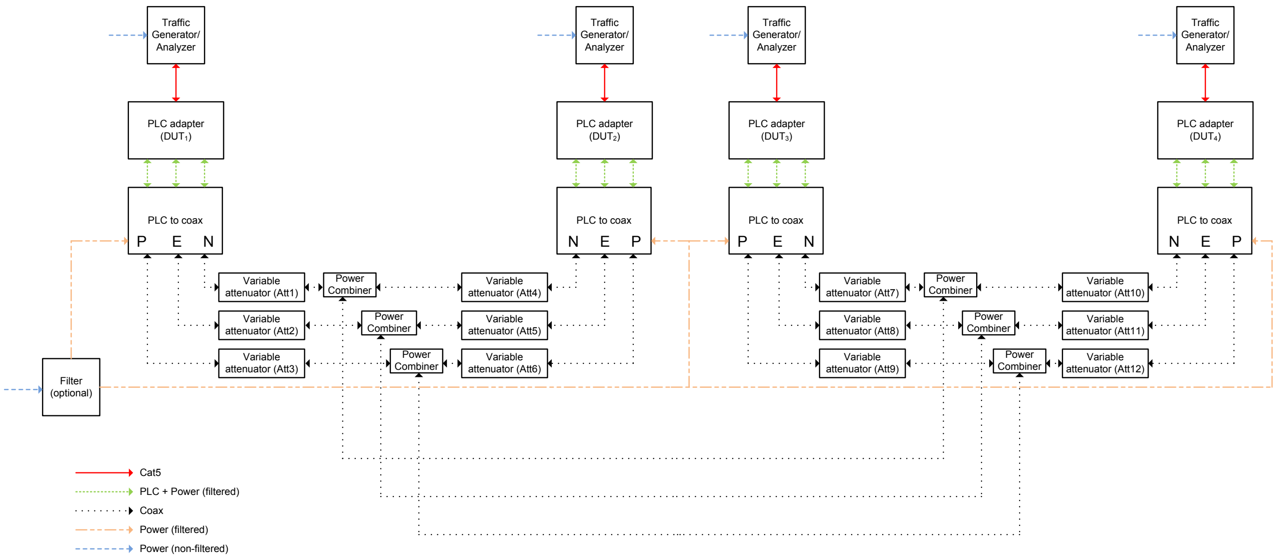

Figure 9-12: Setup S-MN2

9.1.13 Relay Setup

This section is for further study

9.1.14 Setup S-PSD1

This section describes the setup that shall be used for PSD tests, both for SISO and MIMO systems.

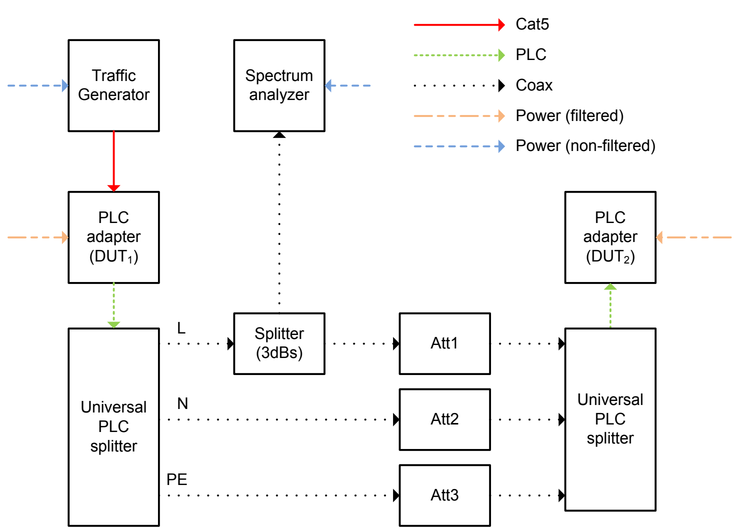

Figure 9-13: Setup S-PSD1

Note: In this setup, the Splitter can be connected to the line to be measured (L, N, PE)
Note: If DUT_1 is capable of transmitting frames autonomously, DUT_2 is not needed in this setup.

9.2 Notches

The DUT shall be configured to mask sub-carriers for the bands specified in 6.3.1.1
Additional notches may be applied to the DUT. In that case, these additional notches shall be clearly indicated in the test report.

9.3 Traffic configuration

This section presents different traffic configurations. Each of these traffic configurations can be used during the tests described in section 10.

In this section, we will use the following terminology:

- **a.a.a.a (IPv4) or a.a.a.a.a.a.a.a (IPv6)** = IP address of the device connected to Node A
- **b.b.b.b (IPv4) or b.b.b.b.b.b.b.b (IPv6)** = IP address of the device connected to Node B
- **c.c.c.c (IPv4) or c.c.c.c.c.c.c (IPv6)** = IP address of the device connected to Node C

In the rest of the document, IPv4 will be used unless otherwise specified; however, it can be replaced by IPv6 when needed.

This general configuration shall be used unless otherwise specified:
- **Layer2 packet type**: Ethernet Class II
- **Ethertype**: 0x0800 (IPv4) or 0x86DD (IPv6)

Note: only the same machines, without changes between tests, should be used for comparison purposes unless clearly noted in published results

The traffic priorities shall be the same for all traffic streams, unless changed within a specific test.

9.3.1 Traffic configuration 1 – timed ping

From a PC set up a timed ping in the direction Node A -> Node B using the following command:

- **Windows:** ping b.b.b.b -n T
- **Linux:** ping b.b.b.b -w T

where T = time of the ping test in seconds

9.3.2 Traffic configuration 2 – continuous ping

For a packet size P, and interval I (in seconds), from a PC set up a continuous ping in the direction Node A -> Node B using the following command:

- **Windows:** ping b.b.b.b –t -l P
- **Linux**: ping b.b.b.b -s P –i I

Notes: 1) Packet size = IP header (20 bytes) + ICMP header (8 bytes) + payload; P specifies the payload size only.
2) Stop ping using CTRL+C
3) Unless otherwise specified, a packet size of P =1514 bytes and an interval I = 1s shall be used
4) The interval cannot be set in Windows ping and is fixed at 1s

9.3.3 Traffic configuration 3 – continuous traffic (UDP)

Traffic analyzer to record packet loss and traffic generator generating UDP traffic with the following packet sizes (unless stated otherwise):

Table 9.2: Traffic configuration 3 options

	3A	3B	3C
Packet size (including CRC)	1500 bytes	512 bytes	64 bytes

9.3.4 Traffic configuration 4 – continuous traffic (TCP)

Traffic analyzer to record packet loss and traffic generator generating TCP traffic with the following packet sizes (unless stated otherwise):

Table 9.3: Traffic configuration 4 options

	4A	4B	4C
Packet size (including CRC)	1500 bytes	512 bytes	64 bytes

9.3.5 Traffic configuration 5 – RFC2544 Throughput

Traffic analyzer and generator executing RFC2544 Throughput test to record maximum throughput with no packet loss for the following settings (unless stated otherwise):

Table 9.4: Traffic configuration 5 options

	5
Frame sizes	64, 128, 256, 512, 1024, 1280, 1518 (bytes)
Trial Duration	60 seconds
Frame Format	UDP Echo Request with enough data to fill out the required frame size
Load Type	Binary Search
Acceptable Frame Loss	0%
Initial Rate	500 Mbps
Minimum Rate	10 Mbps
Maximum Rate	700 Mbps
Resolution	1 Mbps

9.3.6 Traffic Configuration 6 – Security Setup 2 Nodes

For a packet size P, and interval I (in seconds), set up a continuous ping in the directions Node A to Node B using the following command:

- **Windows:** ping x.x.x.x –t -l P
- **Linux**: ping x.x.x.x -s P –i I

Notes: 1) Packet size = IP header (20 bytes) + ICMP header (8 bytes) + payload; P specifies the payload size only.
2) Stop ping using CTRL+C
3) Unless otherwise specified, a packet size of P =1514 bytes and an interval I = 1s shall be used
4) The interval cannot be set in Windows ping and is fixed at 1s

9.3.7 Traffic Configuration 7 – Security Setup 3 Nodes

For a packet size P, and interval I (in seconds), set up a continuous ping in the directions Node A to Node B, Node A to Node C, Node B to Node C using the following command:

- **Windows:** ping x.x.x.x –t -l P
- **Linux**: ping x.x.x.x -s P –i I

Notes: 1) Packet size = IP header (20 bytes) + ICMP header (8 bytes) + payload; P specifies the payload size only.

2) Stop ping using CTRL+C

3) Unless otherwise specified, a packet size of P =1514 bytes and an interval I = 1s shall be used

4) The interval cannot be set in Windows ping and is fixed at 1s

10 Test description

In the following tests the way to verify certain vendor specific items depend on monitoring tool provided by each vendor. It is assumed in each test that tool exists and provides the corresponding information.
The information assumed to be provided by each vendor is:

- Network creation status
- Devices registered/associated to a network
- Time that takes a device to join a network
- Mechanism to perform pairing of two devices

10.1 Throughput Performance tests

10.1.1 Rate vs Attenuation tests

10.1.1.1 UDP point to point throughput

Table 10.1: UDP point to point throughput: Test procedure

Test ID	S1
Test Name	UDP point to point throughput under different attenuations
Purpose	Calculate UDP throughput in a context of two nodes with programmable attenuation.
Test Setup	S-S1 (SISO) ; S-M1 (MIMO)
Traffic configuration(s)	3A; 3B; 3C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Configure the attenuator (Att1 in the case of SISO; Att1, Att2 and Att3 in the case of MIMO) to an attenuation of 8dBs 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic configuration 3A with maximum bandwidth 7. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 8. Repeat steps 5 to 8 with Att1=20dB (in the case of SISO) or Att1=Att2=Att3=20 dBs (in the case of MIMO) 9. Repeat steps 5 to 8 with Att1=50 dBs (in the case of SISO) or

	Att1=Att2=Att3=50 dBs (in the case of MIMO) 10. Repeat steps 5 to 8 with Att1=70dBs (in the case of SISO) or Att1=Att2=Att3=70 dBs (in the case of MIMO) 11. Repeat steps 5 to 10 with traffic configuration 3B instead of 3A in step 6 12. Repeat steps 5 to 10 with traffic configuration 3C instead of 3A in step 6 13. Repeat steps 1 to 11 exchanging DUT1 and DUT2
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table.

10.1.1.2 TCP point to point throughput

Table 10.2: TCP point to point throughput: Test procedure

Test ID	S2
Test Name	TCP point to point throughput under different attenuations
Purpose	Calculate TCP throughput in a context of two nodes with programmable attenuation.
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Configure the attenuator (Att1 in the case of SISO; Att1, Att2 and Att3 in the case of MIMO) to an attenuation of 8dBs 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic configuration 4A with maximum bandwidth 7. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 8. Repeat steps 5 to 7 with Att1=20 dBs (in the case of SISO) or Att1=Att2=Att3=20 dBs (in the case of MIMO) 9. Repeat steps 5 to 7 with Att1=50 dBs (in the case of SISO) or Att1=Att2=Att3=50 dBs (in the case of MIMO) 10. Repeat steps 5 to 7 with Att1=70dBs (in the case of SISO) or Att1=Att2=Att3=70 dBs (in the case of MIMO) 11. Repeat steps 5 to 10 with traffic configurations 4B instead of 4A

	in step 6 12. Repeat steps 5 to 10 with traffic configuration 4C instead of 4A in step 6 13. Repeat steps 1 to 12 exchanging DUT1 and DUT2
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.1.1.3 UDP point to point throughput under noise

Table 10.3: UDP point to point throughput under noise: Test procedure

Test ID	S3
Test Name	UDP point to point throughput under different attenuations and noises
Purpose	Calculate UDP throughput in a context of two nodes with programmable attenuation and noise.
Test Setup	S-S2 (SISO); S-M2 (MIMO)
Traffic configuration(s)	3A; 3B; 3C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Create the noise (N1) 5. Configure the attenuator (Att1 in the case of SISO; Att1, Att3 and Att5 in the case of MIMO) to an attenuation of 20 dBs and attenuator Att2 with an attenuation of 0 dBs 6. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 7. Set the traffic generator to generate a stream of traffic configuration 3A with maximum bandwidth 8. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 9. Repeat steps 5 to 8 with Att1=50 dBs (in the case of SISO) or Att1=Att3=Att5=50 dBs (in the case of MIMO) and Att2=0dBs 10. Repeat steps 5 to 8 with Att1=70 dBs (in the case of SISO) or Att1=Att3=Att5=70 dBs (in the case of MIMO) and Att2=20dB 11. Repeat steps 5 to 10 with traffic configuration 3B instead of 3A in step 7 12. Repeat steps 5 to 10 with traffic configuration 3C instead of 3A in step 7

	13. Repeat steps 1 to 12 with noises, N2, N3, and N4
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table.

10.1.1.4 TCP point to point throughput under noise

Table 10.4: TCP point to point throughput under noise: Test procedure

Test ID	S4
Test Name	TCP point to point throughput under different attenuations and noises
Purpose	Calculate TCP throughput in a context of two nodes with programmable attenuation and noise.
Test Setup	S-S2 (SISO); S-M2 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Create the noise (N1) 5. Configure the attenuator Att1 to an attenuation of 20 dBs in the case of SISO; Att1, Att3 and Att5 in the case of MIMO) and attenuator Att2 with an attenuation of 0 dBs 6. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 7. Set the traffic generator to generate a stream of traffic configuration 4A with maximum bandwidth 8. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 9. Repeat steps 5 to 8 with Att1=50dB (in the case of SISO) or Att1=Att3=Att5=50 dBs (in the case of MIMO)and Att2=0 dBs 10. Repeat steps 5 to 8 with Att1=70dB (in the case of SISO) or Att1=Att3=Att5=70 dBs (in the case of MIMO) and Att2=20dBs 11. Repeat steps 5 to 10 with traffic configuration 4B instead of configuration 4A in step 7 12. Repeat steps 5 to 10 with traffic configuration 4C instead of configuration 4A in step 7 13. Repeat steps 1 to 12 with noises N2, N3, and N4
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.1.2 Bidirectional traffic

10.1.2.1 UDP bidirectional traffic. No noise

Table 10.5: UDP bidirectional traffic. No noise: Test procedure

Test ID	S5
Test Name	UDP bidirectional throughput under different attenuations
Purpose	Calculate UDP throughput in a context of two nodes with programmable attenuation
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	3A; 3B; 3C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 4. Configure the attenuator (Att1 in the case of SISO; Att1, Att2 and Att3 in the case of MIMO) to an attenuation of 8dBs 5. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generators to generate a stream of traffic configuration 3A with maximum bandwidth 7. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 8. Repeat steps 5 to 7 with Att1=20dB (in the case of SISO) or Att1=Att2=Att3=20 dBs (in the case of MIMO) 9. Repeat steps 5 to 7 with Att1=50 dBs (in the case of SISO) or Att1=Att2=Att3=50 dBs (in the case of MIMO) 10. Repeat steps 5 to 7 with Att1=70dBs (in the case of SISO) or Att1=Att2=Att3=70 dBs (in the case of MIMO) 11. Repeat steps 5 to 10 with traffic configuration 3B instead of configuration 3A in step 6 12. Repeat steps 5 to 10 with traffic configuration 3C instead of configuration 3A in step 6
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table.

10.1.2.2 TCP bidirectional traffic. No noise

Table 10.6: TCP bidirectional traffic. No noise: Test procedure

Test ID	S6
Test Name	TCP bidirectional throughput under different attenuations
Purpose	Calculate UDP throughput in a context of two nodes with programmable attenuation
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 4. Configure the attenuator (Att1 in the case of SISO; Att1, Att2 and Att3 in the case of MIMO) to an attenuation of 8dBs 5. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generators to generate a stream of traffic configuration 3A with maximum bandwidth 7. Run a traffic test from DUT1 to DUT2 at 100% utilization of the channel for 10s and record the throughput in Mbit/s 8. Repeat steps 5 to 7 with Att1=20dB (in the case of SISO) or Att1=Att2=Att3=20 dBs (in the case of MIMO) 9. Repeat steps 5 to 7 with Att1=50 dBs (in the case of SISO) or Att1=Att2=Att3=50 dBs (in the case of MIMO) 10. Repeat steps 5 to 7 with Att1=70dBs (in the case of SISO) or Att1=Att2=Att3=70 dBs (in the case of MIMO) 11. Repeat steps 5 to 10 with traffic configuration 4B instead of configuration 4A in step 6 12. Repeat steps 5 to 10 with traffic configuration 4C instead of configuration 4A in step 6
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table.

10.1.2.3 Variable UDP Traffic

Table 10.7: Variable UDP traffic: Test procedure

Test ID	S7
Test Name	UDP bidirectional throughput under different conditions of traffic
Purpose	Calculate UDP throughput in a context of two nodes with different

	traffic conditions
Test Setup	S-S1 (SISO) ; S-M1 (MIMO)
Traffic configuration(s)	3A; 3B; 3C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 4. Configure the attenuator Att1 to an attenuation of 40 dBs in the case of SISO; Att1, Att2 and Att3 to an attenuation of 40 dBs in the case of MIMO) 5. Send during 1 minute traffic from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generators to generate a stream of traffic configuration 3A with a Tx Rate of 10 Mb/s 7. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 8. Repeat steps 5 to 7 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 9. Repeat steps 5 to 8 with traffic configuration 3B instead of configuration 3A in step 6 10. Repeat steps 5 to 8 with traffic configuration 3C instead of configuration 3A in step 6
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.1.2.4 Variable TCP Traffic

Table 10.8: Variable TCP traffic: Test procedure

Test ID	S8
Test Name	TCP bidirectional throughput under different conditions of traffic
Purpose	Calculate TCP throughput in a context of two nodes with different traffic conditions
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created

	in step 1 3. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 4. Configure the attenuator Att1 to an attenuation of 40 dBs in the case of SISO; Att1, Att2 and Att3 to an attenuation of 40 dBs in the case of MIMO) 5. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generators to generate a stream of traffic configuration 4A with a Tx Rate of 10 Mb/s 7. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 8. Repeat steps 5 to 7 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 9. Repeat steps 5 to 8 with traffic configuration 4B instead of configuration 4A in step 6 10. Repeat steps 5 to 8 with traffic configuration 4C instead of configuration 4A in step 6
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.2 Neighbouring Networks

10.2.1 Rate in NN conditions

10.2.1.1 UDP, 2 networks

Table 10.9: UDP, 2 networks: Test procedure

Test ID	N1
Test Name	UDP bidirectional throughput under different conditions of traffic in presence of 1 NN
Purpose	Calculate UDP throughput (Network 1, Technology 1) in a context of two nodes with different traffic conditions in presence of a neighbouring network (Network 2) of the same technology (Technology 1).
Test Setup	S-NN1 (SISO); S-NN3 (MIMO)
Traffic configuration(s)	3A; 3B; 3C
Device requirements	DUT1, DUT2, DUT3 and DUT4
Initial conditions	SISO: Attenuators Att1, Att2, Att3 and Att4 set to 15 dB Attenuator Att5 set to 70 dBs MIMO:

	Attenuators Att1 to Att12 set to 15 dB Attenuator Att13 to Att15 set to 70 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network (Network 1) 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it creates a network (Network 2) 4. Power-up DUT4. Verify that it is registered in the network created in step 3 5. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 6. Connect one traffic generator/analyzer to DUT3 and traffic generator/analyzer to DUT4 7. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 8. Set the traffic generators to generate a stream of traffic configuration 3A with a Tx Rate of 10 Mb/s 9. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 10. Run a traffic test between DUT3 and DUT4 10s and record the received throughput in Mbit/s 11. Repeat steps 8 to 11 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 12. Repeat steps 7 to 11 with Att5=60dBs in the case of SISO and Att13 = Att14 = Att15 = 60dB in the case of MIMO 13. Repeat steps 7 to 11 with Att5=50dBs in the case of SISO and Att13 = Att14 = Att15 = 50dB in the case of MIMO 14. Repeat steps 7 to 11 with Att5=40dBs in the case of SISO and Att13 = Att14 = Att15 = 40dB in the case of MIMO 15. Repeat steps 7 to 11 with Att5=30dBs in the case of SISO and Att13 = Att14 = Att15 = 30dB in the case of MIMO 16. Repeat steps 7 to 11 with Att5=20dBs in the case of SISO and Att13 = Att14 = Att15 = 20dB in the case of MIMO 17. Repeat steps 7 to 11 with Att5=10dBs in the case of SISO and Att13 = Att14 = Att15 = 10dB in the case of MIMO 18. Repeat steps 7 to 11 with Att5=0dBs in the case of SISO and Att13 = Att14 = Att15 = 0dB in the case of MIMO 19. Repeat steps 7 to 18 with traffic configuration 3B instead of configuration 3A in step 8 20. Repeat steps 7 to 18 with traffic configuration 3C instead of configuration 3A in step 8 21. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=20dBs in the case of SISO and Att1 to Att12 set to 20dB in the case of MIMO 22. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=25dBs in the case of SISO and Att1 to Att12 set to 25dB in the case of MIMO 23. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=30dBs in the

	case of SISO and Att1 to Att12 set to 30dB in the case of MIMO 24. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=35dBs in the case of SISO and Att1 to Att12 set to 35dB in the case of MIMO
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.2.1.2 TCP, 2 networks

Table 10.10: TCP, 2 networks: Test procedure

Test ID	N2
Test Name	TCP bidirectional throughput under different conditions of traffic in presence of 1 NN
Purpose	Calculate TCP throughput (Network 1, Technology 1) in a context of two nodes with different traffic conditions in presence of a neighbouring network (Network 2) of the same technology (Technology 1).
Test Setup	S-NN1 (SISO); S-NN3 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	DUT1, DUT2, DUT3 and DUT4
Initial conditions	SISO: Attenuators Att1, Att2, Att3 and Att4 set to 15 dB Attenuator Att5 set to 70 dBs MIMO: Attenuators Att1 to Att12 set to 15 dB Attenuator Att13 to Att15 set to 70 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network (Network 1) 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it creates a network (Network 2) 4. Power-up DUT4. Verify that it is registered in the network created in step 3 5. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 6. Connect one traffic generator/analyzer to DUT3 and traffic generator/analyzer to DUT4 7. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 8. Set the traffic generators to generate a stream of traffic configuration 4A with a Tx Rate of 10 Mb/s 9. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 10. Run a traffic test between DUT3 and DUT4 10s and record the received throughput in Mbit/s

	11. Repeat steps 8 to 11 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 12. Repeat steps 7 to 11 with Att5=60dBs in the case of SISO and Att13 = Att14 = Att15 = 60dB in the case of MIMO 13. Repeat steps 7 to 11 with Att5=50dBs in the case of SISO and Att13 = Att14 = Att15 = 50dB in the case of MIMO 14. Repeat steps 7 to 11 with Att5=40dBs in the case of SISO and Att13 = Att14 = Att15 = 40dB in the case of MIMO 15. Repeat steps 7 to 11 with Att5=30dBs in the case of SISO and Att13 = Att14 = Att15 = 30dB in the case of MIMO 16. Repeat steps 7 to 11 with Att5=20dBs in the case of SISO and Att13 = Att14 = Att15 = 20dB in the case of MIMO 17. Repeat steps 7 to 11 with Att5=10dBs in the case of SISO and Att13 = Att14 = Att15 = 10dB in the case of MIMO 18. Repeat steps 7 to 11 with Att5=0dBs in the case of SISO and Att13 = Att14 = Att15 = 0dB in the case of MIMO 19. Repeat steps 7 to 17 with traffic configurations 4B instead of configuration 3A in step 8 20. Repeat steps 7 to 17 with traffic configurations 4C instead of configuration 3A in step 8 21. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=20dBs in the case of SISO and Att1 to Att12 set to 20dB in the case of MIMO 22. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=25dBs in the case of SISO and Att1 to Att12 set to 25dB in the case of MIMO 23. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=30dBs in the case of SISO and Att1 to Att12 set to 30dB in the case of MIMO 24. Repeat steps 1 to 18 with Att1=Att2=Att3=Att4=35dBs in the case of SISO and Att1 to Att12 set to 35dB in the case of MIMO
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table.

10.2.1.3 UDP, 3 networks

Table 10.11: UDP, 3 networks: Test procedure

Test ID	N3
Test Name	UDP bidirectional throughput under different conditions of traffic in presence of 2 NN
Purpose	Calculate UDP throughput (Network 1, Technology 1) in a context of two nodes with different traffic conditions in presence of two neighbouring network (Network 2 and Network 3) of the same technology (Technology 1).
Test Setup	S-NN2 (SISO); S-NN4 (MIMO)

Traffic configuration(s)	3A; 3B; 3C
Device requirements	DUT1, DUT2, DUT3, DUT4, DUT5 and DUT6
Initial conditions	SISO: Attenuators Att1, Att2, Att3, Att4, Att5 and Att6 set to 15 dB Attenuator Att7, Att8 and Att9 set to 25 dBs MIMO: Attenuators Att1 to Att18 set to 15 dB Attenuator Att19 to Att24 set to 25 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network (Network 1) 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it creates a network (Network 2) 4. Power-up DUT4. Verify that it is registered in the network created in step 3 5. Power-up DUT5. Verify that it creates a network (Network 2) 6. Power-up DUT6. Verify that it is registered in the network created in step 5 7. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 8. Connect one traffic generator/analyzer to DUT3 and traffic generator/analyzer to DUT4 9. Connect one traffic generator/analyzer to DUT5 and traffic generator/analyzer to DUT6 10. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 11. Set the traffic generators to generate a stream of traffic configuration 3A with a Tx Rate of 10 Mb/s 12. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 13. Run a traffic test between DUT3 and DUT4 10s and record the received throughput in Mbit/s 14. Run a traffic test between DUT5 and DUT6 10s and record the received throughput in Mbit/s 15. Repeat steps 10 to 14 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 16. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=20dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 20 dBs in the case of MIMO 17. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=15dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 15 dBs in the case of MIMO 18. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=10dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 10 dBs in the case of MIMO

	19. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=5dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 5 dBs in the case of MIMO 20. Repeat steps 1 to 19 with traffic configuration 3B instead of configuration 3A in step 11 21. Repeat steps 1 to 19 with traffic configuration 3C instead of configuration 3A in step 11
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.2.1.4 TCP, 3 networks

Table 10.12: TCP, 3 networks: Test procedure

Test ID	N4
Test Name	TCP bidirectional throughput under different conditions of traffic in presence of 2 NN
Purpose	Calculate TCP throughput (Network 1, Technology 1) in a context of two nodes with different traffic conditions in presence of two neighbouring network (Network 2 and Network 3) of the same technology (Technology 1).
Test Setup	S-NN2 (SISO); S-NN4 (MIMO)
Traffic configuration(s)	4A; 4B; 4C
Device requirements	DUT1, DUT2, DUT3, DUT4, DUT5 and DUT6
Initial conditions	SISO: Attenuators Att1, Att2, Att3, Att4, Att5 and Att6 set to 15 dB Attenuator Att7, Att8 and Att9 set to 25 dBs MIMO: Attenuators Att1 to Att18 and Att6 set to 15 dB Attenuator Att19 to Att24 set to 25 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network (Network 1) 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it creates a network (Network 2) 4. Power-up DUT4. Verify that it is registered in the network created in step 3 5. Power-up DUT5. Verify that it creates a network (Network 2) 6. Power-up DUT6. Verify that it is registered in the network created in step 5 7. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2 8. Connect one traffic generator/analyzer to DUT3 and traffic generator/analyzer to DUT4 9. Connect one traffic generator/analyzer to DUT5 and traffic

	generator/analyzer to DUT6 10. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 11. Set the traffic generators to generate a stream of traffic configuration 3A with a Tx Rate of 10 Mb/s 12. Run a traffic test between DUT1 and DUT2 10s and record the received throughput in Mbit/s 13. Run a traffic test between DUT3 and DUT4 10s and record the received throughput in Mbit/s 14. Run a traffic test between DUT5 and DUT6 10s and record the received throughput in Mbit/s 15. Repeat steps 10 to 14 with steps of 20 Mbit/s for Tx Rate in the traffic generators until one of the links does not accept more traffic 16. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=20dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 20 dBs in the case of MIMO 17. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=15dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 15 dBs in the case of MIMO 18. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=10dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 10 dBs in the case of MIMO 19. Repeat steps 10 to 15, with attenuation of Att7=Att8=Att9=5dBs in the case of SISO and Att19=Att20=Att21=Att22=Att23=Att24 to 5 dBs in the case of MIMO 20. Repeat steps 1 to 19 with traffic configuration 4B instead of configuration 4A in step 11 21. Repeat steps 1 to 19 with traffic configuration 4C instead of configuration 4A in step 11
Captured metrics	1. Capture received throughput at traffic analyzer and record the results in the corresponding report table

10.2.2 Admission in NN conditions

10.2.2.1 Joining a new node to an already established network

Table 10.13: Joining a new node to an already established network

Test ID	N5
Test Name	Joining a new node to an already established network
Purpose	Study the effect on the joining time of the traffic of a domain in presence of a neighbouring network (Network 2) of the same technology (Technology 1).

Test Setup	S-NN1 (SISO); S-NN2 (MIMO)
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	SISO: Attenuators Att1, Att2, Att3 and Att4 set to 15 dB Attenuator Att5 set to 30 dBs MIMO: Attenuators Att1 to Att12 set to 15 dB Attenuator Att13 to Att15 set to 30 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network (Network 1) 2. Power-up DUT3. Verify that it creates a network (Network 2) 3. Power-up DUT4. Verify that it is registered in the network created in step 3 4. Power-up DUT2. Verify that it is registered in the network created in step 1. Record the time it took to register in Network 1 5. Repeat five times the steps 1 to 4, noting the metrics of step 4 each time and doing an average at the end.
Captured metrics	1. Measure the time that took DUT2 to be incorporated into the network and record the results in the corresponding report table.

10.3 PSD Measurements

10.3.1 Validation of PSD

10.3.1.1 PSD measurement 100kHz-200 MHz

Table 10.14: PSD measurement 100 kHz-200 MHztest procedure

Test ID	PS1
Test Name	PSD measurement 100 KHz-200 MHz
Purpose	Study the PSD injected by a DUT in the 100 KHz-200 MHz range.
Test Setup	S-PSD1
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	Attenuators Att1 is set to 17dBs Attenuators Att2, Att3 are set to 20 dBs Splitter connected to line L

	Transmit continuous data with the transceiver active for at least 10% of the time
Procedure	1. Measure the frequency response, attenuation and noise floor of the measurement system 2. Power-up DUT_1. Verify that it creates a network (Network 1) 3. Power-up DUT2. Verify that it joins Network 1 4. Measure the PSD in the frequency 100 KHz to 200 MHz (with a step size of 5 KHz). Apply a correction to the measured PSD to account for the response of the measurement system (as measured in step 1 of the configuration procedure) 5. Repeat steps 1 to 3 changing the splitter to lines N and the attenuation values Att1=Att3=20dBs; Att2=17dBs 6. Repeat steps 1 to 3 changing the splitter to lines PE and the attenuation values Att1=Att2=20dBs; Att3=17dBs
Captured metrics	1. Capture PSD injected by DUT_1 over each of the lines and record the results in the corresponding report table.

10.3.2 Notches

10.3.2.1 Notch validation

Table 10.15: Notch validation test procedure

Test ID	PS2
Test Name	Notches test
Purpose	Test the ability to configure notches. Measure the depth of the configured notches
Test Setup	S-PSD1
Traffic configuration(s)	3A
Device requirements	Ability to configure notches
Initial conditions	Attenuators Att1 is set to 17dBs Attenuators Att2, Att3 are set to 20 dBs Splitter connected to line L Transmit continuous data with the transceiver active for at least 10% of the time Setup the spectrum analyzer with a resolution bandwidth of 10kHz and with the “maximum hold” function activated.
Procedure	1. Measure the frequency response, attenuation and noise floor of the measurement system. 2. Power-up DUT1. Verify that it creates a network (Network 1) 3. Power-up DUT2. Verify that it joins Network 1

	4. Configure the DUT to mask sub-carriers from a band starting at a random frequency (F_{START}) between 3 MHz and the maximum frequency of the modem with a width of 1 MHz 5. After a number of sweeps sufficient to capture transmission of all active sub-carriers, store the PSD measured in the in the measurement band F_{START}-4MHz to F_{START}+4MHz. 6. Apply a correction to the measured PSD to account for the response of the measurement system (as measured in step 1 of the configuration procedure). 7. Remove the notches 8. After a number of sweeps sufficient to capture transmission of all active sub-carriers, store the PSD measured in the measurement band (with a step size of 5 kHz). 9. Apply a correction to the measured PSD to account for the response of the measurement system (as measured in step 1 of the configuration procedure). 10. Repeat steps 1 to 9 changing the splitter and attenuators to lines N and PE
Captured metrics	1. Capture PSD injected by DUT_1 in a notch over each of the lines and record the results in the corresponding report table.

10.4 Noise immunity

10.4.1 Noise immunity

10.4.1.1 Noise immunity and performance

Table 10.16: Noise immunity and performance: Test procedure

Test ID	NI1
Test Name	SISO/MIMO Impulsive noise immunity
Purpose	Measure the immunity and performance against impulsive noise of the technology
Test Setup	S-S2 (SISO) or S-M2 (MIMO)
Traffic configuration(s)	3A, 4A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic

	analyzer to DUT2 (receiver). 4. Configure the attenuator Att1 to an attenuation of 14 dBs. Configure Att3 and Att5 to an attenuation of 20 dBs in the case of MIMO. Configure attenuator Att2 with an attenuation of 50 dBs 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic configuration 3A with a throughput of 100 Mb/s 7. Create the noise (Noise N1). 8. Capture the number of lost packets and achieved throughput. 9. Repeat steps 5 to 8 with Att2 =45dBs 10. Repeat steps 5 to 8 with Att2=40dBs 11. Repeat steps 5 to 8 with Att2 =35dBs 12. Repeat steps 5 to 8 with Att2 =30dBs 13. Repeat steps 5 to 8 with Att2 =25dBs 14. Repeat steps 5 to 8 with Att2 =20dBs 15. Repeat steps 5 to 8 with Att2 =15dBs 16. Repeat steps 5 to 8 with Att2 =10dBs 17. Repeat steps 5 to 8 with Att2 =5dBs 18. Repeat steps 5 to 8 with Att2 =0dBs 19. Repeat steps 1-18 with TCP traffic (configuration 4A instead of configuration 3A in step 6) 20. Repeat steps 1-19 with noise N2 instead of noise N1 in step 7 21. Repeat steps 1-19 with noise N3 instead of noise N1 in step 7 22. Repeat steps 1-19 with noise N4 instead of noise N1 in step 7
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer. Record the results in the corresponding report table.

10.4.1.2 On/Off Impulsive noise immunity and performance

Table 10.17: On/Off Impulsive noise immunity and performance: Test procedure

Test ID	NI2
Test Name	On/Off Impulsive noise immunity and performance
Purpose	Measure the immunity and performance against impulsive noise of the technology and recovery time when noise disappears
Test Setup	S-S2 (SISO) or S-M2 (MIMO)
Traffic configuration(s)	3A, 4A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic

	analyzer to DUT2 (receiver). 4. Configure the attenuator Att1 to an attenuation of 14 dBs. Configure Att3 and Att5 to an attenuation of 20 dBs in the case of MIMO. Configure attenuator Att2 with an attenuation of 50 dBs 5. Send traffic for 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic configuration 3A with a throughput of 100 Mb/s 7. Every 120 seconds change the channel conditions by plugging and unplugging the created impulsive noise (Noise N3) 8. Capture the number of lost packets, the throughput at each 120 seconds period and the time that takes to recover from low throughput (when noise is present) to high throughput (when noise is OFF) 9. Repeat steps 5 to 8 with Att2 =45dBs 10. Repeat steps 5 to 8 with Att2 =40dBs 11. Repeat steps 5 to 8 with Att2 =35dBs 12. Repeat steps 5 to 8 with Att2 =30dBs 13. Repeat steps 5 to 8 with Att2 =25dBs 14. Repeat steps 5 to 8 with Att2 =20dBs 15. Repeat steps 5 to 8 with Att2 =15dBs 16. Repeat steps 5 to 8 with Att2 =10dBs 17. Repeat steps 5 to 8 with Att2 =5dBs 18. Repeat steps 5 to 8 with Att2 =0dBs 19. Repeat whole test with TCP traffic (configuration 4A instead of configuration 3A in step 6).
Captured metrics	1. Capture the packets lost 2. Capture the throughput at each 120 seconds period 3. Capture recovery time (time that takes to recover the maximum throughput in clean line after a noisy period) 4. Record the results in the corresponding report table.

10.5 Topology

10.5.1 Network setup

10.5.1.1 Network setup

Table 10.18: Network setup: Test procedure

Test ID	T1
Test Name	Network setup
Purpose	Verify the timings associated to the inclusion of a new node on the network
Test Setup	S-S1 (SISO) or S-M1 (MIMO)

Traffic configuration(s)	3A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Configure the attenuator Att1 (also Att2 and Att3 for MIMO) to an attenuation of 20 dBs 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Power-up DUT2. Measure the time that takes to incorporate DUT2 to the network created in step 1
Captured metrics	1. Measure the time that took DUT2 to be incorporated into the network. Record the results in the corresponding report table.

10.5.1.2 Joining a new node to an already established network

Table 10.19: Joining a new node to an already established network: Test procedure

Test ID	T2
Test Name	Joining a new node to an already established network
Purpose	Study the effect on the joining time of the traffic of a domain
Test Setup	S-S4 (SISO) or S-M4 (MIMO)
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 and Att2 (also Att3, Att4, Att5, and Att6 for MIMO) to an attenuation of 20 dBs and attenuator Att2 with an attenuation of 20 dBs 4. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic configuration 3A with a throughput of 10 Mb/s 7. Power-up DUT3. Measure the time that takes to incorporate DUT3 to the network created in step 1. 8. Switch off all the nodes of the network. 9. Repeat five times steps 1 to 8, noting the metrics of step 7 each of the times 10. Repeat steps 1 to 9 for a value of generated traffic on step 6 of 50 Mb/s 11. Repeat steps 1 to 9 for a value of generated traffic on step 6 of

	100Mb/s 12. Repeat steps 1 to 9 for a value of generated traffic on step 6 of 200Mb/s
Captured metrics	1. Measure the time that took DUT3 to be incorporated into the network. Record the results in the corresponding report table.

10.5.2 Relay

10.5.3 Single-node relay

This test is for further study

10.5.4 Multi-node relay

This test is for further study

10.6 Traffic

10.6.1 Latency

10.6.1.1 Round-trip latency

Table 10.20: Round-trip latency: Test procedure

Test ID	TS1
Test Name	Round-trip latency
Purpose	Study the average latency of a network
Test Setup	S-S1(SISO) or S-M1 (MIMO)
Traffic configuration(s)	2
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 (also Att2 and Att3 for MIMO) to an attenuation of 20 dBs 4. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 5. Send traffic for 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic

	configuration 2 7. Measure the roundtrip latency. 8. Repeat five times steps 1 to 7, noting the metrics of step 7 each time and doing an average at the end.
Captured metrics	1. Measure the round trip latency of the continuous ping. Record the results in the corresponding report table.

10.6.2 Bursts

10.6.2.1 Ability to deal with bursty traffic

Table 10.21: Ability to deal with bursty traffic: Test procedure

Test ID	TS2
Test Name	Ability to deal with bursty traffic
Purpose	To test the stability of a point to point connection in bursting traffic conditions.
Test Setup	S-S1(SISO) or S-M1 (MIMO)
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 (and Att2 and Att3 in case of MIMO) to an attenuation of 50 dBs 4. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of 50Mbps with traffic configuration 3A (frame length 1500 bytes) during 1 minute 7. Stop the traffic during 1 minute 8. Repeat steps 6 and 7 four times.
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer. Record the results in the corresponding report table.

10.6.3 Flow maintenance

10.6.3.1 Flow maintenance

Table 10.22: Flow maintenance: Test procedure

Test ID	TS3
Test Name	Flow maintenance
Purpose	To test the stability of a point to point connection.
Test Setup	S-S1 (SISO) or S-M1 (MIMO)
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 (and Att2 and Att3 in case of MIMO) to an attenuation of 50 dBs 4. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of 25Mbps with traffic configuration 3A (frame length 1500 bytes) during 8 hours 7. Repeat step 6 for a stream of 50 Mbps instead of 25 Mbps 8. Repeat step 6 for a stream of 100 Mbps instead of 25 Mbps
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer. Record the results in the corresponding report table.

10.6.4 Throughput

10.6.4.1 Maximum throughput with no frame loss for Unidirectional Traffic

Table 10.23: Maximum throughput with no frame loss for Unidirectional Traffic : Test procedure

Test ID	TS4
Test Name	Maximum throughput with no frame loss for Unidirectional Traffic
Purpose	The throughput is the fastest rate at which the count of test frames transmitted by the DUT is equal to the number of test frames sent to it by the test equipment (PLR 0%). Based in RFC2544 Throughput test [1].

Test Setup	S-S1 (SISO) or S-M1 (products-M1)
Traffic configuration(s)	5
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 (also Att2 and Att3 for MIMO) to an attenuation of 50 dBs 4. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Set the traffic generator to generate a stream of traffic for each of the frame sizes as described in Table 9.4 for traffic configuration 5 (Throughput Test as stated in RFC2544, see clause 9.3.5). 7. Repeat steps 3 to 6 for attenuation value Att1 (SISO case) or Att1=Att2=Att3 = 20 dBs (MIMO case) set to 20 dB instead of 50 dB
Captured metrics	1. For each frame size: Maximum Rate with 0% frame loss. Record the results in the corresponding report table.

10.6.4.2 Maximum throughput with no frame loss for Bidirectional Traffic

Table 10.24: Maximum throughput with no frame loss for Bidirectional Traffic: Test procedure

Test ID	Maximum throughput with no frame loss for Bidirectional Traffic
Test Name	PLR 0%
Purpose	The throughput is the fastest rate at which the count of test frames transmitted by the DUT is equal to the number of test frames sent to it by the test equipment (PLR 0%). Based in RFC2544 Throughput test [1].
Test Setup	S-S1 (SISO) or S-M1 (MIMO)
Traffic configuration(s)	5
Device requirements	None
Initial conditions	None
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Configure the attenuator Att1 (also Att2 and Att3 for MIMO) to an attenuation of 50 dBs 4. Connect one traffic generator/analyzer to DUT1 and traffic generator/analyzer to DUT2

	5. Send traffic during 1 minute from the two traffic generators for channel estimation to complete (10 Mbit/s each direction) 6. Set each traffic generator to generate a stream of traffic for each of the frame sizes as described in table Table 9.4 for traffic configuration 5 (Throughput Test as stated in RFC2544, see clause 9.3.5). 7. Repeat steps 3 to 6 for attenuation value Att1 (SISO case) or Att1=Att2=Att3 = 20 dBs (MIMO case) set to 20 dB instead of 50 dB
Captured metrics	1. For each frame size: Maximum Rate in both directions with 0% frame loss. Record the results in the corresponding report table.

10.7 Security

10.7.1 Access Control

10.7.1.1 Access Control

Table 10.25: Access Control: Test procedure

Test ID	SEC1
Test Name	Access Control
Purpose	Study the access control mechanisms of a network
Test Setup	S-S4 (SISO); S_M4 (MIMO)
Traffic configuration(s)	7
Device requirements	None
Initial conditions	SISO: Attenuators Att1 and Att2 are fixed to an attenuation of 20 dBs MIMO: Attenuators Att1 to Att6 are fixed to an attenuation of 20 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it is registered in the network created in step 1 4. Connect the traffic generator and traffic analyzer to DUT1, DUT2, and DUT3. 5. Wait a minute to stabilize 6. Set the traffic generator to generate a stream of traffic configuration 7 7. Traffic flows among the nodes (no ping loss) 8. Configure DUT1 to create a new network. 9. Wait a minute to stabilize 10. Verify that DUT1 is NOT registered in the network created in step

	1 11. Set the traffic generator to generate a stream of traffic configuration 7 12. Traffic flows among DUT2 and DUT3 (no ping loss), but not to DUT1 (100% ping loss) 13. Perform a pairing of DUT2 with DUT1 14. Wait a minute to stabilize 15. Verify that DUT2 is registered with DUT1 in the network created in step 8 16. Set the traffic generator to generate a stream of traffic configuration 7 17. Traffic flows among DUT1 and DUT2 (no ping loss), but not to DUT3 (100% ping loss) 18. Perform a pairing of DUT3 with DUT1 19. Wait a minute to stabilize 20. Verify that DUT1, DUT2, and DUT3 are registered in the network created in step 8 21. Set the traffic generator to generate a stream of traffic configuration 7 22. Traffic flows among the nodes (no ping loss)
Captured metrics	1. Check if nodes are registered to their corresponding network at each step 2. Check if traffic only flows (no ping loss) among nodes registered to the same network 3. Record the results in the corresponding report table.

10.7.2 Encryption

10.7.2.1 P2P Encryption

Table 10.26: P2P Encryption: Test procedure

Test ID	SEC2
Test Name	P2P Encryption
Purpose	Study the encryption mechanisms of a P2P network
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	6
Device requirements	None
Initial conditions	SISO: Attenuator (Att1) is fixed to an attenuation of 50 dBs MIMO: Attenuators (Att1 to Att3) are fixed to an attenuation of 50 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network. The network

	may operate either with security enabled or disabled. 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. If communication is not encrypted by default, enable encrypted communication between DUT1 and DUT2. Ensure that the same encryption key is used in DUT1 and DUT2. After this step, the network operates with security enabled. 4. Connect the traffic generator and traffic analyzer to DUT1 and DUT2 5. Wait a minute to stabilize 6. Set the traffic generator to generate a stream of traffic configuration 6. Traffic flows successfully between the nodes. Ping between DUT1 and DUT2 is successful. 7. Configure DUT1 to use an specific ASCII encryption key different from step 3 8. Wait a minute to stabilize 9. Verify that DUT1 is registered in the network created in step 1 10. Set the traffic generator to generate a stream of traffic configuration 6 11. Ping between DUT1 and DUT2 fails because of different encryption keys on the nodes. 12. Configure DUT2 to use the same encryption key as in step 7 13. Wait a minute to stabilize 14. Verify that DUT2 in the network created in step 1 15. Set the traffic generator to generate a stream of traffic configuration 6 16. Traffic flows successfully between DUT1 and DUT2. Ping between DUT1 and DUT2 is successful
Captured metrics	1. Check if traffic does not flow successfully (ping lost) between nodes using different encryption keys 2. Check if traffic flows successfully (no ping loss) between the nodes registered to the same network and using the same encryption key 3. Record the results in the corresponding report table

10.7.2.2 P2P Encryption in a multinode network

Table 10.27: P2P Encryption in a multinode network: Test procedure

Test ID	SEC3
Test Name	P2P Encryption in a multinode network
Purpose	Study the encryption mechanisms of a multinode network
Test Setup	S-S4 (SISO); S-M4 (MIMO)

Traffic configuration(s)	7
Device requirements	None
Initial conditions	SISO: Attenuators Att1 and Att2 are fixed to an attenuation of 20 dBs MIMO: Attenuators Att1 to Att6 are fixed to an attenuation of 20 dBs
Procedure	1. Power-up DUT1. Verify that it creates a network. The network may operate either with security enabled or disabled 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3. Verify that it is registered in the network created in step 1 4. If communication is not encrypted by default, enable encrypted communication among DUT1, DUT2 and DUT3. Ensure that the same encryption key is used in DUT1, DUT2, and DUT3. After this step, the network operates with security enabled 5. Connect the traffic generator and traffic analyzer to DUT1, DUT2, and DUT3. 6. Wait a minute to stabilize 7. Set the traffic generator to generate a stream of traffic configuration 7 8. Traffic flows successfully among the nodes. Pings between DUT1 and DUT2, between DUT1 and DUT3, and between DUT2 and DUT3 are successful 9. Configure DUT1 to use an specific ASCII encryption key different from step 4 10. Wait a minute to stabilize 11. Verify that DUT1 is registered in the network created in step 1 12. Set the traffic generator to generate a stream of traffic configuration 7 13. Pings between DUT1 and DUT2 and between DUT1 and DUT3 fail because of different encryption keys on the nodes 14. Configure DUT2 to use the same encryption key as in step 9 15. Wait a minute to stabilize 16. Verify that DUT2 is registered in the network created in step 1 17. Set the traffic generator to generate a stream of traffic configuration 7 18. Ping between DUT1 and DUT2 is successful and ping between DUT1 and DUT3 still fails because of different encryption keys on the nodes 19. Configure DUT3 to use the same encryption key as in step 9 20. Wait a minute to stabilize 21. Verify that DUT3 is registered in the network created in step 1 22. Set the traffic generator to generate a stream of traffic configuration 7

	23. Traffic flows successfully among the nodes. Pings between DUT1 and DUT2, between DUT1 and DUT3, and between DUT2 and DUT3 are successful
Captured metrics	1. Check if traffic does not flow successfully (ping lost) between nodes using different encryption keys 2. Check if traffic flows successfully (no ping loss) between the nodes registered to the same network and using the same encryption key 3. Record the results in the corresponding report table.

10.8 QoS

10.8.1 QoS

Table 10.28: QoS: Test procedure

Test ID	QoS1
Test Name	Quality of Service Test
Purpose	Check that the devices are able to prioritize traffic without losing high prio packets.
Test Setup	S-S1 (SISO); S-M1 (MIMO)
Traffic configuration(s)	3A
Device requirements	None
Initial conditions	Attenuators Att1 (SISO case) or Att1 to Att3 (MIMO case) set to enough attenuation so as the maximum capacity of the channel is aprox. half the maximum bandwidth achievable by the devices
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Connect the traffic generator to DUT1 (transmitter) and traffic analyzer to DUT2 (receiver). 4. Configure the attenuator Att1 to an attenuation of 20dBs 5. Send traffic during 1 minute for channel estimation to complete (10 Mbit/s unidirectional) 6. Wait a minute to stabilize 7. Set the traffic generator to generate two streams of traffic configuration 3A: 8. Stream 1: From DUT1 to DUT2 at 800 Mbit/s with DSCP = 000000 (Note 1) 9. Stream2: From DUT1 to DUT2 at 100 Mbit/s and at a higher priority than stream 1 with DSCP = 110000 (Note 1). 10. Run a traffic test from DUT1 to DUT2 for 60s and record the

	throughput in Mbit/s 11. Repeat steps 1 to 10 with Stream 1 at 800 Mbit/s and DSCP = 000000, and Stream 2 at 100 Mbit/s and DSCP = 101000 12. Repeat steps 1 to 10 with Stream 1 at 800 Mbit/s and DSCP = 001000, and Stream 2 at 100 Mbit/s and DSCP = 100000
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer for each data stream. Record the results in the corresponding report table.
Note 1: For DSCP definition, see RFC2474	

10.9 Multinode Performance

10.9.1 Multinode Performance

10.9.1.1 Multinode, UDP

Table 10.29: Multinode, UDP: Test procedure

Test ID	MN1
Test Name	UDP unidirectional throughput with multiple nodes
Purpose	Calculate UDP throughput in a context of four nodes
Test Setup	S-MN1 (SISO); S-MN2 (MIMO)
Traffic configuration(s)	3A
Device requirements	DUT1, DUT2, DUT3 and DUT4
Initial conditions	SISO: Attenuator Att set to 15 dB MIMO: Attenuators Att1 to Att3 set to 15 dB
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3 Verify that it is registered in the network created in step 1 4. Power-up DUT4. Verify that it is registered in the network created in step 1 5. Connect one traffic generator/analyzer to each DUT 6. Send traffic during 1 minute between all traffic generators for channel estimation to complete (10 Mbit/s unidirectional)

	7. Set the traffic generators to generate three streams of traffic configuration 3A, each one with a Tx Rate of 25 Mbps between DUT1 and the other 3 DUTs (DUT1→DUT2, DUT1→DUT3 and DUT1 → DUT4) . 8. Run a traffic test for 60s and record the received throughput in Mbit/s for each stream 9. Repeat steps 7 to 8 with a stream of 50 Mbps instead of a stream of 25 Mbps 10. Repeat steps 7 to 8 with stream of 75 Mbps instead of a stream of 25 Mbps 11. Repeat steps 7 to 8 with stream of 100 Mbps instead of a stream of 25 Mbps
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer for each data stream. Record the results in the corresponding report table.

10.9.1.2 Multinode, TCP

Table 10.30: Multinode, TCP: Test procedure

Test ID	MN2
Test Name	TCP unidirectional throughput with multiple nodes
Purpose	Calculate TCP throughput in a context of four nodes
Test Setup	S-MN1 (SISO); S-MN2 (MIMO)
Traffic configuration(s)	4A
Device requirements	DUT1, DUT2, DUT3 and DUT4
Initial conditions	SISO: Attenuators Att set to 15 dB MIMO: Attenuators Att1 to Att3 set to 15 dB
Procedure	1. Power-up DUT1. Verify that it creates a network 2. Power-up DUT2. Verify that it is registered in the network created in step 1 3. Power-up DUT3 Verify that it is registered in the network created in step 1 4. Power-up DUT4. Verify that it is registered in the network created in step 1

	5. Connect one traffic generator/analyzer to each DUT 6. Send traffic during 1 minute between all traffic generators for channel estimation to complete (10 Mbit/s unidirectional) 7. Set the traffic generators to generate three streams of traffic configuration 4A , each one with a Tx Rate of 25 Mbps between DUT1 and the other 3 DUTs (DUT1→DUT2, DUT1→DUT3 and DUT1 → DUT4) 8. Run a traffic test for 60s and record the received throughput in Mbit/s 9. Repeat steps 7 to 8 with a stream of 50 Mbps instead of a stream of 25 Mbps 10. Repeat steps 7 to 8 with stream of 75 Mbps instead of a stream of 25 Mbps 11. Repeat steps 7 to 8 with stream of 100 Mbps instead of a stream of 25 Mbps
Captured metrics	1. Capture received throughput and packet loss at traffic analyzer for each data stream. Record the results in the corresponding report table.

11 Conclusion

The intent is to show the capabilities of the powerline technology under test in a standardized and repeatable test suite, able to be verified by others. The test lab may publish the results as an independent report to the industry or to an appropriate conference.

End of Broadband Forum Technical Report TR-208